Dissertation

on

"THE DAILY VARIATION OF COSMIC RAY INTENSITY AT AHMEDABAD"

presented

by

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STATEMENT

The study of the daily variation of cosmic ray intensity provides a unique tool for the evaluation of the anisotropy of the primary cosmic radiation, and changes occurring in it. The bulk of the published work relates to studies at high latitudes and relates to measurements with instruments of omnidirectional sensitivity, but in recent years the Physical Research Laboratory has been conducting a comprehensive investigation at several stations in low latitudes where the daily variation can be studied with advantage.

The thesis presents the results of investigations conducted at Ahmedabad ($\lambda = 13^{o}N$, h = 180 ft.) on the daily variation of meson intensity in the east and the west directions and a comparative study of the daily variation of meson intensity with vertical telescopes of different semiangles in the E-W plane.

The results of the present investigations establish the following,

(1) The nature of the daily variation of meson intensity in the east and the west directions has been determined. Comparison of the daily variations with telescopes pointing to the vertical, the east and the west directions indicates that the time of maximum in the

vertical direction lies between those of the east and the west, the east showing an earlier maximum than the west, but the spread of times of maxima in the three directions is much less than expected.

(2) The amplitude of the daily variation depends very much on the directional sensitivity of the measuring instrument. When observed with narrow angle telescopes pointing to the vertical at low latitudes, it is found to be as high as 1% and thus comparable to that observed by neutron monitors.

(3) The amplitude of the daily variation depends on the period for which data are averaged. The ratio of the daily variation in narrow angle telescopes to that in wide angle telescopes varies from period to period. It is larger on magnetically disturbed days than on quiet days.

(4) The nature of the daily variation of meson intensity on individual days is highly variable in character. In low latitudes it is due to the presence of at least two different types of anisotropies, one producing a maximum during day and the other at night.

(5) There exists a 27 day recurrence tendency in the daily variation.

An attempt has been made to present a possible interpretation to explain these various features of the daily variation on the assumption that it is caused by the anisotropy of the primary radiation produced by ionized beams emitted by the sun. It is found that the broad features as well as many of the reported discrepancies can be understood.

The author has included at the end of his thesis a list of 139 references to original papers published in different parts of the world. The thesis mentions the specific information derived from each of them.

PREFACE

The thesis describes the part of the investigation conducted by the Physical Research Laboratory, Ahmedabad for studying the time variation of various components of cosmic rays in low latitudes. In particular, it deals with the results of studies at Ahmedabad of the cosmic ray meson intensity measured with (1) inclined telescopes in the east and the west azimuths and (2) vertical telescopes with different angles of opening.

The apparatus described in Chapter II has been built entirely by the author. The author wishes to thank all his colleagues and the technical staff of the Laboratory for their kind cooperation during the course of the investigation and in particular to Mr.P.D.Bhavsar, M.Sc. for his assistance in preparing the diagrams of the thesis.

The project under which the present investigation was carried out, has been supported by the Atomic Energy Department, Government of India for which the author is extremely grateful. The author is very much indebted to the Gujarat University for an award of a Research Scholarship in the initial stages of the work.

The author wishes to express his deep debt of gratitude to Professor Vikram A. Sarabhai for the suggestion of the problem, his continued interest and guidance throughout the period of investigation.

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CONTENTS

Page

REFERENCES.

LIST OF TABLES.

LIST OF FIGURES.

CHAPTER I

INTRODUCTION

Several decades have elapsed since the discovery of cosmic radiation but our ideas regarding its variations are still undergoing radical changes. For a long time it was believed that the radiation was constant and isotropic within a fraction of a percent. Large variations which were invariably connected with transient solar or geomagnetic activity were rarely observed. But in recent years with the development of sensitive recording techniques, it is being increasingly realised that variations can be quite large and seem to be more common than had been suspected.

The role of the variations of atmospheric origin has become clearer and even after corrections have been applied to eliminate this influence significant variations persist and these have been shown to be of extraterrestrial origin. Many of these seem to be connected with the electromagnetic state of interplanetary and interstellar space. Indeed, the variations now provide us with a valuable tool for studying the electromagnetic condition of space surrounding the earth. The close relationship between many of the variations and solar events also helps our understandin of the high energy processes in the solar atmosphere. A great deal of effort has, therefore, been directed in recent years to the systematic study of the time variations of cosmic radiation.

The status of knowledge regarding the intensity variations studied upto 1951 has been reviewed by Elliot[1]. Since then significant advances have been made. Individual authors[2] have summarised particular aspects of the field in the light of the work of their own group. A review of the progress in the subject as a whole has been prepared recently by Sarabhai & Nerurkar[3] and by Singer[4].

The majority of experimental results dealing with variations relates to studies performed on the surface of the earth after the primaries have suffered deflection in the geomagnetic field and interacted with matter in the atmosphere. An allowance for these terrestrial effects is necessary before one can interpret the variations in terms of the primary component of the radiation.

1.1 Geomagnetic Effects

Early work on the subject by Lemaitre & Vallarta[5] and by Stormer[6] was done by numerical computation of the orbits of charged particles in the earth's magnetic field. However, later workers in trying to explain the observed geomagnetic effects like latitude effect etc. could derive a satisfactory theory through the use of Liouville's theorem and assuming isotropy of primary radiation so that calculation of individual orbits was no longer needed. The results have been summarised and presented in a convenient form by Alpher[7]. However in the interpretation of the anisotropy of radiation, and of variations such as solar flare effect where the isotropy of cosmic radiation is no longer observed, it becomes necessary to revert to a calculation of the orbits of charged particles.

Schluter[8] and Firor[9] have approached this problem by computing the individual orbits of protons of energies extending upto 10 BeV and have confined the calculations to observing stations in the middle latitudes. This work is recently refined by Jory[10] by including the effect of the quadrupole field on the stormer cones. A similar attempt has also been made by Vallarta and his collaborators[11] by taking into account the complete quadrupole field.

Brunberg & Dattner[12] have approached the problem by model experiments. They have examined the motion of an electron beam in the vicinity of a magnetised terrela designed first by Malmfors[13] to represent the earth. The asymptotic coordinates of the velocity vectors for protons of energies greater than 2 BeV which can arrive at specified angles with respect to zenith in the N-S and E-W planes have been determined and presented in a graphical form. A comparison of some of the results of the model experiments with those from calculations has demonstrated the great accuracy of the former. This study forms a most valuable and essential basis for the interpretation of work not dealing with isotropic radiation.

1.2 Diffusion of Cosmic Radiation in the Atmosphere.

Transition of the primary radiation to the secondary radiation in the atmosphere takes place through various complicated processes. The primary spectrum has to be related through a specific yield function or a generating function to the spectrum of secondaries observed at various depths in the atmosphere. Let $N(\lambda, x)$ be the observed intensity at latitude λ and atmospheric depth x g/cm^2. If $i(E)$ is the differential energy spectrum for primaries and if we define the generating function $m(E, x)$ as the number of secondaries appearing at depth x due to one primary proton of energy E incident on the top of the atmosphere we get

$$m(E, x) = - \frac{1}{i(E)} \quad \frac{dN(\lambda, x)}{d\lambda} \quad \frac{d\lambda}{dE}$$

The last term is determined from the geomagnetic theory. The second term can be evaluated only for the latitude sensitive region of primaries by studying the latitude effect of secondary components at different atmospheric depths. Various authors such as Treiman[14], Fonger[15], Nagashima[16] and Dorman[17] have worked out this yield function from the data of latitude variation obtained by Simpson[18], Berry & Hess[19] and various other workers.[20]

The differential contribution to the secondary intensity is given by

$$n(\lambda, E, x) = m(E, x)\, i(E)$$

and the total intensity

$$N(\lambda, x) = \int_{E_{c\lambda}}^{\infty} n . dE$$

where $E_{c\lambda}$ is the geomagnetic cut off energy. The results have been summarised in Fig. 1.1 after reasonable extrapolations have been made to primary energies beyond the latitude sensitive spectrum. It would be observed that

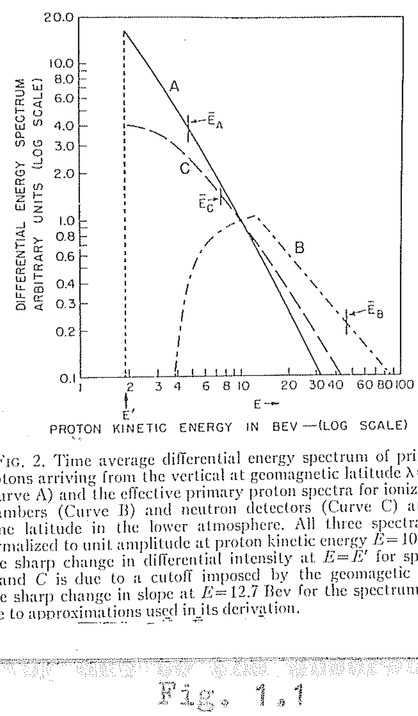


FIG. 2. Time average differential energy spectrum of primary protons arriving from the vertical at geomagnetic latitude λ=48° (Curve A) and the effective primary proton spectra for ionization chambers (Curve B) and neutron detectors (Curve C) at the same latitude in the lower atmosphere. All three spectra are normalized to unit amplitude at proton kinetic energy E=10 Bev. The sharp change in differential intensity at $E=E'$ for spectra A and C is due to a cutoff imposed by the geomagetic field. The sharp change in slope at E=12.7 Bev for the spectrum B is due to approximations used in its derivation.

Fig. 1.1

the nucleonic component as measured by the local production of neutrons at Climax corresponds to a mean primary energy of 7.3 BeV, while the ionization chamber at sea level corresponds to a mean primary energy of 46 BeV. Dorman[17] has made similar calculations and furnished figures from which one can read out the values of coupling coefficients for various components at sea level and at 4300 meters altitude for the latitudes 0°, 30° and 50° upto primary energies of 1000 BeV.

Since the mean energy of primaries to which a neutron monitor responds is much lower than that for a meson telescope, the dependence of time variations on mean primary energy can be studied by comparing the changes observed in the two types of instruments. In making this comparison, allowance requires to be made for difference in the sensitivity of the instruments to radiation in directions inclined to the vertical and for the zenith angle dependence of the observed variation.

1.3 Variations of Atmospheric Origin

As far back as 1927, it was first reported by Myssowsky & Tuwim[21] that there exists a negative correlation between the day to day variations of pressure and cosmic ray intensity at ground level. The decrease in cosmic ray intensity with an increase in atmospheric pressure was interpreted as being due to the absorption of the radiation during its passage through the atmosphere. This was expressed as $\frac{\delta I}{I} = \alpha_B \, \delta B$ (1) where I is the cosmic ray intensity and B is the barometric pressure. α_B was called a barometer coefficient. However, later work on the anamolous absorption of cosmic radiation in matter clearly demonstrated that the large part of cosmic radiation at sea level consists of unstable particles (μ mesons) and the observed decreases in cosmic ray intensity can no longer be considered as a pure absorption effect but also includes the effect due to the instability of μ mesons.

Duperier[22] in 1944 first made an attempt to separate these two effects by introducing the height of the meson producing layer as a second independent variable. The regression equation was thus written as

$$\frac{\delta I}{I} = \alpha_B \, \delta B + \alpha_H \, \delta H \qquad (2)$$

where H is the mean height of the meson producing layer and α_B and α_H are called barometer and decay coefficients respectively. His analysis of the multiple correlation between H, I and B for various levels in the atmosphere resulted in the maximum partial correlation with H = 100 mb. He concluded, therefore, that most mesons originate in the vicinity of this level or above. However even if the experimental data are analysed according to the above equation, the barometer term still contains a contribution from the μ-e decay. Trefall[23] has pointed out that because of relativistic time dilatation, the mean life time of μ mesons depends upon their energy. Furthermore the probability for decay between the place of production and sea level depends not only on the height of the production level but also on the energy with which μ mesons are produced and on the energy loss in the atmosphere. As the energy loss increases with increasing barometric pressure, the survival probability decreases even if the height of the production level remains unchanged. The barometer coefficient will, therefore, be greater than the true absorption coefficient. He has provided curves for these two effects which show that upto a third of the barometer coefficient may arise from the change of survival probability. He has also shown that there is satisfactory agreement between theory and experiments.

Olbert[24] has approached this problem from a different view point. His barometer coefficient is directly related to the measurements of the altitude dependence of the integral intensity spectrum of μ mesons and according to his definition it represents the slope of the intensity depth curve in the lower atmosphere.

Trefall[23] points out that the correlation between sea level pressure and heights of isobar levels is not likely to be the same at different times. Therefore, the changes in the general behaviour of the atmosphere from period to period may very well affect the decay contribution differently on different occasions. Since the barometer coefficient obtained from a regression equation of the type used by Duperier is not identical with the true absorption coefficient but also includes appreciable contribution due to μ-e decay, we can understand discrepancies in the barometer coefficient obtained by different methods i.e. those reported by Duperier[25] and Jacklyn[26]. Trefall remarks that an experimental separation of the true absorption effect from the other atmospheric effects is not possible by means of correlation analysis.

Since it was found by Duperier[27] in 1949 that equation (2) is not adequate to explain completely the day to day changes in cosmic ray intensity, he introduced a third term in the regression equation which was presented as

$$\frac{\delta I}{I} = \alpha_B \, \delta B + \alpha_H \, \delta H + \alpha_T \, \delta T \qquad (3)$$

where T is the temperature of the region between 50 and 200 mb. The method of partial correlation gave α_T with a positive value. He called this the positive temperature coefficient and suggested that it was due to the competition between disintegration and nuclear capture of π mesons. With decrease in the density of air, due to an increase in temperature, which allows more $\pi - \mu$ decay, a positive correlation would exist between μ meson intensity and the temperature of the region in which π mesons play an important role.

This equation and the physical meaning ascribed to α_T by Duperier has met with two major difficulties. It was found that like α_B and α_H, the values of the coefficient α_T experimentally determined were not constant. They varied from period to period for the same instrument and differed according to whether seasonal or day to day changes were considered. Furthermore the life time of μ-e decay derived from α_T was too large compared to the value from other estimates.

Barrett et al[28] have pointed out that it is not the temperature of a single layer or a narrow band of the atmosphere that matters but a weighted average of the temperature throughout the atmosphere. This is so closely related with the heights of isobar levels that α_H associated with μ-e decay and the temperature effect associated with the production of μ mesons cannot be entirely separated. They suggest the adoption of a mean atmospheric temperature which is derived by a process of weighted averaging of the temperatures of successive isobaric levels from ground upwards. They have made observations at a depth of 1574 m.w.e. and since the contribution of μ-e decay was negligible for mesons corresponding to an energy at production of 10^{11} eV, they were able to study the positive temperature effect arising only due to $\pi - \mu$ decay. They were then able to reconcile the observed positive temperature effect of 0.46% per °C with the calculated effect using for π mesons a mean life time $T = 2 \times 10^{-8}$ seconds in conformity with evidence from other sources. Sherman[29] finds at a depth of 846 m.w.e. an α_T which is smaller than what was expected according to calculations of Barrett et al for an appropriate energy of μ mesons. Even though this may constitute some evidence for a $K - \mu$ decay process, he points out that within the statistical accuracy of the determination, the value is not inconsistent with a $\pi - \mu$ decay scheme alone.

The difference in the estimates of α_H and α_T

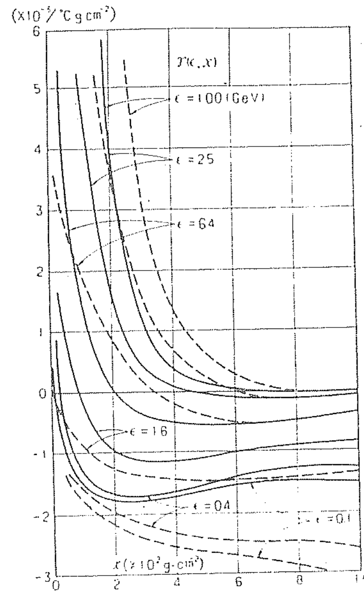
when meteorological changes of a day to day and seasonal character are considered, have been examined by a number of workers. Neglecting $\pi - \mu$ decay, and with a production spectrum of μ mesons as given by Sands[30], Olbert[24] has given a rigorous treatment of the change of survival probability of μ mesons in the atmosphere. His analysis shows that the survival probability of μ mesons can be expressed as a function of (1) height where the meson is formed and (2) the distribution of momentum loss along its path depending upon the density distribution in the troposphere. If there is a proportionately greater mass encountered towards the end of the range, there is correspondingly a reduced ionization loss and degradation of energy during the earlier part of the path of the meson, thus increasing the survival probability in the atmosphere. Since an increase of density in the lower layers is often accompanied by a decrease of temperature in these layers and a increase of temperature at higher levels, this effect due to the change of distribution of mass in the atmosphere shows itself as an apparent positive temperature effect of the type observed by Duperier. Olbert has demonstrated that such an effect can be as large as half the value of α_T observed by Duperier.

On theoretical grounds, Olbert has suggested a regression equation such as

$$\frac{\delta I}{I} = \alpha_B \; \delta B + \alpha_H \; \delta H + \alpha_T \; \delta T$$

where I, H and B have the same meaning as given in equation (2) but T is the mean temperature of the troposphere. When one considers a regression equation connecting δI with δH and δB only, neglecting the role of δT, the contribution of δT gets included in the term containing δH. Olbert has found that the relationship between δT and δH in seasonal and diurnal changes is given as $(\delta T_{AV} / \delta H)_{seasonal}$ = 20°C/km and $(\delta T_{AV} / \delta H)_{diurnal}$ = 50°C/km so that the apparent α_H will have two values given by $\alpha_{H\ seasonal}$ = 4.3%/km and $\alpha_{H\ diurnal}$ = 6.1%/km. These values are in good agreement with those found by Elliot & Dolbear[31] and hence the apparent difference in the value of α_H can be reconciled.

Maeda & Wada[32] have extended Olbert's work by taking into account the process of $\pi - \mu$ decay. They have calculated the contribution to α_T of $\pi - \mu$ and μ-e decay processes by temperature variations at successive levels in the atmosphere. They find that the contribution of μ-e decay is almost constant irrespective of depth from the 50 mb level downwards. However, the contribution of $\pi - \mu$ decay decreases exponentially with increasing atmospheric depth. They have presented the results graphically in a very convenient form as shown in Fig. 1.2 from which can be read out the values of α_T for any energy at different depths. These values of α_T are to be used in conjunction with mass temperature of the atmosphere, and not with the temperature of individual layer as used by Duperier.



The coefficient of partial temperature effect combined with both effects of π-meson decay and μ-meson decay.

Fig. 1.2

Hayakawa et al[33] have extended the work of Maeda & Wada by considering the effect of nucleonic cascades on the production of μ mesons. They find that for the purpose of the $\pi - \mu$ decay process, it is more appropriate to consider the temperature of the 200 mb level than the average temperature between 50 mb and 200 mb. They have furnished more accurate estimates than Barrett et al for the increase of α_T with increasing energy of μ mesons. Their estimates of temperature coefficient are higher than those given by Maeda & Wada and agree well with observations by Dawton & Elliot[34], by Chasson[35] and by Trumpy & Trefall[36]. However the values obtained by Duperier and by Wada & Kudo[37] are still higher than the theoretical estimates.

Trefall[38] has tried to analyse the implications of various assumptions made in Duperier's regression equation in terms of the interpretation given to the coefficients that are derived from it. He points out that an apparent positive temperature effect can arise if the chosen level at which one considers δH differs from the true mean level of meson production. If, for instance, δH is taken in relation to the height of the 50 mb level and the true level of meson production is below it, the distance between the true level of meson production and ground is not only controlled by the height of the assumed level of 50 mb but by the temperature between it and the 50 mb level. An increase in this temperature will reduce the distance between sea level and the production level, provided H and B are to be kept constants. The survival probability will then increase and a positive temperature effect will be obtained. This effect depends on the mean energy of the recorded radiation not only because the mean life time is a function of energy but the mean depth of meson production also depends upon the energy. Trefall points out that this effect will always be negative when the reference level is assumed at 200 mb, but it will be positive when the reference level is assumed at 50 mb. Thus Duperier's result that α_T with H = 50 mb is greater than α_T with H = 100 mb can be understood. It must, however, be emphasized that this effect results because of the improper choice of parameters and would vanish if an appropriate level for meson production is considered.

The positive temperature effect at sea level thus arises due to the following three causes.

(1) Competition between π- μ decay and nuclear capture of π mesons.

(2) Change in survival probability of μ mesons.

(3) The difference between chosen reference level and the mean level of meson production.

In physical terms the barometer coefficient α_B includes effects due to mass absorption and μ-e decay, the coefficient α_H relates to μ-e decay while α_T relates to π- μ decay as well as to μ-e decay.

The meteorological elements are known to exhibit systematic daily variations and these influence cosmic ray intensity. The corrections to be applied to the daily variation of meson intensity for the removal of effects of atmospheric origin have been considered by several workers. Sarabhai et al[39] have discussed the expected contributions due to the daily variations of barometric pressure, of heights of isobaric levels and of temperatures of various levels in the atmosphere. From a study of radio-sonde ascents made at Ahmedabad, Venkateswaran & Desai[40] have pointed out that significant and regular diurnal variation of temperature occurs only in the turbulent, surface layer of the atmosphere upto 2 km above the ground. In the higher levels, the main changes of temperature are not diurnal but of irregular day to day character which are expected to be smoothed out when the data are averaged over an extended period. The amplitude of the semidiurnal oscillation of the atmosphere at the 100 mb level does not exceed a few meters even at the equator. Thus in the daily variation of meson intensity there is expected to be little contribution of the change of height of isobaric levels or of upper air temperature. Sarabhai et al, therefore, conclude that the barometer effect is the only atmospheric effect of importance in the diurnal variation of meson intensity. Maeda[41] has shown that the temperature variation in the atmosphere may be expected to give rise to a small diurnal variation of amplitude of about 0.05% with maximum at 1400 hours. This is in addition to the contribution of the barometric pressure.

1.4 Solar Anisotropy of Primary Cosmic Radiation

In the past the daily variation has been generally studied with instruments measuring intensity from as wide a range of directions as was possible. This helped to increase the measured intensity and reduce sampling errors. To improve the statistical significance of the determinations, it was customary to take average of data extending over as large a period as was possible. A small effect with an amplitude of about 0.2% was then observed. However, uncertainties regarding the corrections to be made for the daily variation of meteorological elements led many workers to question the validity of drawing conclusions regarding the anisotropy of radiation.

A possible method of eliminating variations of atmospheric origin would be to measure the daily variation of the radiation coming from different directions and take the difference of the two. The meteorological effects are expected to be the same in the two directions but the variation due to anisotropy of the primary radiation would be different and hence the former would cancel out in taking the difference.

The first measurements of this nature were done by Kolhorster[42] in Berlin and by Alfven & Malmsors[43] in Stockholm by using counter telescopes. Their results suggest that the north pointing telescope exhibits an earlier maximum than the south pointing telescope. Malmfors[44] has repeated the study with a slight modification of the original arrangement and has confirmed the earlier results. In addition, he has noticed that on a harmonic dial the scatter of the harmonic coefficients of the north and the south difference curves for different periods of time is much less than for the individual directions. He, therefore, attributes the difference in the phase of the diurnal variations in two different directions to the different deflections in the earth's magnetic field. From model experiments he concludes that the observed difference in the diurnal variation in the north and the south directions indicates the existence of an anisotropy of the primary radiation in the high energy part of the primary spectrum which undergoes little deflection in the geomagnetic field. Further recent studies with a terrela by Brunberg & Dattner[45] have shown that Malmfors's results correspond to a mean energy of the primary radiation in the vicinity of 25 BeV.

The most extensive measurements on the dependence of the diurnal variation of cosmic ray meson intensity on the direction of arrival of particles at the earth, have been carried out by Elliot & Dolbear[46]. They have confirmed the earlier results of Alfven & Malmfors for the north and the south directions. In addition, they have found that the daily variation from the south direction contains a larger semidiurnal component than that from the north. The amplitude and the time of maximum of the diurnal variation from the south direction vary with the season while only the amplitude of the variation from the north direction shows a seasonal variation. Since the time of maximum of the diurnal variation from the north pointing telescope did not show any seasonal variation, it was put forward that in northern latitudes at about 50°N it points to the fixed direction in space and hence would not be affected by the anisotropy. The difference between the north and the south pointing telescopes is interpreted as the daily variation corresponding to the anisotropy in the south direction. Sarabhai & Kane[47] have suggested that the observed difference in the north and the south directions can arise from a geomagnetic effect and the observed difference curve reflects only an arithmatic difference between the daily variation in the two directions. Their study on the daily variation in the east and the west directions shows a difference of about two hours in the phase of the diurnal variation, the east showing an earlier maximum than the west. In terms of Brunberg & Dattner's experiments, this indicates an anisotropy of cosmic radiation in the region above 30 BeV.

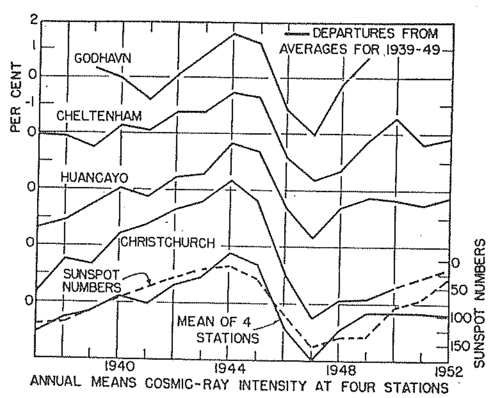
Dolbear & Elliot have investigated the effect on cosmic rays of ionized solar streams which are supposed to cause geomagnetic disturbances. They proved, from the suggestion of Alfven[48], that these streams will have transverse electric fields associated with them due to the polarisation resulting from the motion of the ionized stream through the solar magnetic field. Assuming the solar dipole field having the same orientation as that of the earth, they point out that the direction of the electric field within the streams, as seen from the earth, will be opposite for streams emitted from the east and the west limbs of the sun. This will produce an increase in the early afternoon and a decrease during the late morning. They have calculated the difference curve that is likely to be produced from the measurements in the east and the west directions, and have shown that the results agree with the estimates if the solar equatorial field is 8 gauss.

As far back as 1950, experimental evidence was not lacking to show that an over_simplification was being made in dismissing evidence connected with the daily variation of meson intensity as being mainly due to effects of terrestrial origin. Ehmert & Sittkus[49] have revealed the difference in amplitudes between the daily variation simultaneously measured with ion chamber of omnidirectional sensitivity and by a vertical counter telescope having more limited directional sensitivity. Sekido et al[50] have pointed out that the amplitude of the daily variation increase from 0.19% to 0.24% when the semiangle of the telescope was reduced from 40° to 12°. At low latitudes the monthly mean daily variation of meson intensity with telescope of semiangle 22° in the E-W plane has been found to fluctuate between 0.3% to 1.0% and is considerably larger than the amplitude observed with ion chamber at Huancayo. The daily variation of comparable amplitude is hardly expected to be of atmospheric origin. Thus it was concluded that the observed daily variation could in fact be attributed to the anisotropy of cosmic radiation.

Firor et al[51] have reported from the study of the nucleonic component measured with neutron monitors at different latitudes that averaged over a group of days, the daily variation has peak to peak amplitude of about 1.0% which is comparable to the amplitudes observed at low latitudes in meson telescopes of moderate semiangle. There is no great latitude dependence of the amplitude of the daily variation. Similar is the case with ion chamber data.

1.5 Long Term Changes of Primary Radiation

1.51 <u>Changes of total intensity</u> :- A change in the general cosmic ray intensity revealed by the annual mean intensity measured by Carnegie Institution stations is shown by Glokova[52] and by Forbush[53] to be of the order of 4.0% between sunspot minimum and sunspot maximum and to be present to almost an equal degree in all four stations ranging in latitude from the equator to 80°N. This result has been reproduced in Fig. 1.3. Forbush has separated his



Annual means of cosmic-ray intensity measured with shielded ionization chambers by Forbush.

Fig. 1.3

data for magnetically quiet and disturbed days and shows that the change of intensity is present almost equally in both the groups. This is indicative of the fact that the change is not produced in a simple way by a series of magnetic storm type decreases occurring with varying frequency during different periods of the solar cycle.

Evidence of similar change at high altitudes is provided in balloon experiments by Neher[54]. Corresponding to the change of only 4.0% observed at sea level, Neher shows that at the latitude of 85°N to 88°N, there was a change in total ionization of about 50% at an altitude of 70000 ft. from the sunspot maximum year of 1937 to the sunspot minimum year of 1954. Meyer & Simpson[55] in aeroplane flights at 30000 ft. have recorded a change of 13% in intensity measured by neutron monitors from 1948 to 1951.

1.52 <u>Change of "knee" of the latitude effect</u> :- Neher[56] has summarised experimental data extending upto 1950 concerning the measurement of the latitude effect of cosmic rays at various altitudes. A most remarkable feature was the absence of low energy component of primary cosmic radiation. The "knee" in the latitude effect indicated that beyond a latitude of about 55° there was no further change in the total cosmic ray intensity even at the highest altitudes that could be reached with balloons. The sharp cut off in the cosmic ray primary spectrum was at an energy of about 0.8 BeV.

In attempting to study the finer features of the latitude variation of intensity at high altitudes in high latitudes beyond the "knee", Neher et al[57,58], profiting by the experience gained about the appreciable day to day changes in the intensity of cosmic rays, have since 1951 made simultaneous flights of balloon borne instruments at different latitudes. Thus they have developed a technique to study the "knee" independently of general fluctuations in cosmic rays. Fig. 1.4 from Neher shows the "knee" of

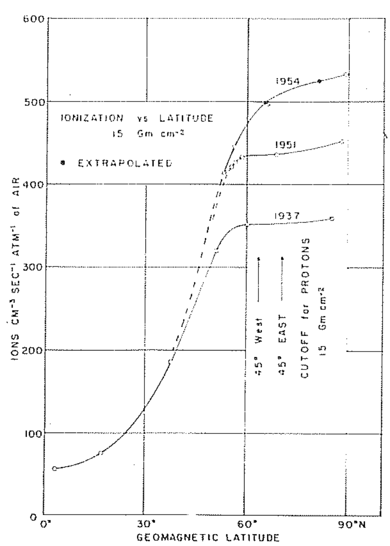


Fig. 1.4

the intensity versus latitude curves for an atmospheric depth of 15 g/cm^2 during 1937, 1951 and 1954. The figure illustrates clearly the shift of the "knee" to higher latitudes from 1937 to 1951. The low energy cut off for protons at 0.8 BeV during 1951 is absent during 1954 when a very large intensity of soft particles down to energies of 150 MeV for protons is measured and there is no evidence of a "knee". Meyer & Simpson[55] have reported that from 1948 to 1951, the "knee" of the latitude effect has shifted by 3° from 55°N to 58°N. They did not observe much change between 1951 and 1954, but since the results of Neher show that this change was almost entirely due to the influence of particles, if protons between 0.15 to 0.8 BeV, it is to be expected that these would produce little effect at 30000 ft. altitude where Simpson's observations were carried out.

Ellis et al[59] point out that during 1953 there was a cut off for heavy primaries at about the same latitude as for protons. This indicates a cut off dependent on the rigidity rather than the energy of the primaries. The results, which require confirmation during other years, therefore favour a mechanism involving magnetic fields as being responsbile for the cut off.

1.53 <u>Changes of solar anisotropy</u> :- From the analysis of data on meson intensity from 1937 to 1946 Sarabhai & Kane[60] have shown that there exists a correlation between changes of amplitude and time of maximum of the diurnal component of the daily variation at Carnegie Institution stations. These changes are related to the 11 year cycle of solar activity and with the magnetic character figure. Thambyahpillai & Elliot[61] have reported long term changes of the time of maximum of the diurnal component. They have combined data from various sources to study the trend of change from 1932 to 1952 which showed that the change probably followed a 22 year cycle of solar activity.

Steinmaurer & Gheri[62] have recetly compared results taken over groups of years during the past 23 years. They show that during sunspot minimum in 1933, the time of maximum of the diurnal component was at about 0700 hours, comparable with the time of maximum about 20 years later in 1953-1954, but was much earlier than the time of maximum 11 years later in 1944. This again indicates a relationship with the 22 year cycle of solar activity. It is noteworthy that a maximum as early as 0200 hours in 1954, has never before been observed. In a recent report by Possner & Heerdan[63] it is shown that, in some months in 1953 and 1954, the daily variation in the north and the south pointing telescopes exhibited maxima around midnight.

Further analysis of Carnegie Institution data from 1946 to 1953 by Sarabhai et al[64] revealed that changes of amplitudes at different stations were not correlated as they were between 1937 and 1946, but the change of time of maximum continues to exhibit worldwide characteristics. Furthermore the change is better correlated with activity of 5303°A coronal emission than with the relative sunspot number or the magnetic character figure. The shift of time of maximum of the diurnal component has been shown by Sandstrom[65] to be independent of the direction of arrival of particles and of the magnetic disturbance of the days characterised by Cp indices. However, results of Sarabhai et al[66] show that although the changes in the time of maximum of the diurnal variation with counter telescope at Ahmedabad and ionization chamber at Huancayo are well correlated, the former exhibits about 2.5 times greater change than the latter in 1951-1953. They have demonstrated that associated with these changes, large changes also take place in the semidiurnal component.

When the daily variation is considered as a whole instead ~~of~~ in terms of its harmonic components, a very remarkable sequence of changes is revealed as shown in Fig. 1.5. At Huancayo, the 12 monthly mean daily variation

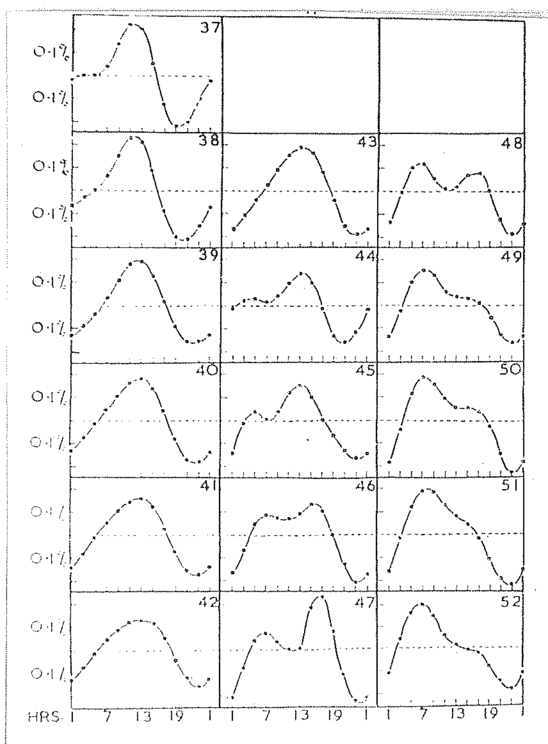


Fig. 1.5

which exhibits one maximum near noon from 1937 to 1943, changes over by 1952 to a variation exhibiting one maximum early in the morning. In the intervening period, there is clear evidence of the progressive increase of the early morning maximum followed by a decrease of the noon maximum. During the period 1945 to 1950 the daily variation therefore exhibits two maxima instead of one. Sarabhai et al[66] thus conclude that for the understanding of the physical processes of change of the daily variation, it is clearly necessary to discard individual consideration of only the diurnal component of the variation, and to look into the daily variation as such. Fig. 1.5 shows that only half the cycle of change appears to be completed in 11 years. This is again indicative of a 22 year cycle of change of the anisotropy.

Sarabhai et al[67] have suggested that these changes of the daily variation could be considered in terms of the contributions of two distinct types of variations, one having maximum near noon and the other having maximum at about 0300 hours. These are called 'd' and 'n' contributions respectively. The relative change of these two contributions is worldwide in character and can satisfactorily explain the observed changes from year to year in the daily variation of meson intensity at Huancayo and Cheltenham. The activity of these two contributions is related to solar cycle of activity and their relative contribution appears to be reversed after 11 years.

1.6 Short Term Changes

1.61 Magnetic storm type changes :- Worldwide decreases of cosmic ray intensity upto 10% soon after the beginning of the main phase of the magnetic storms have been reported in the past. These decreases are followed by a slow recovery lasting several days. These are called CR storms by the Japanese workers and are also known as Forbush events. Chasson[35] and Trumpy[68] have examined characteristics of some magnetic storm type decreases and found that all magnetic storms are not associated with decrease of cosmic ray intensity, and when effective storms take place, the ratio of change of magnetic field strength to the change of cosmic ray intensity is not constant from event to event. In storms such as the large storm on 1st March 1942, there is almost no latitude effect observable in the magnitude of the decrease at different stations extending from equator to high latitudes. On the other hand in some storms, the low energy component of the primary cosmic radiation appears to be disturbed more than the high energy component. Fonger[15] has reported that CR storm observed by a neutron monitor is five times larger than that observed by an ion chamber. Neher & Forbush[69] have compared a storm type decrease observed at 70000 ft. over Texas with the decrease in the ion chamber at Mt. Wilson and have shown that the effect was about four times more pronounced in the former case.

During the past three years, further work has been done in studying the solar and terrestrial relationships of magnetic storm type decreases in cosmic ray intensity. Chasson[35] has shown that decreases of intensity occurred on two occasions an appreciable time before the measurable geomagnetic disturbances. Trefall[70] has concluded that magnetic storms with dominant positive peak and a negative peak which is small or absent, produce no change of intensity. Kitamura[71] has shown that large decreases are accompanied by magnetic storms with sudden commencement. Miyasaki & Wada[72] have reported from the analysis of ion chamber data from Huancayo, that CR storms and magnetic disturbances follow an 11 year cycle but their times of maxima are not identical with that of sunspot maximum but shifted several years earlier. Moreover, at sunspot minima magnetic storms are not absent while CR storms become very small even to the extent of natural fluctuations. Taking Kp index as a measure of the magnitude of the worldwide geomagnetic disturbances, Forbush[53] has shown that cosmic ray intensity tends to be less for the five magnetically disturbed days than for the quiet days.

Sekido et al[73] have studied the solar relationship of cosmic ray effective and non-effective magnetic storms, which they designate as S and M type storms respectively. They have found that the frequency of S type storms varies in step with the 11 year cycle of solar activity, but this is not the case with M type storms which they associate with the supposed M regions on the sun. There is correlation between the occurrence of S type storms and the CMP of large sunspot groups. This feature is absent for M type storms. The 27 day recurrence tendency as seen with Chree diagrams, shows sharp peaks for M type storms but sinusoidal changes for S type storms. They conclude that S type storms are caused by wide corpuscular clouds ejected from sunspot groups, but the M type storms are caused by narrow corpuscular beams.

1.62 Day to day changes of intensity :- The day to day changes of intensity, some of which are of the 27 day recurring type, have been extensively studied in recent years. Early work[74] related to small increases and decreases in cosmic ray intensity which were found to recur with a period of approximately 27 days. A significant step forward was possible with data from Simpson's neutron monitors in which it was quite obvious that large and significant changes of intensity of a few percent in amplitude were occurring almost continuously from day to day. Simpson et al[75] have shown that these changes may some times be as large as 10%. They have also shown the association of the increases in cosmic ray intensity with the CMP of active solar regions, and particularly of regions of green coronal emission on the sun. These increases were often seen to be followed within two or three days by increased geomagnetic activity. Recently Simpson et al[76] have shown the close association of the CMP of UM regions with cosmic ray increases during 1953. These regions as well as the increases of intensity persisted for several solar rotations.

Several workers have now demonstrated that the day to day changes are worldwide in character. Fonger[15] has found that changes in the neutron monitor at Climax are similar to simultaneous changes observed in the ion chamber at Freiburg, Cheltenham and Huancayo, but on the average five times greater in amplitude. Neher & Forbush[69] have demonstrated the correlated changes occurring in the ion chambers at Huancayo and Cheltenham, the neutron monitor at Climax and ionization at 70000 ft. over Bismarck. Neher et al[57] have demonstrated that the changes at high altitudes over Bismarck and near the north geomagnetic pole are correlated among themselves and with changes in an ion chamber at ground level. Heerdan & Thambyahpillai[77] have recently investigated the correlated changes measured with a neutron monitor and a counter telescope at London. In the study of the 27 day recurrence of these changes, they find a decrease of mean intensity connected with the increase in amplitude of the fluctuations. They conclude that the changes represent decreases of intensity. Meyer & Simpson[78] have studied the 27 day recurrence tendency in the ion chamber data of Huancayo and the neutron monitor at Climax, and have demonstrated that the recurrence tendency is altered during the solar cycle. It is more pronounced during sunspot maxima, when incidently general intensity is low, and is weak at sunspot minima when the general intensity is maximum.

1.63 Day to day changes of anisotropy :- The change of the diurnal component of the daily variation of cosmic rays during magnetically disturbed days has been extensively studied by various workers[79-83]. The principal conclusions are that on days with high Kp, the amplitude of the diurnal component increases and its time of maximum becomes earlier. This effect was shown by Sekido & Kodama[79] to be present to a greater degree in measurements made with narrow angle telescopes than with instruments with wider directional sensitivity. Sekido & Yoshida[80] have moreover demonstrated that the semidiurnal component which is normally present to a greater extent in the daily variation measured with narrow angle telescopes than with telescopes of large semiangle, gets reduced on magnetically disturbed days.

Sekido et al[81] have shown that storm time vector, which represents the difference in the diurnal components of the disturbed period daily variation and quiet period daily variation, points on the average towards the radially outwards direction from the sun, and undergoes a change broadly in step with the 11 year cycle of solar activity.

Following the discovery of long term changes in the anisotropy of the primary radiation as revealed by changes in the 12 monthly mean daily variation of meson intensity, various attempts have been made to study the short term changes of anisotropy, not necessarily connected with magnetic disturbances. Firor et al[51] have demonstrated the highly variable character of the daily variation of the nucleonic component as revealed by the neutron monitor. They found groups of days on which there was a large diurnal variation with a maximum during the day. There were other days on which there was no appreciable daily variation, and indeed on others, the daily variation appeared to have a maximum in the night. Sittkus[84] has looked at the amplitude of the diurnal variation measured by an ion chamber on individual days and has noticed the tendency for a variation of large amplitude with a maximum near noon to occur during groups of days. He has found a 27 day recurrence tendency for these groups but compared to the rest of the days the days with large noon time amplitude are not associated with a significantly different magnetic character figure. Remy & Sittkus[85] have shown that during 1954, the occurrence of days on which there was a large day time maximum intensity was rarer than in 1953. They have moreover noticed a great variability of the time of maximum of the diurnal component of the daily variation.

The recurrence tendency of the anisotropy observed in the ion chamber data at Huancayo has been studied by Yoshida & Kondo[86]. They have found a strong recurrence tendency, extending to two solar rotations, which was more marked than the recurrence tendency in either the general cosmic ray intensity or in the magnetic character figure during the same period. Kane[87] has studied the recurrence tendency in the daily variation measured by neutron monitors at several stations and by the Freiburg ion chamber for the years 1951, 1952 and 1953. He has shown that this recurrence tendency in the daily variation, unlike the tendency in the general intensity, remains almost unaltered during the three years.

1.7 Solar Flare Effect

On five occasions during the last 14 years the cosmic ray intensity has been observed to increase sharply an hour or two following the occurrence of large flares. The observational data for the first four events have been summarised by Daudin[88], Elliot[1] and Forbush et al[89] and their important characteristics are as follows.

(a) These increases were worldwide in character being observed at stations in latitude higher than 25°. Their magnitude differed widely for stations at different longitudes and latitudes.

(b) On one occasion (Nov. 19, 1949) neutron monitor, counter telescope and an air shower recording apparatus were in operation. The neutron intensity increased very much more than the ionizing component recorded by a counter telescope, while there was no evidence of any significant increase in the rate of air showers during the period. This fact coupled with the absence of recorded increase at low latitudes suggest that the radiation responsible for them was more energy dependent than normal cosmic ray intensity.

During the last three years much further examination and analysis of earlier data has been done. Graham & Forbush[9] have confirmed in the records of an ion chamber at Thule on July 25, 1946 the occurrence of a polar type increase as reported earlier from Resolute and Godhavn. These results seem to suggest that the increases are due to new charged particles arriving at the top of the atmosphere with steep energy dependence. On the assumption that these particles of cosmic ray energy come from the sun, Schluter[8] and Firor[9] have examined the trajectories of charged particles in the geomagnetic field. Their results show that these particles in the rigidity range 2 to 10 BV can arrive in two narrow zones around 4 a.m. and 9 a.m. in terms of local time at the place of observation. The actual times vary by a few hours depending on the geomagnetic latitude of the sun, which of course varies with the season. In addition to these two main bands which are only an hour or so wide, there exist other diffuse zones which produce a general background having no strong local time dependence. In the latitude range 25° to 35° the background zone is effective while between 35° to 50° the increase in early morning zone will be three times as large as that in the background zone. Above 50° the morning zones would see additional increase upto seven times as large as in the background zone.

The impact zone theory, on assuming a solar diameter of about 30° as viewed from the earth, satisfactorily explains the principal features of the increases observed in middle latitudes. However there is difficulty in explaning polar type increases at latitudes higher than 65° on the basis of direct orbits from the sun.

Sekido & Murakami[91] have analysed the amplitude and the duration of the solar flare increases observed at different stations during each of the four early events. They distinguish between the effect occurring within the impact zones from the polar type increases, which have a longer duration and a less steep rise than the former. This is suggestive of a different mode of travel of particles for the polar type increases as compared to the direct trajectories for arrivals within the impact zones. It appears that the impact zone increases are due to particles coming from the vicinity of the sun as shown by Firor[9]. Since the corresponding visual eruptions on the sun did not bear any unique relation with heliographic latitudes or longitudes, these particles may be either emitted in wide cones or scattered by a trapping field around the sun and thus make these increases independent of the longitude of the eruption.

Since the time of intensity maximum of the impact zone increases is not so much different from the time of maximum of the solar flare, Sekido & Murakami[91] have assumed this increase to represent the energy spectrum and the time variation of cosmic rays emitted by the sun. These authors suggest that the flare radiation has a spectrum as E^{-5}. However there is a varying amount of averaging of the solar flare increases at different stations and there is also a difference in the geometry of the recorders at various stations. Hence a derivation of any definite power law spectrum at the present moment appears premature.

Treiman[92] has calculated that the solar magnetic moment should not exceed 5×10^{32} gauss cm^3, if the calculations of the impact zones by Firor are to be retained. Kraushaar[93] has made a similar calculation concerning the galactic magnetic field and puts an upper limit of 3×10^{-6} gauss for it. Kraushaar[94] has offered an interesting suggestion involving deflections in a galactic field of this magnitude and emission of particles from the sun over a wide range of angles for explaining the polar type of increases. A verification of this explanation would be possible from the seasonal dependence of the flare effect at polar latitudes, but it is difficult at present to confirm the validity of his hypothesis from the few instances which have been recorded.

From the analysis of data of cosmic ray neutron monitor at Climax, Firor has shown that a small increase in intensity of about 1%, as shown in Fig. 1.6, is associated with small solar flares if the detector happens to be in morning impact zones while no increase was observed when the station was outside the impact zones. That these increases

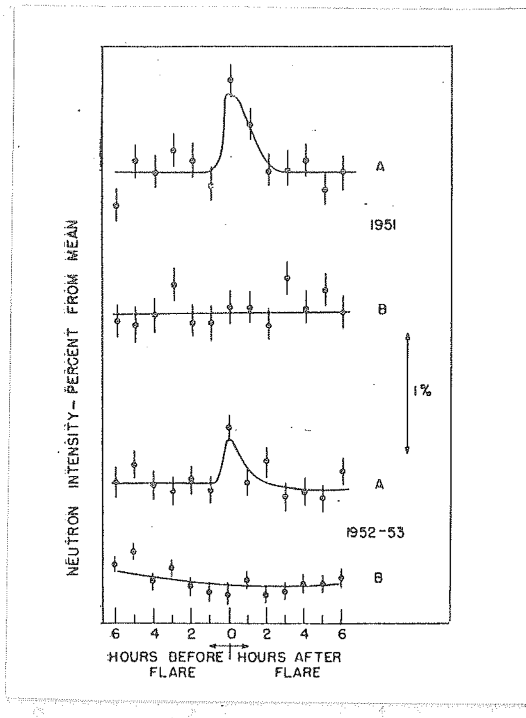


Fig. 1.6

are due to new particles produced on or near the sun is suggested by analogy with the large flare events where the size of the increase clearly exludes the possibility of a modulation effect on preexistent cosmic rays.

The most recent flare of Feb. 23, 1956 has been remarkable in many respects. It was of magnitude 3+ but apparantly more pronounced cosmic ray increases have been recorded than during the earlier events. An increase of about 4500% has been reported in a neutron monitor at Leeds by Marsden et al[95]. Incidently this station was in the early morning impact zone. But even at stations like Climax, which were far removed from the morning impact zones, a

2000% increase has been reported by Meyer & Simpson[96]. Moreover an increase of 5.7% averaged over an hour and 15% over an interval of 15 minutes at stations near the magnetic equator have been reported by Sarabhai et al[97] and Forbush[98] respectively. These increases, on the assumption of being caused by solar protons travelling along more or less direct paths, suggest that the energy spectrum of flare particles is extended even upto 40 to 50 BeV. Thus the upper limit of energy of flare particles is in some cases much higher than has been hitherto believed.

1.8 The Interpretation of Variations

1.81 Solar and terrestrial relationships of cosmic rays :- There is now a vast amount of evidence that the sun strongly influences the cosmic rays that are measured on the earth. Most of these influences have been revealed through relationships with the activity of the sun which changes markedly from time to time. Some activity persists through several rotations and produces characteristic 27 day recurrences. General solar activity changes with an 11 year period, while the state of magnetic polarity of bipolar sunspots has a period of 22 years.

The sun appears to influence the low energy cut off of the primary spectrum over an 11 year cycle. Independently of the change of the low energy cut off, it is known to also produce a change of intensity all over a spectrum with a cycle of 11 years. It produces changes of intensity of shorter duration. Some of these are related to the CMP of regions of solar activity such as sunspot groups, UM regions, filaments and regions of intense coronal 5303°A emission. The occurrence of the regions at low heliographic latitudes appears to favour their effectiveness in influencing cosmic rays.

The 12 monthly average anisotropy illustrate a change which is consistent with a cycle of 22 years and perhaps constitutes the first solar influence detected so far on the earth which has a period corresponding to what may be considered the true solar cycle of activity. This requires to be verified by observations extending over several cycles. The sun also produces day to day changes of anisotropy some of which are related to the CMP of active regions as in the case of variations of intensity.

The terrestrial relationships of cosmic ray variations with geomagnetic activity arise from the latter being themselves associated with solar activity. Similar is the case with some ionospheric disturbances. For instance Dolbear et al[99] have shown the association of cosmic ray increases with ionospheric disturbances during day time hours. Also flare type increases of cosmic rays are associated with ionospheric disturbances and radio fade outs.

1.82 <u>The mechanisms of variations</u> :- The close relationship of cosmic ray variations with solar activity has prompted various workers to investigate whether these changes are caused by the emission of cosmic rays from the sun. At the present moment there is general agreement on solar emission only in respect of the flare type increases. View is tending towards the modulation of cosmic ray intensity to explain other variations because of the combined weight of one or more of the following arguments which by themselves do not warrant an unequivocal answer.

(a) At minimum of solar activity, as judged by visual evidence on the solar disc or by comparative absence of terrestrial effects such as magnetic and ionospheric disturbances and auroral activity, there is an absence of "knee" with the presence of many low energy particles with energy down to about 150 MeV. Associated with these particles, there is an increase in general intensity, not only because of the absence of the low energy cut off but, due to enhanced intensity throughout the whole spectrum.

(b) Magnetic storms on many occasions are accompanied by decreases in cosmic ray intensity, but never with increases. Heerdan & Thambyahpillai[77] have shown that an increase in the general intensity is associated with the reduction of amplitude of 27 day recurrences, thus suggesting that 27 day recurring changes are decreases. They are therefore similar to magnetic storm type changes and indicate that screening of cosmic ray intensity has occurred. This is in general agreement with the minimum of amplitude of 27 day recurrences occurring at minimum solar activity when there is general enhanced total intensity.

The only evidence for an increase in cosmic ray intensity associated with visible solar disturbances is that put forward by Simpson et al[75,76]. Fig. 1.7 illustrates the sharp peaks of intensity which coincide

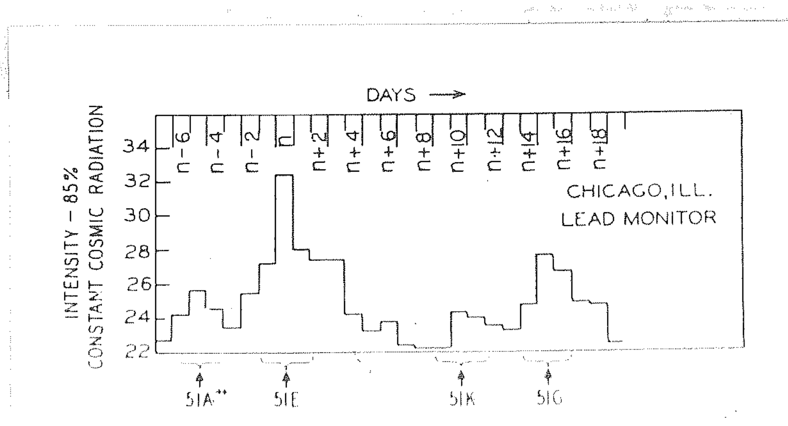


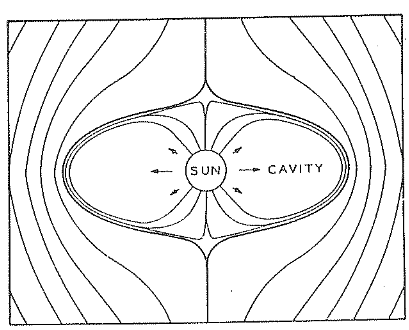
Fig. 1.7

with the CMP of active solar regions. It is not clear at the present moment that there is any reasonable argument to minimise the significance of this type of observation. Therefore, on the question whether the fluctuations in cosmic ray intensity are all decreases or decreases as well as increases, there would appear at the present moment a real difficulty in accepting the former view. More data on the type of visible solar activity with which the increases are associated are required to settle this point.

Because of close relationships with terrestrial disturbances, early workers tried to explain these variations in terms of the modulation of cosmic ray intensity by changes in the geomagnetic field. Simpson[100] has shown that the variations in the neutron intensity at latitudes above the "knee" of the intensity versus latitude curve were very similar to those observed at low and middle latitudes. Hence these variations in the nucleonic and ionizing components are not produced by geomagnetic field disturbances. Nagashima[16] has proposed a static electric field surrounding the earth and assumes changes in it to explain the worldwide nature of the intensity variations. His model explains fairly well the altitude dependence of the variations reported by Neher et al[57] and by Fonger[15], as well as their latitude dependence examined by Yoshida & Kamiya[101]. However, Simpson[100] has examined the effect on cosmic ray intensity of axially symmetric geoelectric fields, which may be produced by the radial polarisation of the ring current, at different distances from the earth. He observes that in the latitude range 45°N to 60°N, the latitude dependence of the fractional changes in neutron intensity during different periods does not agree with the latitude effect calculated for different distances of the field. He concludes that no accelerating decelerating geoeletric field is responsible for these variations. In addition, such a mechanism will be unable to account for large cosmic ray changes during periods when there are no geomagnetic disturbances and presumably no perturbing geoelectric fields. It will be rather difficult to tie up polar decreases as reported by Forbush et al[89] and Singer[102] with any symmetrical field hypothesis. Simpson therefore suggests that the mechanism responsible for the changes is of extraterrestrial origin and its association with solar phenomena is independent of the earth's system.

Alfven[103] first suggested that the emission of corpuscular matter from the sun which is responsible for magnetic storms is also responsible for cosmic ray fluctuations. An electric field is set up due to the polarisation of the neutral ionized beams which takes place in the presence of trapped solar magnetic field carried with it. The acceleration and deceleration of cosmic rays traversing the field may be expected to cause increases and decreases. This model has been discussed in greater detail by Brunberg & Dattner[104], to explain the decreases observed with magnetic storms. They consider the orbits of cosmic rays in a general field in the solar system and require a magnetic field of 10^{-5} gauss in the vicinity of the earth, if only decreases are to be observed. Alfven[105] has recently shown that the emission of corpuscular matter from the sun, being highly conducting, will modify the general dipole field of the sun to such an extent that it may be possible to have a field of 10^{-5} gauss in the vicinity of the earth, even if the sun's equatorial field strength is about 10 gauss.

Davis[106] has discussed the influence of the emission of ionized matter from the sun on solar and galactic magnetic fields within the solar system. He explains that the tendency would be to sweep the magnetic fields away and leave a field free cavity of a mean radius of about 200 a.u. around the sun. Fig. 1.8 shows



possible disposition of a solar magnetic field inside the cavity in the galactic field. The arrows represent the solar corpuscular radiation.

Fig. 1.8

the configuration of the magnetic fields around the sun by such a cavity. Cosmic rays of rigidity less than 10^{12} volts would be trapped within the cavity and their intensity would depend on its volume. He has tried to show that a 1% change of the mean radius of such a cavity with the 11 year solar cycle could explain the 4% change of intensity as observed by Forbush[53]. However this mechanism fails to explain the much larger long term changes of intensity for low energy thanfor high energy primaries, as observed by Neher[54] and Meyer & Simpson[55].

Morrison[107] has recently proposed a model which attempts to explain most of the principal features of various types of fluctuations observed in cosmic ray intensity which he believes to be decreases of intensity. He supposes that clouds of ionized matter are emitted more or less continually from all active regions on the sun. These clouds have within them turbulent magnetic fields instead of trapped coherent magnetic fields visualized by Alfven.[103] The clouds would be free of cosmic ray intensity when they are emitted, but intensity will slowly build up in them as cosmic rays diffuse into them. The intensity of cosmic rays at any time within the cloud, would be governed by the age of the cloud and the rate of diffusion of cosmic rays into it. The diffusion time depends on the scale of turbulence and the strength of the magnetic field and is therefore greater for low energy particles than for high energy particles. As the earth gets enveloped in one of these clouds, it experiences decreases of cosmic ray intensity depending on the intensity within the cloud at that moment.

Morrison expects that at great distances from the sun of the order of 100 a.u., there would be a fairly uniform diffuse cloud in place of the discrete structures seen at closer distances from the sun equivalent to the distance of the earth. Scattering in the distant diffuse clouds is expected to produce the general change of intensity as well as the change in the low energy cut off accompanying the solar cycle. This scattering would be more effective for low energy particles than for high energy particles and thus explains the experimental observations in this regard.

Morrison has suggested the possibility of being able to explain a cosmic ray intensity increase associated with the CMP of UM regions by postulating the presence of streams on either side of UM regions which would have more turbulence and therefore less intensity than the stream from the UM region. However not all cosmic ray increases have been associated with UM regions, and there might be difficulty in explaining the day to day increases on Morrison's model.

An attractive feature of Morrison's theory is that turbulent chaos and not a highly ordered model is called upon to explain the observed facts. Morrison thus comments on his model " it lacks the specific details of other proposals, but this weakness perhaps allows better experimental agreement".

Explanations of the daily variations of cosmic rays in terms of a solar magnetic field or the variations of a geomagnetic field became untenable quite early, because of the failure to detect the expected large latitude dependence of the variation. In the past few years, theories have been advanced for the average solar anisotropy due to modulation of primary radiation by changes in the electromagnetic condition surrounding the earth or in the interplanetary space. However, the occurrence of the storm time anisotropy and the frequent day to day changes makes it necessary to evaluate the physical meaning to be attached to the anisotropy derived from data averaged over a long period. In this connection theories which have been advanced by various workers to explain the characteristics of the storm type anisotropy assume a special significance. A detailed account of the various theories is given in Chapter V, but even though it is possible to explain the average amplitude of the order of 0.2% to 0.5% for the meson intensity and some of its changes on these theories, it is rather difficult to understand how a shift in the time of maximum in the daily variation by as much as 10 to 12 hours can arise.

1.9 Statement of the Problem.

The magnitude and the nature of the various types of variations of cosmic ray intensity depend upon the location of the observer, the characteristics of the instrument used for study as well as the physical phenomena responsible for the variations. Since most of the observations are made on the surface of the earth the observed variations arise partly because of terrestrial effects and partly due to changes in the primary cosmic radiation. Because of the spin of the earth, solar and galactic anisotropy of the primary radiation would produce a daily variation in solar and sidereal time respectively. Hence a study of the diurnal variation plays an important role in understanding the nature of the anisotropy of primary radiation.

The variations induced by terrestrial effects are (1) those of meteorological origin and (2) those caused by the changing magnetic or electric fields in the vicinity of the earth. These effects are often mixed up with the variations of primary intensity and those caused by the anisotropy of the primary radiation. It is therefore very important to understand and correct the terrestrial effects before one can interpret the nature of the primary variations or the anisotropy.

Since in low latitudes, the daily variations of atmospheric pressure and temperature occur with great regularity and are more pronounced than the day to day variations, it has been possible to estimate fairly well the role of meteorological factors in the daily variation of cosmic ray intensity. The contribution of the anisotropy of primary radiation which can be derived after applying correction for meteorological effects, can be confirmed by studies of the daily variation in counter telescopes pointing to the east and the west directions. The effect of the meteorological factors is eliminated by taking the difference between the daily variation of intensity in the east and the west pointing telescopes which are inclined at the same angle to the zenith. This difference does not reveal the true anisotropy, but enables us to satisfy ourselves that our concept of the anisotropy are compatible with an experiment in which the terrestrial effects are properly eliminated.

The cosmic ray group at the Physical Research Laboratory has, for some years, been devoted to a detailed study of the daily variation of cosmic ray intensity at low latitudes. Standard triple coincidence telescopes with semiangle of 22° in the E-W plane and 37° in the N-S plane have been in operation at Ahmedabad ($\lambda = 13^{\circ}$N, h = 180 ft.), Kodaikanal ($\lambda = 1^{\circ}$N, h = 7688 ft.) and Trivandrum ($\lambda = 1^{\circ}$N, sea level). Results of great significance to our understanding of the nature of the anisotropy of the primary radiation have been reported.

The author has initially been concerned with a study of the daily variation with standard telescopes pointing to the east and the west directions inclined at 45° to the vertical. Two completely independent instruments have been constructed and data collected for 28 months. The results are analysed and discussed in relation to the energy dependence of the solar anisotropy of the primary radiation.

When results of the daily variation measured in India with counter telescopes of moderate angle of opening are compared with the measurements at Huancayo, also at a low latitude, with an ionization chamber of omnidirectional sensitivity, it is quite obvious that the angle of opening of the telescope has a significant relationship with the nature of the daily variation and its changes with time. Sekido and his collaborators have drawn attention in a series of publications to the remarkable differences observed in the nature of the daily variation and its changes during periods of magnetic disturbance when measurements are made with vertical telescopes having semiangles of 12°, 40° and 85°. Having concluded that the daily variation is better observed with narrow angle telescope they have conducted an experiment with a telescope having a semiangle of 5° to determine the source of cosmic rays in the galaxy.

About three years ago experiments were commenced at Ahmedabad to determine the results of pushing the technique of narrow angle telescopes to what was considered a practical lower limit. Observations have been made by Mr.P.D.Bhavsar with a triple coincidence telescope of 1.8° in the E-W plane and a semiangle of 6.7° in the N-S plane. The intensity relates to the component of the cosmic radiation which can penetrate a minimum thickness of about 27 cm of iron at sea level. Harmonic analysis of the daily variation given by the bihourly percent deviations from mean shows that in 1953 the diurnal amplitude is 2.2 ± 0.5% and occurs at about noon. The semidiurnal component with an amplitude of 0.4 ± 0.5% is not significant but has a negative correlation of 0.81 with a semidiurnal component of the daily variation of barometric pressure.

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

The author has constructed an apparatus for this study and operated it for about 12 months. Interesting new characteristics of the daily variation of meson intensity have been revealed. Furthermore the solar anisotropy of the primary radiation has been found to be highly variable in character. Its solar and terrestrial relationships have been examined. The author has suggested a modification of the existing theories of the solar anisotropy of primary radiation developed by Nagashima and has discussed its implications in terms of the new experimental observations.

CHAPTER II

THE APPARATUS

2.1 Experimental Arrangement for Measuring Meson Intensity from the East and the West Directions.

The experiment has been performed with two completely independent equipments each consisting of a pair of telescopes pointing to the east and the west directions inclined at 45° to the vertical. Each pair is mounted on a stand which can be rotated around the vertical so that each telescope can be made to point to the east and the west azimuth. With such an arrangement each telescope can be made to spend equal amount of time towards each azimuth, and any systematic difference in the sensitivity of the two telescopes can be eliminated.

The configuration of the telescopes is shown in Fig. 2.1. Each telescope consists of three trays A, B and C with A and C placed 40 cm apart. Each tray contains four counters connected in parallel, each counter having a diameter 4 cm and a length of 30 cm. The area of a tray is therefore equal to 480 cm^2. The soft component is eliminated by placing 116 g/cm^2 lead between the trays B and C

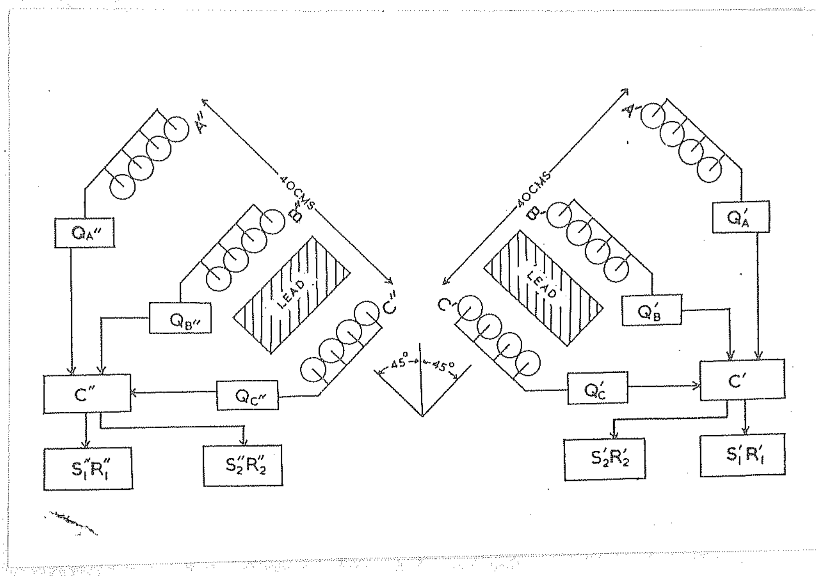


Fig. 2.1

Each telescope is enclosed in a box with sides of thermally insulating sheets to reduce the temperature variations affecting the counters. The box is mounted on rigid iron frame strong enough to carry the weight of the lead. The telescopes are set alternately in the east and the west azimuths. The movement of the telescope pair through 180° around the vertical is achieved by means of a worm gear drive. The change of position is done manually and takes approximately five seconds.

Central wires of all counters in a tray are tied together and connected to a quenching unit. Low capacity of the geiger counter circuit and a compact design is achieved by mounting quenching units Q_A, Q_B and Q_C very close to the respective counter trays. Outputs from the quenching units are fed to a coincidence unit C. In the present experiment double coincidences (BC) as well as triple coincidences (ABC) are recorded. The triple coincidence telescope admits radiation with a semiangle of 22° in the E-W plane and 37° in the plane perpendicular to it. The double coincidence telescope measures radiation with a semiangle of 39° in the E-W plane and 75° in the plane perpendicular to it. Outputs of the coincidence channels are fed to scaling and registering units where the recording is done by electromechanical recorders, which are photographed automatically at hourly intervals.

2.2 Experimental Arrangement for Studying Cosmic Ray Meson Intensity by Telescopes of Different Semiangles in the East and the West Plane.

In Fig. 2.2 is shown a diagram drawn to scale of the experimental set up. It consists of three trays viz. A, B and C containing 12 counters each, with a vertical seperation of 180 cm between A and C. The individual counters are 60 cm long and 4 cm in diameter. Each tray is divided into six pairs of counters, the central wires of each pair being connected together. The apparatus furnishes triple coincidences from three independent telescopes having semiangles of 2.5°, from two telescopes

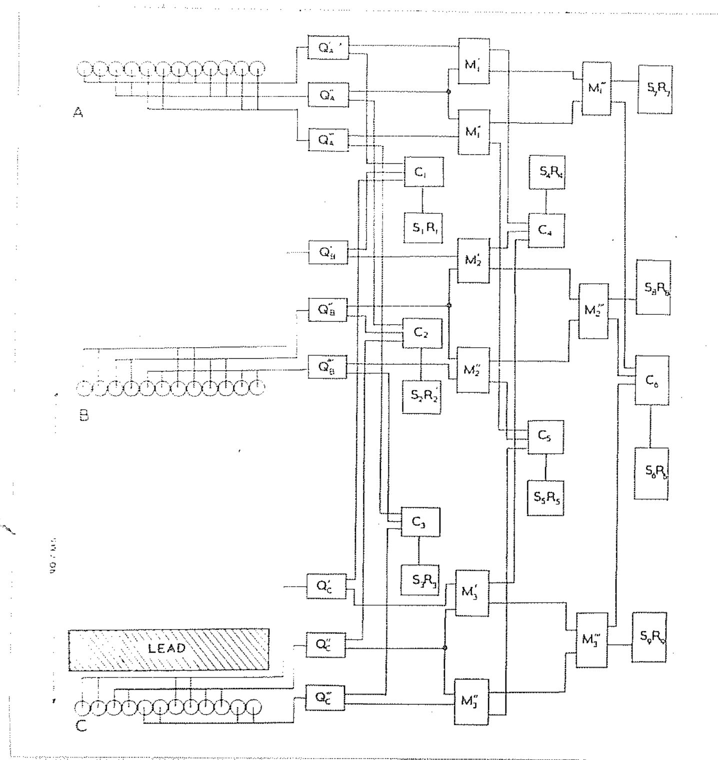


Fig. 2.2

with semiangles of 5° and from one telescope with a semiangle of 15° in the E-W plane. All telescopes have a semiangle of 19° in the N.S plane. 12 cm of lead has been used as shielding in every case. To increase the counting rate of telescopes without change of semiangle, duplicate sets of counters are placed horizontally displaced from the first set, but connected with them in parallel. This introduces no error except for a negligible contribution from penetrating air showers.

The apparatus is orientated so that the axes of the counters lie along the N-S direction which gives telescopes of different semiangles in the E-W plane but with same semiangle in the N-S plane. The different counting rates are derived in the following way.

The output of each pair of counters is fed to seperate electronic quenching units. The outputs of $Q_{A'}$, $Q_{B'}$ and $Q_{C'}$ are taken to the coincidence unit C_1 and so on for other pairs as shown in Fig. 2.2. The output pulse from C_1 is fed to a scaling and recording unit S_1R_1. Thus three independent recorders R_1, R_2 and R_3 register intensity from six telescopes each having a semiangle of 2.5° in the E-W plane. The outputs from $Q_{A'}$ and $Q_{A''}$ are fed to a mixer unit M_1' and those from $Q_{A''}$ and $Q_{A'''}$ to M_2' and so on in case of other trays. The outputs of M_1', M_1'' and M_1''' are fed to the coincidence unit C_4 and those of M_2', M_2'' and M_2''' to C_5 which in turn feed to S_4R_4 and S_5R_5 respectively. The combining of pulses from adjacent pairs of counters by mixer circuits in effect increases the sensitive area of the telescope by bringing more counters in parallel, and hence increases the semiangle of the telescope. In this case the sensitive area of the telescope is doubled and two recorders R_4 and R_5 register intensity from four telescopes each having semiangle of 5° in the E-W plane. These two rates are not totally independent since the four telescopes have A", B" and C" common and therefore register 20% intensity which is common to both.

The outputs of M_1' and M_2' are combined by the mixer unit M_3' and so on in case of other trays, and the outputs of M_3', M_3'' and M_3''' are fed to the coincidence unit C_6 connected to the scaling and recording unit S_6R_6. The mixing of all the pulses in a tray by M_3' brings effectively all counters in a tray in parallel and increases the sensitive area to about 3000 cm^2. R_6 measures, therefore, the radiation from a telescope having a semiangle of 15^o in the E-W plane. It is to be noted that the semiangle in the N-S plane is same in all different telescopes.

In addition, outputs of M_3', M_3'' and M_3''' are fed to scaling and recording units S_7R_7, S_8R_8 and S_9R_9 respectively. It is thus possible to have a continuous record of the rate of all the counters in a tray and this serves to keep a check on their behaviour. Atmospheric radioactivity makes an unknown and variable contribution to these rates and hence these cannot be taken to represent omnidirectional cosmic ray intensity.

The high voltage for G-M counters is obtained from an electronically regulated power supply described in Section 2.7. Decoupling condensers are put across all voltage terminals to prevent interfeeding between various electronic units. By using properly earthed shielded cables for connecting counters to the quenching units and the latter to the coincidence units, spurious counting is completely avoided.

2.3 Estimates of Errors in Measurements of Intensity.

In making a study of directional intensity with counter telescopes, the corrections that must be made to the observed counting rate have been described by Johnson[108]. Since the primary interest of the present investigation is to study the intensity variations and not the absolute intensity, many of the corrections except the contribution from side showers can be safely neglected. The contribution of side showers to the measurements made with triple coincidence telescopes used in the east west study described in Section 2.1 is 4%. In vertical telescopes described in Section 2.2 it is less than 1%. The estimates have been made by shifting laterally the central tray of the triple coincidence telescope so that a single particle cannot traverse all the three trays. The contribution of side showers to the measurements made with double coincidence telescopes used in the east west study is 8% which is derived from the study of Greisen & Nereson[109].

The finite resolving time of the electronic units makes it possible for unrelated particles to be recorded as single particles due to accidental coincidences. If N_1, N_2 and N_3 are the counting rates of three trays respectively and 't' is the resolving time of a coincidence unit the contribution of chance coincidences to double coincidence of trays 1 and 2 is given by Janossy[110] as $2N_1N_2t$. In a triple coincidence telescope it is given by

$$3N_1N_2N_3t^2 + 2C_{N_1N_2}N_3t + 2C_{N_2N_3}N_1t + 2C_{N_1N_3}N_2t \qquad (2.1)$$

where $C_{N_1N_2}$ is the coincidence rate of the double coincidence telescope of trays 1 and 2 etc. The maximum contribution comes from the middle two terms. In Table 2.1 the percent contribution of chance coincidences for various arrangements has been given.

Table 2.1

Percent contribution of chance coincidences.

Telescope	Percent
2.5_T	0.44
5_T	0.43
15_T	1.32
22_T	0.25
22_{ET}	0.25
39_{ET}	0.50

2.4 The Directional Response Characteristics of Counter Telescopes.

The coincidence rate of a counter telescope depends not only upon the intensity of the radiation but also on factors such as efficiency, effective length, diameter and seperation of counters. Hence it can be written as $N = G\,I$ where N is the counting rate, I is the intensity and G is a function of both the geometry of the telescope and the characteristics of the radiation. In calculating the form of G we use the formulae of Newell & Pressly[111] who have made the following simplifying assumptions.

(1), The shape of the effective volume of counters is a right circular cylinder.

(2) The counters are placed with their axes parallel to each other and normal to the line joining the centres of their axes.

(3) The radiation surrounding the telescope travels in rectilinear paths and suffers negligible scattering within the telescope. Greisen & Nereson[109] have shown that the mean square angle of scattering is only about 1.5° for scatter by 7 cm of lead.

(4) All and only those rays, which traverse the counters in extreme trays are counted.

A direction in space can be specified uniquely by an ordered pair of parameters $[\alpha, \beta]$ as shown in Fig. 2.3.

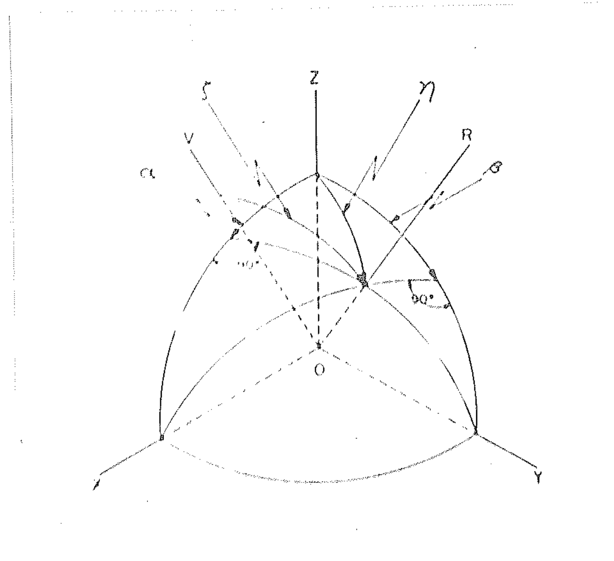


Fig. 2.3

Let $\sigma(\alpha,\beta)$ be the plane area normal to the direction $[\alpha,\beta]$ which a ray travelling parallel to $[\alpha,\beta]$ must cross in order to traverse extreme counters of the telescope. Let Σ denote the solid angle over which $\sigma(\alpha,\beta)$ does not vanish. Then the coincidence rate is given by

$$N = \iint I(\alpha,\beta)\,\sigma(\alpha,\beta)\,d\Sigma \qquad \text{—}(2\cdot2)$$

The total range of integration with respect to α and β is from $-\alpha_0$ to α_0 for α and $-\beta_0(\alpha)$ to $\beta_0(\alpha)$ for β, where

$$\alpha_0 = \sin^{-1}\delta \quad \text{and} \quad \beta_0(\alpha) = \tan^{-1}\left\{\frac{\cos\alpha}{\Delta}\left[\cos\alpha - (\delta^2 - \sin^2\alpha)^{1/2}\right]\right\} \qquad \text{—}(2\cdot3)$$

$\sigma(\alpha,\beta)$ over most of the range of integration is given by

$$\sigma = \frac{a^2}{(1-\sin^2\alpha\sin^2\beta)^{1/2}} \times \left\{(\delta - \sin\alpha)(\Delta\cos\beta - \cos^2\alpha\sin\beta) + \cos\alpha\cos\beta \left[\frac{\delta^2}{4}\cos^{-1}\frac{2\sin\alpha - \delta}{\delta} + \frac{1}{2}(\delta - 2\sin\alpha)(\delta\sin\alpha - \sin^2\alpha)^{1/2}\right]\right\} \qquad \text{—}(2\cdot4)$$

where $\delta = d/a$ and $\Delta = l/a$. The quantities a, d and l are the separation of centres, the diameter and the length of counters respectively.

If the axis OZ of the telescope is inclined at an angle to the vertical, the integrand is not symmetric in α and β. Assuming that the intensity of the radiation varies with the zenith angle γ in accordance with the cosine squared law, $I(\alpha, \beta)$ is given by $I(\alpha,\beta) = I\cos^2\gamma(\alpha,\beta)$. —(2.5)

The counting rate from a single hemisphere only is given by

$$N = I \int_{-\alpha_0}^{+\alpha_0}\int_{-\beta_0}^{+\beta_0} \cos^2\gamma(\alpha,\beta)\,\sigma(\alpha,\beta)\,d\Sigma \qquad \text{—(2.6)}$$

When the telescope axis is vertical, OZ coincides with OV in Fig. 2.3 and γ coincides with η. In this case

$$\cos^2\gamma = \frac{\cos^2\alpha\cos^2\beta}{1-\sin^2\alpha\sin^2\beta} \qquad \text{—(2.7)}$$

and the counting rate of the telescope is given by

$$N = 4I \int_0^{\alpha_0}\int_0^{\beta_0} \frac{\sigma(\alpha,\beta)\cos^3\alpha\cos^3\beta}{[1-\sin^2\alpha\sin^2\beta]^{5/2}}\,d\beta\,d\alpha\,. \qquad \text{—(2.8)}$$

Newell & Pressly have shown that the true counting rate lies between N_{2m} and N_{2M} where

$$N_{2m} = 4I \int_0^{\alpha_0}\int_0^{\beta_1(\alpha)} \frac{\sigma(\alpha,\beta)\cos^3\alpha\cos^3\beta}{[1-\sin^2\alpha\sin^2\beta]^{5/2}}\,d\beta\,d\alpha, \text{ and} \qquad \text{—(2.9)}$$

$$N_{2M} = N_{2m} + 4I \int_0^{\alpha_0}\int_{\beta_1(\alpha)}^{\beta_0(\alpha)} \frac{\sigma(\alpha,\beta,(\alpha))\cos^3\alpha\cos^3\beta}{[1-\sin^2\alpha\sin^2\beta]^{5/2}}\,d\beta\,d\alpha\,. \qquad \text{—(2.10)}$$

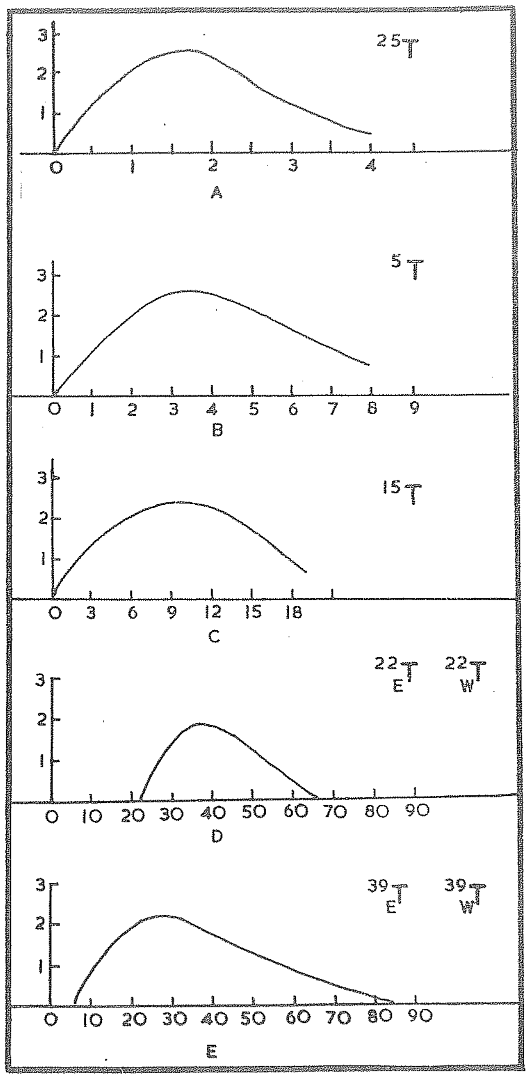


Fig. 2.4

In Fig. 2.4 are shown the polar diagram for various telescopes used by the author and described in Sections 2.1 and 2.2. The abscissae and the ordinates in (A), (B) and (C) represent the zenith angle $\gamma(\alpha,\beta)$

and the fractional intensity $N(\psi(\alpha,\beta))$ respectively, while in (D) and (E) they denote the zenith angle $\psi(\alpha)$ in the E-W azimuth and the fractional intensity $N(\psi(\alpha))$ respectively. The ordinates are expressed in arbitrary units. In ${}^{2.5}T$, ${}^{5}T$ and ${}^{15}T$ the fractional intensity at zenith angle $\psi(\alpha,\beta)$ is calculated by using equation (2.8) and is averaged over all azimuths. In the east and the west pointing telescopes, the fractional intensity represents the added up intensity at different zenith angles $\psi(\alpha,\beta)$ which correspond to the same angle α in the E-W azimuth.

An important thing to be noticed is that, in a telescope having a semiangle of 5° in the E-W plane and 19° in the N-S plane, more than three-fourth of the particles arrive from directions less than 5° with zenith. Comparison of polar diagrams of telescopes having semiangles of 5° and 15° in the E-W plane shows that the direction of maximum sensitivity is at 3.5° from the zenith for the former and 10° from the zenith for the latter. It is this direction which is important for cosmic ray measurements rather than the angular opening by themselves. Polar diagrams of the telescopes inclined to the vertical show that the direction of maximum intensity is at $\simeq 25^{\circ}$ for ${}^{39}_{E}T$ and ${}^{39}_{W}T$ and at $\simeq 35^{\circ}$ for ${}^{22}_{E}T$ and ${}^{22}_{W}T$.

2.5 Geiger Muller Counters.

The theory of operation and the methods of construction of G-M counters have been widely described in literature[112]. In the following sections the principal features of the discharge mechanism and the construction of the G-M counters which the author himself has prepared and used in the present investigation are described.

2.51 Mechanism of counter discharge :- A G-M counter is a gas filled diode operated in the region of unstable corona discharge. The condition for initiating the discharge is the production of at least one ion pair in the sensitive volume of the counter. The free electron triggers an avalanche discharge which spreads rapidly thoughout the length of the counter. The discharge lasts for few microseconds before it is extinguished by the positive space charge formed in the region of high field sensitivity near the central wire. Within a fraction of a millisecond after the triggering event, all ions and electrons are cleared out of the interelectrode space and the counter is ready for the passage of another ionizing particle. This process of extinguishing the discharge is facilitated by use of external quenching units which maintain the voltage across the counter below the geiger threshold while the removal of ions takes place.

The important characteristics of a counter are

(1) Threshold voltage i.e. the voltage at which the geiger region commences and this is the start of the

plateau in the counting rate as the voltage across the counter is increased.

(2) Plateau i.e. the voltage range above the threshold for which the counting rate does not change by more than 5% with change in the operating voltage.

(3) The useful life i.e. the number of events registered after which the plateau deteriorates to such an extent that the counter can no longer be relied upon.

(4) The efficiency i.e. the probability of obtaining a discharge when an ionizing radiation passes through the sensitive volume of a counter. This is dependent on the formation of a single ion pair in the counter gas.

The counters used in the present investigation had threshold voltages between 1200 to 1300 volts and a plateau of about 200 volts. The useful life of the counters was of the order of 10^7 counts. The efficiency of the counters is expected to be of the order of 99.5%.

2.52 Construction of all metal G-M counters :- The cathode consists of a brass tube of diameter 4 cm and of length 2.2 ft. The ends of the tube are faced off and the inside surface is polished with steel wool, or successively with three grades of emery paper, the last one being No. 1 grade. It has been found that minor grooves parallel to the axis of the counter tube seldom give counters which operate satisfactorily. The ends of the tube are closed with end pieces which are cut from a brass rod of diameter 4.5 cm. These pieces are turned on a lathe to fit tightly inside the brass tube. The inside surface of these end pieces is polished with steel wool as before. These are then drilled with holes in the centre for glass bushings which serve to hold the central wire in its place as well as to provide for the evacuation of counters and their filling. It is advisable to have holes for the bushings drilled slightly smaller than needed, and to enlarge them with a reamer to insure a good fit of the glass bushings.

Before assembling the parts of the counters, the inside surface of the counter tubes and end pieces are carefully cleaned with ethyl acetate to remove loose dirt, grease, etc. It is not advisable to use cloth for cleaning since cloth fibres remaining inside the tube may later cause spurious discharges. The above treatment probably leaves a fine coating of ethyl acetate on the inner walls of the counter and results in its better performance. For satisfactory operation of counters, the described treatment has been found adequate.

All parts of the counter are then assembled together and a thin tungsten wire of diameter 4 mil is threaded through the glass bushings. All metal to metal joints and metal to glass joints which fit closely are cleaned and warmed to 280°F to 300°F, and Araldite type I is then applied direct to them in stick form to make joints leak proof. Araldite is a new class of hardenable resins called Ethoxylines. It is thermosetting adhesive used primarily for metal to metal and glass to metal joints. The technique of applying Araldite is very similar to that of soft soldering. All joints are kept warm until Araldite sets, a process which can be observed by a change in colour. The entire assembly is then cured for few minutes. Tungsten wire of appropriate length is spot welded at both ends to thick tungsten pieces which are then sealed into the thin capillary ends of the glass bushings. The ends of the thick tungsten pieces which protude outside the glass bushings are then provided with metal beads prepared out of nickel and silver so that copper wire for external electrical contact can be joined to them. The inside ends of the glass bushings extend inside the counter for little more than an inch, thereby forming protective sleeves over the ends of the central wire[113].

Counters thus assembled are evacuated and joints are tested against leakage for about 16 hours. The leak proof counters are then filled with 90% of argon and 10% of pure ethyl acetate to a total pressure of 10 cm of Hg. The gases are allowed to mix for two hours and the characteristics of each counter are then tested separately.

Fig. 2.5 shows the schematic arrangement for testing counters. Pulses developed across the quenching resistance

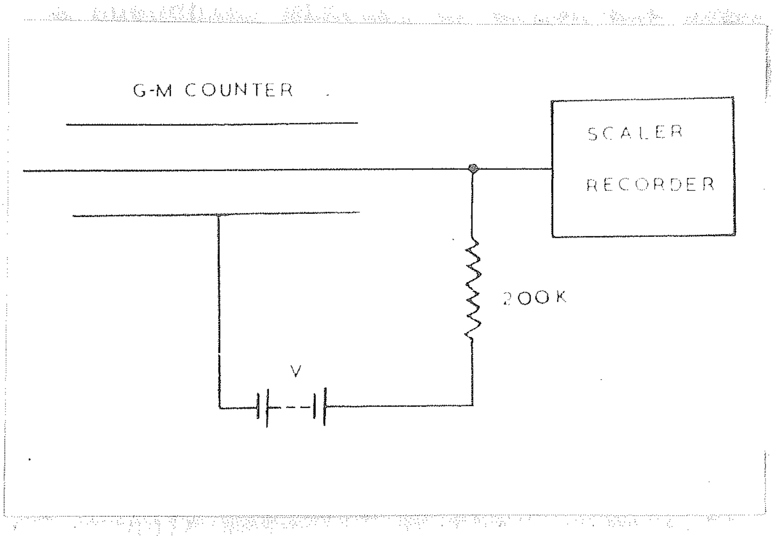


Fig. 2.5

of 200K are fed to a shaping unit which in turn feeds to the scaling and recording unit. The shaping unit is a one shot multivibrator which is triggered by all pulses above 5 volts. The voltage across the counter is slowly raised and the value at which the scaling unit starts counting is noted down. The voltage is then raised in steps of 40 volts and the rate of each step is noted down. If there is satisfactory indication of a flat plateau i.e. not more than 2% change in the counting rate for every 100 volts above the threshold for 200 volts, the counter is sealed at the constriction provided in the glass bushings. The characteristics of counters are rechecked after allowing them to operate at the middle of the plateau region for a period of about 16 hours. Counters retaining their characteristics after this process of aging are accepted for use.

2.53 <u>Improvement of characteristics of used counters</u> :- It is well established that G-M counters filled with a quenching mixture of argon and organic vapour deteriorate with use and hence have normally a few months of useful life when they are in continuous operation. Towards the end of their life the plateau shortens and proper adjustment of operating voltage becomes impossible. It has been shown by Friedland[114] that one of the main factors for the deterioration of counters is the decomposition of organic vapour with probable deposition of a film of organic material on the electrode surfaces. The refilling of counter with a new mixture of gases, though it may improve the operation somewhat, does not restore the original characteristics. Hence an investigation of some of the techniques of reviving used G-M counters was carried out on lines suggested by Hagen & Loughbridge[115].

End faces of bad counters were removed and the cathode surface was polished with emergy paper. The counters were rebuilt as described before. In half the number of counters, the original central wire was mounted while in other half new cleaned wire was installed. None of the first half gave satisfactory operation while all the counters in second half showed good characteristics. Thereupon in a group of 20 counters only the central wire was changed and counters refilled. 18 counters were restored to their original characteristics thus suggesting that the central wire is the most important factor in playing out of the counters and the condition of the cathode surface is not critical.

The replacement of the central wire is rather a labourious and uneconomical process and any other simple treatment of the central electrode is advisable. Shepard[116] has reported a simple treatment to restore the counter to its original characteristics. The treatment consists in heating the central wire to dull red by an electric current for about 5 minutes while the counter is being evacuated preparatory to filling the new gas.

As stated earlier the counter assembly is such that an electrical connection can be made at each end of the central wire. Heating current of 0.5 amp. is supplied from a variac which is adjusted until the wire observed through one of the glass bushings is visibly red. This treatment was adopted as a standard practice for every counter to be refilled and about 95% of the counters responded to such a treatment.

2.6 Associated Electronic Units.

2.61 Quenching unit :- As shown in Fig. 2.6 the quenching unit employs a univibrator followed by a differentiating network and a cathode follower. The former is used mainly as a source of a rectangular negative voltage pulse of 350 volts and of duration about 1 millisecond. The plate of one section of 6SN7 is directly connected to the central wire of the Geiger counter and pulses developed on the plate load are employed for triggering the univibrator which in turn feeds a negative rectangular pulses of 350 volts to the central wire. Thus the voltage across the counter is lowered considerably below the threshold for a period long enough for the collection of positive ions at the cathode and thus the occurrence of a secondary avalanche

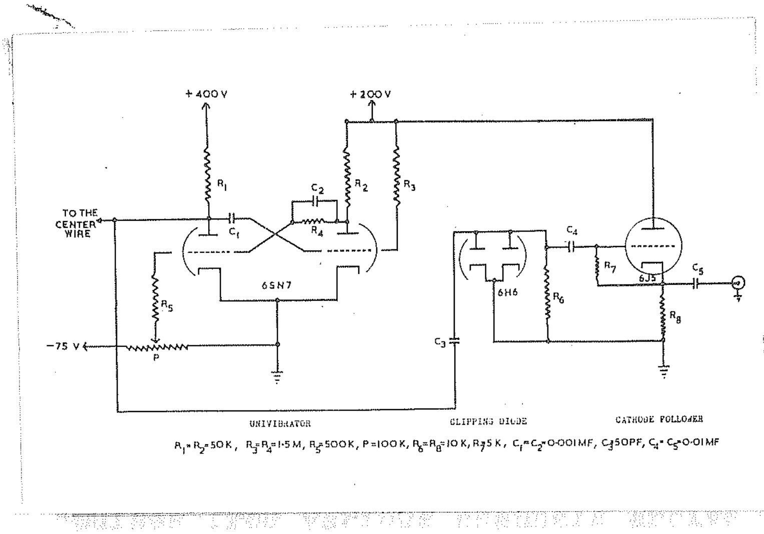


Fig. 2.6

is prevented. Such an arrangement, as shown by Putman[117], suppresses multiple discharges likely to be developed in selfquenched counters after a few months of continuous operation. In addition to an improvement in plateau slope and stability, Elliot[118] has demonstrated that by the above arrangement there is an appreciable increase in counter life due to the decrease in the spread of the initial discharge by the quenching action of the univibrator.

The square negative pulse given by the univibrator is differentiated by means of RC coupling network having a short time constant (RC = 0.5×10^{-6} sec.). Such a differentiation gives a negative pulse at the onset of the discharge and a positive pulse delayed by about 1000 µsec. The positive part is clipped by the diode which as shown in Fig. 2.6 offers a high impedence for negative signals and low impedence for positive signals. Since the negative pulse is to be fed to a number of channels, it is preferable to feed it through a cathode follower which having a low output impedence minimises the loss of signal[119].

2.62 <u>Coincidence unit</u> :- To achieve the directional property of a telescope, a coincidence circuit described by Rossi is normally used. The principal feature of the circuit is that an output pulse is obtained only when input pulses from various channels arrive within a very short interval of time of the order of a few µseconds. To ensure good discrimination between partial and total coincidence outputs, pentodes with low internal resistance should be used. In the present experiment sharp cut off 6SJ7 pentodes are used and the ratio of threefold to twofold coincidence outputs is greater than 20.

In the experiment with inclined telescopes there is need to simulteneously record twofold and threefold coincidences. Following Howland et al[120], a combination of a diode pentode coincidence circuit for generating several related coincidences is used as shown in Fig. 2.7.

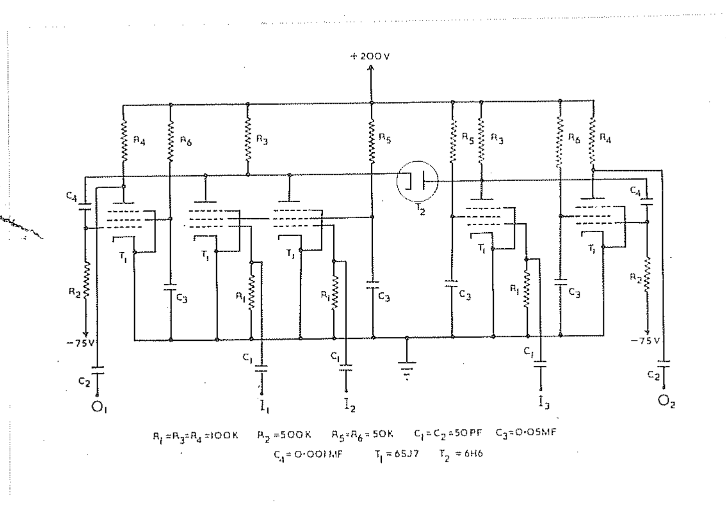


Fig. 2.7

The first coincidence is formed by using pentodes in a conventional Rossi type arrangement. The signal is then coupled through a diode to the plate of the other pentode from which point the second output is taken. The polarity of the diode is such that no positive signal occurs at the second output unless it occurs simulteneously with the signal at the first output. Thus with only three pentodes and a diode, twofold and threefold coincidences can be recorded separately. The resolving time of the circuit is found to be of the order of 5 μseconds.

2.63 Scaling and recording unit :- Output pulses from coincidence units are of very small duration and require tobe shaped before they can be recorded by mechanical devices. This is achieved by a scaling and recording unit shown in Fig. 2.8. There are two distinct functions

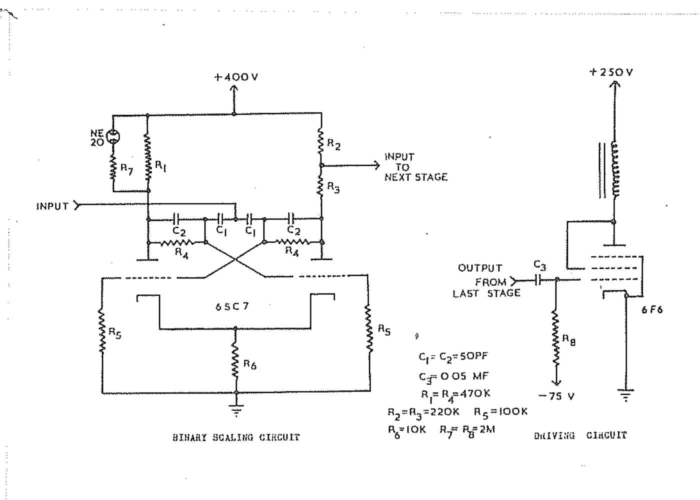


Fig. 2.8

performed by this unit. The first one is that of reducing the input rate to the mechanical recorder and the second is to change the random distribution of pulses into one where the time intervals between pulses are more nearly equal. It has been shown by Alaoglu & Smith[121] that the time interval between every r^{th} pulse will have standard deviation given by $\{1/(1+r)\}^{1/2}$ so that as r increases the r^{th} pulse will be more regularly placed.

The circuit in Fig. 2.8 is based upon the well known Eccles Jordon circuit and has a flipflop time of about 15 µsec. This time determines the resolving time of the circuit and puts a limit to the maximum number of pulses that can be efficiently handled. For higher scaling ratio, similar circuits are used in cascade. Whenever the circuit used in the arrangement has a low scaling ratio it is equipped with indicating neon for visual check on its behaviour. In case of circuits of high scaling ratio, they can be tested on oscilloscope without disturbing their normal operation.

The cascade of such scaling units is followed by a driving circuit for the mechanical recorder. The minimum operating current is 10 ma and they have an inductance of 7.5 henries and a DC resistance of 2200 ohms. They can be operated at upto 10 pulses per second provided these pulses are regularly distributed in time.

2.7 Power Supplies.

In this section a short account is given of the power supplies which are used for providing power to various electronic units described in Sec. 2.6. Most of the units described earlier have been designed for plate supply of 400, 200 and 150 volts and a bias voltage of -75 volts when this is required. Although the choice of these values is somewhat arbitrary, it is experienced that they represent the best compromise when the properties of vacuum tubes, convenient signal levels etc., are all taken into account. It is necessary in investigations such as the present one, that the supply voltages should be constant in order that the efficiency of various units does not alter. Hence all the power supplies are designed and built with stabilising circuits.

A voltage stabilised power supply accomplishes more than simply furnishing a DC voltage of a fairly stable value. It affords a source of low impedence considerably reducing the interaction between various parts of the circuit to which it furnishes power and the stabilising circuit itself acts as an excellent filter for ripple voltages. Hunt & Hickman[122] have discussed in detail various types of voltage stabilising circuits and have shown those of the simple degenerative type are generally the most satisfactory. Hence for the present investigation mostly degenerative type stabilising circuits are used. The range of input voltage over which the stabilisation is operative is at least 180 to 250 volts and is greater when the supply is not fully loaded. The mains supply voltage at Ahmedabad fluctuates in extreme cases between 190 to 240 volts and has a frequency of

50 ± 0.5 c.p.s.

2.71 <u>High voltage power supply</u> :- Fig. 2.9 shows the circuit diagram of the high voltage power supply used for providing high voltage to G-M counters. The potentiometer P helps in controlling the output voltage over a wide range from 1000 to 1700 volts. The circuit is based on model 200 power supply described in "Electronics"[119], with the

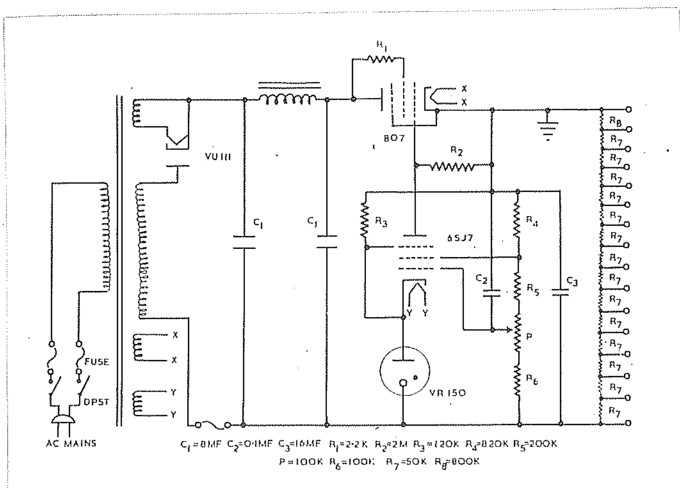


Fig. 2.9

modification that the sharp cut off pentode 6SJ7 which is used as a difference amplifier is operated in the starvation region[123]. In the present investigation the power supply is adjusted to an output of 1200 volts and the various voltage tappings for counters are obtained from the bleeder circuit shown in the diagram. The decoupling of each tapping with a 0.05 MF condenser avoids any interfeeding of the counter pulses which may result in spurious counts.

2.72 <u>Low voltage power supplies</u> :- Figs.2.10(a)(b) show the circuit diagrams of power supplies which give 400 and 200 volts. The circuit is based on model 50 unit which employs a double triode difference amplifier followed by a simple triode amplifier. The circuit constants are computed for the above output voltages and with minor adjustments the stabilised output voltage of the supply shows very little drift with 20% change of heater voltage.

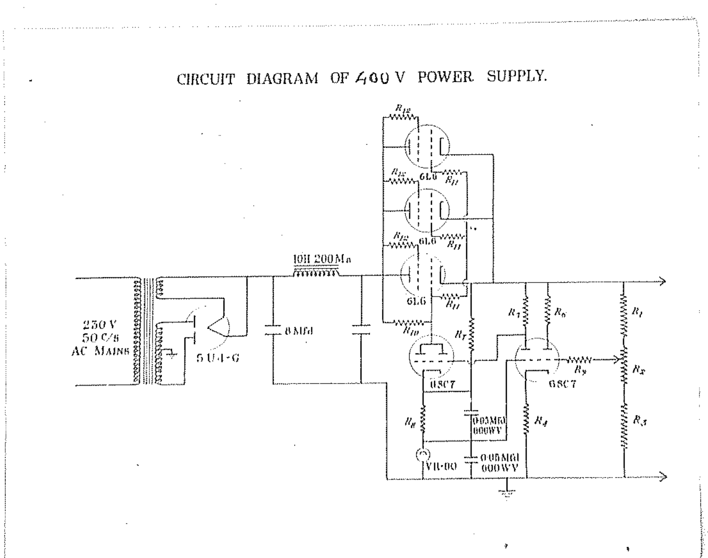


Fig. 2.10(a)

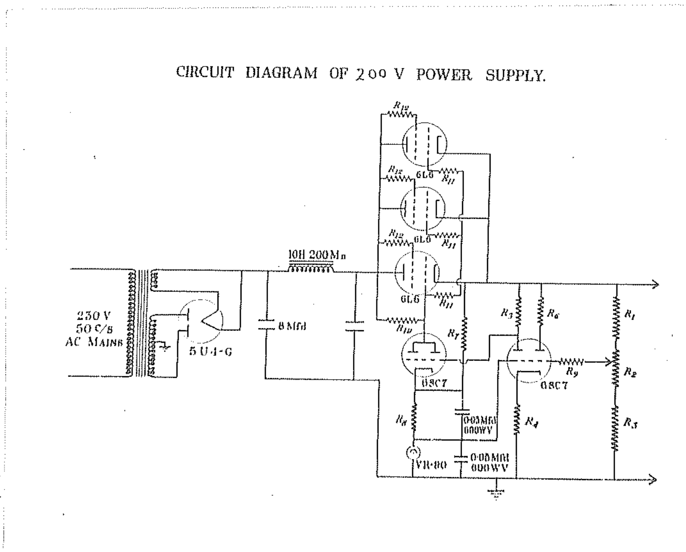


Fig. 2.10b

In applications where the current load is relatively small and subject to limited variations and the degree of stabilisation necessary is not very high, it is more economical to employ a simple gas filled VR tube stabilisation than to construct an electronically stabilised power supply. In the present circuits, the current consumed from the negative bias supply is in the range of 15 to 20 ma and hence a VR75 tube is used. For 150 volts supply VR150 is used as the degree of stabilisation required is not very high. Fig. 2.11 gives the circuit diagram of -75 volts power supply.

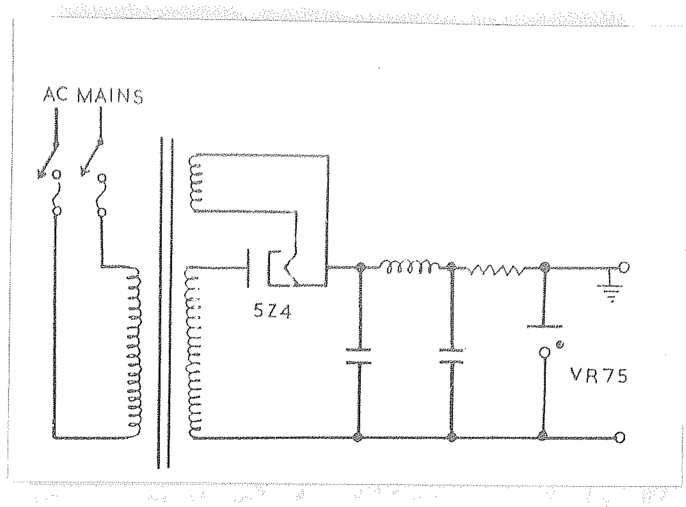


Fig. 2.11

2.8 Automatic Photographic Device.

The mechanical counters are mounted on a panel along with the indicator lamps showing the azimuthal direction of the inclined telescopes, a twelve hourly clock and the date of the day. This panel forms one end of a light tight box containing two bulbs to illuminate the panel when required, and on the opposite side a detachable camera is attached which takes periodic photographs of the panel on 35mm Super XX film. A typical enlarged photograph is reproduced in Fig. 2.12.

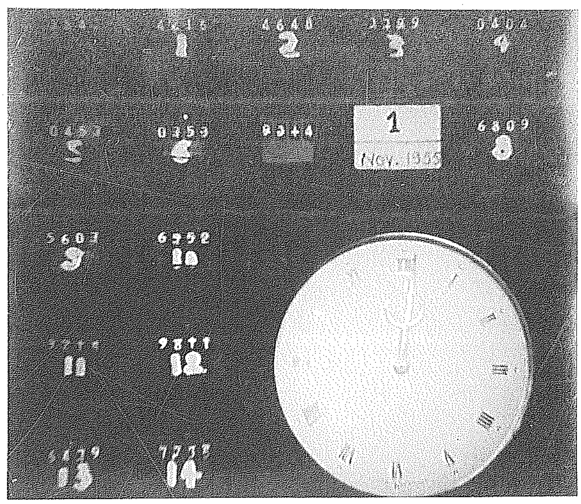


Fig. 2.12

The camera control is illustrated in Fig. 2.13.

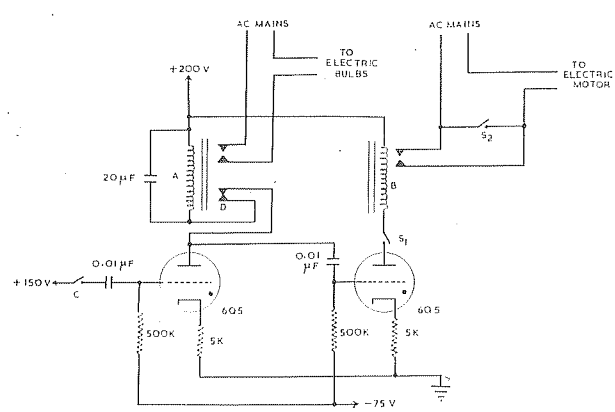


Fig. 2.13.

The lighting of bulbs to illuminate the panel is controlled by the relay A which closes and hence lights the bulbs for 1/10 of a second whenever the contact C is made once every hour. The closing of contact D when the relay A is put off triggers the second thyratron and closes the relay B thus starting the motor which winds the exposed film in the camera. The motor is internally provided with switches S_1 and S_2. By virtue of S_1 the relay is kept on for 15 seconds and by virtue of S_2 the motor is kept running for 15 seconds more. After 30 seconds the circuit returns to the original condition and the sequence only begins once again when C is closed after one hour.

The camera holds about 50 ft. of film at a time, and therefore every day in the morning just after 9 a.m. the exposed part of the film is removed in the dark room, developed and washed. The readings of the mechanical recorders are noted down and analysed as described in Chapter III.

CHAPTER III

METHODS OF ANALYSIS

3.1 Tabulation of Primary Data

The hourly photographic record shown in Fig. 2.12 shows the reading of mechanical counters corresponding to different cosmic ray telescopes. For the purpose of the present investigation, the records of odd hours only are noted down. From a set of 13 readings corresponding to 0100, 0300,........2300 hours and 2300 hours of the previous day, the differences in successive readings are evaluated. This gives a series of twelve bihourly values centered at 0000, 0200, ...2200 hours which are named as C_0, C_1,.........C_{11} respectively. The presentation of data at bihourly intervals is chosen mainly to reduce routine labour. For the daily variation of meson intensity, this is quite adequate. The mean bihourly value for the day $\overline{C}$ centered at 1100 hours is computed as $\overline{C} = (C_0 + C_1 + \ldots C_{11})/12$.

The values of atmospheric pressure are read out for 0000, 0200,.........2200 hours from the daily weather charts supplied by the India Meteorological Department.

These values represent instanteneous values of ground pressure as against those of cosmic ray counts which refer to the average intensity during bihourly intervals. The daily data chart thus contains twelve bihourly values for each cosmic ray telescope and corresponding values of barometric pressure. It also contains the daily mean intensity of cosmic rays and the daily mean pressure. The daily mean values of identical telescopes are plotted to see whether individual telescope readings run parallel to each other within the limits of statistical accuracy. Data from a telescope whose behaviour is very different from other similar telescopes are discarded. All the accepted data are then expressed as deviations from mean.

3.2 Determination of the Daily Variation

The daily variation on any day is determined by adding the deviations of the same bihourly interval of similar telescopes and the added data are expressed as a series of 12 deviations from the mean intensity. In general from the data of any one day, it is difficult to judge the genuine periodic variation since the statistical uncertainties are rather large. Hence to demonstrate these periodicities with statistical significance, it is customary to derive the average of the daily variation over a large number of days, selected and grouped according to appropriate criteria. The daily variation for a group of days is found by combining the deviations corresponding to the same bihourly interval of all days in the group. The data are then represented by a series of twelve values namely $\Sigma\Delta C_0, \Sigma\Delta C_1, \ldots\ldots\ldots \Sigma\Delta C_{11}$ and the mean intensity for the group as $\Sigma\bar{C}$. Finally the data are expressed in percentage deviations from mean, to facilitate comparison between variations of different sets.

In the same manner, the average daily variation of ground pressure is evaluated and represented by twelve values viz. $\Sigma\Delta P_0, \Sigma\Delta P_1, \ldots\ldots\ldots \Sigma\Delta P_{11}$ and the mean pressure for the group as $\bar{P}$.

3.3 Fourier Analysis

Many variations in geophysical phenomena which are related to the spinning of the earth, have periods of 24 and 12 hours. To elucidate these mixed periodicities, it is often convenient to resolve the variation into its harmonic components. Any variation can be expressed as a Fourier series i.e. a series of the type,

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

This can be written as $F(x) = a_o + \sum_1^{\infty}(a_n \cos nx + b_n \sin nx)$ where $0 < x < 2\pi$. If data consist of twelve equally spaced value viz. $U_0, U_1 \ldots\ldots\ldots U_{11}$ corresponding to time $t_0, t_1, \ldots\ldots\ldots t_{11}$ respectively, harmonic analysis consists in determining the coefficients a_o, a_n and b_n so that the residual $(U_i - F(t_i))$ should be as small as possible. The coefficients a_n and b_n corresponding to a series of 12 values are given by

$$a_n = \left(\sum_{1}^{12} U_i \cos nx_i \right)/6 \quad \text{and} \quad b_n = \left(\sum_{1}^{12} U_i \sin nx_i \right)/6$$

where values of $n = 1, 2, \ldots\ldots$ correspond to 1st, 2nd.... harmonics respectively. F(x) can also be written as

$$F(x) = a_o + \sum_{1}^{\infty} A_n \sin (nx + \alpha_n)$$

where $a_n = A_n \sin \alpha_n$ and $b_n = A_n \cos \alpha_n$. A_n and α_n are called the amplitude and the phase of the n^{th} harmonic and can be evaluated as

$$A_n^2 = a_n^2 + b_n^2 = \frac{1}{36} \cdot \sum_{1}^{12} (U_i \cos nx_i)^2 + \frac{1}{36} \cdot \sum_{1}^{12} (U_i \sin nx_i)^2$$

$$\text{and} \quad \tan \alpha_n = \frac{a_n}{b_n} = \frac{\sum (U_i \cos nx_i)}{\sum (U_i \sin nx_i)} .$$

Since the present data U_i are expressed as deviations from mean we have $a_o = 0$. The twelve values are taken over an interval of a day or 24 hours. A_1 and α_1, therefore, represent the amplitude and the phase of the fundamental harmonic having a period of 24 hours. A_2 and $_2$ give corresponding parameters for the second harmonic having a period of 12 hours.

The actual labour of computation involved in evaluating the harmonic coefficients can be minimised by suitable arrangement of the work. Various authors have described methods with different degree of simplification. The method suggested by Kane[124] is followed which possibly gives the first and the second harmonic coefficients with minimum labour and time.

3.4 Harmonic Dial Representation

When the periodic components of the same frequency n derived from different series of data are to be compared, it is very convenient to use graphical representation which indicates both the amplitude and the phase of the harmonic component. The Fourier coefficients a_n and b_n can be considered as the components of a vector A_n on mutually perpendicular axes as shown in Fig. 3.1. The maximum of

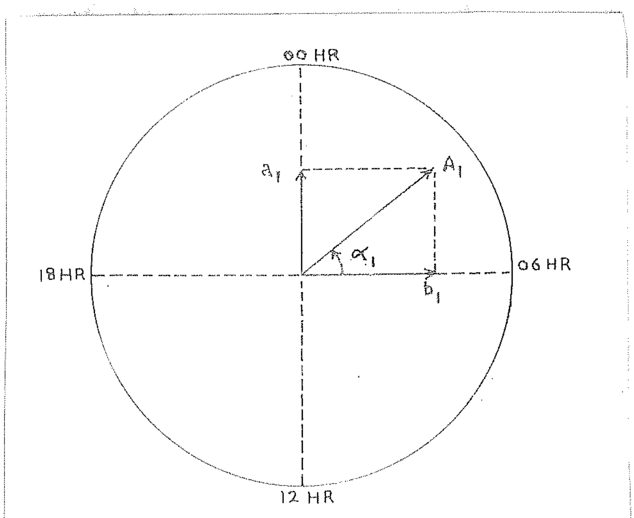


Fig. 3.1

the sine wave occurs when $nx + \alpha_n = \pi/2$. The vector is therefore directed along the time of maximum. A time scale such that 360° measured in a clockwise direction is equal to 24 hours is introduced to represent the first harmonic. The higher harmonics can be represented similarly by inserting appropriate time scales viz. 360°= 12 hours for the second harmonic component etc. Such a representation has been named "Harmonic dial" by Chapman[125].

3.5 Errors of the Fourier Coefficients.

The standard error σ_F of the quantity F which is a function of r variables viz. $C_1, C_2, \ldots\ldots C_r$ is given by

$$\sigma_F^2 = \left(\frac{\partial F}{\partial C_1}\right)^2 \sigma_{C_1}^2 + \ldots \left(\frac{\partial F}{\partial C_i}\right)^2 \sigma_{C_i}^2 + \ldots \left(\frac{\partial F}{\partial C_r}\right)^2 \sigma_{C_r}^2$$

In our case r = 12 and

$$F^2 = A_1^2 = \frac{4}{r^2}\left\{ \sum_1^{12} (U_i \cos x_i)^2 + \sum_1^{12} (U_i \sin x_i)^2 \right\}$$

$$\therefore A_1 \frac{\partial A_1}{\partial U_i} = \frac{4}{r^2}\left[\sum (U_i \cos x_i) \cos x_i + \sum (U_i \sin x_i) \sin x_i \right]$$

or $$\frac{\partial A_1}{\partial U_i} = \frac{2}{r} \sum \sin(\alpha_1 + x_i), \quad \sigma_{A_1}^2 = \frac{4}{r^2} \sum \sin^2(\alpha_1 + x_i) \sigma_{U_i}^2$$

All U_i have equal hourly standard errors and $\overline{\sin^2(\alpha_1 + x_i)} = \frac{1}{2}$

$$\sigma_{A_1}^2 = \frac{\epsilon^2}{6} \quad \text{where } \epsilon = \sigma_{U_i} . \quad \therefore \sigma_A = \epsilon/\sqrt{6} .$$

Let $$\tan \alpha_1 = \psi = \frac{\sum U_i \cos x_i}{\sum U_i \sin x_i}$$

$$\therefore \frac{\partial \psi}{\partial U_i} = \frac{\cos\alpha_1 \sum \cos x_i - \sin\alpha_1 \sum \sin x_i}{6A_1 \cos^2\alpha_1}$$

$$= \frac{\cos(\alpha_1 + x_i)}{6A_1 \cos^2\alpha_1}$$

$$\therefore \overline{\sigma\psi}^2 = \frac{1}{6} \frac{\overline{\sigma U_i}^2}{A_1^2 \cos^4\alpha_1} \quad \text{and} \quad \overline{\sigma\psi} = \frac{1}{\sqrt{6}} \frac{\varepsilon}{A_1 \cos^2\alpha_1}$$

$$\text{Since} \quad \alpha_1 = \tan^{-1}\psi, \quad \overline{\sigma\alpha_1} = \cos^2\alpha_1 \, \overline{\sigma\psi} = \frac{\overline{\sigma A_1}}{A_1}$$

Thus the errors in A_1 and α_1 are given by $\varepsilon/\sqrt{6}$ and $\varepsilon/A_n\sqrt{6}$ respectively. These errors are shown by drawing an error circle at the tip of the vector in the harmonic dial. The significance of the harmonic coefficients can be judged by the relation between this error circle and the length of the vector.

3.6 Correction for Influence of Meteorological Factors.

The implications of various assumptions made in Duperier's regression equation in terms of the interpretation given to the coefficients that are derived from it, have been discussed in Chapter I and it is found that it is not possible to ascribe a unique physical interpretation to each of the coefficients. However, the physical processes governing them are known fairly well so that most of the experimental discrepancies can be explained. The considerations which govern the contribution of the daily variation of barometric pressure and the temperature of the atmosphere have been discussed earlier. Sarabhai et al[66] have suggested on various considerations, that it is appropriate to use a barometer coefficient $\alpha_B = -2.2\%$ per cm Hg. for the daily variation of the vertical meson intensity to eliminate atmospheric effects affecting the daily variation. In applying correction to data derived from the east and the west pointing telescopes inclined at an angle of 45° to the vertical, it is necessary to realise that for the same change of pressure at ground, cosmic rays coming in inclined directions undergo a greater change of atmospheric mass than rays coming from the vertical direction. Thus the barometer coefficient applicable to the meson intensity in an inclined direction must be larger by approximately a factor sec η when η is the zenith angle of the direction of arrival of particles. Therefore, data from telescopes pointing to the east and the west directions inclined at an angle of 45° to the vertical are corrected for barometer variations by a barometer coefficients 2.7% per cm Hg and − 2.5% per cm Hg. when measurements are made with telescopes having semiangles 22° and 39° in the E-W plane respectively.

For data from the narrow angle telescopes a barometer coefficient of −2.2% per cm Hg. applicable to vertical radiation is applied. Since the uncorrected daily variation in telescopes with semiangles 2.5°, 5° and 15° have large amplitudes, the application of a barometric correction of this magnitude makes little material difference to the nature of the variation.

3.7 Nomenclature

M	The daily variation of meson intensity, corrected for variations in barometric pressure.
P	The daily variation of barometric pressure.
M^D	The percentage amplitude of the diurnal component of M.
$M\phi^D$	The time of maximum of M^D given by the angle in a clockwise direction between the direction of midnight and of the vector for M^D on a 24 hourly harmonic dial.
M^S	The percentage amplitude of the semidiurnal component of M.
$M\phi^S$	The time of maximum of M^S given by the angle in a clockwise direction between the direction of midnight and of the vector M^S on a 12 hourly harmonic dial.
$^*M$	The daily variation M before applying correction for barometric pressure.
$^*22_M$	The daily variation *M by a telescope having semiangle of 22° in the E-W plane.
$_E M$	The daily variation M by an east pointing telescope.
$_W M$	The daily variation M by a west pointing telescope.
$\bar{M}$	The 12 monthly mean value of M.

22_T Telescope having a semiangle of 22° in the E-W plane.

T_1 Telescope No. 1.

CHAPTER IV

EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Study with East and West Pointing Telescopes.

The apparatus described in Sec. 2.1 first came into operation in February 1953, when records were obtained only from triple coincidence telescopes. In March 1954 the coincidence unit was replaced by one described in Fig. 2.7 which permitted simultaneous records of meson intensity in the east and the west directions with double and triple coincidence arrangements. A duplicate apparatus was constructed and put into operation in April 1954. The data extend, therefore, from March 1953 to July 1955 for triple coincidence telescopes from one unit and from April 1954 to July 1955 for triple coincidence telescopes from the other unit. For double coincidence telescopes the data are obtained from April 1954 to July 1955 from both the units. However to avoid any seasonal effect which seems to be very complicated and not yet properly understood, the data over a period of two complete years from May 1953 to April 1955 for triple coincidence telescopes and of one complete year from May 1954 to April

1955 for the double coincidence telescopes are discussed here.

During the experiment the instruments were rotated through 180° about the vertical axes on alternate days. The two telescopes of each unit have therefore spent about the same number of days pointing to the east and the west. In Table 4.1 are given the bihourly percent deviations from mean recorded by various telescopes. These are also presented in Fig. 4.1. The coefficients of the first two harmonics of these deviations are given in Table 4.2 and are expressed on harmonic dials in Fig. 4.2. It is satisfactory to note that the coefficients of the variation recorded by double coincidence telescopes T_1, T_2, T_3 and T_4 agree well within the limits of statistical accuracy so that it can be safely concluded that there is no systematic difference between the records of the four telescopes. In the case of triple coincidence telescopes T_1 and T_2 as well as T_3 and T_4 agree well among themselves, but the records of T_1 and T_2 differ from those of T_3 and T_4 both in the diurnal and the semidiurnal components. This difference is due to the difference in period for which data are averaged and does not suggest that T_1 and T_2 show a different behaviour from T_3 and T_4.

In Table 4.3 are given the percent bihourly deviations from mean for the east and the west directions. These values have been corrected for variation of barometric

Percent deviations from mean of the cosmic ray meson intensity measured with telescopes inclined to the zenith in the E-W azimuth.

Hours.	May 1954 to April 1955				May 1953 to April 1955.		May 1954 to April 1955.	
	39_{T_1}	39_{T_2}	39_{T_3}	39_{T_4}	22_{T_1}	22_{T_2}	22_{T_3}	22_{T_4}
00	-0.03	-0.02	-0.12	-0.04	-0.14	-0.08	-0.07	-0.02
02	0.18	0.20	0.30	0.27	0.15	0.17	0.30	0.33
04	0.33	0.36	0.40	0.33	0.45	0.37	0.25	0.26
06	0.19	0.22	0.34	0.29	0.24	0.23	0.28	0.22
08	0.11	0.09	-0.08	-0.04	-0.02	0.00	-0.05	-0.04
10	-0.09	-0.16	-0.16	-0.11	0.00	0.02	-0.17	-0.14
12	-0.06	0.00	-0.16	-0.13	0.14	0.15	-0.25	-0.27
14	0.01	0.04	0.06	0.12	-0.08	-0.03	0.08	0.09
16	-0.01	0.03	0.09	0.07	-0.09	-0.04	0.07	0.08
18	-0.18	-0.20	-0.13	-0.14	-0.16	-0.24	0.15	0.04
20	-0.26	-0.31	-0.26	-0.23	-0.26	-0.28	-0.25	-0.22
22	-0.21	-0.26	-0.31	-0.37	-0.17	-0.18	-0.31	-0.30
Std. erroe	±0.08	±0.08	±0.09	±0.09	±0.12	±0.12	±0.15	±0.15

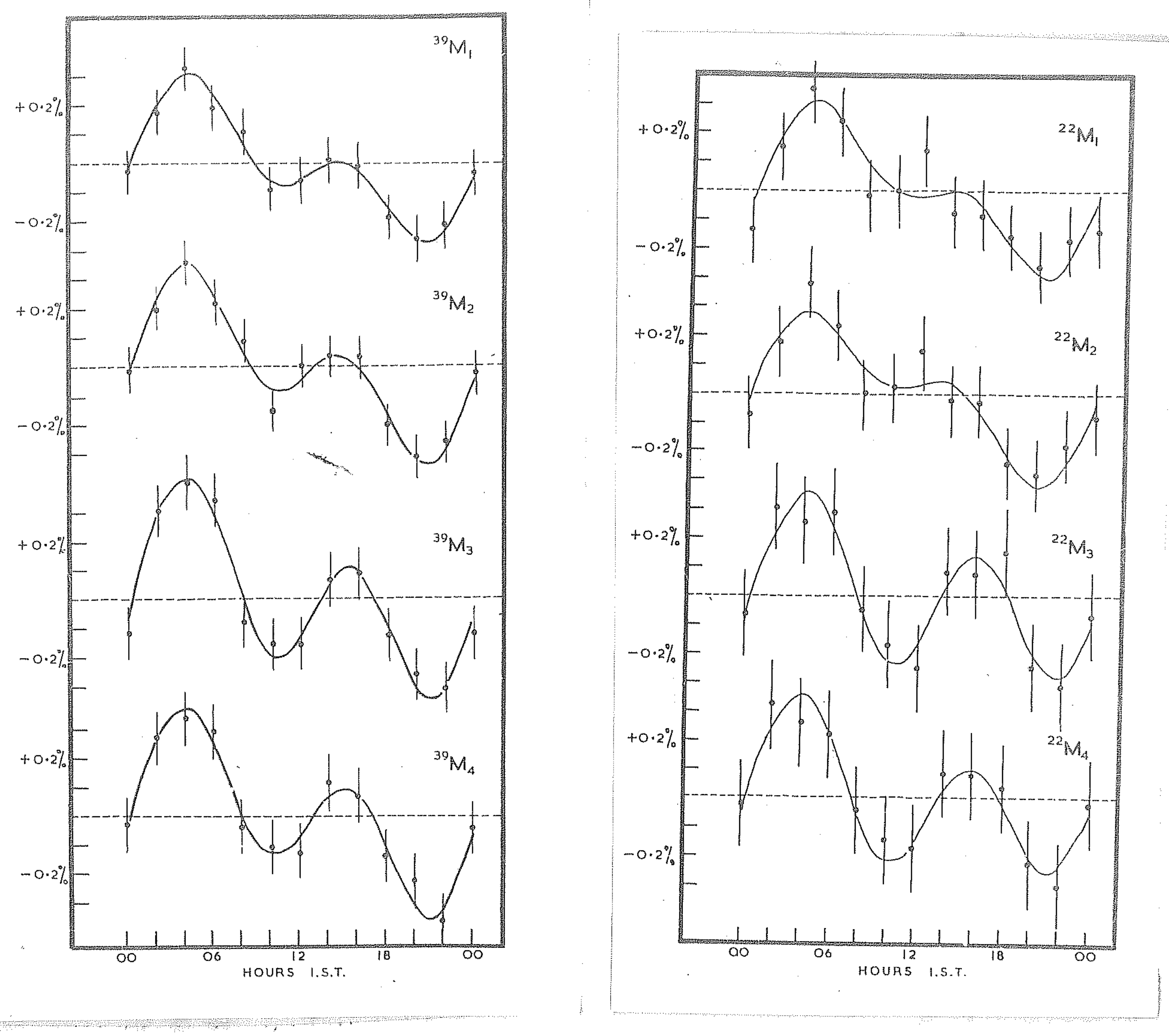


Fig. 4.1 Daily variation curves of meson intensity measured by various telescopes inclined at an angle of 45° to the zenith.

Table 4.2

Percentage amplitudes and the times of maxima of the first and the second harmonics of the daily variation M measured with telescopes inclined to the zenith in the E-W azimuth.

	May 1954 to April 1955				May 1953 to April 1955.		May 1954 to April 1955.	
	$^{39}T_1$	$^{39}T_2$	$^{39}T_3$	$^{39}T_4$	$^{22}T_1$	$^{22}T_2$	$^{22}T_3$	$^{22}T_4$
M^D	0.19	0.20	0.18	0.17	0.21	0.21	0.11	0.13
$M\phi^D$	87°	90°	81°	88°	93°	97°	70°	75°
M^S	0.14	0.19	0.26	0.23	0.13	0.13	0.25	0.21
$M\phi^S$	106°	101°	113°	108°	103°	87°	122°	116°
Std. error	±0.03	±0.03	±0.04	±0.04	±0.05	±0.05	±0.06	±0.06

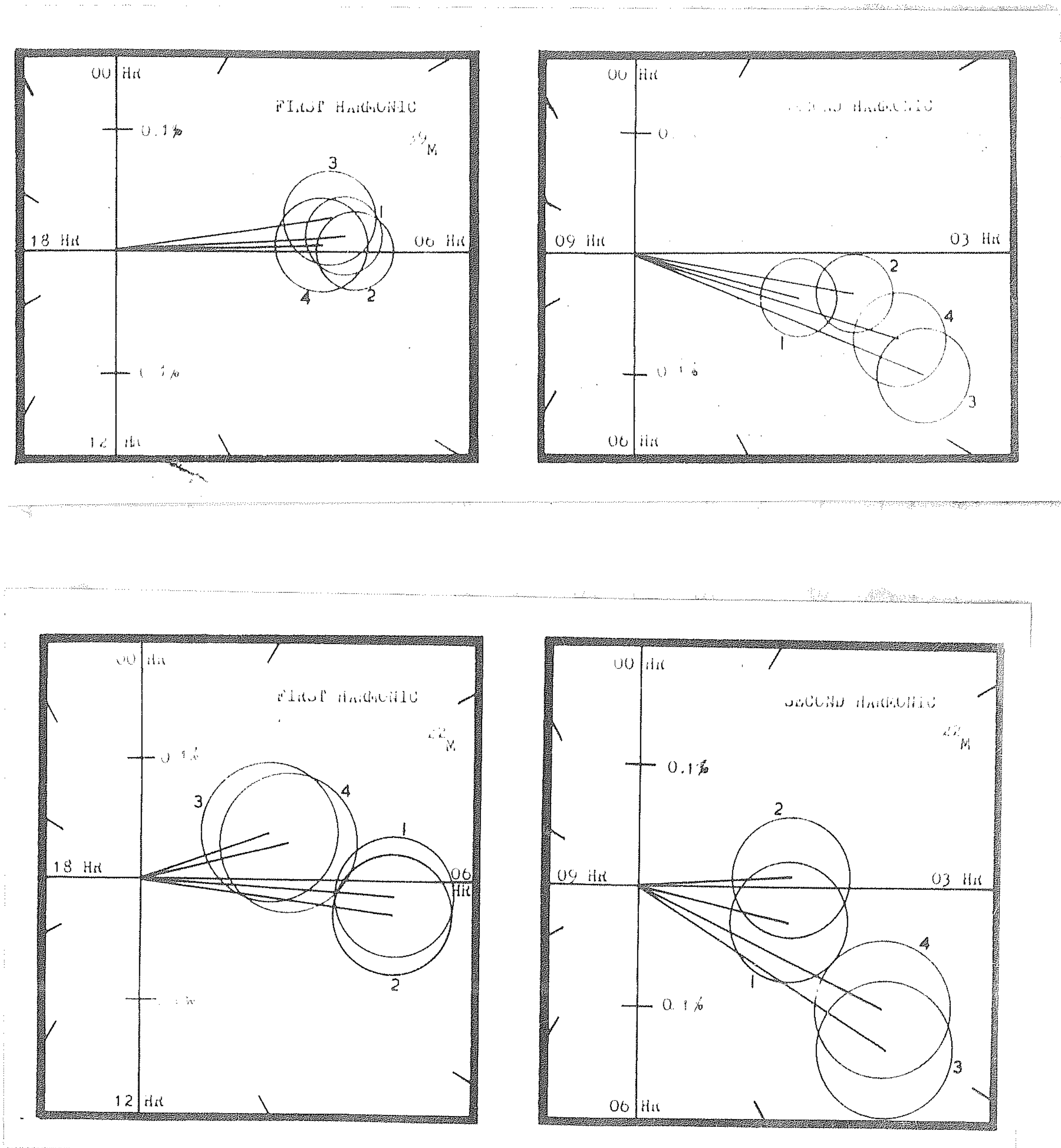


Fig. 4.2 Harmonic dials showing the first and the second harmonics of the daily variation shown in Fig. 4.1.

Percent deviations from mean of the cosmic ray meson intensity in the east and the west directions.

Hours.	May 1954 to April 1955					May 1953 to April 1955.	
	$\underset{E}{39_M}$	$\underset{W}{39_M}$	$\underset{E}{22_M}$	22_M	$\underset{W}{22_M}$	$\underset{E}{22_M}$	$\underset{W}{22_M}$
00	0.05	-0.13	0.05	0.01	-0.20	0.02	-0.19
02	0.32	0.16	0.30	0.28	0.08	0.34	0.08
04	0.35	0.35	0.32	0.19	0.28	0.38	0.30
06	0.21	0.28	0.18	0.14	0.30	0.17	0.30
08	-0.01	0.07	-0.04	-0.03	0.19	-0.14	0.13
10	-0.18	-0.09	-0.08	0.00	0.06	-0.06	0.06
12	-0.13	-0.04	-0.05	0.16	0.05	-0.02	0.09
14	0.00	0.09	0.00	0.11	0.07	-0.04	0.02
16	0.03	0.05	-0.09	-0.13	-0.10	-0.09	-0.04
18	-0.17	-0.16	-0.22	-0.32	-0.03	-0.19	-0.08
20	-0.24	-0.28	-0.28	-0.23	-0.27	-0.26	-0.31
22	-0.23	-0.32	-0.13	-0.16	-0.37	-0.14	-0.31
Std. error	±0.07	±0.06	±0.11	±0.07	±0.11	±0.10	±0.09

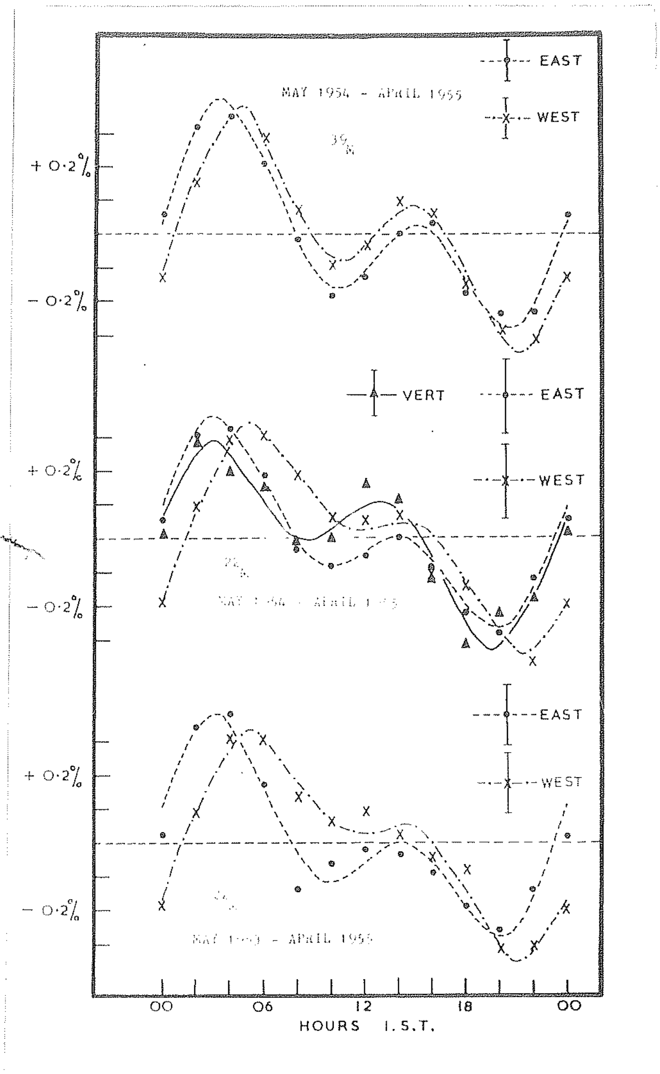


Fig. 4.3 Daily variation in the east, the west and the vertical directions in different periods.

Table 4.4

Percentage amplitudes and the times of maxima of the first and the second harmonics of the daily variation M in the east and the west directions.

	May 1954 to April 1955					May 1953 to April 1955.	
	39_E^M	39_W^M	22_E^M	22^M	22_W^M	22_E^M	22_W^M
M^D	0.19	0.20	0.20	0.18	0.24	0.20	0.23
$M\phi^D$	69°	102°	71°	94°	117°	67°	115°
M^S	0.20	0.20	0.16	0.16	0.14	0.17	0.14
$M\phi^D$	101°	113°	82°	61°	131°	83°	122°
Std. error	±0.03	±0.03	±0.05	±0.03	±0.05	±0.04	±0.04

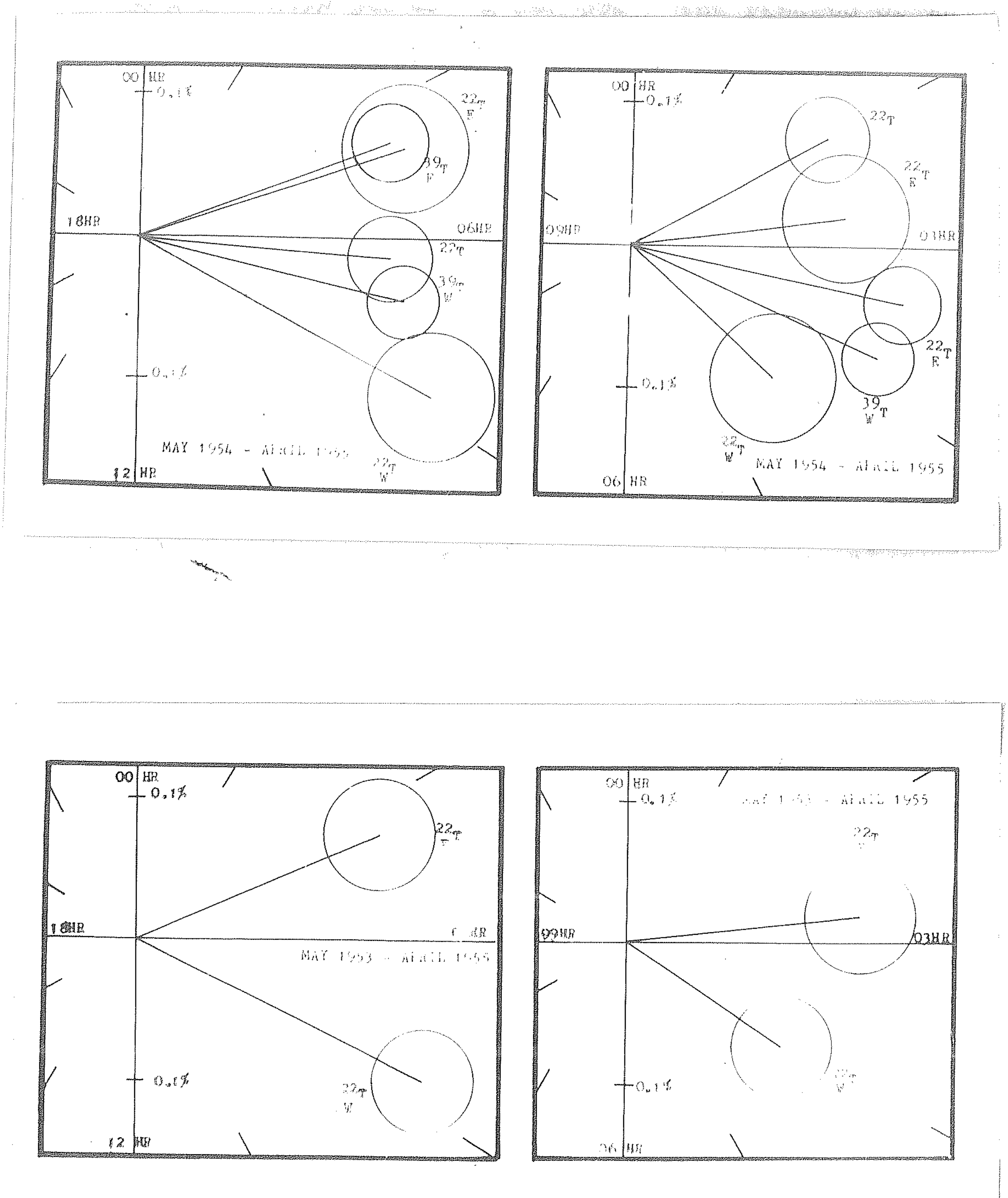


Fig. 4.4 Harmonic dials showing the first and the second harmonics of the variations shown in Fig. 4.3.

pressure using a barometer coefficient of -0.27% per mm Hg for ^{22}M and -0.25% per mm Hg for 39M. The results of the double coincidence and the triple coincidence arrangements are shown in Fig. 4.3. The curves represent the superposition of the first and the second harmonics. Harmonic coefficients of these curves are given in Table 4.4 and expressed on harmonic dials in Fig. 4.4.

Following points are noticeable from Fig. 4.4.

(a) The amplitude of the first harmonic of the daily variation measured by a west pointing telescope appears higher than measured by an east pointing telescope. This difference cannot be said to be significant in view of the errors of the order of 0.04%.

(b) The hour of maximum of the daily variation in the east direction is about 3.0 hours earlier than that in the west direction for ^{22}M and about 2 hours earlier for ^{39}M. Taking into account standard errors as shown in Fig. 4.4 we can put an upper limit of about 4.5 hours on the difference between the time of maxima of ^{22}M recorded in the east and the west directions and about 3 hours in the case of ^{39}M.

(c) Over a period of one year from May 1954 to April 1955 when the data from the vertical telescope ^{22}T are available, a time of maximum of the diurnal component of ^{22}M lies between those of ^{22}M in the east and the west directions.

(d) There does not appear to be any significant difference between the amplitudes of the daily variation recorded by the double coincidence and the triple coincidence arrangements.

Due to the spinning of the earth, the two telescopes pointing east and west would scan in succession the same region of the space if the earth's magnetic field were absent. An examination of results of terrela experiment by Brunberg & Dattner[45] enables us to estimate the modification that is produced by the deflection of orbits in the earth's magnetic field. Brunberg & Dattner have shown that, at latitude 50°, there would be no difference in the time of maxima of the daily variation in the east and the west directions for a mean primary energy of 25 BeV.

We discuss in the following chapter the comparison between the experimental results and expectations according to a suggested theory for the anisotropy of the primary radiation. In this comparison an allowance is made for the above mentioned factors related to the deflection in the geomagnetic field and the sensitivity of the inclined telescopes.

4.2 Daily Variation of Meson Intensity Measured with Narrow Angle Telescopes.

4.21 <u>The 12 monthly mean solar daily variation</u> :- The experiment was started in October 1953 and pilot readings were taken for two months to test the long term stability of the electronic units. Towards the end of 1953 the experiment was discontinued as the apparatus was to be shifted to the new building of the laboratory. In the beginning of 1954 the author was engaged in assembling the apparatus for directional studies described in Sec.2.1, but the study was recommenced in August 1954. Since it is known that the daily variation of meson intensity can alter with the passage of time, it is obviously necessary to compare the performance of different telescopes over a period when all of them are working simultaneously. From August 1954 the instrument as a whole functioned satisfactorily and in the present investigation data from August 1954 to July 1955 only are discussed.

In Table 4.5 are given the percent deviations from mean of each of the three independent telescopes of 2.5^o and of the two telescopes of 5^o for the entire period, August 1954 to July 1955. The values are presented in Fig. 4.5. There is a striking similarity among the data from three independent telescopes of 2.5^o as well as those from the two telescopes of 5^o. Hence the performance of the telescopes during this period is believed to be reliable and it is appropriate to combine data of similar telescopes. In the investigation reported hereafter, the data of the 2.5^o telescopes or the 5^o telescopes on any day relate to the added up data of all the available telescopes of 2.5^o or 5^o respectively, working satisfactorily on that day.

Table 4.5

Percent deviations from mean of the meson intensity measured with different telescopes.

Hours	2.5_{T_1}	2.5_{T_2}	2.5_{T_3}	5_{T_1}	5_{T_2}
00	-0.72	-0.95	-0.85	-0.69	-0.68
02	0.30	0.13	0.25	0.04	-0.01
04	0.60	0.69	0.49	0.53	0.35
06	0.67	0.79	0.65	0.63	0.70
08	0.53	0.59	0.50	0.41	0.28
10	0.71	0.64	0.69	0.50	0.82
12	0.38	0.54	0.39	0.28	0.51
14	0.45	0.14	0.47	0.30	0.07
16	-0.46	0.20	-0.06	-0.13	0.12
18	-0.35	-0.39	-0.42	-0.24	-0.37
20	-1.17	-1.25	-0.96	-0.79	-0.88
22	-0.94	-1.12	-1.18	-0.84	-0.91
Std. error	±0.30	±0.30	±0.32	±0.14	±0.16

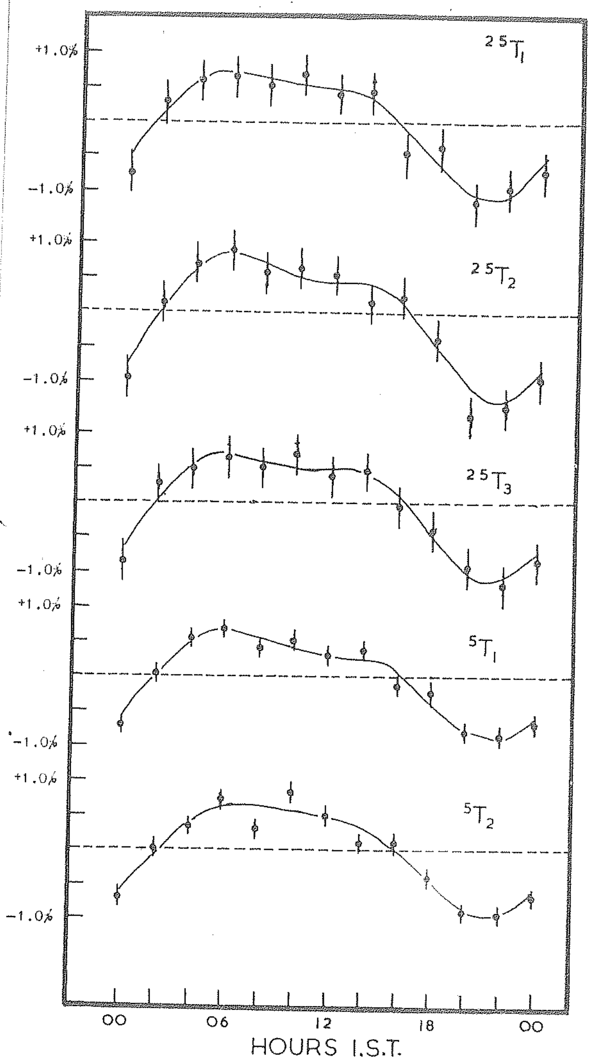


Fig. 4.5 12 monthly mean daily variation of meson intensity measured by three telescopes of $^{2.5}T$ and two telescopes of ^{5}T.

Table 4.6

12 monthly mean daily variation of meson intensity measured by ${}^{2.5}T$, ${}^{5}T$ and ${}^{15}T$ and of pressure during Aug. 1954 to Jul. 1955.

Hours.	$^*2.5_{\underline{M}}$	$^*5_{\underline{M}}$	$^*15_{\underline{M}}$	$\underline{P}$ mm
00	-0.84	-0.69	-0.36	0.13
02	0.23	0.02	0.20	-0.06
04	0.60	0.45	0.39	-0.28
06	0.71	0.66	0.43	-0.11
08	0.55	0.35	0.23	0.70
10	0.68	0.64	0.16	1.54
12	0.44	0.38	0.01	1.27
14	0.35	0.20	0.07	0.03
16	-0.11	-0.02	0.01	-1.02
18	-0.38	-0.29	-0.23	-1.33
20	-1.13	-0.83	-0.45	-0.80
22	-1.08	-0.87	-0.47	-0.07
Std. error	±0.18	±0.10	±0.09	

In Table 4.6 are given the 12 monthly mean daily variation recorded by $^{2.5}T$, ^{5}T and ^{15}T during August 1954 to July 1955. The values are expressed as percent deviations from their respective means. For comparison the daily variation of atmospheric pressure P in mm of Hg is also furnished. These values along with their standard errors have been reproduced in graphical form in Fig. 4.6. The abscissae correspond to Indian Standard Time which is 40 minutes ahead of Ahmedabad local time. The ordinate represents the percent deviations from mean for cosmic ray meson intensity and deviations from mean for pressure.

Data given in Table 4.6 have been analysed to determine the first six Fourier coefficients. The amplitude and the angle corresponding to the time of maximum of each of them is given in Table 4.7. It is realised that for all variates except barometric pressure, only the first harmonic is predominent while for pressure both the first and the second are equally prominent. The higher harmonics in all the cases are too small to need any consideration. Therefore attention has been concentrated only to the first two harmonics. Fig. 4.7 shows the coefficients of the first two harmonics on harmonic dials.

4.22 <u>Comparison of data with different telescopes</u> :- In Fig. 4.8 has been presented the percent daily variation of meson intensity corrected for the variations of barometric pressure for the telescopes $^{2.5}T$, ^{5}T and ^{15}T. A barometer

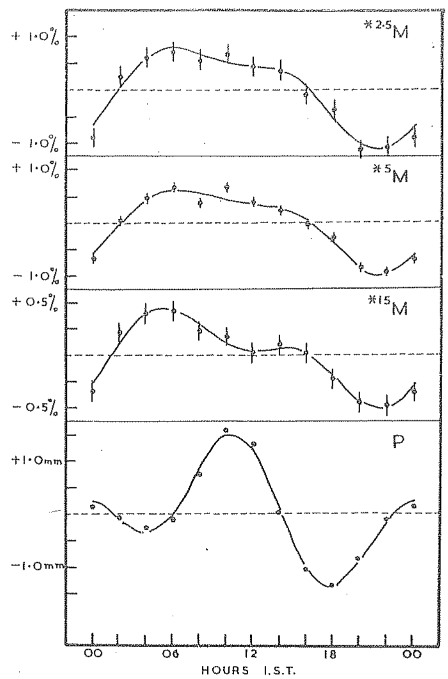


Fig.4.6 12 monthly mean daily variation of meson intensity by $^{2.5}T$, ^{5}T and ^{15}T and of pressure.

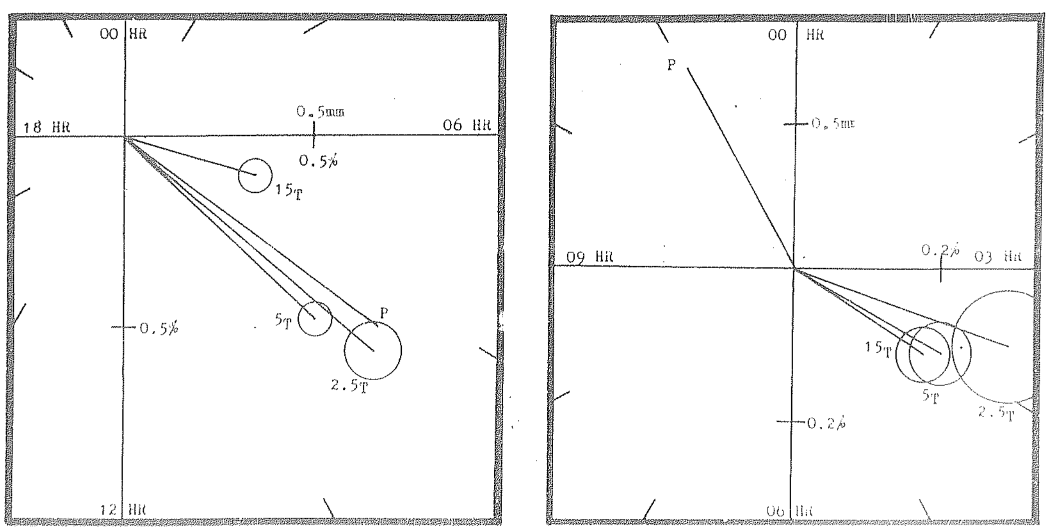


Fig. 4.7 Harmonic dials showing the first and the second harmonics of the daily variation curves given in Fig.4.6.

Table 4.7

Percentage amplitudes and the times of maxima of the first six harmonics of the daily variation of meson intensity and of pressure.

Fourier Coeffs.	*2.5 $\bar{M}$	*5 $\bar{M}$	*15 $\bar{M}$	$\bar{P}$ mm
r_1	0.87	0.70	0.36	0.82
ϕ_1	130°	133°	106°	127°
r_2	0.31	0.23	0.21	0.81
ϕ_2	109°	119°	122°	-29°
r_3	0.10	0.09	0.02	0.08
ϕ_3	119°	135°	117°	141°
r_4	0.02	0.07	0.04	0.04
ϕ_4	206°	-73°	194°	257°
r_5	0.03	0.03	0.02	0.01
ϕ_5	246°	73°	117°	139°
r_6	0.08	0.06	0.03	0.00
ϕ_6	180°	180°	180°	180°
Std. error	±0.07	±0.04	±0.04	

$r_1,\ldots\ldots r_6$ refer to amplitudes.

$\phi_1,\ldots\ldots\phi_6$ refer to angles corresponding to hours of maxima.

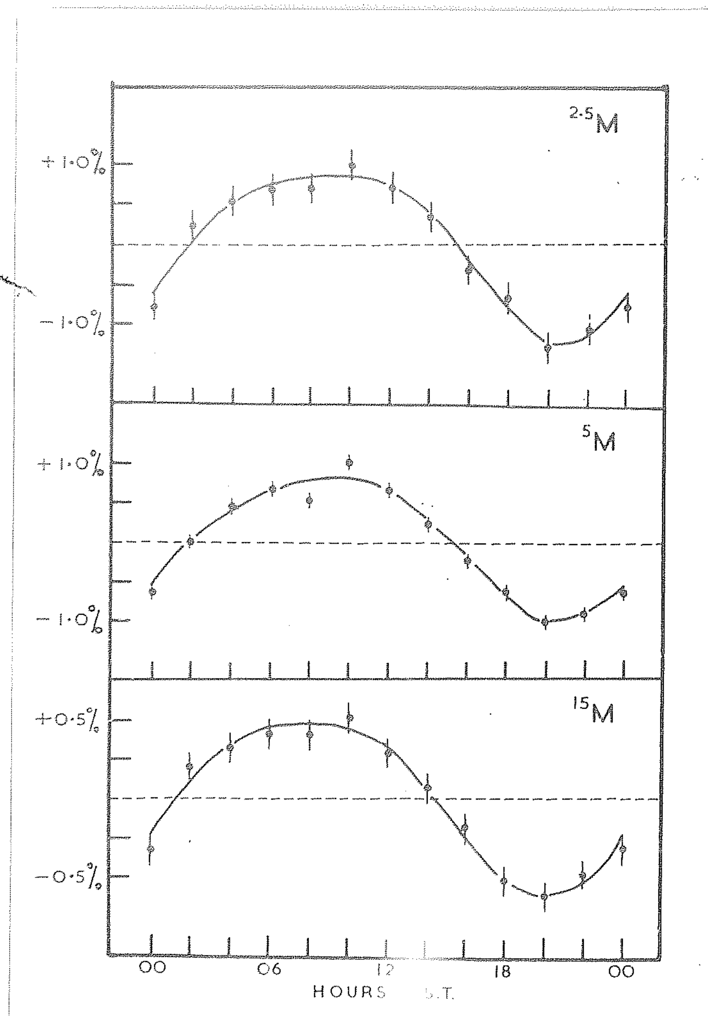


Fig. 4.8 Daily variation of meson intensity corrected for variations of barometric pressure.

coefficient α_B = 2.2% per cm Hg is adopted. The coefficients of the first two harmonics are given in Table 4.8 and presented on harmonic dials in Fig. 4.9.

Table 4.8

Percentage amplitudes and the times of maxima of the first and the second harmonics of the daily variation 2.5_M, 5_M and 15_M.

	2.5_M	5_M	15_M
M^D	1.05	0.88	0.55
$M\phi^D$	130°	132°	120°
M^S	0.22	0.12	0.10
$M\phi^S$	75°	67°	62°
Standard error	±0.07	±0.04	±0.04

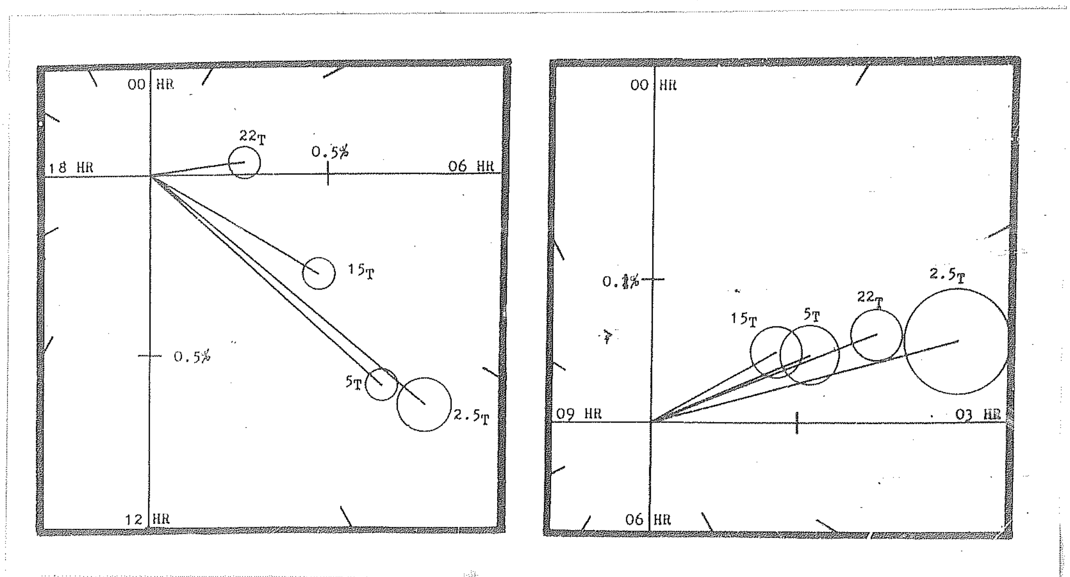


Fig. 4.9

The harmonic coefficients of the daily variation observed with ^{22}T for the same period have also been indicated. The main features that emerge from a comparison of the daily variation of the meson intensity are as follows.

(1) The 12 monthly mean daily variation exhibited by $^{2.5}M$ and ^{5}M is almost identical but differs markedly from that of ^{15}M and ^{22}M.

(2) The percent amplitude of the diurnal component $^{2.5}\overline{M}^{D}$ is greater than $^{5}\overline{M}^{D}$ but not significantly so. However, the amplitude which is about 1.0% for narrow angle telescopes decreases rapidly for wider semiangle beyond 5^{o} and is only about 0.55% for $^{15}\overline{M}^{D}$ and 0.3% for $^{22}\overline{M}^{D}$. Although strict comparison is not warranted it is rather interesting to note that the amplitude of the diurnal variation of $^{1.8}\overline{M}^{D}$ was 2.2 ± 0.5% in 1953 while $^{45}M^{D}$ was 0.3 ± 0.01% in 1955.

(3) The time of maximum $M\phi^{D}$ of the diurnal component corresponds to 0900 hours for $^{2.5}\overline{M}$ and $^{5}\overline{M}$ but becomes earlier for telescopes with wider semiangle in the E-W plane. $^{15}\overline{M}\phi^{D}$ corresponds to about 0800 hours and $^{22}\overline{M}\phi^{D}$ to about 0530 hours. $^{45}\overline{M}\phi^{D}$ shows a maximum at about 0700 hours in 1955. Since the vertical intensity by a wide angle telescope in 1955 showed a maximum two hours later than that in the later months of 1954, $^{45}\overline{M}\phi^{D}$ would correspond to a maximum at about 0500 hours for the period August 1954 to July 1955.

4.23 Monthly mean daily variation :- Tables 4.9(a)(b)(c) indicate monthly mean percent bihourly deviations from mean for $^{2.5}T$, ^{5}T and ^{15}T respectively. after correcting data for meteorological variations with a barometer coefficient of -0.22% per mm Hg. They also furnish the mean bihourly counting rates as well as the standard error for the deviations. The replacement of the counters sometimes changes the geometry of the telescope and thereby causes a change in the mean counting rate of that telescope. Hence the change in the mean bihourly counting rate from month to month as seen in tables 4.9(a)(b)(c) does not represent a genuine long term change.

The data are insufficient to derive conclusions regarding long term or seasonal changes. However two types of changes are seen to occur in the data from month to month. The relative importance of the diurnal and the semidiurnal components which is a consequence of the change of the general form of the daily variation is reflected in a similar way in $^{2.5}T$, ^{5}T and ^{15}T. However the ratio of the diurnal amplitudes of ^{5}T and ^{15}T varies from 0.8 to 2.4 as shown in Table 4.10. This variation is significant and as described later may be an important clue for our understanding the reason for the high amplitude of the daily variation observed with narrow angle telescopes.

The main difference between recording with counter

Table 4.9(a)

Monthly mean daily variation $^{2.5}M$ from August 1954 to July 1955.

Hrs.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.
00	-1.12	-0.19	-0.60	-1.14	-1.19	-0.84	-0.79	-0.23	-0.40	-2.07	-1.25	-0.30
02	0.75	0.44	-0.16	-0.58	-0.40	0.10	0.10	0.24	0.06	0.76	1.19	0.21
04	0.70	0.91	0.48	0.23	0.53	0.64	1.21	0.79	1.43	0.08	0.38	-0.70
06	0.84	0.91	0.54	0.53	0.69	1.20	1.27	0.76	1.07	-0.34	0.59	0.29
08	0.30	0.81	0.54	0.75	0.92	1.44	1.06	0.78	1.45	0.16	-0.33	0.73
10	1.09	0.80	0.81	1.42	1.62	1.84	1.19	0.93	0.38	-0.22	0.98	1.45
12	0.66	0.06	0.44	1.34	1.20	1.69	0.69	0.34	-0.21	1.15	0.62	0.85
14	0.11	-0.32	0.28	0.93	0.87	0.55	0.31	-0.12	-0.25	1.09	0.16	0.74
16	-0.17	-0.73	-0.08	0.27	0.06	-0.98	-0.34	-0.65	-1.46	0.65	-0.33	-0.24
18	-1.11	-0.85	-0.36	-0.42	-0.71	-1.64	-0.90	-0.86	-0.60	0.74	-0.97	-0.60
20	-1.42	-1.00	-0.83	-1.49	-1.58	-2.20	-1.78	-1.03	-1.06	-1.10	-1.14	-1.46
22	-0.58	-0.92	-1.08	-1.83	-1.99	-1.83	-2.04	-0.95	-0.37	-0.89	0.10	-0.93
Std. error	±0.79	±0.66	±0.55	±0.62	±0.63	±0.65	±0.66	±0.55	±0.62	±0.66	±0.56	±0.59
Bihourly mean	397.9	399.6	399.2	399.7	400.0	399.0	398.5	394.9	392.1	395.6	393.5	390.9

Table 4.9(b)

Monthly mean daily variation ^5M from August 1954 to July 1955.

Hrs.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.
00	-0.48	-0.53	-0.85	-1.10	-1.21	-0.83	-0.72	-0.39	-0.21	-0.72	-0.50	-0.38
02	0.09	-0.03	-0.49	-0.48	-0.23	0.10	0.03	0.14	0.06	0.11	0.69	0.15
04	0.21	0.14	0.29	0.00	0.15	0.45	0.42	0.65	0.64	0.87	0.74	0.14
06	0.62	0.73	0.80	0.52	0.78	1.01	0.91	1.00	-0.13	-0.16	0.63	0.73
08	0.61	0.67	0.83	0.61	0.68	0.93	0.84	0.98	0.39	-0.09	-0.33	0.14
10	0.69	1.27	0.86	1.24	1.46	1.56	1.32	1.40	0.69	0.44	0.75	0.66
12	0.56	0.64	0.56	1.02	1.12	0.91	0.84	0.45	0.94	0.19	0.52	0.37
14	0.30	0.01	0.12	0.64	0.81	0.26	0.22	-0.29	-0.09	0.75	-0.09	0.01
16	-0.19	-0.27	0.03	0.34	0.18	-0.21	-0.34	-0.62	-0.18	0.03	-1.36	-0.21
18	-0.49	-0.80	-0.39	-0.40	-0.67	-1.01	-0.94	-1.01	-1.44	-0.29	-0.70	-0.09
20	-1.00	-0.97	-0.73	-1.02	-1.49	-1.56	-1.32	-1.02	-0.66	-1.06	-0.47	-1.02
22	-0.88	-0.91	-1.01	-1.39	-1.59	-1.58	-1.26	-0.91	-0.95	-0.15	0.13	-0.49
Std. error	±0.44	±0.44	±0.32	±0.35	±0.35	±0.41	±0.35	±0.32	±0.39	±0.37	±0.33	±0.32
Bihourly mean x 4	499.6	501.4	501.7	502.0	501.7	500.4	500.1	501.0	500.3	497.6	504.0	498.7

Table 4.9(c)

Monthly mean daily variation ^{15}M from August 1954 to 1955.

Hrs.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.
00	-0.05	-0.13	-0.43	-0.61	-0.51	-0.28	-0.27	-0.26	0.10	-0.64	-0.39	-0.22
02	0.03	0.11	-0.04	-0.17	-0.05	0.06	0.08	0.08	0.44	0.04	0.55	0.37
04	0.30	0.32	0.32	0.24	0.29	0.28	0.36	0.38	0.14	0.65	0.28	0.38
06	0.41	0.43	0.50	0.42	0.42	0.36	0.46	0.54	0.14	0.64	0.36	0.36
08	0.64	0.50	0.49	0.49	0.50	0.46	0.54	0.62	0.23	0.18	0.24	0.31
10	0.55	0.44	0.42	0.59	0.61	0.58	0.59	0.64	0.33	0.26	0.64	0.43
12	0.15	0.21	0.26	0.48	0.46	0.44	0.43	0.33	0.21	-0.18	0.35	0.33
14	-0.02	-0.13	0.05	0.29	0.20	0.05	0.04	-0.10	-0.16	0.33	0.00	0.20
16	-0.31	-0.40	-0.12	0.04	-0.09	-0.28	-0.40	-0.43	-0.19	0.36	-0.61	-0.28
18	-0.52	-0.57	-0.32	-0.32	-0.41	-0.53	-0.61	-0.61	-0.72	-0.99	-0.62	-0.20
20	-0.69	-0.56	-0.53	-0.67	-0.67	-0.63	-0.71	-0.64	-0.39	-0.40	-0.69	-0.97
22	-0.46	-0.31	-0.56	-0.79	-0.69	-0.55	-0.55	-0.48	-0.19	-0.58	-0.14	-0.68
Std. error	±0.52	±0.50	±0.42	±0.42	±0.41	±0.40	±0.41	±0.42	±0.38	±0.35	±0.32	±0.32
Bihourly mean x 16	453.5	451.2	425.9	425.1	421.5	448.8	421.9	426.4	431.5	429.7	432.1	429.8

Table 4.10

The ratio of the diurnal amplitude measured with telescopes of different semiangles on identical days during different periods

	1954 Aug.	Sept.	Oct.	Nov.	Dec.	1955 Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Total
$\frac{5_M D}{15_M D}$	1.52	1.79	1.72	1.74	2.17	2.40	1.83	1.65	1.68	0.79	1.18	1.04	1.60
$\frac{45_M D}{90_M D}$													1.5 to 2.4 Ehmert[127]

telescopes and ion chambers is in respect of the zenith angle response of the instruments. It has been suggested by Sandstrom[126] that in a telescope which records cosmic rays from different directions, there would be superposition of daily variations with phase shifts which, in extreme cases, can be greater than 90°. This explanation, qualitative as it is, does not suffice to explain the present results as well as those reported by Ehmert[127]. It has been pointed out that the relation between diurnal variation recorded by ^{5}M and by ^{15}M is not constant from month to month. Similar evidence has been presented by Ehmert. He finds that the amplitude of the diurnal variation measured by a counter telescope of semiangle 45° to that of the ion chamber varies between 1.5 to 2.5 in different periods. Such a behaviour is hardly expected from a phase shift which will be constant at all times. Moreover, the data suggest that the change in amplitude between ^{5}M and ^{15}M is rather too large to be accounted for merely by phase shift within an angular region of 15° from the zenith.

It has been suggested by Ehmert that the increase in amplitude in narrow angle telescopes may be due to the additional variation of the radiation limited near the zenith. This variation will be revealed only by narrow angle telescopes mounted vertically, where radiation from inclined directions does not play a role. Assuming that this radiation is incident in the angular region from the zenith given by $0 \leq \alpha \leq \alpha_0$ and has an amplitude a% for the diurnal variation, it will be realised that the amplitude of the diurnal variation recorded by a telescope is given by

$$a_T = \frac{a \int_0^{\alpha_0} F(\theta) \sin\theta \cos^2\theta \, d\theta}{\int_0^{\theta_0} F(\theta) \sin\theta \cos^2\theta \, d\theta}.$$

where θ_0 is the semiangle of the telescope in the E-W plane and $F(\theta)$ is the function of the geometry of the telescope described in Sec. 2.4. The relative amplitudes recorded by two telescopes ^{5}T and ^{15}T are in the ratio given by

$$\frac{a_{T_1}}{a_{T_2}} = \frac{\int_0^{\alpha_0} V_{T_1}(\theta)\, d\theta}{\int_0^{\alpha_0} V_{T_2}(\theta)\, d\theta} \cdot \frac{\int_0^{\theta_{0_2}} V_{T_2}(\theta)\, d\theta}{\int_0^{\theta_{0_1}} V_{T_1}(\theta)\, d\theta} \; ; \; V_T(\theta) = F(\theta)\sin\theta\cos^2\theta$$

The second factor will be a constant of the telescopes but the ratio a_{T_1}/a_{T_2} will change with α_0. With small values of α_0, V_{T_1} and V_{T_2} will be almost same, and the ratio will approach the value of the second factor. With large values of α_0 i.e. radiation spreading over large angle, this ratio approaches unity. Putting $\theta_{0_2} = 15^\circ$ and $\theta_{0_1} = 5^\circ$ and taking the experimentally determined ratio of amplitudes of $^{5}\overline{M}$ and $^{15}\overline{M}$ as 1.6, the value of α_0 is obtained as $\sim 11^\circ$. The different values of a_{T_1}/a_{T_2} in different months as shown in table 4.10 give an indication that α_0 varies from time to time. A similar conclusion has been reached by Ehmert.

To investigate whether the change in the value of is linked up with magnetic disturbance in the earth's magnetic field, the entire data are divided into two groups. The first one contains days with $Cp > 0.5$ and thus represents a magnetically disturbed period. The second has days with $Cp < 0.5$ signifying a magnetically quiet period. The ratio a_{T_1}/a_{T_2} for the first group with $Cp > 0.5$ is 2.4 while for the second group it is only 1.2. Thus this ratio is greater for magnetically disturbed days. It seems therefore, that with increasing amount of magnetic disturbance the additional radiation responsible for the increase in the amplitude in narrow angle telescopes gets more and more concentrated near the zenith. α_0 is $\sim 8^\circ$ and $\sim 14^\circ$ in the two cases respectively. This conclusion is in good agreement with the results of Ehmert wherein he finds that in high latitudes on magnetically disturbed days, $\alpha_0 = 5^\circ$ as compared to 15° on magnetically quiet days. The large amplitude of the daily variation in narrow angle telescopes as compared to that in wide ones, observed by Sekido and Kodama on magnetically disturbed days, can similarly be explained.

The above calculations are carried out on the assumption that the measured radiation has a zenith angle dependence of the form $\cos^2\theta$. Any deviation from this law will necessiate small corrections to the value of α_0 but their effect is not likely to be serious. Thus the large difference in amplitude and its variability, when results from various telescopes are compared, appears to be mainly the result of the radiation which can only arrive at small zenith angles.

4.24 Day to day changes in the daily variation :- So far the daily variation averaged over a month or a year has been examined. This has permitted a study of the dependence of daily variation on the geometry of the instrument. But a description of geophysical phenomena giving average characteristics is never complete. Such an account must always be supplemented by a discussion of the irregular variability of phenomena. For example, the diurnal variation of meson intensity with a maximum in the early part of noon is no sufficient abstract of the observations but such information as for instance, the frequency of the maximum in other parts of the day is needed for a complete picture.

In addition, the process of averaging does not furnish information as to whether the daily variation on any particular day is similar to the daily variation averaged over a month or a year in which the day has been included. The description of the average variation implies that this is a variation occurring every day with given average amplitude while it could, even, have been an intermittent or recurring phenomena, so that large variations on few days may be averaged over the entire period and therefore, over days of no variations. If for a particular telescope the daily variation on each day is similar to the average, the experimental determination of the daily variation on a day to day basis should be subject only to errors of random sampling. The individual daily determinations regardless of their standard errors should then be distributed around the average in a definite manner.

It is difficult to select parameters which could quantitatively specify the features of the daily variation. It has been a general practice to study the daily variation in terms of its first two harmonic components. In Fig. 4.10 is shown the daily variation on successive six days. Although the standard error is too large to draw definite conclusions, it can be noticed that the daily variation undergoes drastic changes not only in amplitude and the time of maximum but also in the characteristics such as relative importance of other maxima. Only when the latter are unimportant the amplitude M^D and the time of maximum $M\phi^D$ of the diurnal component specify fairly well the nature of the daily variation. Hence before one uses these two parameters one must be sure that the 12 bihourly percent deviations exhibit one maximum and not two maxima.

Initially the daily variations on all days are made smooth by taking moving averages over three consecutive bihourly deviations. Then the daily variation is examined to judge whether it exhibits one maximum or more. The following somewhat arbitrary criteria have been adopted to select days, when the telescopes ^5T have revealed a daily

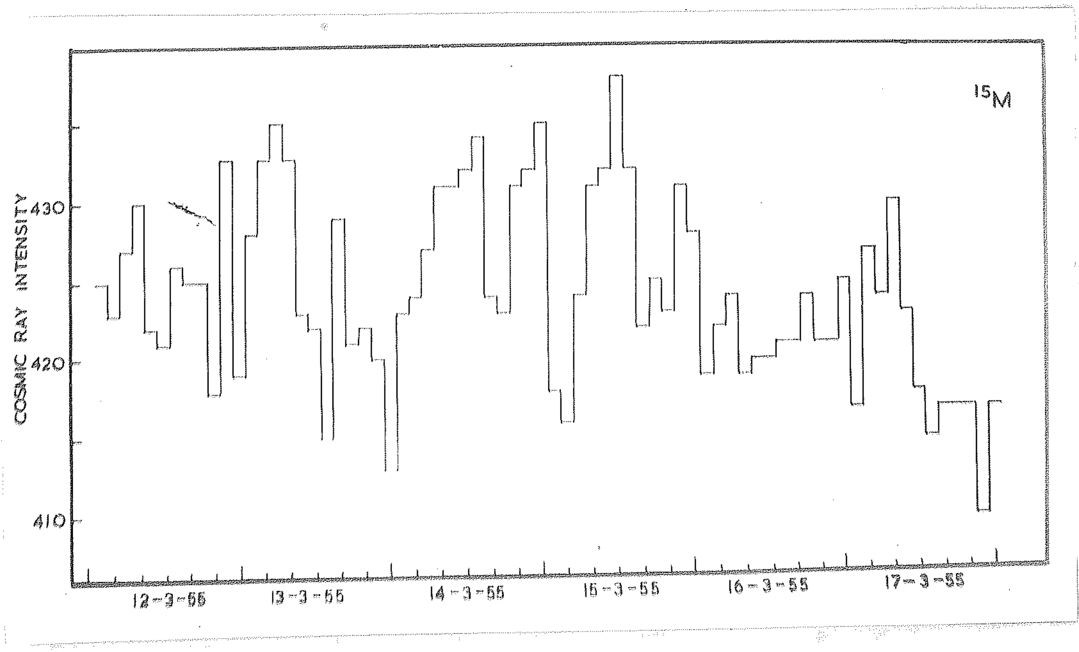


Fig. 4.10 Daily variation of meson intensity by ^{15}T.

variation ^{5}M which is deemed to have one maximum. On these days there should be

(1) five consecutive bihourly deviations from mean which are positive and

(2) amongst the remaining seven bihourly deviations, there should be no individual value which is positive and greater than a third of the maximum positive bihourly deviation.

These criteria in some cases may lead to misclassification of days, but in most cases the first harmonic will be appreciably greater than the second harmonic thus giving more weight to the curve exhibiting a single maximum. The days which do not comply with the above requirements are designated as 's' days. The data on each day are then harmonically analysed and keeping apart 's' days, the distribution of the ends of the vectors representing diurnal component has been plotted in Fig. 4.11 on a harmonic dial. These vectors relate to data not corrected for barometer variations. But in view of very large amplitudes on individual days and comparatively insignificant contribution of the meteorological variations, the diagram is not likely to be greatly in error. Fig. 4.12 gives the distribution of occurrence of the diurnal maximum for each of the 24 hours of the day. For comparison the corresponding values of $^{2.5}T$ are also presented. The characterisation of days for

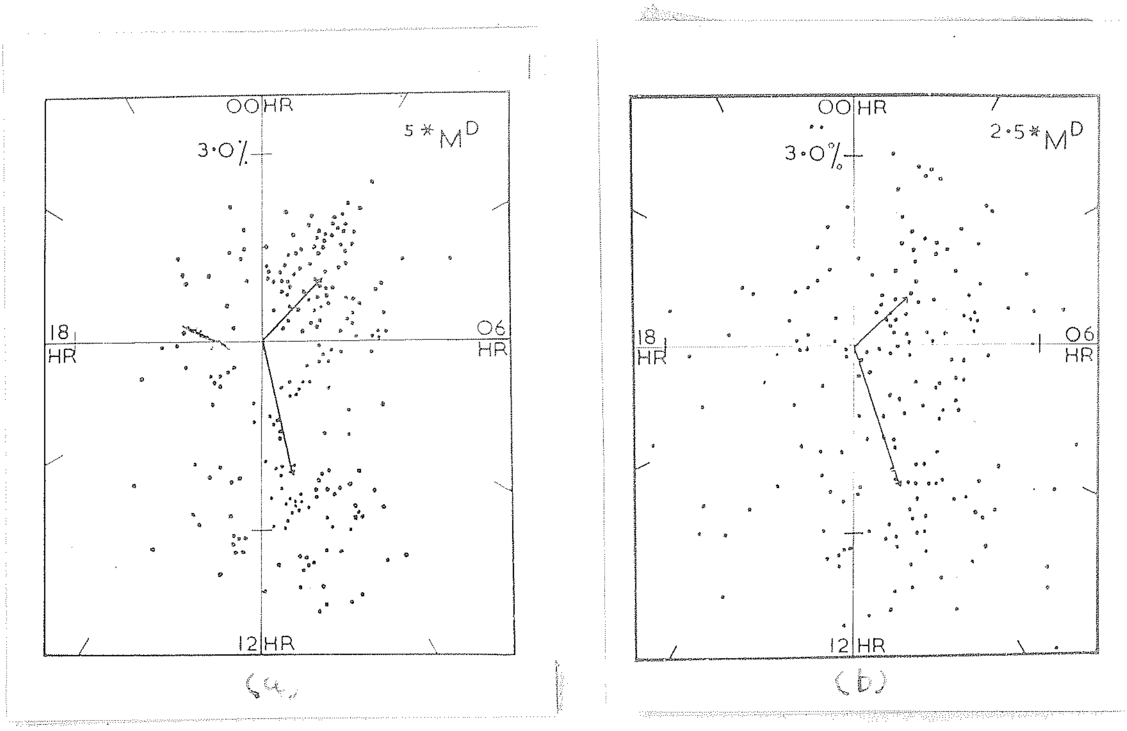


Fig. 4.11 24 hourly harmonic dials showing the distribution of the ends of the vectors representing the diurnal component on each day. (a) refers to ^{5}T and (b) to $^{2.5}T$.

$^{2.5}T$ is not done independently but is adopted from the data of ^{5}T telescopes. Only when the latter are missing the above criteria are applied to $^{2.5}T$.

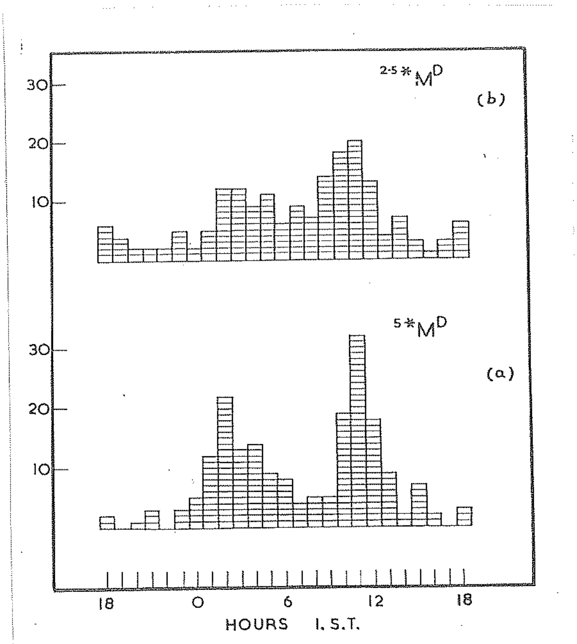


Fig. 4.12

It is noticed from figures 4.11 and 4.12 that there are large variations in the time of maximum and the amplitude of the daily variation and one is therefore dealing with data which are subject to not just the sampling error that would be expected in the determination of a daily variation of a constant type. In addition, there is a pronounced tendency for the diurnal maximum to occur either during the night at about 0300 hours or a little before noon at about 1100 hours I.S.T. The spread of these two groups is rather large in data from $^{2.5}T$ where the statistical uncertainty is large as compared to ^{5}T. Attention is therefore confined to data from ^{5}T which are further divided into two groups as follows. Whenever the diurnal maximum occurs between 2000 and 0800 hours, that particular day is regarded as exhibiting a night maximum, and the daily variation on that day is designated as M^n and the day as belonging to the 'n' type. Similarly when the diurnal maximum occurs between the hours 0800 and 2000 one has M^d type daily variation on a 'd' type day. Finally there remains the M^s type daily variation exhibiting more than one maximum, which occurs on 's' type days.

Having thus characterised all days from the data of ^{5}T, the daily variation for the days in each group is combined. The average daily variation of meson intensity with $^{2.5}T$, ^{5}T and ^{15}T telescopes on 'n', 'd' and 's' days is shown in Fig. 4.13. It is satisfactory that on days when we have M^d, M^n and M^s type of variations in the ^{5}T telescopes, $^{2.5}T$ and ^{15}T telescopes reveal the same type of variation as the ^{5}T telescopes. This lends confidence in the physical reality of the three types of daily variation.

It is seen that there is no significant difference

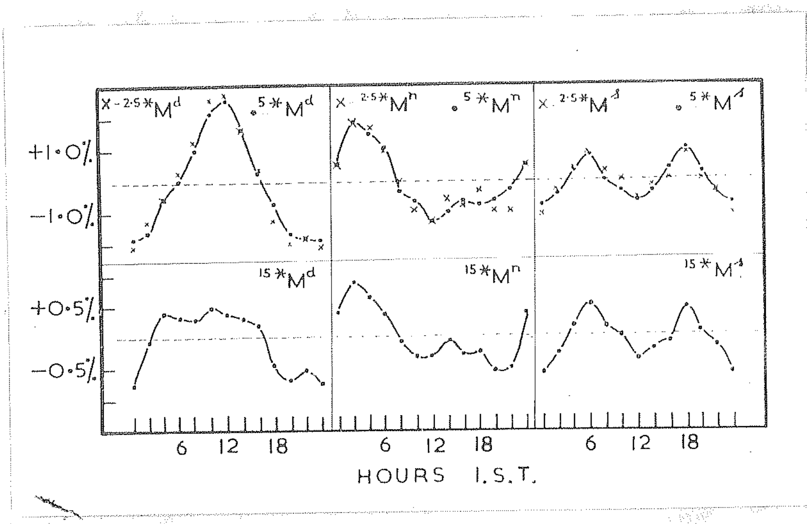


Fig. 4.13

in the daily variation of different types of $^{2.5}T$ and ^{5}T telescopes. However the amplitude of the daily variation in ^{15}T telescope is in every case smaller than that in ^{5}T telescopes. This decrease of amplitude because of the increase of semiangle of telescope from 5^{o} to 15^{o} is by a factor $\sim$ 3.0 for the daily variation M^{d} with day maximum, which is greater than for the variations M^{n} and M^{s} where it is $\sim$ 2.0 and $\sim$ 1.0 respectively. In terms of the limiting angle α_o of the effective radiation, we have α_o $\sim 7^{o}$ and $\sim 9^{o}$ on 'd' and 'n' days respectively. More data are required to determine the precise difference in the attenuation of the amplitude of the three types of daily variation with increasing semiangle of the telescope.

Table 4.11 gives for each solar rotation the number of 'd', 'n' and 's' type days and the number of days on which no data are available. For each solar rotation the mean planetary character figure Cp is computed for the days of each type. It will be noticed that during the entire period there have been recorded 125, 109 and 79 days of 'd', 'n' and 's' types respectively. The mean Cp for 'd' days is not different from the mean Cp for 'n' type days. However there is some indication that 's' type days are associated with smaller values of Cp. This result is in conformity with the observations of Sekido et al that on magnetically quiet days there is found large semidiurnal component of daily variation in narrow angle telescopes.

4.25 Recurrence tendency in the diurnal variation :- To study the recurrence tendency of each of the three types of daily variations, the data are analysed by the well known Chree method of superposed epochs. The amplitudes of daily variation on all days are arranged in a series. Whenever the time of maximum occurs during day time the amplitude is termed positive and whenever it occurs during night hours the amplitude is given a negative sign. The moving averages over three successive values are taken to make smooth the irregularities. Groups having high positive values are then picked out and the day having

Table 4.11

The number of 'd', 'n' and 's' type days for each solar rotation and the mean planetary character figure Cp for the days of each type.

Solar Rotation	'd'	'n'	's'	No data	$\overline{C_p d}$	$\overline{C_p n}$	$\overline{C_p s}$
1658	11	10	4	2	0.68	0.59	0.38
1659	8	12	4	3	0.86	0.72	0.82
1660	9	7	8	3	1.01	0.70	0.32
1661	10	8	5	4	0.45	0.43	0.50
1662	14	4	3	6	0.36	0.20	0.33
1663	8	4	10	5	0.41	0.40	0.27
1664	7	9	5	6	0.92	0.65	0.24
1665	9	11	5	2	0.80	0.53	0.56
1666	7	8	8	4	1.10	0.81	0.41
1667	9	11	5	2	0.41	0.80	0.62
1668	11	7	6	3	0.66	0.38	0.66
1669	8	12	4	3	0.36	0.56	0.52
1670	12	4	9	2	0.34	0.43	0.35
1671	2	2	3	2	0.50	0.15	0.23
Aug. 1954 to Jul. 1955	125	109	79	45	0.57	0.53	0.41

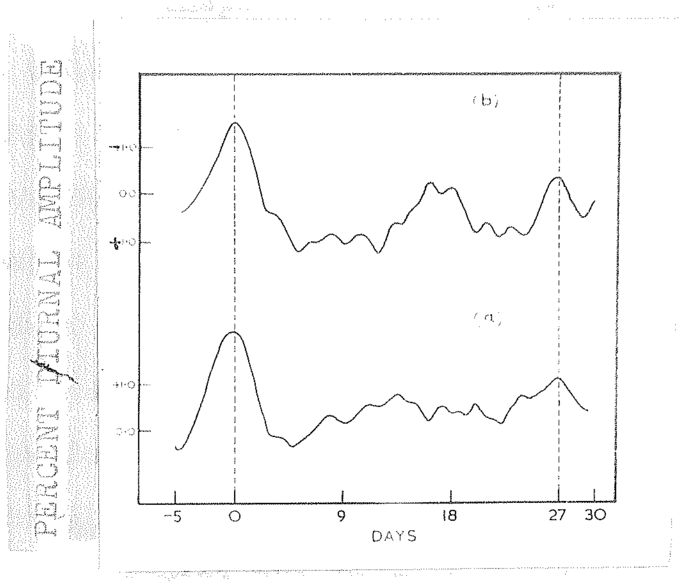


Fig. 4.14

the highest amplitude is selected as the zero epoch day. After selecting the zero epoch days, Chree analysis is conducted of the exact amplitudes and the result is presented in Fig. 4.14(a). There is clear evidence that 'd' type days exhibit 27 day recurrence tendency. A similar study is presented in Fig. 4.14(b) where the epoch days have the maximum amplitude with negative sign. These correspond to days having maximum during night hours. It appears, therefore, that both 'd' and 'n' type days occur in groups which recur after 27 days.

4.26 Solar and terrestrial relationships :- During most of the period of investigation, the number of active solar regions was very small and their activity was very weak. Inspection of the data shows that only a few days with large amplitudes of the daily variation in narrow angle telescopes are associated with the CMP of the active solar regions and hence only a loose genetic relationship could be established between solar activity and the days having large amplitudes. A similar conclusion has been reached by Sittkus[84]. Although there is some evidence as shown in table 4.11 that days with large diurnal amplitudes are associated with high values of Cp and hence with the increased disturbance in the earth's magnetic field, a one to one correlation could not be established.

CHAPTER V

INTERPRETATION

5.1 Characteristics of the Daily Variation

Evidence that has been reported during the past two years as well as that presented in the previous chapter, has brought a marked change in the general concept about the daily variation of meson intensity. Any explanation which is put forward to understand the daily variation must take into account the following observed facts.

(1) The daily variation cannot at all times be satisfactorily described in terms of the diurnal component alone. For several years in the past, the daily variation has two significant maxima. However, it has been observed that in general only the first two harmonic components, the diurnal and the semidiurnal, are adequate to represent fairly satisfactorily the main features of the daily variation.

(2) The 12 monthly mean daily variation can be explained in terms of two components, one having a maximum

during day and the other having a maximum at night. The relative contribution of these two types of variations changes from year to year and the data over the past two solar cycles is suggestive of its relation to the 22 year cycle of solar activity. This makes the maximum of the diurnal component of the daily variation shift by as much as 10 to 12 hours over a number of years.

(3) When data on individual days are examined there is a tendency for the time of maximum of the diurnal component to occur either at noon or in early morning hours. Days having maximum at one of the two periods usually occur in groups that sometimes recur after 27 days.

(4) Days having large amplitudes are normally associated with high values of Cp or CMP of active solar regions. However large amplitudes can also arise on days when no such specific solar or terrestrial phenomena are present.

Firor et al[51] have examined the changes in the geomagnetic field as a possible cause for the daily variation. They find that the maximum daily variation would be less than 0.2%. Clearly the variations in the geomagnetic field cannot account for the observed 1% variation in neutron intensity. The modulation of primary cosmic radiation by the general magnetic field of the sun was first examined in detail by Dwight[128]. His calculations have been further refined by Singer[129], Treiman[130] and Firor et al[131]. However this gives a diurnal variation confined to the primary spectrum between 1.5 to 6 BeV and exhibits a very large latitude effect which is contrary to the observations. The magnetic fields associated with active solar regions on the sun do not stretch as far as the earth and possibility of modulation of intensity near the earth by these regions seems to be very remote. Although the injection or acceleration of new particles in the active solar regions cannot at this stage be disproved, there would be difficulty in explaining the night maximum in meson intensity at low latitudes. Even the day time maximum in neutron intensity at low latitudes will be difficult to understand because their primaries, having low energies, are deflected through very large angle in the geomagnetic field. Furthermore the diurnal variation is equally prominent in the absence of active solar regions.

In the past few years theories have been advanced for the solar anisotropy of cosmic radiation due to modulation of primary intensity by changes in the electromagnetic conditions of interplanetary space. Brunberg & Dattner[45] have pointed out that seen from a fixed coordinate system, the rotating sun will be strongly polarised so that there would be a voltage difference between the poles and the solar equator of the order of 10^9 volts. The combined action of this electric field produced by polarisation, and the solar magnetic field, will make charged particles within the solar system partake in the general rotation of the sun so that the earth will receive an excess of particles in the 18 hourly direction. This is called by them as a tangential anisotropy. Alfven[132], on the other hand, has shown that the general magnetic field of the sun is very much distorted by the presence of corpuscular matter emitted by the sun. This will set up electric fields in interplanetary space so that particles after repeated traversals through them will be accelerated upto cosmic ray energies. Depending upon the rate of acceleration, there will be an outward radial flow of particles across the earth's orbit and a radial anisotropy of cosmic rays will be created. The combined effect of the tangential and the radial anisotropies has been invoked by Alfven to explain the anisotropy as revealed by the diurnal variation. Since the radial anisotropy is directly connected with corpuscular emission from the sun, it will change broadly in step with the 11 year cycle of solar activity. Thus Alfven tries to explain the change of amplitude of the diurnal variation following an 11 year cycle of sunspots. This theory explains a diurnal variation of the order of 0.2% but, it will be difficult to interpret large amplitudes as well as the time of maximum during night hours.

Nagashima[16] has examined the possibility of explaining a diurnal variation of the order of 0.2 to 0.5%

on the basis of the electric field theory suggested by him to explain the magnetic storm type change of total intensity. There would, however, be a large latitude dependence of the daily variation which is not observed.

To explain the anisotropy produced on days when there is a magnetic storm, Elliot & Dolbear[46] and Alfven[48] have suggested that the beam of ionized particles emitted from the sun will be polarised in the presence of the solar magnetic field and electric fields will be set up in the beam. Acceleration of cosmic ray particles traversing these beams produce an anisotropy in particular directions depending on the relative position of the beam and the earth. Nagashima[133] has examined the detailed implications of this model taking into consideration the deflection within the beam of particles in the trapped magnetic field which is derived from the solar dipole field. He has shown that at the time of magnetic storms an anisotropy would be produced in the direction pointing towards the sun. This agrees with the experimental determination of the storm time vector by Sekido et al. He has also examined whether the average diurnal variation can be understood from the standpoint of an electric field associated with storm producing beams. Even though he could explain the average amplitude of the order of 0.2 to 0.5% for the meson intensity, it is rather difficult to understand how a maximum during night hours can arise on his theory. In spite of this drawback his theory has many interesting features which will be discussed later.

At the present juncture, it is important to find an explanation for the two main types of variable anisotropies responsible for the day and the night maxima in the daily variation of cosmic ray intensity. To understand these the author has extended in the following sections Nagashima's work by admitting the possibility of random orientation of the magnetic field trapped within the beam. Due to the spin of the earth, the daily variation at equatorial stations is the manifestation of the anisotropy in the E-W plane. Therefore, to explain the anisotropy in equatorial stations only the component of the trapped magnetic field perpendicular to the equatorial plane needs consideration. Depending upon the orientation of the magnetic field this component will have either a positive or a negative value.

5.2 Anisotropy of the Primary Radiation and its Changes.

Fig. 5.1 shows the equatorial section of the beam. It has infinite extension along the Z axis i.e. perpendicular to the solar equatorial plane and finite width equal to b cm along the X axis. It moves with a velocity v cm/sec. along the Y axis. The magnetic field trapped within the beam has a component H_z along the Z axis and is called positive along the positive direction of the Z axis. It is assumed that the magnetic field outside the beam is negligible. The trapped field is supposed to move with the beam with the same velocity and in a coordinate system moving with the beam, there is only a magnetic field present. But an observer on the earth, with respect to which the beam is moving with a velocity v cm/sec., observes in addition to the magnetic field a charge displacement in the direction perpendicular to the velocity and the magnetic field i.e. along the X axis. The strength of the electric field will be $\frac{v}{c} H_z$.

The width of the beam being b cm, the electric potential between the two sides of the beam is $\frac{v}{c} H_z b$ volts. Cosmic rays which cross the beam will change their energies by $\frac{v}{c} b e H_z$ electron volts regardless of

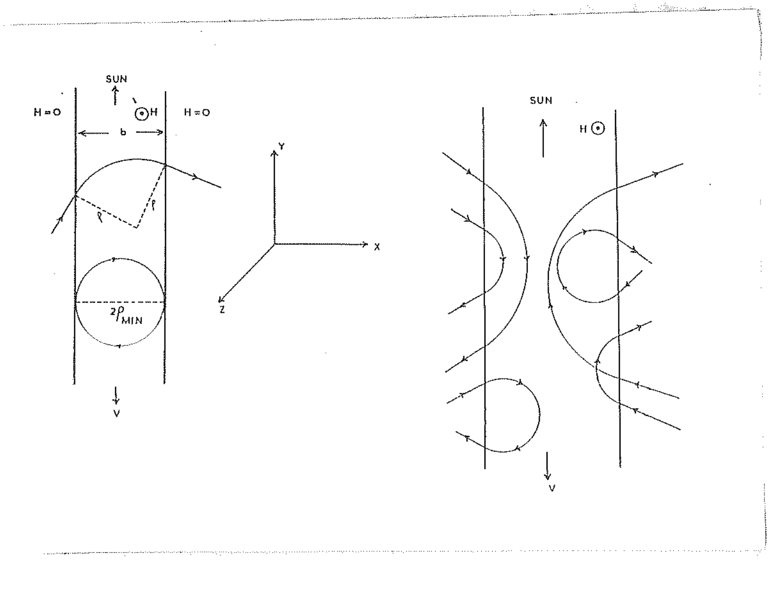


Fig. 5.1 Fig. 5.2

their initial energies and velocity directions. This will change the energy spectrum of the primary radiation. But all cosmic rays will not be able to cross the beam because low energy particles will be deflected in the magnetic field of the beam. If the radius of curvature of the deflected particles is less than half the beam width, these will curl around and emerge on the same side of the beam from which they entered. Fig. 5.2 shows the deflection of such particles in the beam. Since these particles have not crossed the beam, there will be no change in their energies. It will also be realised from Fig. 5.2 that deflections in general will not alter the intensity of these particles in any direction and their initial degree of isotropy will be maintained.

If H_z is the strength of the magnetic field and b is the width of the beam, the minimum energy which the particles must have to cross the beam is $\frac{H_z\, e\, b}{2} = W_{min}$. One needs consider therefore, the effect of the polarised beam on the energy spectrum above W_{min}. Fig. 5.3(a) and 5.3(c) show the deflection of cosmic ray particles in the beam when the observer is outside the beam on either side of it. Particles having their velocity directions lying in the shaded portion have crossed the beam and have either gained or lost their energies by an amount $\frac{v}{c}\, e\, b\, H_z\, z$, where z is the charge of primary particle. The particles in the remaining region have not crossed the beam and hence do not

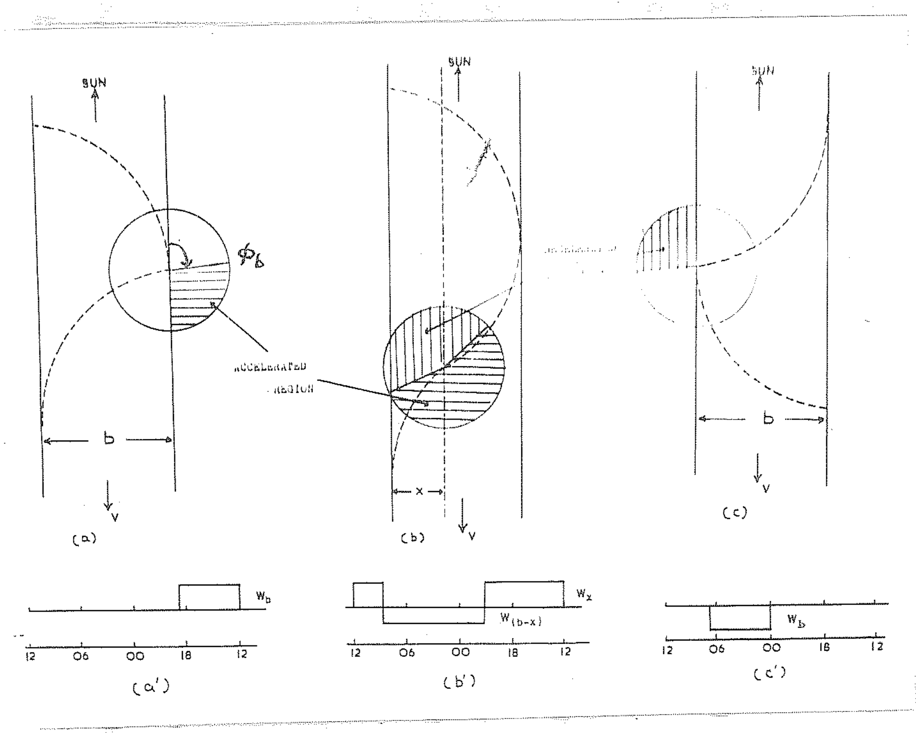


Fig. 5.3 Deflections of high energy cosmic ray primaries when the component of the magnetic field perpendicular to the equatorial plane is positive. (a),(b) and (c) refer to the cases when the earth is on the right, within and on the left side of the beam. (a')(b')and (c') show the corresponding accelerated and decelerated regions in local time in the absence of the earth's magnetic field.

gain or loose energies. An observer will record more intensity when his instrument points towards region of acceleration and normal intensity at other times. This is shown in Fig. 5.3(a') and 5.3(c'). The angular region of accelerated or decelerated particles is given by the following relation.

$$\phi_b = \cos^{-1}\left(1 - \frac{2W_{min}}{W}\right)$$

$$\text{where } \pi \geq \phi \geq \phi_b \qquad (5.1)$$

It is evident that this region is an increasing function of the energy of the particle.

Since the daily variation is normally expressed in terms of its harmonic components, ΔW_b i.e. the change in the energy, can also be expanded regarding ΔW_b as a function of ϕ

$$\Delta W_b(\phi) = \frac{a_0}{2} + (a_1 \cos\phi + b_1 \sin\phi) + (a_2 \cos 2\phi + b_2 \sin 2\phi) + \ldots$$

$$= \frac{a_0}{2} + A_1 \cos(\phi - \delta_1) + A_2 \cos(2\phi - \delta_2) + \ldots \qquad (5.2)$$

where a_0 is the intensity variation independent of local time. The diurnal variation is represented by the quantities a_1 and b_1 or A_1 and δ_1, which are obtained as

$$a_1 = -\frac{2\Delta W_b}{\pi}\sqrt{\frac{1}{x}\left(1-\frac{1}{x}\right)}, \quad b_1 = \frac{2\Delta W_b}{\pi}\left(1-\frac{1}{x}\right),$$

$$A_1 = \frac{2\Delta W_b}{\pi}\sqrt{1-\frac{1}{x}}, \quad \tan\delta_1 = -\sqrt{x-1} \qquad (5.3)$$

$$\text{where } x = W/W_{min}.$$

Fig. 5.3(b) shows the case when the observer is inside the beam at a distance of x cm from one side. The beam can now be considered as made up of two parts, one having width equal to x cm and the other having width equal to (b - x)cm. The observer is on the right side of the first part and on the left side of the second part. The problem is now exactly similar to what has been considered in Fig. 5.3(a) and 5.3(c). Since the strength of the magnetic field is same but the width is reduced, the minimum energy which can reach the earth after crossing the part of the beam has been reduced. Hence low energy particles will also take part in the diurnal variation. In Fig. 5.3(b') the accelerated and decelerated regions are shown. The harmonic coefficients a_1 and b_1 are given by

$$a_1 = -\frac{2\Delta W_b}{\pi}\left[\sqrt{\frac{b-x}{b}\cdot\frac{1}{X}\left(1-\frac{b-x}{b}\cdot\frac{1}{X}\right)} + \sqrt{\frac{x}{b}\cdot\frac{1}{X}\left(1-\frac{x}{b}\cdot\frac{1}{X}\right)}\right],$$

$$b_1 = \frac{2\Delta W_b}{\pi}\left(1-\frac{1}{X}\right) \qquad (5.4)$$

When the observer is located at the centre of the beam i.e. x = b/2 the harmonic coefficients a_1 and b_1 are given by

$$a_1 = -\frac{2\Delta W_b}{\pi}\sqrt{\frac{1}{X}\left(2-\frac{1}{X}\right)},$$

$$b_1 = \frac{2\Delta W_b}{\pi}\left(1-\frac{1}{X}\right) \qquad (5.5)$$

The vectors $-a_1$, b_1 and A_1 point to the earth from the directions of 12, 18 and T_1 i.e. ($2\pi - \delta_1$) hour local time respectively and can be regarded as 12 hour 18 hour and resultant component of the diurnal variation respectively.

In Figs. 5.4(a)(b)(c) is shown the deflection of particles if the component of field H_z is negative i.e. directed opposite to what has been considered so far. Accelerated and decelarated regions are shown in Figs. 5.4(a')(b')(c'). Analysis similar to one done in the previous section gives

$$a_1 = -\frac{2\Delta W_b}{\pi}\sqrt{\frac{1}{x}\left(1-\frac{1}{x}\right)}\,, \quad b_1 = -\frac{2\Delta W_b}{\pi}\left(1-\frac{1}{x}\right),$$

$$A_1 = \frac{2\Delta W_b}{\pi}\sqrt{1-\frac{1}{x}}\,, \quad \tan\delta_1 = \sqrt{x-1} \qquad (5.6)$$

When the observer is located at the centre of the beam i.e. x = b/2 the harmonic coefficients a_1 and b_1 are given by

$$a_1 = -\frac{2\Delta W_b}{\pi}\sqrt{\frac{1}{x}\left(2-\frac{1}{x}\right)}\,,$$

$$b_1 = -\frac{2\Delta W_b}{\pi}\left(1-\frac{1}{x}\right) \qquad (5.7)$$

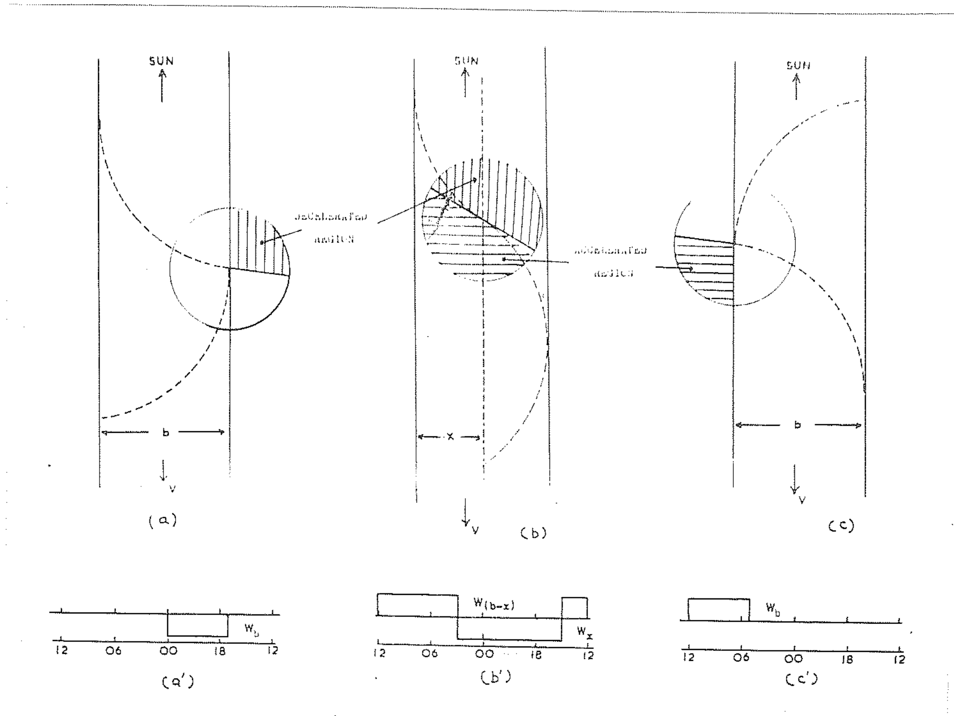


Fig. 5.4 Deflections of high energy cosmic ray primaries when the component of the magnetic field perpendicular to the equatorial plane is negative. (a),(b) and (c) refer to the cases when the earth is on the right, within and on the left side of the beam. (a')(b') and (c') show the corresponding accelerated and decelerated regions in local time in the absence of the earth's magnetic field.

It will be observed that the direction of the 18 hour component is reversed and it now points to the earth from the 6 hourly direction when H_z is negative. Thus if the orientation of the magnetic field is in the positive direction of the Z axis as shown in Fig. 5.3 the resultant component of the diurnal variation will be between 1200 hours and 1800 hours as shown by equations 5.3. While the reversal of the magnetic field will make this resultant component occur between 0600 hours and 1200 hours as shown by equations 5.6. The electromagnetic fields of solar beams thus create anisotropy in the primary radiation in the interplanetary space, which are revealed as a diurnal variation with maximum either in the forenoon or afternoon hours. The anisotropic cosmic radiation is however deflected in the earth's magnetic field and an appropriate correction for the deflection should be applied before comparison is made with experiments. It is preferable for this purpose to consider the entire cosmic ray spectrum above the geomagnetic cut off rather than a mean energy of the radiation.

5.3 The Diurnal Variation.

In the absence of any disturbing field, the vertical intensity of cosmic radiation $N(\lambda, x)$ observed at an atmospheric depth x g/cm^2 and at geomagnetic latitude λ is given by

$$N(\lambda, x) = \int_{E_{c\lambda}}^{\infty} m(E, x)\, i(E)\, dE$$

where m(E, x) and i(E)dE are the overall multiplicity and the differential intensity spectrum of primary cosmic radiation respectively and $E_{c\lambda}$ is the cut off energy for vertical incidence at geomagnetic latitude λ. If by the presence of a beam primary particles of energy E now gain an energy $\Delta E(E, T)$ after passing through the electric field of the beam, the change in the intensity ΔN is given by

$$\Delta N = \int_{E_{c\lambda}+\delta E_{c\lambda}}^{\infty} m(E, x)\, L(E)\, i(E - \Delta E)\, \Delta E(E, T)\, dE \qquad (5.8)$$

The factor L(E) is introduced to take care of the change in the differential energy spectrum due to the additional energy gain ΔE and is given by

$$L(E) = \frac{1}{1+E}\left[\frac{2}{1-(1+E)^{-2}} + 2.07\right] \qquad (5.9)$$

For the product $m(E, x)\, i(E - \Delta E)$, the values given by Nagashima[16] assuming Neher's spectrum

$$\text{i.e.} \quad i(E) = \frac{0.048}{E^{2/3}(1 + 0.09E^{4/3})^{3/2}}$$

are used.

The time T refers to the direction outside the influence of the earth's magnetic field. Its relation with local time t is given by

$$t = T - \psi_E \qquad (5.10)$$

where ψ_E is the angle through which cosmic ray particles of energy E are deflected in the earth's magnetic field in the E-W plane. Its value can be read out from the curves supplied by Brunberg & Dattner[12]. $\Delta E(E, T)$ in equation 5.8 is replaced by $\Delta E(E, t)$ and the diurnal variation of cosmic rays is calculated numerical integration. The results are presented in Fig. 5.5.

It is noticed that depending on the orientation of the magnetic field in the beam, the diurnal variation in equatorial latitudes will exhibit maximum either during night at about 0200 hours or during day at about 1200 hours. The exact time of maximum is dependent on W_{min} and therefore on the strength of the magnetic field and width of the beam. Beams emitted at different periods cannot be expected to have identical characteristics and the time of maximum of these two variations may vary within an interval of two hours as shown in Fig. 5.5. It is therefore expected that the diurnal variation in equatorial latitudes will have maximum grouped around 0200 hours or 1200 hours which is in good agreement with the results demonstrated in Fig. 4.12. Observations by Sarabhai et al[67] that the broad features of the daily variation of meson intensity at Huancayo can be explained in terms of two types of variations, one having a maximum at 1100 or 1300 hours and the other at 0100 or 0300 hours can now be understood.

It has been seen in Sec. 5.2 that with a

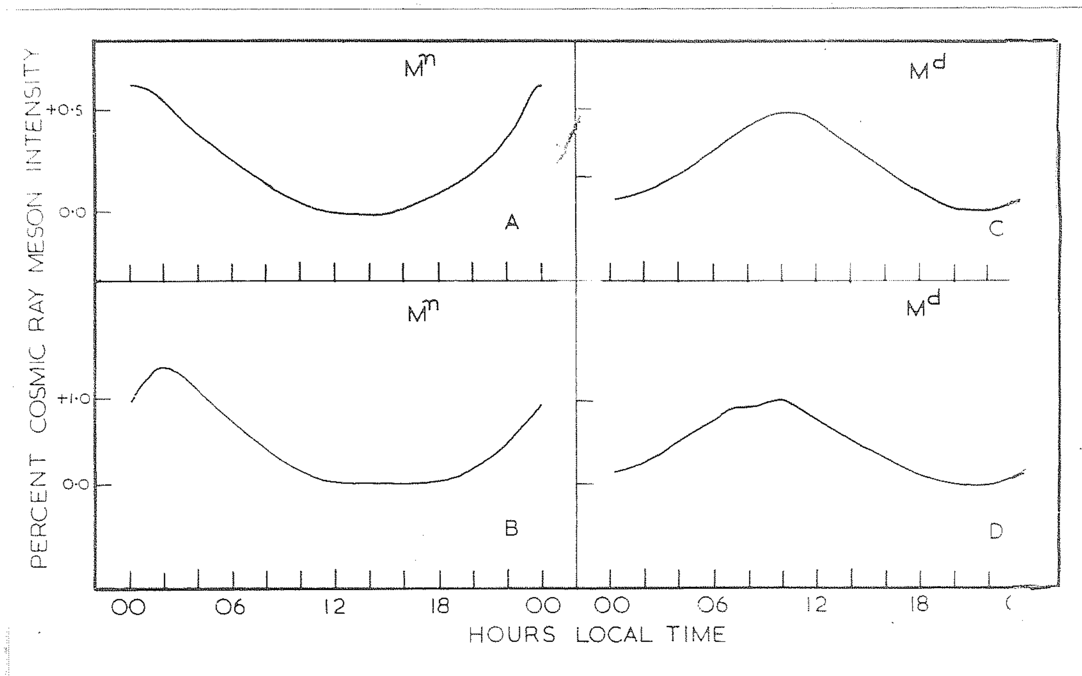


Fig. 5.5 The diurnal variation of the vertical meson intensity at sea level produced by the mean. (A) and (B) refer to cases when H_z is negative and (C) and (D) to cases when H_z is positive. (A) and (C) relates to the beam with $\Delta W_b = 0.6 \times 10^8$ ev. and $V/C = 2/3\ 10^{-2}$. (B) and (D) relate to the beam with $\Delta W_b = 1.3 \cdot 10^8$ ev. and $V/C = 2/3\ 10^{-2}$.

particular orientation of the magnetic field the same type of anisotropy will be effective when earth is on either side of a beam for a few days. Hence each type of anisotropy is expected to occur separately in groups of days and the two types of variations would not be simultaneously present. The results presented in Sec. 4.25 as well as those of Kane[87] and Sittkus[84] show that these variations in general occur in groups of days and also exhibit recurrence tendency of 27 days. This recurrence tendency is a natural consequence of the persistence of an active region responsible for the beam over several solar rotations.

For the two different anisotropies to exhibit a 22 year cycle , it will be necessary to have the relative contribution of the beams having positive and negative components of the trapped magnetic field, follow a pattern of 22 year cycle of solar activity. The most prominent feature which exhibits a 22 year cycle is the magnetic field associated with active solar regions. It would then suggest that the coherent magnetic field trapped within the beam is in some way related to the magnetic field of the active solar regions.

5.4 The Daily Variation from the East and the West Directions.

The results presented in section 4.1 have shown that the difference in the times of maxima of the diurnal variation of meson intensity in the east and the west directions is of the order of two to four hours while calculations from Brunberg & Dattner's curves give a difference of 7 hours for a mean primary energy of 25 BeV and 5 hours for a mean primary energy of 40 BeV. Since the anisotropy of the primary radiation should be a function of the energy of the primary particle according to the theory given in Sec. 5.2 and the cut off energy due to geomagnetic field is less in the west direction than in the east, it does not seem appropriate to refer the difference in the variation in the two directions as simply to the same mean primary energy in both the directions. If the anisotropy is due to the presence of the beams, its nature will be governed by a function A(E,t) as explained in Sec. 5.3. The diurnal variation recorded in the east and the west directions is given by

$$\int_{E_{c\lambda}}^{\infty} m(E,x)\, L(E)\, i(E-\Delta E)\, A(E,T)\, dE \qquad (5.11)$$

where i(E)dE is the differential energy spectrum of primaries, m(E, x) is the yield function and $E_{c\lambda}$ is the cut off energy in the east or the west azimuth due to the geomagnetic field. At Ahmedabad for an inclination of 35° to the zenith $E_{c\lambda}$ is ~ 11 BeV for the west direction and ~ 20 BeV for the east direction. This difference in the value of $E_{c\lambda}$ is of some significance in low latitudes, since the low energy primaries that come in the west directions but not in the east directions are in the range of 10 to 20 BeV which can contribute substantially to the meson intensity. At high latitudes where $E_{c\lambda}$ is of the order of 3 to 4 BeV, the difference is of no practical significance because of the inability of such particles to contribute an appreciable fraction to the meson intensity at sea level.

Using the form of the function A(E, t) given by the equations 5.3, the diurnal variation is evaluated for an inclination of 25° and 35° in the east and the west directions as described in Sec. 5.3. It is found that the difference in times of maxima of the diurnal variation in these two directions is about two hours in the former case and about three hours in the latter case. This is in good agreement with the experimental results of Sec. 4.1.

The function m(E, x) used is that given by Nagashima. It is not strictly appropriate to use it for the intensity in inclined directions. However for calculations of comparative measurements in two equally inclined directions, as in the present investigation, no serious error would be introduced.

The west pointing telescope records primaries of lower energies and since the percent anisotropy is a decreasing function of energy above W_{min} the amplitude of the diurnal variation in the west direction should be greater than that in the east direction. This deduction is also in agreement with the experimental results of Sec. 4.1 although they are not statistically significant.

This analysis is not rigourous but it makes it possible to explain satisfactorily the difference in the daily variation in the east and the west directions at low latitudes, on the assumption that the anisotropy created is by the solar beams carrying with them coherent magnetic field. The energy dependence of the anisotropy to be expected on this theory helps in removing a possible discrepancy between experiment and theory where this dependence does not arise as a natural consequence of the assumptions made.

5.5 Magnetic Field within the Beam.

The beam hypothesis incorporating coherent magnetic fields has been found to explain many features of the diurnal variation, and it is imperative at this stage to look into the other variations that may be affected by the presence of such beams. The depth to which the particle can penetrate into the beam is given by

$$d = \rho(1 - \cos\theta) = \frac{W}{He}(1 - \cos\theta)$$

where θ is the grazing angle. This depth is a function of the energy of the particle so that as the earth moves into the beam the primary spectrum will be progressively devoid of more and more low energy particles. This implies that the cut off in the primary spectrum will shift to higher energies. If W_{min} is of the order of 10 BeV the earth may not receive any primary particle below 5 BeV when it is at the centre of the beam. Simpson's observation[100] on the latitude variation of neutron intensity at the time of weak magnetic storms do not show any change in the cut off energy of the primary spectrum. This single argument is contrary to the assumption of coherent magnetic field inside the beam.

If small degree of turbulence is introduced inside the beam, the magnetic field will be partly ordered and partly turbulent in nature. The beam will now resemble a partly magnetised bar magnet wherein small individual domains are orientated in different directions but on the average give rise to a component along the line of magnetisation. The deflections of the individual particles will not be governed by the equations 5.3 and 5.6 but these can still represent with fair amount of accuracy the average behaviour of primary particles. Under such circumstances, it will be possible for the low energy particles to diffuse into the beam and penetrate to greater depths. But the number of such particles will be small so that percentwise low energy component will be affected more than the high energy component as far as the total number is concerned. This fact is supported by the observation of Neher & Forbush[69] that magnetic storm type decrease in ionization at balloon altitudes was four times that at sea level on 26th July 1946.

The partial turbulent nature of the magnetic field permits the presence of low energy particles which would have been otherwise absent in the beam. These particles will introduce certain directional asymmetries, the nature of which will be varied in character. Such asymmetries will influence the diurnal variation so that the actual variation recorded on an individual day will not always be as shown in Fig. 5.5 but much more complicated. Even the deflections of high energy particles will be influenced and modified by the turbulent nature of the magnetic field so that the daily variation on individual days on equatorial latitudes will also be complicated. The results presented in Fig. 4.10 and those of Simpson and Sittkus in fact show such a behaviour. On the average, these asymmetries are expected to be cancelled out so that the daily variation averaged over a long period will be characteristic only of the coherent magnetic field inside the beam. The times of maxima of the daily variation on individual days will not be sharply between 0100 and 0300 hours or 1100 and 1300 hours but will be statistically grouped around 0200 hours and 1200 hours. This is in good agreement with the results presented in Fig. 4.11.

5.6 Corpuscular Emission from the Sun.

The model advancedso far to explain the various features of the diurnal variation assumes the emission of corpuscular matter in the form of discrete streams from the solar surface, and it will be of some interest to record the evidence on the corpuscular emission from the sun[134].

Worldwide disturbances in the earth's magnetic field and their relation to solar activity suggest that the sun emits corpuscular matter in the form of beams. From the data on comet tails Bierman[135] suggests that the sun emits particle streams with an intensity of 10^8 particles per second at all times and in all directions. To explain the fine structure of the comet tails he, in addition, visualizes the existence of narrow beams of solar corpuscules which are also responsible for weak geomagnetic storms. Babcock & Babcock[136] have recently reported that various phenomena like prominences, M regions etc. can be understood in terms of a weak solar magnetic field on the assumption that electrically neutral streams of ions are more or less continually ejected from all turbulent regions on the solar surface. Since matter in the beam is in a highly ionized state, such beams are essentially invisible except in so far as they excite weak radiation. Recent experiments by Meinel[137] and Gartlein[138] on the aurora demonstrate their existence.

It is believed that at the time of solar flares a neutral but ionized cloud is ejected from the solar surface and is responsible for the subsequent magnetic storm. But at sunspot minimum geomagnetic storms are observed even though flares are almost absent. Therefore, the beams responsible for magnetic disturbances do not require flares for their production. There may exist a common cause for the production of activity like sunspot, flares etc. and for the emission of corpuscular matter. This cause may not necessarily produce a spot or a flare when it expels a stream of corpuscular matter. The presence of corpuscular beam in the absence of any active solar region can give rise to large amplitudes of the diurnal variation. Therefore, a one to one correlation of the abnormal diurnal variation with active solar regions is not always warranted. This agrees with the results quoted in Sec. 4.26 as well as those of Sittkus[84].

Even if corpuscular matter is ejected in the form of expanding clouds, as it proceeds outwards the clouds will assume a ribbon like or a sheetlike structure. Such a configuration may be compared to the section of shells blown off from ordinary novae. This view is strengthened by the observations that even though there is a remarkable persistence of 27 day sequence of geomagnetic storms, thus signifying the long lived nature of the solar emission, the individual disturbance on the earth lasts for a few days in each solar rotation. One therefore suspects that the corpuscular beams have a sheetlike shape and these beams rotate with the sun so that the earth is engulfed in them only a few days in each solar rotation.

If these beams originate in turbulent regions having coherent magnetic fields, it is normally expected that the trapped magnetic field in the beam, because of its high conductivity, will be partly turbulent and partly coherent in nature. It has not been possible so far to relate the trapped field with any coherent field on the solar surface. If, however, this field is in some way related to the magnetic field of the active solar regions, it will be possible to have the trapped field orientated in different directions. It has been assumed that the beam resembles a magnetised slab with no magnetic field in the external medium. The magnetic field in the slab demands a current sheet circulating around its boundary. Such a sheet in itself would call for a return magnetic flux outside the beam. This flux would be small at any point but widely spread out so that its total integrated value will be equal to the total flux through the slab. Swann[139] has shown that the magnetic flux outside the beam can be made zero by having another current sheet flowing in reverse sense outside the first one and having an appropriate area in the same plane. These two current sheets will however give rise to a uniform magnetic field inside the beam. Whether such a current system exists inside the beam is not known at present. What Swann has shown is a physical picture whereby a uniformly magnetised beam with no external magnetic field can be realised in practice.

It is seen that the assumptions made in Sec.5.2 offer a plausible basis for explaining some of the principal features of the daily variation. The principal exception at the present time is the large daily variation observed in radiation near zenith when measurements are made with narrow angle telescopes. The mechanism suggested by Alfven[132] may have a physical reality but as it stands, it fails to explain the anisotropy which can produce a maximum in the daily variation at night. What has been attempted here is to investigate an alternative model that can explain many features of the intensity variations. The model presented here is an extension of Nagashima's original work and many features of the model to be discussed later are already incorporated in the work, though some of them have not been adequately stressed.

In the following two sections further derivations of the proposed model are discussed to explain some more features of the variations of intensity.

5.7 Energy Dependence of the Diurnal Variation.

Since the daily variation has been present in the neutron intensity at Climax, Firor et al[51] have concluded that the primary spectrum with mean energy as low as 5 BeV undergoes daily variation. In Fig. 5.6 is reproduced the result giving the amplitude of the monthly mean daily variation in neutron intensity at Climax and Huancayo and ionization at Freiburg. The average amplitudes of the diurnal variation of neutron intensity at Huancayo and

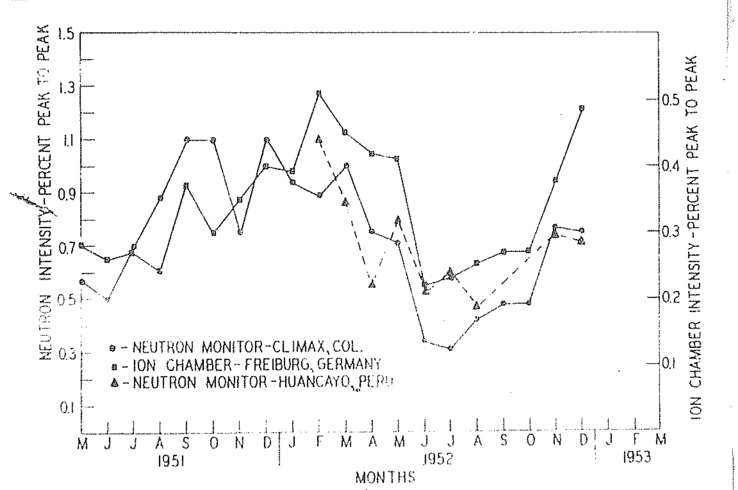


Fig. 5.6

Climax are almost equal and there are months when the amplitude at Huancayo is greater than that at Climax. Over a period of several years, the percent amplitude of the diurnal variation of ionization at Huancayo is about 10% greater than at Cheltenham. Thus within the latitude sensitive spectrum of primaries there appears to be no marked change in anisotropy.

Since the neutron monitor at Climax responds to a mean primary energy of 7 BeV while that at Huancayo to 19 BeV and no latitude dependence is observed between latitude range 1°S to 50°N, it apparently looks as if the primary spectrum at 7 BeV and at 19 BeV is affected percentwise to the same extent. Comparing the results of the ion chamber at Freiburg and the neutron monitor at Climax, it is observed that on the average the latter exhibits about 2.3 times the amplitude shown by the former. Since the ion chamber at Freiburg responds to mean primary energy of about 30 BeV it appears that there is large change ~~in~~ the diurnal variation in the energy region between 19 and 30 BeV. Thus the variations are not as latitude dependent as a comparison of the neutron monitor with charged particle detectors at the same latitude would seem to suggest. In the light of the theories advanced so far it is rather difficult to understand this type of energy dependence derived from experimental results.

It has been stated earlier that the anisotropy of the primary spectrum produced by the beam is confined to the primary spectrum above a certain energy designated as W_{min} and for the energies above W_{min}, the percent anisotropy decreases with increasing energy. If W_{min} is $\sim$10 BeV, the complete available spectrum in equatorial latitudes i.e. above 15 BeV takes part in the diurnal variation and since neutron monitor responds to a lower energy part of the primary spectrum than the meson monitor, the amplitude of the diurnal variation measured by the former will be greater than that by the latter. A rough calculation shows the ratio to be of the order of 2.5 as against the observed ratio of 2.3. At middle latitude say 50°N, more than half the neutron intensity comes from the primary spectrum below 10 BeV, while meson monitor records less than one-fourth from the primaries below 10 BeV. Now so far as the primary spectrum above 10 BeV is concerned, the neutron monitor will record larger percent charge than the meson monitor but this change is much reduced by the intensity from the part of the spectrum below 10 BeV which only adds to the background rate. Thus even though there is a large difference between the mean primary energy of the radiation to which both types of detectors respond viz. 7 BeV and 30 BeV respectively, the ratio is still about the same as that at low latitudes in agreement with experimental observations.

If neutron monitors at different latitudes are considered and the minimum energy below which no anisotropy is present is about 10 BeV, it is observed that the ratio of the amplitude of the neutron monitor in equatorial latitudes to that in middle latitudes is about unity. This is again due to the fact that larger change in middle latitudes is compensated by an equally large intensity which does not take part in the diurnal variation. The percent amplitude of variation is the same as of the neutron monitor at Huancayo but is still greater than that of the meson monitor.

W_{min} will change with different beams and the ratio of the diurnal variation recorded at the two stations will change from period to period as is actually observed in Fig. 5.6. It is possible now to understand the discrepancy in the energy dependence derived from the results shown in Fig. 5.6 which from the point of the mean energy of primaries to which they respond are difficult to understand.

5.8 Day to day Changes in the Low Energy Cut Off.

Neher (private communication) has found a very curious phenomena in the balloon flights in 1955. On a group of days the ionization depth curve was continuously rising indicating the presence of low energy radiation upto 200 MeV, as was observed in 1954. This was immediately followed by a few days when the ionization depth curve turned over signifying the absence of very low energy particles. Curiously enough, the high energy particles which could penetrate at greater depths showed more intensity in the latter group of days than the former one. It would have been normally expected that when the low energy radiation can arrive at the earth all the high energy radiation will also be present, so that the intensity of the high energy radiation in the former group should have been either greater or at least equal to that in the latter group. The observed result is contrary therefore, to the normal expectation.

If it is assumed that the earth is outside the beam for the first few days and the spectrum of the primary radiation extends even to very low energy in 1955 as it was in 1954, it is noticed as shown in Fig. 5.7

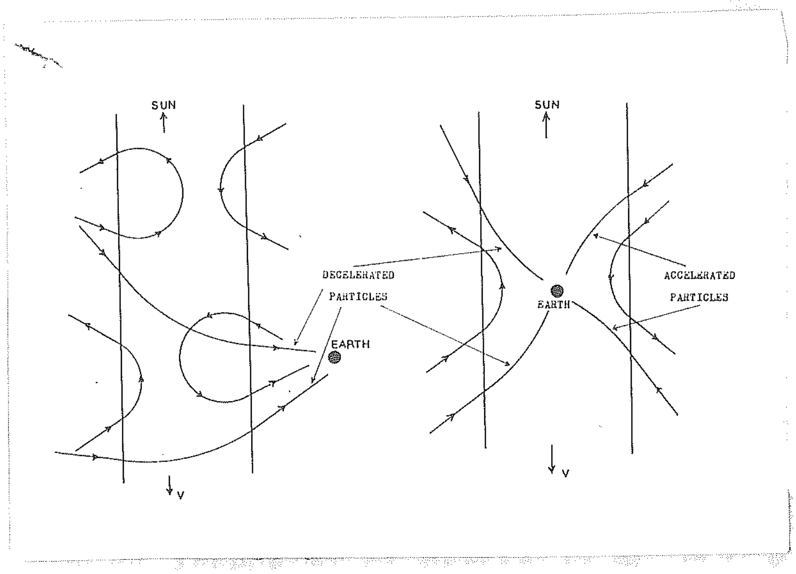


Fig. 5.7 Fig. 5.8

that the low energy particles which cannot cross the beam are deflected in such a way that their initial degree of isotropy is not disturbed. Thus even in the presence of a beam in the neighbourhood of the earth, the very low energy part of the primary spectrum will be present. But the part of the high energy radiation which now has crossed the beam will be decelerated if there is an appropriate magnetic field trapped in it. In consequence, the intensity of the high energy particles will be below normal. If now the earth moves into the beam having a coherent magnetic field, it is realised that the low energy component will be absent. If the field is partly turbulent in nature low energy component will diffuse to the earth but the beam can still serve as a reflector for very low energy radiation below 1 BeV. Thus for a group of days there will be a cut off at the low energy end of the primary spectrum. However as shown in Fig. 5.8, part of the high energy component will be accelerated while the part which was initially decelerated is reduced, so that the intensity of the high energy particles will be more than when the earth is outside the beam. Pending publication of the results, it is difficult to test this explanation quantitatively. From a comparison of various types of fluctuations it is found that there is often a larger change of intensity of particles of energy less than 10 BeV than of those above it. However there are occasions when, as shown by Neher, the reverse is true and there can be increase of intensity at intermediate energies without corresponding change at low energies. This is possible if the earth is outside the beam and the magnetic field inside the beam is more coherent than turbulent. In this case little change is produced for low energy primaries below W_{min} while significant change is expected at higher energies. Hence it seems possible to reconcile various results on the beam hypothesis incorporating coherent magnetic fields.

CHAPTER VI

CONCLUSION

Comparison of the daily variations observed with telescopes pointing to the vertical, the east and the west directions shows that the time of maximum of the diurnal component of the daily variation in a vertically pointing telescope lies between those in the east and the west pointing telescopes, but the spread in times of maxima in the three directions is much less than would be normally expected.

The amplitude of the daily variation depends very much on the directional sensitivity of the measuring instrument and on the period for which data are averaged. Simultaneous measurements made with telescopes with different semiangles of opening from 15° to 2.5° in the E-W plane reveal that in 1954-1955 the amplitude of the daily variation of meson intensity at low latitudes is about $1.05 \pm 0.07\%$ in $^{2.5}T$ and $0.88 \pm 0.04\%$ in ^{5}T but is $0.55 \pm 0.04\%$ in ^{15}T. The amplitude of the daily variation observed with narrow angle telescopes is thus comparable to that observed by neutron monitors. The effective directional sensitivity as well as the mean energy of the primaries to which these two types of instruments respond are different. At the present moment we have no available data where the amplitude of the daily variation observed with a neutron monitor can be compared directly with the amplitude of the daily variation in meson intensity measured with a telescope of equivalent directional sensitivity. Until this is done, it would be difficult to conclude whether the anisotropy is greater in respect of the spectrum in the mean energy range of about 7 BeV which is measured in a neutron monitor at middle latitudes than in the spectrum with a mean energy of 40 BeV which is measured by a meson intensity recorder in low latitudes. More experimental work is required to understand the energy dependence of the anisotropy of primary radiation. The ratio of the amplitude of the daily variation in narrow angle and wide angle telescopes varies from period to period. It is larger on magnetically disturbed days than on quiet days. The experience of Ehmert in this regard is similar. Ehmert suggests that unsymmetric ring currents around the earth may introduce directional asymmetries of the types observed. This explanation is hypothetical in character but it would be worthwhile to investigate in detail its implications.

The daily variation of meson intensity and the anisotropy of primary cosmic radiation is highly variable in character. The results of the present investigation indicate that the daily variation is due to the presence of at least two different types of anisotropies. These produce on different days a single maximum in the daily variation at low latitudes either during night at about 0200 hours or during day at about 1200 hours. A possible third type produces two maxima in the daily variation at about 0600 and 1800 hours. On any particular day there is present either one of these types of anisotropies. If this picture is correct, one would expect that a daily variation derived by averaging data over a large number of days would exhibit two maxima corresponding to the maxima of the day and the night type of daily variations occurring on different days during the period over which the data are averaged. It is satisfying to note that the 12 monthly mean daily variations measured at Huancayo with an ion chamber and at Ahmedabad and Kodaikanal with counter telescopes exhibit two maxima, one in the early morning and one near noon.

The amplitude of the daily variation occurring on the first two types of days is large and is of the order of 1 to 2% when observed with narrow angle telescopes. The anisotropies which give maximum in day hours or night hours occur in groups of days which sometimes recur after 27 days.

Considering the above facts, the existence of a permanent solar anisotropy may be considered to be uncertain at the present moment. If indeed it exists, it is not likely to cause an amplitude of the daily variation greater than 0.5%. Theories which have been advanced in the past to explain the average characteristics of the diurnal component of the daily variation do not permit the change in the time of maximum of the diurnal component of the daily variation by as much as 8 to 10 hours and are therefore clearly inadequate. A theory which explains the variable anisotropy by a modulation of the primary intensity seems most promising in this context.

On the assumption that the ionized beams emitted by the sun contain randomly orientated magnetic fields, changes in the primary radiation that would be produced after traversing the electromagnetic fields of such beams indicate that in low latitudes, they produce on the average maxima in the daily variation either during day at about noon or at night at about 0200 hours for a group of days. A recurrence tendency is a consequence of the persistence of the beam responsible for solar anisotropy over several solar rotations.

The anisotropy is only produced for primary cosmic rays of energy above a certain minimum value W_{min}. W_{min} depends on the width of the beam, the magnitude of the trapped magnetic field and its orientation in respect to the E-W plane. No appreciable anisotropy is produced for cosmic ray particles of energy less than W_{min}, while for increasing energy above W_{min}, the percent anisotropy goes on diminishing. This explains why averaged over long periods the amplitude of the daily variation measured with a neutron monitor is about the same at Huancayo as it is at Climax even though the mean energy of primary radiation is 20 BeV and 7 BeV respectively. The energy dependence of the anisotropy also reconciles with theory the experimentally observed small difference in times of maxima of the daily variation measured in the east and the west directions. Changes in the low energy cut off from day to day observed by Neher in 1955 can also be understood.

Hence there appears a possibility of being able to understand various features of the daily variation of cosmic radiation in terms of the changes in the primary cosmic radiation produced in interplanetary space by solar beams carrying with them trapped magnetic fields. The most satisfactory scheme of things would be, to be able to explain the intensity variations as well as anisotropy on a unified theory. Further work is required in this direction. The changes in the primary cosmic radiation therefore hold out promise to provide a valuable tool to study electromagnetic fields and distribution of matter in interplanetary space.

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TABLES

Page

FIGURES

Page

2620

Page