V. DISCUSSION

5.1 Influence of meteorological factors on the daily variation of cosmic ray intensities.

5.1.1. Barometric coefficient for correcting daily variation of meson intensities:

Extensive studies have been made to correlate the day-to-day variation of cosmic ray intensity with meteorological changes in the atmosphere. Duperier has shown that variations of meson intensity are connected with a mass absorption effect, an effect due to alteration of the probability of meson decay accompanying changes of heights of isobaric levels and an effect of the temperature or density of the atmosphere near the 100 mbs. level.

As has been mentioned earlier, in terms of these three factors Duperier has suggested the following expression for the variation in the meson intensity produced by atmospheric changes.

\[ \delta I = \beta_1 \delta \beta + \beta_2 \delta H + \beta_3 \delta T. \]
It should not be expected that in the daily variation the influence of these factors in the meson intensity would be identical to what is found in day-to-day variations. This is because in barometric pressure as well as in atmospheric temperature, the day-to-day changes are brought about under very different circumstances from those that produce the daily variation. Processes responsible for the day-to-day changes of the barometric pressure are entirely different from those causing the dynamical periodic pressure oscillations. The use of the barometric pressure coefficient obtained from studies of the day-to-day variation for correcting cosmic ray daily variation data for effects due to the daily variation of pressure is therefore questionable. A better method appears to be to derive, if possible, a barometric coefficient from daily variation studies. In doing this, we have to keep in mind available knowledge on the physical processes responsible for the daily variation of the meteorological elements and the special features of atmospheric oscillations.

It is difficult to draw conclusions about the effects of meteorological factors on cosmic ray intensity by comparison of the daily variation curves of Fig. 3.1. Solar radiation and gravitational forces are the most important causes for the daily variations observed in geophysical elements. These variations, as well as one that could be caused in meson intensity by an anisotropy of the primaries of solar origin, would have a predominant 24 hourly diurnal
component. Therefore it is not clear how much of the $M^2$ variation is connected with $p^2$ and $\theta^0$ or a hypothetical upper air diurnal temperature variation, and how much is due to primaries of solar origin.

The atmospheric pressure, unlike temperature, has an appreciable semi-diurnal component. As was originally pointed by Kelvin, the semi-diurnal variation of pressure is due to resonance in the atmosphere which has a free period of oscillation of nearly 12 hours. Thus, even though the exciting solar forces are diurnal, the semi-diurnal component of pressure becomes important and its predominant at low latitudes. The daily pressure variation at low latitudes is fairly systematic and reflects the periodic changes of air mass of the absorbing column of air. If attention is therefore confined only to the semi-diurnal component, we have a means of studying the influence of pressure, uncontaminated with effects due to temperature variation of the atmosphere or due to anisotropy of cosmic ray primaries both of which should have a diurnal component of variation.

The first two harmonic components of $T$, $M$ and $E$ along with $P$ and $\theta$ are shown in Fig.3-7 on 24 hourly and 12 hourly harmonic dials. It will be observed that while in the 24 hourly dial, the vectors lie all around the clock, there is on the 12 hourly dial a very striking grouping of the cosmic ray vectors almost completely opposite in phase with
the pressure vector. This clearly shows that high negative correlation exists between cosmic ray components and the pressure.

Correlation analysis of the semi-diurnal vectors of cosmic ray components with atmospheric pressure gives correlation coefficients and barometric coefficients as shown in Table 5.1.

<table>
<thead>
<tr>
<th>Cosmic ray component</th>
<th>Correlation coefficient ( r )</th>
<th>Barometric coefficient ( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T^S_A )</td>
<td>( r_{TP} ) = -0.97</td>
<td>( \beta_T ) = -4.3% per cm.Hg</td>
</tr>
<tr>
<td>( H^S_A )</td>
<td>( r_{NP} ) = -0.95</td>
<td>( \beta_m ) = -2.5% per cm.Hg</td>
</tr>
<tr>
<td>( E^S_A )</td>
<td>( r_{EP} ) = -0.98</td>
<td>( \beta_E ) = -14.1% per cm.Hg</td>
</tr>
</tbody>
</table>

Table 5.1

The barometric coefficient \( \beta_m = -2.5\% \) per cm. Hg for mesons may be compared with the value found by other workers from day-to-day variations of cosmic ray meson intensity. Coefficients of \(-3.0\% \) per cm. Hg for Huancayo and \(-1.8\% \) per cm. Hg for Cheltenham, Christchurch and Godhavn have been determined and used for barometric pressure correction by Lange and Forbush for the Carnegie Institution ionisation chamber data. It is not clear why at Huancayo the coefficient could be so much larger than at the other stations in spite of the shielding being the same for all the instruments. Duperier's barometric coefficient is \(-1.5\% \) cm. Hg and Dolbear and Elliot have reported a value of \(-1.88\% \) cm.Hg.
obtained from seasonal variation of intensity. These authors by partial correlation analysis, give estimates for the three meteorological coefficients which affect meson intensity. These are shown in Table S.2. Our value of the barometric coefficient for mesons is larger than the true mass absorption coefficient of Duperier but agrees well with the coefficient of Dolbear and Elliot.

Table S.2

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Duperier</th>
<th>Dolbear and Elliot</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>- 1.50%/cm.Hg*</td>
<td>- 1.88 % /cm.Hg</td>
</tr>
<tr>
<td>$\mu$</td>
<td>- 1.05%/cm.Hg</td>
<td>- 2.07 % /cm.Hg</td>
</tr>
<tr>
<td>$\rho'$</td>
<td>- 3.90% /km.</td>
<td>- 4.22 % /km.</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.12 % /°C.</td>
<td>0.14 % /°C.</td>
</tr>
</tbody>
</table>

* Weighted mean for 5 periods of observations.

It is important to examine if there is a substantial decay contribution in the semi-diurnal variation. Pekeris and more lately Wilkes and Weekes have examined the details of the modes of oscillation of the atmosphere. Nicolson and Sarabhai have estimated the effect on meson intensity of the semi-diurnal change of height of isobaric levels due to atmospheric oscillations. For meson production near 16 km, there should be a semi-diurnal oscillation for the isobaric level which would not exceed 4 metres and thus would not change significantly the contribution of the pure mass absorption effect to the barometric coefficient.
Finally, we have to consider a possible contribution from a positive temperature effect. The results of our upper air meteorological investigations have shown that in the atmosphere near the 100 mb level, the main changes of temperature are not diurnal but of irregular day-to-day character. When data are averaged over an extended period, the latter fluctuations are expected to be smoothened out. Since the amplitude of the diurnal temperature variation near the tropopause is not significant, we are lead to believe that the barometric effect derived by us from the semi-diurnal variation corresponds mainly to the true absorption coefficient for the meson component.

The validity of a pressure coefficient derived from the semi-diurnal component of the daily variation in the manner described above depends on the non-existence of an intrinsic semi-diurnal component\textsuperscript{x} of meson variation due to causes other than pressure oscillation. It is not certain whether this assumption is always justified. The following factors if they are present to an appreciable degree, would require abandoning of our method of applying a barometric correction to the daily variation of mesons.

(1) A daily variation will not in general have only the diurnal harmonic component even though it is characterised by one maximum and one minimum in 24 hours. The variation would rarely be perfectly sinusoidal, and depending on the extent to which its from differs from this type, higher harmonics would be present. In particular, if due to
anisotropic primaries, there is an increase in intensity produced only during the day, but at night the intensity is constant, we would get an appreciable $\mathbf{M^3}$ with maximum almost coinciding with that of $\mathbf{M^D}$. We can refer to this semi-diurnal component $\mathbf{M^3}$ as a shadow component of the main diurnal component $\mathbf{M^D}$. When $\mathbf{M^D}$ has an hour of maximum near 1030 hours $\mathbf{M^3}$ would also be highly correlated with $\mathbf{P^S}$ and would tend to reduce the effective barometric effect.

2. There may perhaps be a semi-diurnal variation due to anisotropic primaries. Elliot and Dolbear have demonstrated that their South-pointing telescope shows a more pronounced $\mathbf{M^3}$ component than the North-pointing telescope. We are unable to explain the semi-diurnal variation of mesons positively correlated with pressure which is reported by Regener and Rau. Unless the anisotropic component is under solar control, it cannot produce a semi-diurnal component of variation when data according to solar time is averaged round the year. It is not therefore clear how this could arise.

The high negative correlation between $\mathbf{M^3}$ and $\mathbf{P^S}$ at Ahmedabad indicates either an absence of an appreciable intrinsic $\mathbf{M^3}$ component or that its phase is almost in agreement or in opposition to that of $\mathbf{P^S}$. For a shadow component $\mathbf{M^3}$ produced by a daily variation with a maximum shortly before noon, our barometric coefficient would be somewhat underestimated. However its closeness to the values
determined from studies of day-to-day changes gives confidence in applying it for correcting the daily variation data of meson intensity for barometric pressure changes.

5.1.2 The barometric coefficient for the soft component:

Reference to Table 5.1 indicates that the soft component \( E \) has a barometric coefficient - 14.1 \( \% \) per cm.Hg. This is considerably more than the coefficient for mesons, as is to be expected from the additional radiative loss that an electron can suffer at high energies and which predominates over the collision loss, suffered by both electrons and mesons.

The soft component of the cosmic radiation which does not penetrate more than 10 cms. of lead, is composed mainly of electrons, positrons and photons. The processes initially responsible for the soft component \( 'E' \) are believed to be the following:

(1) the decay of \( \pi^0 \) mesons into photons at the top of the atmosphere. These give rise to cascade showers which determined the shape of the height ionization curve for total intensity at high levels. At sea level very little of the electronic component is due to this process.

(2) the decay of \( \mu \) mesons.

(3) the knock-on production of electrons by mesons.

At sea level the last two processes play an important
role.

The multiplicative process in which positive and negative electrons produce photons, and the photons in turn produce electron pairs gives rise to cascade showers. The cross-section for 'bremsstrahlung' by positrons and electrons and for pair creation by photons is proportional to

\[
\frac{417}{137} \cdot \gamma_0 \cdot \log(183 Z^{-\frac{1}{3}}) \quad \text{where} \quad \gamma_0 = \frac{e^2}{mc^2}
\]

The cascade theory has been developed as a result of contributions of a number of investigators. Bhabha and Chakrabarty have calculated the number of electron \( N(w t) \) produced by a primary electron of energy \( W \) at a depth 't' of an absorbing material. For the sake of convenience, 't' and \( W \) are expressed in terms of radiation length 'l' and critical energy \( W_c \) respectively. For a particular substance the radiation length is defined as

\[
l = \left\{ \frac{417}{137} \cdot \gamma \cdot \log(183 Z^{-\frac{1}{3}}) \right\}^{-1}
\]

where \( N \) is the number of atoms per unit volume of the absorber. The energy \( W_c \), the energy lost by a fast particle by the process of ionization in traversing a radiation length is called the critical energy. The value of 'l' in cm and \( W_c \) in Mev for some common substances are given in Table:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Air</th>
<th>H₂O</th>
<th>H</th>
<th>Fe</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>l in cm</td>
<td>34.2</td>
<td>43.4</td>
<td>9.80</td>
<td>184</td>
<td>0.525</td>
</tr>
<tr>
<td>W_c in MeV</td>
<td>103.0</td>
<td>114.6</td>
<td>55.50</td>
<td>25.88</td>
<td>6.927</td>
</tr>
</tbody>
</table>

v 5.2
When energies of the particles are expressed in terms of their critical energies in a particular substance, and lengths in terms of the radiation length in the same substance, the numerical results of the cascade theory are applicable to all substances. Values of $N(w_t)$ as calculated by Bhabha and Chakrabarty, for selected energies and depths of absorber are given below in the Table 5.3.

The energy is expressed in this table in terms of a variable $Y$ defined by $Y = \log \left( \frac{w}{w_0} \right)$.

<table>
<thead>
<tr>
<th>$t$</th>
<th>$Y$</th>
<th>$3$</th>
<th>$4$</th>
<th>$5$</th>
<th>$6$</th>
<th>$7$</th>
<th>$8$</th>
<th>$9$</th>
<th>$10$</th>
<th>$12$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3.1</td>
<td>6.2</td>
<td>10.6</td>
<td>17.1</td>
<td>25.6</td>
<td>36</td>
<td>50</td>
<td>67</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.2</td>
<td>4.8</td>
<td>13.8</td>
<td>33.2</td>
<td>69.9</td>
<td>137</td>
<td>241</td>
<td>423</td>
<td>1117</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.4</td>
<td>2.1</td>
<td>8.6</td>
<td>28.7</td>
<td>80.6</td>
<td>198</td>
<td>460</td>
<td>970</td>
<td>3735</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.1</td>
<td>0.8</td>
<td>4.0</td>
<td>16.7</td>
<td>58.8</td>
<td>181</td>
<td>499</td>
<td>1284</td>
<td>6898</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.3</td>
<td>1.6</td>
<td>7.9</td>
<td>33.3</td>
<td>121</td>
<td>392</td>
<td>1176</td>
<td>8063</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0.1</td>
<td>0.6</td>
<td>3.3</td>
<td>16.1</td>
<td>68</td>
<td>252</td>
<td>859</td>
<td>8018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>0.1</td>
<td>0.8</td>
<td>4.5</td>
<td>22</td>
<td>98</td>
<td>396</td>
<td>5080</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.1</td>
<td>0.4</td>
<td>2</td>
<td>12</td>
<td>63</td>
<td>1268</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>7</td>
<td>198</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>22</td>
<td></td>
</tr>
</tbody>
</table>

It can be seen from the above table 5.3 that the number of particles first increases with depth, attains a maximum at a particular value of 't' and then decreases for...
greater thickness of the absorber. The apparent pressure coefficient would in consequence be positive at the start, become equal to zero at the maximum of shower growth and then would reverse in sign. Physically this implies that for showers, both regenerative as well as attenuative processes are operative, and the experimental value for the pressure coefficient would depend on the location of the point of observation with respect to the development of the shower. If the soft component is measured by differential absorption as in the present case there would be a large proportion of low energy component representing the end of the shower. Hence the barometric coefficient should be greater than what is found in experiments where the soft component is studied by measurement of showers with at least two time associated particles. Table 5.1 indicates the experimentally observed coefficients.

5.2 The barometric pressure corrected variations

The appropriate barometric coefficients experimentally determined from semi-diurnal components can be used to correct the daily variations of $T$, $M$, and $E$ for the barometric daily variation. Smoothed bi-hourly values of the barometric pressure corrected variations designated by $T'$, $M'$ and $E'$ are shown in figure 5.1. The harmonic component of these are indicated in Table 5.1 and presented on harmonic dials in Fig. 5.2.
Table 5.4 (p.111)

Pressure coefficients obtained for the soft component by various investigators.

<table>
<thead>
<tr>
<th>Author</th>
<th>Method of observation</th>
<th>Duration</th>
<th>Absorber</th>
<th>Type of Pressure variation</th>
<th>Pressure coeff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnothy &amp; Forro</td>
<td>Showers</td>
<td>1 year</td>
<td>-</td>
<td>Day-to-day</td>
<td>-42% per cm. Hg</td>
</tr>
<tr>
<td>Stevenson &amp; Johnson</td>
<td>&quot;</td>
<td>4 weeks</td>
<td>12 cm. Pb</td>
<td>&quot;</td>
<td>-5.5% per cm. Hg</td>
</tr>
<tr>
<td>Froman &amp; Starma</td>
<td>&quot;</td>
<td>140 days</td>
<td>-</td>
<td>Daily</td>
<td>&quot;</td>
</tr>
</tbody>
</table>
Table 5.4

Amplitudes and hours of maxima of harmonic components of the daily variation of pressure corrected cosmic ray intensities.

<table>
<thead>
<tr>
<th>Variate</th>
<th>1st Harmonic</th>
<th>2nd Harmonic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 hourly</td>
<td>12 hourly</td>
</tr>
<tr>
<td>T'</td>
<td>0.37 117°</td>
<td>0.11 42°</td>
</tr>
<tr>
<td>H'</td>
<td>0.42 120°</td>
<td>0.08 12°</td>
</tr>
<tr>
<td>E'</td>
<td>0.16 4°</td>
<td>0.23 35°</td>
</tr>
</tbody>
</table>

Fig. 5.1
Fig. 5.2

Harmonic dials of \( F' \) and \( M' \).
It will be noticed that $T'$ and $M'$ are left with a residual diurnal variation of amplitude $0.37 \pm 0.06$ and $0.42 \pm 0.04$ respectively, and hour of maximum near 0800 hours I.S.T. $E'$ on the other hand has no significant variation exceeding the standard deviation of the individual bi-hourly points. This indicates that the daily variation of the electron component at sea level can be explained almost completely by a mass absorption effect connected with the barometric variation.

Duperier has corrected the daily variation of mesons for a decay effect due to an estimated diurnal change of height of about 50 metres in the isobaric levels near 16 km., in consequence of a diurnal heating of the atmosphere. The process has been considered to be analogous to the seasonal variation of meson intensity where, during summer, the general expansion of the atmosphere produces a decrease of meson intensity.

An examination of Fig. 5 reveals that the barometric pressure corrected vector for total intensity and mesons on the 24 hourly dial are both significant and are negligibly correlated with surface atmospheric temperature. If the heating in the upper atmosphere were to take place from lower levels, the maximum temperature would occur at a later hour than the surface temperature and the correlation with $T'$ and $M'$ would be almost zero. For heating of the layers of air near 16 km. from above, the maximum temperature may
occur nearer noon, but even so the correlation between the
diurnal vectors for T' and M' and a temperature vector at
noon would be quite low. One is therefore led to conclude
that the atmospheric temperature has little or no part to
play in producing the daily variation of meson intensity
corrected suitably for barometric pressure.

Having eliminated meteorological effects, it is
necessary to consider possible geomagnetic and heliomagnetic
influences on the residual daily variation of mesons.
Janossy has suggested the possibility of a diurnal variation
of cosmic rays at latitudes beyond 40° due to the helio-
magnetic field. Dwight has worked out detailed implications
but this theory can be safely excluded in view, amongst
other things, of the evidence from several quarters concern-
ing the non-existence of an appreciable general helio-
magnetic field at the present time. Vallarta and Godart
have discussed the influence in low latitudes of an ionospheric
current system responsible for the geomagnetic diurnal vari-
ation. While the latter alters fundamentally in character
with latitude, Thompson has shown that the meson variation
has similar features over a wide range of latitudes. It
appears therefore that the barometric pressure corrected
variation of mesons is of extraterrestrial origin and is
connected with an anisotropy of the primary radiation.

For better appreciation of the residual variation
it is worthwhile to examine the results obtained by my
colleague Dr. R. P. Kane at Kodaikanal by a type of instrument similar to the one operated at Ahmedabad. Because of this the final results at the two places are comparable.

At Kodaikanal the correlation between the semi-diurnal components \( M^S \) and \( P^S \) is only +.29. As however \( M^S \) itself is only .12% in amplitude and is not significant, this positive value might be fortuitous.

The atmospheric pressure plays an important part in the solar daily variation of mesons at the low level station at Ahmedabad but produces a negligible effect at Kodaikanal. The correlation of \( M_k \) with \( \Theta_k \) like the correlation of the pressure corrected meson variation \( M'_A \) and \( \Theta_A \) is negligible. Ground temperature has therefore negligible effect at both places.

The curve of residual meson variation corrected for pressure at Ahmedabad and the meson variation curve at Kodaikanal are both significant and strikingly similar. Both are diurnal with amplitude \( M'_A = 0.42 \) per cent and \( M'_k = 1.10 \) per cent with maxima at 0250 and 0840 hours local time respectively. The increase of the percentage amplitude with elevation suggest the contribution of a larger number of low-energy particles which can make their effect felt at a high-level station but not at a sea level station.

Taking into consideration the occurrence of the maximum of the diurnal variation at about the same period
of the day according to local time at widely separated places on the earth, it is reasonable to conclude that the anisotropy is caused by the solar emission of cosmic rays. Duperier has indeed made a similar suggestion by a consideration of the seasonal change of amplitude of the meson diurnal variation corrected for barometric pressure and decay coefficient. As however, the application of the decay effect is questionable for reasons mentioned earlier, the close agreement between the ratio of summer and winter diurnal amplitudes with what would be expected due to change of the solar zenith distance at the two periods may be fortuitous.

5.3 The hour of maximum of the diurnal variation:

An important question arises about the observed hour of maximum $M_0$ of the meson diurnal variation. There is a divergence amongst the reported results of various workers concerning the precise hour of maximum. It varies in extreme cases from 0800 hours to 1600 hours. A great deal of this divergence is perhaps due to differences in methods of correcting for meteorological effects.

Hogg has compared on a harmonic dial the diurnal vectors for meson daily variation observed by various workers at different places. For Canberra data, a vector has been given for barometric pressure corrected meson variation as well as for one which has, in addition, been corrected for a temperature effect. There is a considerable difference
between the amplitude and the hour of maximum of the resultant variation in the two cases. Forbush for Cheltenham data, has shown how the uncorrected meson diurnal vector at 1400 hours shifts to 1100 or 1000 hours according to the magnitude of the barometric coefficient which is applied for correction.

Some of the differences in the hours of maxima and amplitude observed by various workers are probably connected with the nature of the measuring apparatus and the angle within which it allows incident radiation. Generally an omni-directional instrument would reveal a smaller amplitude of variation than a unidirectional one. In latitudes where there is an E-W asymmetry of the cosmic ray intensity, an ionisation chamber would effectively function like a West-pointing telescope having a later maximum than a vertical telescope. In view of all these factors comparisons between the diurnal variation at different latitudes and elevations can only be made where similar experimental technique is followed at the various stations, and appropriate similar corrections are applied to the basic experimental data. Carnegie Institution studies are therefore very valuable for this purpose, and when further significant data is available from our unidirectional studies at Kodaikanal and Trivandrum (Mag.Lat. 1°N., Alt. 0 metres) it might be possible to get a better insight in this subject. From our own studies, there is every indication that the maximum occurs before noon, and the hour becomes earlier when the
diurnal amplitude increases in going from Ahmedabad to kodaikanal. Though all sea-level stations run by the Carnegie Institution have maxima in the early afternoon, the mountain station of Huyancayo has an earlier maximum before noon and of increased amplitude.

An important point that arises now concerns the relationship that can exist between the amplitude and the hour of maximum of the diurnal variation. The amplitude should be controlled, among other things, by the cut off in the solar cosmic ray energy spectrum either by geomagnetic blocking or atmospheric absorption. The mean energy of the allowed radiation determines the bending in the geomagnetic field and hence the hour of maximum of the diurnal amplitude. When changes in amplitude of the diurnal variation are due to alteration of the cut off energy, a change in the hour of maximum may also be expected.

Very recently Sarabhai and Kane have examined qualitatively, under certain simplifying assumptions, the deflections that can be produced in the trajectories of solar cosmic rays due to the geomagnetic field. A rigorous solution of the problem involves the working out of individual trajectories at various times of the day and in the different seasons. This is not available at present, but preliminary analysis indicates the type of changes in the hour of maximum of the daily variation which may be expected with change of latitude and elevation of the observing station, and for different values of the declination and the hour-angle of the
The principal features that emerge from this analysis are:

(1) The hour of maximum should be earlier at equatorial station than at higher latitudes. If Huancayo result compared to Chelthamham or Christchurch; and Kodaikanal compared to Ahmedabad. Part of the effect may be due to change of altitude.

(2) In northern latitude, a North-pointing telescope should reveal an earlier maximum than a South-pointing telescope. This is because solar cosmic rays, during the hours before noon would be deflected towards South and in the afternoon towards North.

Thus it can be said that the main experimental facts concerning the nature of the daily variation at different points on the earth, and in different directions, do not appear to be inconsistent with our conclusions that the barometric pressure corrected daily variation of meson intensity is caused by the emission of cosmic rays from the sun.

5.4 The effect of cosmic rays from the sun:

The sun is known to emit corpuscular streams which take about 23 hours to travel to the earth and produce geomagnetic and auroral activity. It is also known to emit during some intense solar flares, moderate and low energy cosmic ray particles which travel with a velocity not very
different from that of light and produce measurable effects at sea level on cosmic ray neutron and charged particle intensity. The magnitude of the effect has a marked longitude dependence, and no effects have been observed at equatorial stations. Increases in neutron intensity reported by Simpson et al. and charged particle intensity reported by Neher and Forbush have been associated with the central meridian passage of active regions on the solar disc. These demonstrate the emission of more energetic particles from the sun which make their effects felt even at Huancayo on the geomagnetic equator. The present association of the meson diurnal variation with an anisotropy due to solar cosmic rays shows that the sun is a continuous emitter of cosmic radiation. Unlike the bursts of radiation following the observation of flares, this continuous emission is energetic enough to cause measurable effects in the charged particle intensity at sea level at all latitudes.

There is some evidence to show that the energy distribution of cosmic ray particles from the sun is displaced towards low energies as compared to the general energy distribution of cosmic rays from all other sources. For, the percentage amplitude of the diurnal variation increases with elevation as revealed by our comparative studies at Ahmedabad and Kodaikanal, by the Carnegie studies at Huancayo compared to the low level stations, and the studies made at the Hafelekar. Neher and Forbush have reached similar view from the increase of the worldwide fluctuations.
of ionization with altitude, and the fluctuations being less pronounced at the equator.

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Elliot and Dolbear have made a very significant observation that during days of increased geomagnetic activity the diurnal variations in both North and South directions are enhanced, and the N-S difference changes from being a semidiurnal to a diurnal curve. Since it is known that geomagnetic disturbances are associated with solar corpuscular streams, it would appear that when there is increased activity of the solar K-regions, there is also increased cosmic ray emission from the sun. The radical change in the nature of the difference curve during magnetically disturbed days supports the view that it has no special physical significance apart from being the arithmetic difference of the diurnal variation in the two directions.

5.5 Year to year change of diurnal variation.

In section 3.2.4 on page 80 we have shown curves which are suggestive of a change in the nature of the daily variation of mesons. The significance of the curves does not warrant a positive conclusion to be drawn.

Longtime worldwide changes of the diurnal variation have been demonstrated by Sarabhai and Kane from Carnegie Institution data. They have derived time series which demonstrate changes of 30 to 40 per cent in the diurnal amplitude and significant shift of the hour of maximum. In years of low solar activity, these series appear to be well correlated.
With relative sunspot number R and the American Magnetic Character figure $C_A$. It is likely that the change of form of the daily variation that is indicated in our data is genuine and part of it is representative of long-term worldwide changes.

5.6 The annual change of diurnal variation:

In the introductory chapter, the significance of the annual change of diurnal variation has been discussed from the standpoint of the solar origin of cosmic rays, and a possible sidereal time daily variation of intensity. Most analysis in the past have been done by a study of the annual movement of the tip of the solar diurnal vector on a 24 hourly harmonic dial using the methodology suggested by Thompson. Since we now realise that the hour of maximum intensity is controlled by the geomagnetic bending of trajectories of solar particles, and is therefore expected to undergo a change with an alteration of the solar zenith distance at different times of the year, the situation is more complicated than was visualised by Thompson. Our knowledge about the geomagnetic effect on solar cosmic rays is very limited. It appears that without it, an interpretation of the combined effect of the annual change of amplitude and hour of maximum on a harmonic dial can hardly be attempted. We therefore propose here to deal with the two effects separately.

For the purpose of an accurate study of the month to month or annual changes.
of the diurnal variation, our data is not yet extensive enough. Besides, during some months, the probable error of the bi-hourly deviations from mean of meson intensity is larger than during others. To smoothen random changes in the data, we have calculated the daily variation of $M$ for overlapping bi-monthly periods centered at successive epochs separated by a period of one month. This procedure is equivalent to taking bi-monthly moving averages. Table 5:6 indicates the diurnal amplitude and hour of maximum of the barometric pressure corrected meson diurnal variation for each monthly epoch. Fig. 5:3 shows the annual variation of $M^D$ and $M_0^D$.

It will be noticed that $M^D$ has two maxima in the year, the bigger one almost coinciding with the time when the sun's mean zenith distance is a minimum. If because of the atmospheric path length being least in June-July, lower energy solar cosmic rays are allowed and the maximum variation results due to these additional particles, we should simultaneously expect a lowering of the mean momentum of the radiation. This should be accompanied by the hour of maximum shifting to an earlier time and a consequent reduction in $M_0^D$. Except for the abnormal hump during the months of August and September $M_0^D$ shows a smooth change from a maximum in January to a minimum in June-July.

The weather conditions during monsoon at Ahmedabad are very different from those obtaining during the rest of the year. We are now examining whether the flattening of the $M^D$
Table 5.6

First harmonic constants for pressure-corrected meson intensity.

<table>
<thead>
<tr>
<th></th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>H</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M^D$</td>
<td>0.27</td>
<td>0.33</td>
<td>0.44</td>
<td>0.50</td>
<td>0.76</td>
<td>0.97</td>
<td>0.54</td>
<td>0.48</td>
<td>0.44</td>
<td>0.25</td>
<td>0.64</td>
<td>0.62</td>
</tr>
<tr>
<td>$\phi^D$</td>
<td>132°</td>
<td>126°</td>
<td>126°</td>
<td>112°</td>
<td>94°</td>
<td>84°</td>
<td>85°</td>
<td>176°</td>
<td>176°</td>
<td>181°</td>
<td>115°</td>
<td>125°</td>
</tr>
</tbody>
</table>

$M^D$ = Amplitude of the diurnal component for pressure-corrected meson intensity.
Fig. 5.3

Curve showing the variation of the first harmonic constants of the pressure corrected meson intensity.
Fig. 5.4

The annual variation of the magnetic activity in years of high, medium and low activity.
change curve and the strong maximum in the $M^D$ change curve during this period has any relation to the abnormal weather conditions found in July and September.

The second maximum occurring in $M^D$ during November and December is very striking. Geomagnetic activity, indicated for example by the index 'U', which is known to be due to particle radiation from the sun, undergoes an annual change as shown in Fig. 5.4 taken from Chapman's Geomagnetism (page 366). The two equinoctial maxima during the year are believed to be due to the annual change of the heliographic latitude of the ecliptic. If the sun's equatorial belt is relatively free from the occurrence of M regions, streams of solar particles have an increased probability of approaching the earth when the radius connecting the sun's centre with the earth cuts the sun's surface at maximum heliographic latitude.

It is possible that like particles responsible for 'U' activity, solar cosmic ray streams have a higher probability of hitting the earth during certain months. If the annual change of $M^D$ is considered to be built up of

1. a maximum during June due to minimum solar zenith distance, and

2. two maxima coinciding with solstices; the latter could probably be produced by regions of cosmic ray activity confined to a narrow equatorial belt on the sun.
The annual change of diurnal variation of mesons studied by Duperier with counter telescopes exhibits a maximum amplitude in the summer, just as is found by us at Ahmedabad. In the absence of details of his data, we are unable to check the existence of a variation with maxima in the solstices.

The Carnegie studies show an annual change of $M^D$ and $M\phi^D$ at the four stations where measurements have been made over a long period. While the first harmonic of the annual change of $M^D$ at the different stations offers difficulties of interpretation, the second harmonic shows a maxima near solstices as at Ahmedabad.

The problem of the annual change of the daily variation is very complicated and requires extensive experimental and theoretical studies. The preliminary results mentioned in this thesis represent the initial phase of such a study which has been commenced at the Physical Research Laboratory. The views expressed here are therefore necessarily tentative.