1. **INTRODUCTION**

Ever since the experiments of Hess and Kolhorster proved conclusively that cosmic rays were to be traced to an extra-terrestrial source, the question of their origin has become a subject of much speculation and research. It was realized that to obtain an answer to the problem the most direct approach is to measure the intensity of radiation as a function of time and find out whether any variations exist apart from statistical fluctuations. There are several kinds of variations which might be expected. Variations with a period of a solar day, and with seasons might be expected to arise from the rotation of the earth and its motion around the sun. A diurnal variation of intensity according to sidereal time, if present, would have a bearing on the galactic origin of cosmic rays whereas a periodicity of 27 days (average rotation period of the sun) can arise from its direct solar origin or a geomagnetic or heliomagnetic effect. Non-periodic variations can also yield some information about the origin of cosmic rays.

Long and systematic studies of time-variations of
cosmic ray intensities have established that both regular and irregular variations exist. The irregular variations are associated with changes in meteorological factors, magnetic activity, occurrences of solar flares etc. Several types of periodic variations, some non-persistent in character, have also been reported.

The symposium on cosmic rays held at the University of Chicago, reported in Reviews of Modern Physics (1939) gives a comprehensive account of the work done on time-variations up to 1939. A later survey has been made by Elliot in Progress of Cosmic Ray Physics.

1.1 Variations due to Atmospheric effects:

In 1928, Byssowsky and Tuwim found that the day-to-day variations in ground level pressure are negatively correlated with the variations of the daily mean values of cosmic ray intensity. Initially this 'barometric effect' was ascribed to the changes in the mass absorption suffered by cosmic rays in their passage through the atmosphere.

The pressure coefficients for the total intensity as well as the meson intensity have been obtained by several observers, though the values obtained by them do not agree very well. As pointed out by Duperier this may be due to the fact that the overall pressure coefficient reflects not only the mass absorption effect but also includes an effect due to change in the path-length, which would alter the probability of \( \mu \)-meson decay and produce a variation analogous to the
seasonal variation interpreted by Blackett and discussed in detail at a later stage. To find the height of the layer where most of the mesons are produced, Dupérier investigated the partial correlations of day-to-day changes of cosmic ray intensity ($I$) with the corresponding changes of the heights ($H$) of isobaric levels in the atmosphere and of the barometric pressure ($B$) measured at the ground level. He found that the value of the partial correlation, $\gamma_{IHB}$, between $I$ and $H$ at constant barometric pressure $B$, was maximum for 16.1 km height which was the highest level up to which data were available from balloon ascents. This height corresponds approximately to the 100 mb. pressure level. For the two coefficients $\mu$ (due to mass absorption effect) and $\mu'$ (due to changes in the height of the isobaric level) he obtained the values 2.28 per cm. Hg and 5.4 per km, respectively.

The above constants were obtained from the records of telescopes without any absorber. Experiments with 25 cm. of lead absorber were also conducted and correlation analysis carried out as before. The partial correlation $\gamma_{IIHB}$ increases up to the height corresponding to 200 mb. level but decreases rapidly for heights between 200 and 100 mb. Dupérier has interpreted this as indicating that the variation in meson intensity cannot completely be explained by the two factors mentioned above. The additional factor that he introduced is the density of the air at the level of meson formation. Dupérier has computed the partial correlation coefficients.
between the cosmic ray intensity 'I' and atmospheric
temperature 'T' which determines the density of air at
any particular level. The partial correlation is +0.68
for temperature corresponding to air between 200 and 100
mb. levels. The temperature coefficient obtained in this
way is +0.12% per °C. This positive temperature effect
indicates that the number of mesons at sea level increases
as the density of air at the 200-100 mb. level decreases.
Duperier interprets this as being due to the competitive
processes of nuclear capture of π−mesons and of π−μ decay.
An appreciable proportion of the meson intensity at sea
level is due to μ mesons formed by the decay of the π meson
component created at the top of the atmosphere. The π mesons
which have a strong nuclear interaction, are also captured
in nuclear collisions. If the density of matter increases
at the level where π decays into μ, the probability for
collisions increases and so the ground level meson intensity
decreases. Quantitative considerations yield a much lower
value of this effect than what is observed and so there
remains some doubt as to whether the interpretation put
forward by Duperier is correct.

1.2 Negative temperature effect

Several investigators have reported negative correla-
tion between cosmic ray intensity and ground level temperature.
Blackett⁴ in 1938 pointed out that this temperature effect
can be explained on the basis of the instability of mesons.
The general warming of the atmosphere increases the height of the isobaric levels where mesons are produced. This increases the decay probability and thereby decreases the meson intensity.

According to Blackett’s calculations, assuming an average mean life time \( \tau = 2.7 \times 10^{-6} \) sec. for \( \mu \) mesons, and an average life range as 32 km, the value of the temperature coefficient \( \beta \) comes out to be \(-0.2\% \) per \( ^\circ\)C. The value of the coefficient as observed experimentally by Compton and Turner from seasonal changes is \(-0.16\% \) per \( ^\circ\)C.

Hess has observed that the temperature coefficient in subject to a regular seasonal variation, the coefficient in winter being twice as large as in summer. If Blackett’s interpretation of the effect has to be retained, it should be concluded that the ground level temperature is a very inadequate parameter for the temperature conditions of the whole vertical column of air. The magnitude of the temperature coefficient should be found not from ground-level temperatures alone but by taking into account temperatures at higher levels also. Barnóthy and Fórro have explained the variation of the sign and magnitude of the temperature effect in shower-intensity on the basis that the daily temperature is limited to a height of 2 km. from the ground. Blackett has predicted a latitude dependence of the temperature coefficient. At low latitudes, the incoming radiation is more energetic than at high latitudes and thus in the former case mesons of greater energy end of a longer mean
effective life-time are involved. Due to this, the tempera-

ture coefficient near the equator should be lower than
at high latitudes.

1.3 The Seasonal Variation

A seasonal variation of the cosmic ray intensity
was established as early as 1939 from the studies of Hess,
Compton and Turner, Gill and Forbush. Forbush has
analyzed ionization chamber data of Cheltenham, Christchurch,
Huancayo and Teoloyucan. After deducting a 12-month-wave
from the data at each place except at Huancayo where a wave
does not exist, the residual variations at any two places
were found to be highly correlated. This clearly showed
that major non-periodic changes in the cosmic ray intensity
were world-wide in character. The amplitudes and the time
of maxima of the 12-monthly waves at different stations
are shown in the harmonic dial taken from the original paper.
The 12-monthly wave in the cosmic ray intensity at different stations (except at Teoloyucan) is 180° out of phase with the 12-month wave in temperature at each station. Christchurch and Cheltenham, having similar elevation and geomagnetic latitude, show the same ratio of amplitude of the above two variates. For other stations it is quite different. This indicates that the variations in cosmic rays in general are not closely connected with ground temperature. Forbush suggests that the seasonal variation of distribution of air-density with height in the earth's atmosphere may be better correlated with the 12-monthly wave in cosmic ray intensity.

From the amplitude of the effect observed, Forbush suggests that the solar magnetic moment may be an alternative possible cause for the seasonal variation of cosmic ray intensity. Vallarta and Godart have also ascribed the seasonal variation to the solar magnetic field. However, these calculations according to the above suggestion do not agree well with the experiments of Forbush. Hence the interpretation has received little support. The analysis of recent data obtained at Manchester by Elliot and Dolbear for north and south pointing telescopes shows a definite decrease of intensity in mid-summer amounting to about 2%. The monthly means of cosmic ray intensity, after correcting for barometric coefficient show a high correlation (0.94) with the height of the 100 mb. level. The decay coefficient is found to be -3.55 % per km, which differs significantly.
from the value -5.70% per km. obtained from day-to-day changes of I and H. Small but significant differences in the shape of their annual variation curves have also been pointed out by these authors. They therefore conclude that the positive temperature effect reported by Duperier may be responsible for the minor discrepancies.

1.4 Variations associated with geomagnetic and solar activity.

The observations of Messerschmidt (1935) showed a decrease of about 1.0% in the cosmic ray intensity during a magnetic storm. Steinmauror and Graziadei (1935) found an average decrease of 0.3% for 17 magnetic storms.

The world-wide nature of irregular variations was established from the results of Cheltenham, Huancayo, Christchurch, Tojoloyucan (reported by Forbush) and Hafelekar (reported by Hess and Dommelmair). The storm of 1937 was accompanied by a decrease of intensity of about 4% at widely separated stations (Forbush). A decrease of about 6% in 1938 has been reported by Forbush and there appears to be good correlation between 'H' (the horizontal component of earth's magnetic field) and variations of cosmic ray intensity. However the violent storm of August 1937 was found to be ineffective as far as variations in cosmic ray intensity are concerned. During a storm, 'H' decreases suddenly and comes back to the original value very slowly. Hogg has shown that the changes in intensity....
associated with magnetic storms, are initially invariably of a decreasing nature and are broadly of the same character as the changes in 'H'. It is also found that the cosmic ray changes especially when they are large, are delayed by a few hours relative to the large change of 'H'.

Chapman\textsuperscript{18} suggested an explanation of the storm effect on the basis of Stor\textsuperscript{mor}'s hypothesis that part of the earth's axial magnetic moment is caused by ring currents of charged particles flowing concentrically around the earth at a distance of several earth radii. According to Chapman, the increase of the field strength, outside the region covered by the ring currents and the earth, deflects away from the earth some of the primary cosmic rays. This produces an decrease in intensity. Forbush\textsuperscript{19} suggests that the reason for the occurrences of effective and non-effective magnetic storms could be due to differences in the radii of the ring currents. The calculations of Johnson\textsuperscript{20} and of Hayakaiva\textsuperscript{21} et al. show that changes in cosmic ray intensity produced by the ring currents may be either positive or negative depending upon whether the radius of the ring current assumed is greater or smaller than 1.3 times the earth's radius. Thus there should not in general be a positive correlation between cosmic ray intensity and magnetic field as is observed. There is therefore serious doubt about the validity of Chapman's explanation.

Alfven\textsuperscript{22} has suggested that the decrease in intensity
during magnetic storms may be due to the electric field $\mathbf{E}$ which arises as a result of the motion of corpuscular stream through the solar magnetic field. If an electric field of the magnitude suggested by Alfvén exists, a large increase in intensity will be produced some time during magnetic disturbances.

Increase in intensity of cosmic rays associated with solar flares have been reported by Lange and Forbush$^{23}$, Duperier$^{24}$, Ehmert$^{25}$, Clay$^{26}$ etc. The main characteristics of the variations are as follows:

1. The variations are not always world-wide.
2. The maximum of cosmic ray intensity and the solar flares occur at an interval of about an hour.
3. The effect is greatly reduced at lower latitudes and is not observed at geomagnetic equator, suggesting that the primaries responsible for these variations have momenta less than $10 \text{ BeV}/c$.

Ehmert$^{27}$ has put forward an explanation for the above effects. He suggested that the particles from the sun are accelerated by the betatron action of the changing magnetic field of a growing sunspot. This was proposed by Swann$^{28}$ as early as 1933. The accelerating electric field, as suggested by Menzel and Salisbury$^{29}$ are due to movements of low-frequency electromagnetic waves generated by fluctuations of the sunspot magnetic field due to turbulence in the solar atmosphere.
Forbush, Gill and Vallarta\textsuperscript{30} have examined the mechanism of emission of cosmic rays from the sun during occurrences of solar flares. They suggest that the bi-polar field of a sunspot group may reduce the solar field to allow comparatively low-energy particles to be emitted from the surface of the sun.

It has been demonstrated by Simpson\textsuperscript{31} that neutron intensity responds sensitively to changes in the intensity of medium and low energy cosmic ray primaries. He has reported that apart from small and sharp fluctuations of the duration of minutes and hours, changes of intensity which persist for several days also occur. In a later communication Simpson\textsuperscript{32} and his collaborators have established a connection between the central meridian passage of active solar regions and 19 maxima of neutron intensity distributed over a period of 3 months and observed simultaneously at 3 separated stations. This has led the author to suggest a solar component of cosmic radiation of low and intermediate energies.

Neher and Forbush\textsuperscript{34} have pointed out that correlations exist between the fluctuations of cosmic ray intensity at both high and low altitudes and the above neutron measurements. These fluctuations have been observed at Huancayo on the magnetic equator as well as at stations in high latitudes.

A further connection between solar phenomena and cosmic rays has been demonstrated by Sarabhai and Kane\textsuperscript{35}. They
have shown by an analysis of the cosmic ray intensity data furnished by Lange and Forbush that the nature of the daily variation observed at widely separated stations undergoes substantial changes of a world-wide character. These changes appear to be broadly connected with changes in solar activity during a sunspot cycle.

1.5 Daily variation :-

Periodic variations of cosmic ray intensity according to local solar time have been investigated under different atmospheric conditions and for places differing in latitude and longitude. A summary of the work done upto 1947 has been given by Nicolson and Sarabhai. The following tables include additional data from work published subsequently.

The notations used are :-

\( \lambda \) = geomagnetic latitude of the station,
\( h \) = altitude of station in metres above sea level,
\( \phi \) = angle of cone of measured radiation (classified in general as wide and narrow),
\( \theta \) = inclination of axis of observed cone to the vertical,

\( D(b,c) ; S(b,c) \) = diurnal (semi-diurnal) variation of amplitude \( b \% \) and maximum at \( c \) hours.

\( S ; -S \) imply that the maximum of the variation is displaced by less than one hour from
the maximum (minimum) of the semi-diurnal pressure variation.

I.C.; G.C. indicate use of ionization chamber; Geiger counter apparatus.

B.; E.T.; I.T. indicate correction for barometer effect; external temperature effect; internal temperature effect.
### Table 1 - Variation of the intensity

<table>
<thead>
<tr>
<th>Observer</th>
<th>a (°)</th>
<th>b (°)</th>
<th>c (°)</th>
<th>d (°)</th>
<th>e (°)</th>
<th>Duration of Injection</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haslam (1939)</td>
<td>2.50</td>
<td>2.61</td>
<td>2.61</td>
<td>2.61</td>
<td>3.61</td>
<td>3 months</td>
<td>None</td>
</tr>
<tr>
<td>Betton (1926)</td>
<td>1.50</td>
<td>1.60</td>
<td>1.60</td>
<td>1.60</td>
<td>2.60</td>
<td>10 days</td>
<td>-1.05, 1.54</td>
</tr>
<tr>
<td>B-crest</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>2 months</td>
<td>1.6, 1.6</td>
</tr>
<tr>
<td>Corro</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>2 months</td>
<td>None</td>
</tr>
<tr>
<td>B-crest</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>2 months</td>
<td>None</td>
</tr>
<tr>
<td>Emami</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td>2 years</td>
<td>None</td>
</tr>
<tr>
<td>Audra</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>25 years</td>
<td>None</td>
</tr>
<tr>
<td>Amami (1933)</td>
<td>9.00</td>
<td>9.00</td>
<td>9.00</td>
<td>9.00</td>
<td>9.00</td>
<td>15 days</td>
<td>None</td>
</tr>
<tr>
<td>Superior (1957)</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>3 years</td>
<td>None</td>
</tr>
<tr>
<td>Elliot and</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peller (1939)</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>5.00</td>
<td>1 year</td>
<td>None</td>
</tr>
</tbody>
</table>

Results not Fourier analyzed. Appreciable variation with e. Time of maximum 37% to 15%.
1.5: The diurnal variation

It can be seen from Table 1 that the diurnal variation has an amplitude of about 0.2% at places in the temperate zone. However, the phase seems to vary widely from station to station and is different for stations on the same latitude. Even allowing for the fact that the different workers have applied different corrections to their data, the results are difficult to understand. The only definite conclusion that can be drawn about the diurnal variation is that the maximum occurs sometime during the sunlit hours and the minimum during the dark hours.

Also one can say in general that the percentage amplitudes of the variations observed with ionization chambers are less than those measured by counter telescopes. This can be understood in terms of the difference in the effective solid angles in which cosmic rays are recorded by the two devices. As is clear from the results of Alven\textsuperscript{36} and Halmfors\textsuperscript{37}, Kolhorster\textsuperscript{38} and Elliot and Dolbear\textsuperscript{39}, the phase of the diurnal variation is not the same for all zenith angles. If therefore an experimental device measures cosmic rays in a wide angle, the variation of intensity incident in directions on opposite sides of the zenith but equally inclined to it will have different phases. The resultant amplitude will therefore get reduced. This effect will be more prominent in an ionization chamber where the solid angle is very wide. The percentage amplitudes measured by counter telescopes (especially those with narrow angles) would thus

\[ \text{\dots} \]
be larger than those measured by ionization chambers.

Another point worthy of note is that the hour of maximum of the diurnal variation for higher altitudes is in general shifted towards earlier hours in the day. This is quite clear from the results obtained at Cheltenham, Christchurch and Godhavn which are within an altitude of 100 metres above sea-level as compared with those from Hafelekar and Huyancayo which are at altitudes of 3350 m. and 2300 m. respectively above sea-level. The hours of maxima for the two groups are about 1500 hrs. and 1100 hrs. respectively. The variations obtained by other workers at sea-level show the hours of maxima sometime in the afternoon.

In most attempts at explaining the diurnal variation, the changes in the phase of the variation from station to station are neglected. The diurnal variation is assumed to have a maximum at about midday. As an example, Vallarta and Codart have suggested that such a variation can be produced at high latitudes by a heliomagnetic field and at low latitudes by variations of the geomagnetic field. Obviously, this explanation cannot account for the changes in phase of the diurnal variation for stations on the same latitude. Moreover, Malmfors has shown that the results he has obtained with Alfven in Stockholm are not compatible with this explanation. His results are particularly interesting because they cannot be explained by meteorological effects. As Malmfors suggests, the results may be due to
small disturbances in the isotropy of the primary radiation.

The results obtained recently by Elliot and Dolbear with directional counter telescopes show a marked difference between the diurnal variation for cosmic rays coming in the north and south directions. The hour of maximum for the former is shifted earlier by about 2 hrs. The two telescopes are inclined to the vertical at 45°. Since the latitude of Manchester is 53°N, the north telescope is pointing approximately to a fixed direction in space, whereas the south telescope sweeps across the sky in the equatorial plane of the earth. The atmospheric effects for both the telescopes are alike since the particles from both the north and south have travelled the same amount of the atmosphere under approximately similar conditions. It is in this connection important to bear in mind that if the anisotropy of primaries such as may be caused by solar emission of cosmic rays, can produce a daily variation in both North and South pointing telescopes; the difference curve reflects only an arithmetic difference between the daily variation in the two directions. It does not reveal the true nature of the variation due to primary anisotropy in either direction.

1.52 The semi-diurnal variation:

As is evident from Table 1, the nature of the semi-diurnal variation, like the diurnal variation, differs from place to place and is different for different cosmic ray components. Amongst the results that may be considered to
be statistically significant are firstly those of Rau\textsuperscript{41} which were obtained from two ionization chambers suspended in a narrow vertical fissure of rock, 40 metres under the surface of Lake Constance. The variation is purely semi-diurnal with an amplitude of about .16\% and phase almost coinciding with that of the semi-diurnal variation of daily barometric pressure. In Rau's experiment, the variation measured was only of mesons which could penetrate through 50 metres of water equivalent (including the atmosphere) and hence had an initial energy greater than $10^{10}$ eV. Moreover, the solid angle was narrow because of the presence of fissures in the rock. The intensity measured was thus almost vertical and was unaffected by magnetic variations.

The other results are those of Duperier\textsuperscript{42} for the total intensity of cosmic rays as measured by a counter telescope. Duperier obtained a daily variation with a diurnal component of amplitude .25\% and hour of maximum at about 17 hrs., and a semi-diurnal component with amplitude .18\% and hour of maximum at about 03 hrs. The latter was thus negatively correlated with the daily variation of ground pressure.

An explanation for both these effects is sought in terms of the Pekeris\textsuperscript{43} theory of atmospheric oscillations, the implications of which have been examined by Nicolson and Sarabhai. The main feature of the oscillation is the
reversal of phase after a height of about 30 km. above ground. Thus for heights up to 30 km. the pressure variation has got the same phase as at ground. At 30 km. there exists a nodal surface. The pressure variations above this surface have a phase in opposition to the pressure variations below it.

These pressure variations are directly connected to the variation \( \Delta H \) in the height of an isobaric level situated at a mean height \( 'H' \). For levels up to 30 km. an increase of ground pressure would correspond to an elevation in the different isobaric levels. However for levels above 30 km. the phase of the variation would be reversed and an increase in ground pressure would lower all the isobaric levels. The values of \( \Delta H \) corresponding to a pressure change of amplitude 1 mm. at sea-level are given in Table 2 for various height \( 'H' \). The amplitude of the oscillation increases with decreasing latitudes by a factor of about \( \cos^3 \lambda \). The values given are for \( \lambda = 0 \) and \( \lambda = 50^\circ \).

Table 2.

<table>
<thead>
<tr>
<th>( H(\text{km.}) )</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{\Delta \text{H}}{\text{mm.}} )</td>
<td>0.010</td>
<td>0.012</td>
<td>0.012</td>
<td>0.002</td>
<td>0.086</td>
<td>0.272</td>
</tr>
<tr>
<td>( \frac{\Delta \text{H}}{\text{mm.}} )</td>
<td>0.003</td>
<td>0.03</td>
<td>0.003</td>
<td>0.001</td>
<td>0.023</td>
<td>0.072</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( H(\text{km.}) )</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{\Delta \text{H}}{\text{mm.}} )</td>
<td>0.490</td>
<td>0.510</td>
<td>0.60</td>
<td>1.05</td>
<td>2.22</td>
</tr>
<tr>
<td>( \frac{\Delta \text{H}}{\text{mm.}} )</td>
<td>0.129</td>
<td>0.135</td>
<td>0.16</td>
<td>0.28</td>
<td>0.59</td>
</tr>
</tbody>
</table>

The positive or negative correlation with the semi-
diurnal component of ground pressure can therefore be explained by assuming the meson-formation layer to be either above or below 30 km, respectively. Nicolson and Sarabhai have shown that the positive pressure effect in Rau's results can be explained by assuming that the mesons are formed at an average height of about 65 km, above ground. Above the nodal surface at 30 km, the amplitude of the pressure variation increases rapidly and attains at about 70 km, a value of the right order to explain the ground variation of meson intensity. However, the portion of atmosphere left above 70 km is only 1/8000 th of the whole atmosphere. The primary radiation has therefore to traverse only this much mass before it produces the secondary meson component. Such an assumption leads to an abnormally high value for the cross-section of meson formation, if the primary radiation is supposed to be composed of protons. Even for heavy nuclei in the primary radiation, such as are found by Freier et al. the discrepancy would not be removed.

The negative pressure effect observed by Duperier can be explained qualitatively by assuming the meson-formation-layer to be below 30 km. The height variation is in phase with the pressure variation below 30 km. An increase of ground pressure is associated with an increase in height of the various isobaric levels. The cosmic ray intensity is therefore decreased because of an increased probability of meson decay. Since an increase in ground pressure also
increase the mass absorption effect, both these effects are in the same direction. Duperier has got a pressure coefficient of \(-3.5\, \%\) per cm.Hg. out of which 60\,\% is attributed by him to mass absorption and the remainder to the decay process. This requires an amplitude of height variation of about 22 metres at the height of 16 km. As is seen from Table 2, the maximum displacement of isobaric levels below 30 km. is only about 3 metres at 50° latitude.

It is evident, therefore, that the positive and negative pressure effects obtained by Rau and Duperier cannot be explained quantitatively on the basis of variations of the heights of isobaric levels, produced by the Pekeris oscillation. On the other hand, it is difficult to imagine an alternative process which can produce such variations in cosmic ray intensity.

1.3 True and apparent sidereal daily variation of cosmic ray intensity

A considerable amount of work has been devoted to the investigation of a sidereal time daily variation of cosmic ray intensity. Hogg\textsuperscript{45} has furnished a comprehensive summary of various experimental results and discussed the methodology of separating a sidereal effect from a solar effect. Based on fundamental considerations of Bartels\textsuperscript{46} concerning mixed periodicities, Thompson\textsuperscript{47} has shown how a spurious sidereal effect may be inferred if a seasonal change of the solar diurnal variation takes place. The combination of such a
seasonal variation and a true sidereal effect was expected to produce on a harmonic dial representation, a movement of the tip of the solar diurnal vector along an ellipse. Depending on the relative magnitudes of the two effects, the movement could be either in the clockwise or the anticlockwise direction. One of the fundamental assumptions of Thompson's analysis is that the seasonal change of solar diurnal variation alters only its amplitude but not the hour of maximum.

Hogg's analysis of available cosmic ray data of a number of authors fails to disclose any true sidereal effect of significant magnitude. However Elliot and Dolbear claim that strong evidence exists for a sidereal time daily variation of amplitude about $0.02\%$ and with a time of maximum at about 0500 hours sidereal time. In view of conflicting views on this important question it is necessary to examine the validity of some of the assumptions that have been made in deriving a sidereal time daily variation of cosmic rays. We shall revert to this at a later stage.

Apart from the sidereal effect it is valuable to study the seasonal change of diurnal variation, as this can furnish a clue to the origin of the latter. Duperier has analysed meson intensity data with a Geiger counter telescope operated at London. He has compared the diurnal amplitude in summer and winter after correcting for meteorological
factors (including positive temperature effect) with changes in the zenith distance of the sun. He infers from the close agreement between the two that a solar component of cosmic rays exists.

2. **STATEMENT OF THE PROBLEM** :

It will be realised from what has been said earlier that in spite of a large volume of experimentation, the terrestrial influences which can contribute to the daily variation of cosmic ray intensity are not adequately understood. In investigating the time variations of cosmic rays, the ionisation chamber offers the great advantage of constancy of operation, but being an omni-directional detector of radiation, it is hardly a satisfactory instrument for the study of an anisotropy of the primary radiation. Nevertheless, very valuable data have been collected with it. Unidirectional measurements of the diurnal variation of the vertical meson intensity, performed with narrow angle geiger-counter telescopes could be more revealing than omni-directional measurements. In order therefore to gain an insight into the factors responsible for the daily variation of intensity, further studies are necessary keeping in mind the following:

1) Dependence of the daily variation on the latitude and altitude of the station. The semi-diurnal component of the daily variation of atmospheric pressure is expected to produce variations in the meson intensity. The amplitude
of the pressure variation increases rapidly for decreasing latitude. On the other hand, the day-to-day changes in barometric pressure are more prominent in higher latitudes as compared to the tropics. A study of the day-to-day variations would therefore be more revealing in higher latitudes whereas a study of the daily variation would be more reliable and conclusive in lower latitudes. Also, the amplitude of the variation of cosmic ray intensity is more pronounced at higher altitudes. A study of the variation at mountain stations and at low latitudes is, therefore, desirable.

(2) Dependence on the nature of the particles:— The nature of the daily variation of cosmic ray intensity depends largely upon the nature of particles under consideration, because (a) the interactions of the various types of fundamental particles in cosmic rays with the constituents of the atmosphere are different and (b) certain components of cosmic ray intensity are produced primarily in certain strata of the atmosphere and there is a great deal of difference in the variations of the meteorological factors at different elevations. The nature of the daily variation depends, therefore, upon the component studied. To resolve the complications due to these factors, it is desirable to separate the various components.

(3) Dependence upon the angle of incidence:— The phase and amplitude of the daily variation are dependent upon the angle of incidence of the observed particles with
respect to the zenith. Measurement of the intensities within restricted angle is, therefore, expected to bring out more clearly the amplitude and phase of the true variation. It is desirable, therefore, to use counter telescopes (with narrow angles) instead of ionization chambers which measure intensity from all directions.

Taking these factors into account, a special apparatus was designed to study the time-variation of the various cosmic ray components in low latitudes. The apparatus consisted of a number of triple-coincidence telescopes with varying amounts of absorber. The instrument thus measured the total and the meson intensities restricted to narrow vertical cones.

The author has been mainly responsible for the studies at Ahmedabad and the present thesis is devoted to the experimental results obtained at this station. The attempt has been firstly to understand the nature of the terrestrial effects on the solar daily variation of cosmic ray intensities. These have then been corrected for, leaving a residual variation essentially of extraterrestrial origin.

Three units of this apparatus were constructed and installed. One is at the Solar Physics Observatory, Kodaikanal (mag. lat. 10N, alt. 7688 ft.), another is at Ahmedabad (mag. lat. 130N, alt. 180 ft.) and a third recently installed at Trivandrum (80 31' N, 770 00' E).