TO MY TEACHERS

STATEMENT

This thesis presents the results of investigations of the time variations of cosmic rays carried out by the author with hard component at Gulmarg ($\lambda = 25^{\circ}$, alt.= 2740m) during the years 1956 and 1957, and at Physical Research Laboratory, Ahmedabad ($\lambda = +14^{\circ}$, alt.= s.l.) during 1958 with nucleonic component of cosmic rays. Intensity of hard component was measured with vertical narrow angle counter telescopes and that of the nucleonic component was measured with a standard neutron monitor. Data from other stations of the world operating during the I.G.Y. period were also examined to confirm the worldwide characteristics of some features of long term, short term, and day-to-day changes in solar daily variation and daily mean intensity of cosmic rays. The principal results of the investigations are summarised below :

(1) The change in the annual mean solar daily variation from 1956 to 1958 at Ahmedabad and Huancayo, both at low latitudes, involves the shift of the time of maximum of diurnal and to some extent of the semidiurnal component of solar daily variation, towards later hours. This basic change is independent of geomagnetic activity. Further the pattern of change of annual mean solar daily variation is different at equator and at intermediate latitude ($\lambda = +25^{\circ}$).

(2) The annual mean solar diurnal variation observed at Gulmarg ($\lambda = +25^{\circ}$, alt. = 2740 m) during 1956 and 1957 is consistent with the view that the source responsible for this variation is situated outside the confines of the geomagnetic field. The comparison of theoretical calculations with experimental data show that the source responsible for the observed diurnal variation was situated to the left of the earth sun line at an angle of $\chi = 50^{\circ} \pm 15^{\circ}$ and had a power in the equatorial plane ($\Phi = 0$) given by: a $(\Phi = 0) = 0.09 \pm 0.01$ G.V.

(3) The evidence concerning annual periodic changes in solar daily variation of hard component is not quite consistent. Whereas Sekido and Yoshida (1950) had presented evidence to show that the amplitude of solar diurnal variation is maximum and the time of maximum of the solar diurnal component is earlier in equinoxes, the present evidence indicates that the amplitude of solar diurnal variation is maximum in summer and winter with earliest time of maximum in summer and gradually shifting to later hours. Also the nucleonic component at Mt.Norikura does not exhibit any annual periodic change of solar daily variation. Further studies are therefore necessary, using high counting rate instruments, together with a regular series of radiosonde flights at different seasons which would permit a proper correction to be applied to the meson intensity results, for changes of temperature in lower atmosphere.

(4) Enhanced solar daily variation is a worldwide

effect and high values of the variance of bihourly deviations as represented by χ^2 (>27, see sec.4.23) at Ahmedabad provide us with a convenient index of picking out days, on which enhanced solar daily variation occurs on a worldwide basis.

(5) During 1957-58, increased geomagnetic activity, by itself, does not have any repurcussions on the character of solar daily variation. However, increased geomagnetic activity does accompany certain striking changes in solar daily variation. Some of these are (a) high values of diurnal component of solar daily variation on X_H^2 (see sec.4.23) days are in general accompanied by increased geomagnetic activity, (b) high variability in the time of maximum is accompanied by enhanced geomagnetic activity.

(6) The time of maximum of the solar diurnal variation of the nucleonic component is subject to enhanced variability compared to that for hard component during magnetic storms of the SC type.

(7) No unique and simple relation exists between the solar semidiurnal variation and SC type storms.

(8) There exist correlated changes of daily mean intensity and solar daily variation of cosmic rays which are of worldwide nature. Further these correlated changes involve not only decreases but also increases of daily mean intensity. Taking into account everything one is thus led to

believe that several processes are involved in the various cosmic ray variations that have been observed. Tentatively these processes may be subdivided into the following groups:

(a) Those responsible for causing the 11 year change with solar cycle involving decrease of intensity.

(b) Those responsible for CRS during which the cosmic ray intensity is depressed from a few days to a few weeks.

(c) Those responsible for day to day changes which involve both increases and decreases.

(d) Those responsible for causing prestorm type decreases and increases.

(9) The present investigations have been handicapped by the counting rate of the instruments not being large enough to study hour to hour or day to day changes of intensity with precision. Further confirmation of results reported here is necessary.

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

Guiding teacher :-

H. S. Ahluwalia

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H.S. Ahluwalia

H.S.Ahluwalia

C O N T E N T S

I

GENERAL SURVEY

1.1 Introduction

As a result of the copious amount of work done during the last few years, the complex nature of cosmic ray variations is beginning to be appreciated. The geophysical and astrophysical implications of the study of cosmic ray variations are apparent. The study of cosmic ray variations thus bids fair, not only to establish an intimate link with meteorology, geophysics, heliophysics, and astrophysics but it goes even a step further and promises to put at our disposal an effective probe for investigating the electromagnetic state of the interplanetary and interstellar space. Elliot (1952), Simpson (1955), Sarabhai and Nerurkar (1956) and Singer (1958) have reviewed the progress made in the study of cosmic ray variations during its various stages of development. Dorman (1957) has written a comprehensive treatise on the subject encompassing its many varied aspects.

This thesis deals primarily with the study of the nature of, and the long and the short term changes in the solar daily variation and in the daily mean intensity of cosmic rays. In what follows, therefore, we shall be content with pointing out the experimental results relevant to the present investigation and the various interpretations offered to explain them; a passing reference would, however, be made to other types of cosmic ray variations.

1.2 Primary cosmic rays and their interaction with the geomagnetic field.

Of the order of 80% of primary cosmic rays consist of protons and the rest 20% of the nuclei of heavier elements (Peters, 1952). Thus the source of the variation observed on the earth has to be traced, to a first approximation, in the variations of the most numerous component of primary cosmic rays i.e. protons. Thus in what follows by primaries we would mean, the primary protons.

Because of their charge, the primaries are subjected to the 'magnetic analyser' effect of the geomagnetic field which can be roughly represented by a dipole* having a magnetic moment of 8.06×10^{25} gauss cm^3 (Vestine and Lange, 1947) and situated at 400 km (Jory, 1956a) from the centre of the earth. Assuming isotropy of the primaries and applying Liouville's theorem it is found that at a given geomagnetic latitude** (λ) certain directions became inaccessible for charged particles having momentum less than a certain minimum value p^{min} (the so called forbidden or the

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* Recent work of Rose et al (1956), Waddington (1956), Kodama and Miyazaki (1957), Rothwell and Quenby (1957), Simpson (1958) MacDonald (1957), Pfotzer (1958), Skorka (1958), however, indicates that such a simple representation is inadequate to explain the results obtained by them.

** If geographic latitude and longitude of a place be Λ and Λ' respectively then (McNish, 1936)

$$\lambda = \arcsin\left[0.1983 \cos\Lambda \cos(\Lambda' - 290^\circ) + 0.9801 \sin\Lambda\right.$$

Stormer's cone). Again since the geomagnetic dipole is located at a certain distance from the centre of the earth, p^{min} will also depend on the longitude of the place of observations. Thus for a particle to reach any particular point of observation and along any particular direction it must have a certain effective minimum value of energy E^{min} (corresponding to momentum p^{min}). But since the number of primaries decreases sharply with increasing primary energy (e.g. see the spectrum given by Neher, 1952) the observed intensity of cosmic rays depends strongly on E^{min}. Thus by studying the time variations of cosmic rays at points with different values of E^{min} the dependence of these variations on the energy of primaries can be investigated.

If, in addition, one knows the trajectories, in earth's magnetic field, of the primary particles causing particular type of variation, we can determine the direction of the arrival of these particles outside the geomagnetic field and thus locate and study the properties of the source responsible for these variations.

Stormer (1936), Lemaitre and Vallarta (1936), Dwight (1950), Schluter (1951), Firor (1954), Jory (1956b), Lust (1957) and Gall and Lifshitz (1955) have numerically calculated the trajectories of primaries of energy ranging upto 10 GV. But the credit for putting the results of trajectory calculations in readily usable form goes to Malmfors (1945) and Brunberg and Dattner (1953), who experimentally determined the trajectories of all field sensitive primaries having an energy greater than 2 GV and arriving at stations situated on geomagnetic latitudes 0^{o}, 10^{o}, 20^{o}, 30^{o}, 40^{o}, 50^{o}, 60^{o}, 70^{o} and 80^{o} along the zenith angles 0^{o}, 8^{o}, 16^{o}, 32^{o}.......56^{o} in the E-W and N-S planes. The velocity vector of the primary of known rigidity was specified by two asymptotic coordinates* (Ψ, Φ) for a given latitude and a given direction of arrival and these have been presented in a convenient graphical form. For particular stations Brunberg (1956) has also represented these coordinates on celestial spheres. The meridians here show the angle of 'drift' of the particles, while parallels show the angle Φ. The figures around the curves give the value of E, the energy of the primary proton.

Their results enable one to determine the asymptotic directions of particles of given energy and arriving from a given direction at a given place, outside the influence of the geomagnetic field (at a distance $\gtrsim$ 10 earth radii). However, becuase of the differential bending sufferred by particles having different energies, the impact of the flux emanating from even a well defined source locatad at a large

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* Φ is the angle between the direction of motion of particles at infinity (i.e. $\gtrsim$ 10 earth radii) and the plane of geomagnetic equator; Ψ is the angle between the projection of the direction of motion of the particle at infinity on to the plane of the geomagnetic equator ,and the projection on to the same plane of the radius vector produced from the centre of the earth to the point on the earth's surface where the particle should impinge (the angle of 'drift'). The angles Ψ and Φ largely depend on E, λ, ζ, and φ (Malmfors, 1945; Brunberg, 1953 and Brunberg and Dattner, 1953).

distance (≥ 10 earth radii) would get strongly 'blurred' and its direction of impact as observed on earth would not only depend on the direction of arrival of particles on the earth and the latitude and longitude and the height of the place of observation but also on the type of secondary component being recorded; which makes the problem of locating the direction of the source of variations from the variations recorded on the earth rather complex. To a first approximation, however, it is possible to define 'effective asymptotic angles' $\overline{\Psi}_\lambda^i$, $\overline{\Phi}_\lambda^i$ of the source as follows (Dorman, 1957)

$$\overline{\Phi}_\lambda^i = \frac{\int_{E^{min}_{\lambda,f}}^{\infty} \Phi_\lambda(E)\, W^i_{\lambda,f}\,(E,\, h_o)\, \frac{\delta D(E)}{D(E)}\, dE}{\int_{E^{min}_{\lambda,f}}^{\infty} W^i_{\lambda,f}\,(E,\, h_o)\, \frac{\delta D(E)}{D(E)}\, dE} \qquad (1.1)$$

$$\overline{\Psi}_\lambda^i = \frac{\int_{E^{min}_{\lambda,f}}^{\infty} \Psi_\lambda(E)\, W^i_{\lambda,f}\,(E,\, h_o)\, \frac{\delta D(E)}{D(E)}\, dE}{\int_{E^{min}_{\lambda,f}}^{\infty} W^i_{\lambda,f}\,(E,\, h_o)\, \frac{\delta D(E)}{D(E)}\, dE} \qquad (1.2)$$

where $W^i_{\lambda,f}$ (E, h_o) is the 'coupling coefficient' (see Sec. 1.4 p. 12) giving the magnitude of variation to be expected in the i^{th} (secondary) component recorded at the geomagnetic latitude λ , at a pressure level h_o for a certain variation $\delta D(E)/D(E)$ in the energy spectrum D(E) of the primaries causing the particular secondary variation. The lower limit of integration is determined either by instrumental cut off or geomagnetic cut off or the cut off in the energy spectrum of the primaries due to modulating processes, whichever is more.

Once $\overline{\Psi}_{\lambda}^{i}$ is determined, the direction of the source (X^i) with respect to the sun-earth line is given by (Dorman, 1957)

$$X_{\lambda}^{i} = \overline{\Psi}_{\lambda}^{i} + 15\ (t_{max,\lambda}^{i} - 12) \qquad (1.3)$$

where $t_{max,\lambda}^{i}$ is the time of maximum of the variation of i^{th} component recorded on the earth. For an observer in the northern hemisphere who is looking at the sun, the angle X is positive to his left and negative to his right (Dorman and Feinberg, 1958a).

1.3 Passage of the primaries through earth's atmosphere

The high energy primary protons and heavier nucleii impinging on the top layers of the atmosphere generate electron-nucler showers which consist of secondary nucleons (protons and neutrons), charged and neutral π-mesons (pions) and heavier mesons which also ultimately decay giving pions (Shapiro, 1956). At each interaction the primary particle, at least in the energy region $E \leq 10^{11} \times 10^{12}$ eV, retains a greater part of its energy (about 2/3, Grigorov et al, 1955; Vernov et al, 1955). At energies $\sim$ 20 GV the primary protons form mesons not only on the first encounter but on two or three subsequent ones too (Grigorov and Murzin, 1953). The cascade so generated is shown schemetically in Fig. 1 given by Simpson (1953).

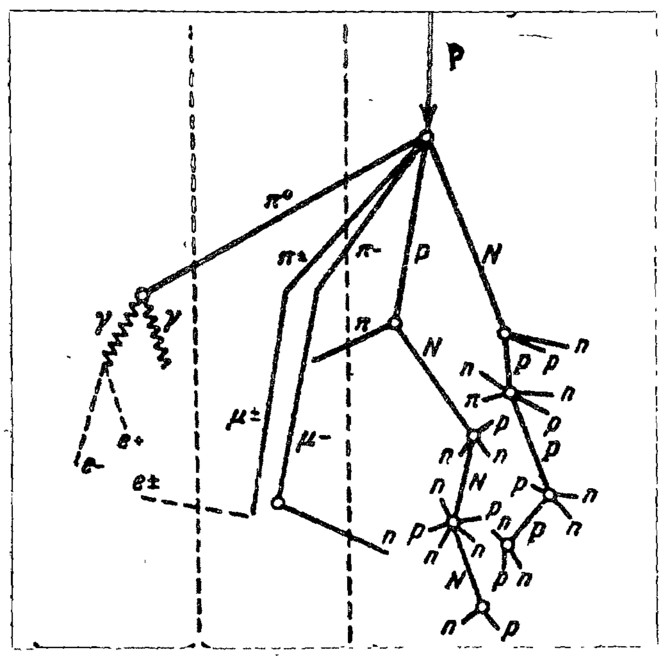

Fig. 1 - Schemetic representation of the typical development of the secondary cosmic rays within the atmosphere arising from an incident primary particle.

The cosmic rays observed at sea level or on mountain tops are predominently secondaries. Phenomenologically they are conveniently divided into two main components known as 'hard' and 'soft' components. Hard component includes all particles which penetrate 10 cm of lead, the remainder being the soft component. At sea level the former consists of roughly 99% of μ-mesons - mouns - (formed by the decay of charged pions in the top layers, 100-200 mb, of the atmosphere) and the remainder are protons ($\sim$ 0.5%) and penetrating shower particles. The latter consists of electrons and low energy mouns and protons.

In phenomenological definition of hard component only ionising particles were considered but besides there are present a number of neutrons which are, of course, secondary particles produced in the atmosphere. The number of these depends strongly on the energy band which is being measured (Gieger, 1956; Brown et al, 1949; Puppi, 1952). Neutrons having energies down to a few MeV are present. These neutrons together with a few high and low energy protons (which can penetrate about 5 to 6 inches thickness of paraffin and produces nuclear interaction in lead) constitute the 'nucleonic component'.

Grigorov and Murzim (1953) and Vernov et al (1955) have shown that the primary protons in the energy range $\leq$ 7 GV (mean 3 GV) transfer about 60% of their energy to nucleons and only 25% to charged pions, while protons of energy $\gtrsim$ 7 GV (mean 20 GV) transfer considerably larger amount of energy $\sim$ 50% to charged pions. Further according to Rose and Katzman (1956) primary particles of energy as low as 1.5 GV and probably a little lower, generate measurable amount of neutrons at sea level (at places where 'Stormer cone' admits such primaries). This information supplemented by the knowledge that meteorological corrections can be more unambiguously applied to nucleonic component (see Sec. 1.5, p.14) makes it possible to relate the variations of nucleonic component registered deep down in the atmosphere, in a unique manner, to the temporal changes of low energy primaries (Fonger, 1953). Hard component (corrected for meteorological effects), on the other hand, can be used to study variations in relatively high (20-50 GV) energy band of the primary spectrum (Brunberg and Dattner, 1954).

1.4 Methods of linking variations of secondaries to those of primaries

The chief objective of the study of time variations of different components of cosmic rays, recorded at different latitudes and altitudes, is to connect these variations with variations in the primary energy spectrum incident on the top of the atmosphere. First step in this direction was taken by Neher (1952) who showed that the latitude effect data at a particular pressure level (h_o) could be used to calculate the number of secondary particles, $m^i(E,h_o)$, of the i^{th} component at h_o formed by a single primary particle of energy E. $m^i(E,h_o)$ was called the 'over-all multiplicity'. Treiman (1952) and Simpson et al (1953) succeeded in transferring the concept of 'multiplicity' to the study of variations of secondary component and thus calculated 'specific yield function'. Fonger (1953) evolved the concept of 'effective spectra'* to determine qualitatively the

* Brown (1957) has since presented the revised values for these. Webber and Quenby (1959) have calculated the 'specific yield functions' taking account of higher order terms to represent earth's magnetic field at large distances from the surface of the earth.

dependence of the various secondary variations on the energy of primaries producing them. Dorman's 'coupling coefficients' W^i_λ (E,h_o) (1955) represented essentially a refinement and an extension of the above concepts.

Basically all authors have made use of the experimental data on latitude effect on the ionising or neutron component obtained by instruments of particular geometry for the altitudes they were interested in. The advantage of such a procedure lies in the fact that no assumption need be made regarding the nature of processes involved in the transformation of primaries into various secondaries. The limitation of this method, on the other hand, is that it applies only to field sensitive primaries ($E \leq 15$ GV) and for higher energies extrapolations have to be made which by their very nature introduce a certain element of unreliability.

The total vertical intensity $N^i_{\lambda,f}(h_o)$ of i^{th} component (mouns, neutrons, stars, bursts, soft component etc.) observed at latitude λ, longitude f and at the pressure level h_o is given by

$$N^i_{\lambda,f}(h_o) = \int_{E^{min}_{\lambda,f}}^{\infty} D(E)\, m^i\,(E,\, h_o)\, dE \qquad \ldots(1.4)$$

where D(E) is the differential energy spectrum of primaries,

$m^i(E, h_o)$ is the multiplicity and $E^{min}_{\lambda,f}$ the effective value of the minimum (critical) energy allowed by earth's magnetic field; for detectors located deep down in the atmosphere $E^{min}_{\lambda,f}$ may be taken to represent vertical cut-off energy.

Differentiating (1.4) with respect to the lower limit of integration we get

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

or

$$- \frac{1}{N^i_{\lambda,f}(h_o)} \cdot \frac{\delta N^i_{\lambda,f'}(h_o)}{\delta E^{min}_{\lambda',f'}}$$

$$= \frac{D(E^{min}_{\lambda',f'}) \; m^i(E^{min}_{\lambda',f'}, h_o)}{N^i_{\lambda,f}(h_o)}$$

$$= W^i_{\lambda,f}(E^{min}_{\lambda',f'}, h_o) \qquad \ldots(1.5)$$

where

$$W^i_{\lambda,f}(E^{min}_{\lambda',f'}, h_o) = \frac{D(E)\, m^i(E, h_o)}{N^i_{\lambda,f}(h_o)} \qquad \ldots(1.6)$$

$W^{i}_{\lambda,f}(E, h_o)$ is called the coupling coefficient and it gives the magnitude of variation in i^{th} (secondary) component for a certain variation in primary spectrum. If relative variation of intensity is measured in percent and total energy of primaries (E) is measured in GV then $W^{i}_{\lambda,f}(E, h_o)$ will be in % GV^{-1}. Fig. 2 shows the values of coupling coefficients obtained by Dorman* for various components recorded at various pressure levels h_o.

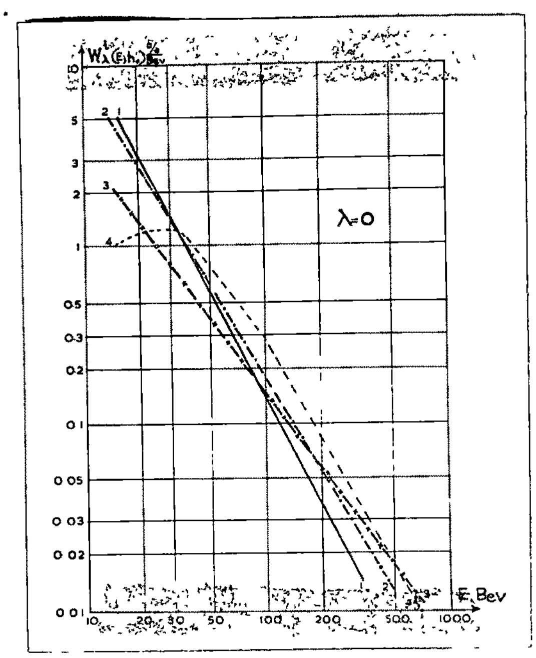

Fig. 2 - Coupling coefficients. (1) For total intensity, (ionising component) at high altitude. (2) For sea level neutron intensity. (3) For 4300 meters altitude total intensity. (4) For sea level hard component.

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* As a first approximation he has neglected the longitude dependence of coupling coefficients.

The time variation of the observed intensity of the i^{th} component of cosmic rays can be got by varying eq.(1.4) with respect to all available parameters and making substitution from eq.(1.6). Thus,

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

$$+ \int_{E^{min}_{\lambda,f}}^{\infty} \frac{\delta m^{i}(E,h_o)}{m^{i}(E,h_o)} \; W^{i}_{\lambda,f} (E,h_o)dE \qquad ...(1.7)$$

If experimental data of variations, recorded by a particular detector, are corrected for meteorological effects, the third term on r.h.s. in eq.(1.7) becomes zero. Further when variations involving changes of extra-terrestrial primary flux are studied, the first term on r.h.s. of eq.(1.7) also becomes zero. Thus,

$$\frac{\delta^{j} N^{i}_{\lambda,f}(h_o)}{N^{i}_{\lambda,f}(h_o)} = \int_{E^{min}_{\lambda,f}}^{\infty} \frac{\delta^{j} D(E)}{D(E)} \; W^{i}_{\lambda,f} (E, h_o)dE \qquad ...(1.8)$$

where index j indicates the type of variation (solar diurnal, semidiurnal, 27 day, annual, 11 year, etc.), and $\delta^{j}D(E)/D(E)$

gives the relative variation of the primary flux and may, therefore, be called 'energy spectrum of the variation of the primaries'. Eq.(1.8) can be utilised for two purposes:

(1) Quantitative verification can be made of specific hypothesis as to the origin of various variations, and

(2) Using data of various secondary components having subsantially different $W^{i}_{\lambda,f}(E, h_0)$, the energy spectrum of the variations of primary cosmic rays $\delta D(E)/D(E)$ for a particular type of variation of secondary component can be determined.

1.5 Methods of eliminating meteorological effects

Before any attempt is made to link the variations of the various secondary components recorded deep down in the atmosphere with variations of the primaries, it is necessary to rid the data of the variations induced in the terrestrial atmosphere. We shall consider meteorological corrections to be applied only to two main components (hard and nucleonic) of cosmic rays which have been studied in this thesis.

1.51 Meteorological corrections for hard compenent

From purely qualitative arguments on meson decay, Duperier (1949) sought to correlate sea level intensity variations ($\delta I/I$) with changes in ground pressure (δB), variations in the mean height of 'production layer' (δH), represented by variations in height of a fixed pressure level (100 mb. layer was chosen) and temperature changes (δT) in the region of reference level (average temperature between 100 and 200 mb. was used). He thus suggested a three term regression formula of the form

$$\frac{\delta I}{I} = \beta \delta B + \alpha_H \delta H + \alpha_T \delta T \qquad \ldots(1.9)$$

However the values of the coefficients β , α_H, α_T determined by different workers (on the basis of extensive data in each case) have yielded widely different values (e.g. see summary given by Bachelot and Conforto, 1956). This is not surprising because as pointed out by Barrett et al (1952), Wada and Kudo (1954), Trefall (1955a,b,c) and more recently by Mathews (1959), no distinct physical meaning can be assigned to the three terms in eq.(1.9) because each of them includes the contribution of effects which should be represented by two other terms separately.

Olbert (1953) has shown that eq.(1.9) is consistent with a theoretical approach (based on the assumptions : (i) mouns are continuously produced in the atmosphere and (ii) they lose energy by ionisation in passing through the air) provided δT represents the variation of mean temperature from sea level to pressure level $\bar{x}_2$ ($\bar{x}_2 \sim 200$ mb) and if δH is the variation in the height of pressure level $\bar{x}_1$ ($\bar{x}_1 \sim 100$ mb). Maeda and Wada (1954) have improved upon Olbert's calculations by taking account of the fact that mouns are produced by the decay of pions and have derived the 'partial temperature coefficients' which take account of temperature changes in each layer of the atmosphere instead of the average temperature change. Hayakawa et al (1955) extended Maeda and Wada's work by considering the contribution of nucleonic cascade to the production of pions which in turn decay into mouns.

Starting from Feinberg's work (1946), Dorman (1954) worked out a comprehensive theory of meteorological effects; his basic assumptions being similar to those of Maeda and Wada (1954). The final result has been expressed by Dorman in the form

$$\frac{\delta I}{I} = \beta \delta B + \int_0^{h_o} W_T(h) \; \delta T(h) \, dh \qquad \ldots(1.10)$$

where δT is the change in temperature of the isobaric level at which the pressure is h atmospheres; for an observations at sea level the pressure h_o (in atmospheres) is equal to unity. Graphs of the 'temperature coefficients density' $W_T(h)$*, as a function of observational levels (h)

* $W_T(h)$ is defined as the contribution to temperature effect due to 1°C change in temperature of isobaric level h (Dorman, 1957).

in the atmosphere and underground has been given by Dorman (1957) for the detectors having different geometries. $W_T(h)$ values are universal and in first approximation hold for all latitudes and longitudes. He has further suggested that for all practical purposes the integral in eq.(1.10) can be converted into a sum and eq.(1.10) can be written as

$$\frac{\delta I}{I} = \beta \delta B + \sum_{i=1}^{i=11} K_i \, \delta T_i \qquad \ldots (1.11)$$

β is the mass absorption coefficient and can be determined unambiguously and δT_i is the temperature variation in the i^{th} isobaric level and K_i are the integral of $W_T(h)$ over the respective layers. The levels normally used are 1000, 900, 800, 700, 600, 500, 400, 300, 200, 100 and 50 mb, the corresponding values of K_i are given in Sec. 3.11. It should however be pointed out that this method cannot be used to correct the data of daily variation of cosmic rays on individual days because δT_i is determined by means of radiosonde, which determination is subject to certain inherent systematic errors (Kay, 1951) reaching as high as 2^o to 3^oC and Dorman and Feinberg (1956) have shown that systematic error of 1^oC in the determination of δT_i results in an error of 0.3% in temperature correction to be applied to the amplitude of diurnal variation of cosmic rays and hence they suggested that the temperature correction should be applied to daily variation data averaged over at least 30 days.

Kuzmin (1955), Glokova (1956) and other Russian workers, who have employed the above method of meteorological corrections for correcting high latitude data of daily variation of cosmic rays, find that temperature correction to diurnal amplitude is about 0.1% with a maximum near noon. Thus if diurnal variation of cosmic rays has its maximum near noon then application of temperature correction will result in an increased amplitude. Maeda (1953), however, is of the opinion that the contribution of temperature variations in the atmosphere to the diurnal cosmic ray effect amounts to only 0.05% with time of maximum at 1400 hours. In the light of the observations of Bemmelan (1916), Barkow (1917), Dines (1919) and Venkateswaran and Desai (1953), all of whom have shown that the amplitude of daily variation of temperature above 2 km, does not exceed 1°C which determination itself is not outside of instrumental error, Sarabhai et al (1953) came to the conclusion that no significant contribution to diurnal effect results from temperature variations above 2 km from the surface of the earth. So that for the purpose of applying temperature correction to the daily variation data it is enough to take into account temperature changes between sea level and 800 mb for sea level stations. A practical method of applying temperature correction to the daily variation data of hard component is given in Sec. 3.11.

Miyazaki (1957) applied temperature correction to the data of low energy cosmic rays by comparing the cosmic ray intensity measured by similar instrument at two stations situated near to each other but at different altitudes. He showed that it was enough to correct the difference in the two intensities (which gives the low energy component) for the changes of temperature in the intervening atmosphere. An accurate estimate of such temperature changes can easily be made by application of Laplace's formula to the temperature variation recorded at the ground stations.

1.52 Meteorological corrections for nucleonic component.

The bulk of the nucleonic component, in the atmosphere is generated by rather stable particles (nucleons) through collision processes and as such the intensity of nucleonic component recorded by the measuring equipment is dependent on the mass of matter between primary particles and the detector. It is well known that incident nucleonic component is peaked in the vertical direction (the angular distribution near sea level varying as $\cos^n\theta$, with $n \sim 4$ to 5), and thereby a measurement of local atmospheric pressure is a measure of the average air mass over the detector. As such the intensity I(h) of nucleonic component at any given depth (h) of atmosphere is given by

$$I(h) \sim e^{-h/L} \qquad \ldots (1.12)$$

where L is the absorption m.f.p. of nucleonic component. Thus

$$\frac{\delta I(h)}{I(h)} = \frac{-\delta h}{L} = \beta \delta h \qquad \ldots (1.13)$$

where $\beta = -1/L$ = barometer coefficient.

Simpson et al (1953) have experimentally determined the value of L. They find that in the region $200 \leq h \leq 500$ mb the value of L changes from 150 $gm.cm^{-2}$ at $\lambda = 54^{\circ}$ to 210 $gm.cm^{-2}$ at $\lambda = 0$. At greater depths L somewhat decreases e.g. at $\lambda = 40^{\circ}$, L decreases from 175 $gm.cm^{-2}$ for $h \leq 500$ mb to 145 ± 3 $gm.cm^{-2}$ for $h \geq 700$ mb. They find that for $h \geq 700$ mb the value of L becomes independent of geomagnetic latitude and remains equal to 145 $gm.cm^{-2}$. So that at sea level or at mountain elevation upto 700 mb,

$$\beta = -\frac{1}{L} = -0.69\% \ mb^{-1}$$
$$= -0.94\% \ mm^{-1} \ Hg.$$

which value is in good agreement with those reported by Tangiorgi (1949), Adams and Bradick (1951), van Heerdan and Thambyahpillai (1955), Rose and Katzman (1956) and Lockwood and Yingst (1956).

The constancy of β for $h \geq 700$ mb implies that at such depths the magnitude of the latitude effect of nucleon component remains constant. This, however, is not the case as has been pointed out by Rose et al (1956) who find that the counting rate at sea level at geomagnetic latitude $\lambda > 55^{\circ}$ is 1.77 times that at $\lambda = 0$ while at atmospheric depth = 680 $gm.cm^{-2}$ this ratio is 2.55. Thus it is evident that the value of L and hence of β would not be independent of geomagnetic latitude even for $h \geq 700$ mb as was originally suggested by Simpson. McCracken (1959), has presented evidence to show that β is also sensitive to changes in the rigidity spectrum of primary radiation, becoming smaller as the primary cosmic ray spectrum hardens. This limitation becomes particularly important in studies conducted at high latitudes where the rigidity spectrum of primary cosmic rays is known to change in step with solar activity (McCracken, 1959; Meyer and Simpson, 1957). This limitation however, is of no appreciable consequence for equatorial stations firstly because the barometric fluctuations are far less at equator and secondly because relatively high energy primaries are involved in producing secondaries that are observed at these places and as such the magnitude of effect arising out of the change of rigidity spectrum of primaries would be rather small.

Detectors involving local production of neutrons are used for recording nucleonic component (the advantages of using such an arrangement have been summarised by Simpson et al, 1953). If all neutrons produced locally were to be generated by nucleons there would be no observable temperature effect, however, pions and mouns also participlate in local production of neutrons. The processes through which locally produced neutrons are linked with pions and mouns are represented schemetically in Fig.3a (Simpson et al, 1953). High energy mouns, low energy negative mouns, high energy pions and low energy pions in the neighbourhood of the pile contribute, respectively, $< 2\%$ (Cocconi et al, 1950), $< 3\%$ (Cocconi and Trongiorgi, 1951), $< 1\%$ (Simpson et al, 1953) and

$< 5\%$ (Bernadini et al, 1949) of the total local neutron rate. Based on these estimates Simpson et al (1953) conclude that upper limit of temperature coefficient is $< -0.02\%\ ^{o}C^{-1}$ at $\lambda = 0$ and $< -0.006\%\ ^{o}C^{-1}$ at $\lambda = 50^{o}$ which are rather insignificant to be considered. This view is shared by Dorman (1957) who has, in addition, provided 'temperature coefficient density' $W_T(h)$ graphs for neutron component recorded at various altitudes and at various latitudes. These are shown in Fig. 3b

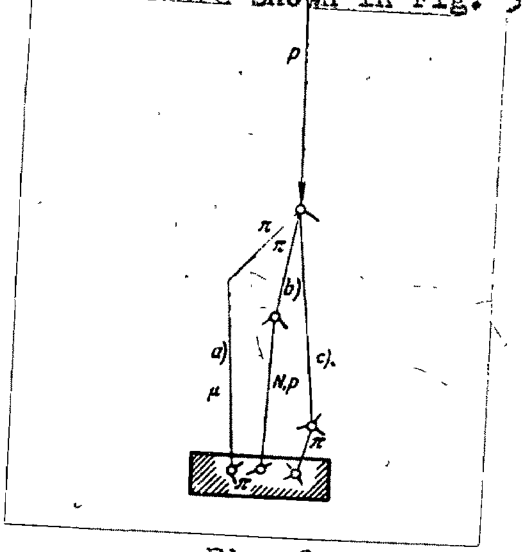

Fig. 3a.

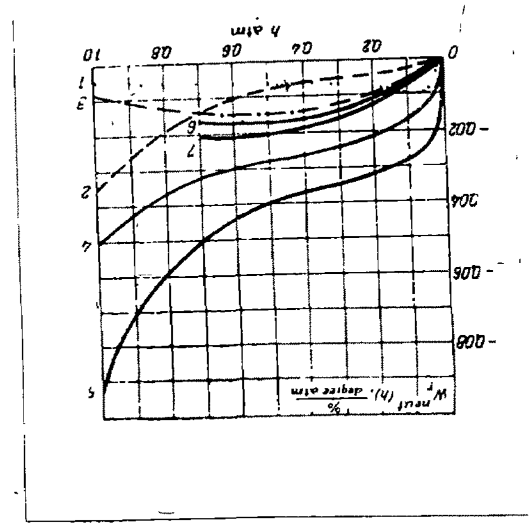

Fig. 3b.

Fig. 3a - Atmospheric temperature sensitive links in the nucleonic cascades.

Fig. 3b - Density of temperature coefficient of neutron intensity. 1 and 2 - contribution of fast and slow muons for sea level, $\lambda = 50^{o}$; 3 - contribution of pions; 4 and 5 - total coefficients for sea level, $\lambda = 50^{o}$ and 0^{o}, respectively; 6 and 7 - total coefficients for mountain elevations, $\lambda = 50^{o}$ and 0^{o}, respectively.

1.6 Long term variations of primary intensity

1.61 Variation of total incensity.

Roka (1950) and Glokova (1952) found that the mean annual intensity of muons at Huancayo and Cheltenham during 1937 to 1947 was inversely correlated (correlation coefficient = -0.80) to the mean annual values of Wolf numbers, being least when solar activity was highest. Forbush (1954) studied ionisation chamber data from Carnegie stations over the period 1937 to 1952. His findings show that :

(a) an 11-year cyclic change of mean annual intensity of cosmic rays inversely related to solar activity, exists;

(b) the amplitude of this change is of the order of 4% and is practically independent of geomagnetic latitude between 0° to 80°N;

(c) the magnitude of the change remains uneffected no matter whether magnetically disturbed or quiet days are chosen for study.

Neher (1955) has shown that at high latitudes, 85° - 88°N, there was a change of ionisation of the order of 50% at balloon altitudes ($\sim$70,000 ft.) during 1937-1954. Meyer and Simpson (1955) reported a change of 13% in intensity measured by neutron monitor at aeroplane altitudes ($\sim$30,000 ft.) from 1948-1951 (waning part of solar activity) corresponding to 1% change observed at ground level. They show that the additional particles in 1951 had rigidities within the range ~1-4 GV/c

The evidence from balloon experiments taken together with Forbush's finding presented above thus show that low energy primaries are the ones that are effected most by solar activity.

Fenton et al (1958) get a slightly higher amplitude (~5%) for 11-year cyclic change for mesons during current solar cycle with respect to the period studied by Forbush (1954), which they say is commensurate with the fact that during the current solar cycle the solar activity was exceptionally high as reported by Ellison (1957). They also find that for neutrons amplitude is ~4.5 times that for mesons; which result is supported by Lockwood (1958) and Simpson et al (1958). During the same period Neher et al (1958) report that the primary particle intensity over the geomagnetic north pole changed by a factor of 4. Fenton et al (1958) have also shown that 11-year cyclic change at ground level does not arise from the cummulative effect of short term transient decreases, a result which is in conformity with Forbush's (1954) earlier result. Fenton et al thus believe that 11-year change is a slow and gradual process over which are superposed transient decreases. Lockwood (1958), however, thinks that the change occurs rather abruptly through sudden drops (not arising out of the cummulative contribution of transient decreases) with long relaxation time, which view is supported by Morrison's (1956) finding during the previous solar cycle. Neher et al (1958) have presented striking evidence for inverse relationship between cosmic ray intensity and solar activity at Huancayo and Thule in relation to the present solar cycle.

In contrast to the above results, all of which indicate an inverse relationship between solar activity and mean intensity of cosmic rays, Katzman (1958) presents lone evidence of increase of mean intensity with increasing solar activity during Sept. 1956 to Feb. 1957, recorded by a narrow angle telescope having a solid angle of 11.5×10^{-4} steradians; the mean primary energy of response for the telescope being 30 GV.

1.62 Variation in the 'knee' of intensity versus latitude curve.

Meyer and Simpson (1955) reported that the 'knee' in the intensity versus latitude curve existed at the altitude of 30,000 ft. in 1948 at $\lambda \approx 55^{o}$ (for nucleonic component) which by 1951 had shifted northwards by 3^{o} i.e. to $\lambda \approx 58^{o}$. Van Allen and Singer (1952) concluded from the results of, Van Allen and Singer (1950), Pomerantz (1950), Pomerantz and McClure (1952) that the 'knee' in the latitude curve existed at $\lambda \approx 55^{o}$N. Their results, however, were based on non-simultaneous flights at different latitudes and as such were subject to errors arising out of appreciable day to day fluctuations of primary cosmic ray intensity. The absence of the increase of primary intensity in 1951 above $\lambda \approx 55^{o}$ was, however, confirmed by Neher et al (1953) who took simultaneous flights at two latitudes reaching 15 $gm.cm^{-2}$ and showed that protons having energy less than 0.8 GV were missing. The results of Staker et al (1951), who measured neutron fluxes in the vicinity of the geomagnetic pole, also indicate the absence of low energy primaries in 1951. However, in 1954 Neher et al (1955) found that the 'knee' had vanished; in fact they deduced from the observed increase between latitudes 58° and 68°N that protons having energy as low as 0.10 GV were present in 1954. Results of Fowler et al (1957) for 1954 when compared with those of Dainton et al (1952) for 1950, however, indicate that there was no change in the α -particle flux between 1950 and 1954. As such the increase observed by Neher in 1954 was due entirely to the presence of more protons in 1954. That these protons were not of solar origin was inferred from the facts (Neher, 1958); that it was a period of extraordinary quiet for the sun, that the intensity of these protons was very steady in 1954 over a period of three weeks and that these protons were not present in the auroral zone when rocket measurements were made by Meredith et al (1955).

Ellis et al (1954) conclude, from an experiment performed in 1953 with ionisation chambers at two latitudes, that cut off exists for heavy primaries also and occurs at very nearly the same latitude as for protons; indicating cut off dependence on rigidity rather than on energy of primaries. This finding, however, is not supported by the more detailed work of Fowler et al (1957).

Neher (1957) infers from the 'shape' of ionisation versus depth curves at low pressure ($\leqslant$ 100 gm.cm^{-2}) that the knee reappeared in 1956. This conclusion is supported by Meyer and Simpson (1957) who took observations in August 1956 and found that protons of energy $\leqslant$1.5 GV were missing thus showing that knee reappeared at $\lambda \approx 52^{\circ}$. Neher (1959) has shown that knee of latitude curve, as was to be expected, exists in southern hemisphere also.

The above facts thus indicate that the appearance and disappearance of the 'knee' in the latitude curve is related directly to the absence or the presence of low energy protons and that α -particles and heavier nuclei are either not involved or play a minor role.

1.7 <u>Short term variations of primary intensity</u>

1.71 <u>Variations of intensity during magnetic storms</u>

The association of decrease in cosmic ray intensity with magnetic storms was first reported by Messerschmidt (1933) and Steinmaurer and Graziadei (1933). The reports of world wide* changes in cosmic ray intensity during magnetic storms were first given by Forbush (1937) and Hess and Demmelmair (1939). Hogg (1949) showed that changes in cosmic ray intensity associated with magnetic storms are invariably decreases. All magnetic storms, however, are not accompanied by decrease in cosmic ray intensity (Forbush, 1938 and Trefall, 1953). MacAnuff (1951) showed that during the storm

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* According to Singer (1954) these changes are observed even at the geomagnetic pole and that they are more magnified.

of January 24, 1949, when sea level intensity of hard component decreased by 5 - 6%, no perceptible variation was observed in cosmic ray intensity (with an accuracy to several tenths of a percent) recorded at 60 m.w.e. underground**. Neher and Forbush (1952) found that the magnitude of decrease in low energy cosmic rays (recorded at 17,000 ft. above sea level) during the storm of July 25, 1946 to be four times larger than the decrease recorded by ionisation chamber of Mt. Wilson (mean energy of primaries $\sim$40 GV). On a few occasions (Chasson, 1954) decrease in cosmic ray intensity has occurred an appreciable time before any measurable geomagnetic disturbances took place.

World-wide decrease of mean intensity (ΔI) of cosmic rays has been called 'cosmic ray storm' (abbreviated as CRS) by Sekido et al (1952). Kitamura (1954) has shown that CRS associated with SC-type magnetic storms are larger than those associated with the other types of magnetic storms. Wada (1954) noticed that CRS occuring in March equinox are larger than those which [redacted] occur in September equinox though the magnetic storms in the two periods are not very different from each other. Sekido et al (1955) have shown that magnetic storms which are accompanied by CRS within two days are closely related to c.m.p. of large sunspot groups and such storms are called 'S-type' storms by them. The magnetic storms not accompanied by CRS are called

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** Later workers, McCracken (1958) and Kuzmin (1959) have, however, observed decrease in cosmic ray intensity following magnetic storms at 40 m.w.e. and 7, 20 and 60 m.w.e. respectively.

'M-type' storms. S-type exhibits a pronounced 11-year cyclic variation similar to one shown by relative sunspot numbers whereas M-type do not show any such effect. The former type they attribute to large magnetic corpuscular clouds ejected from sunspot areas and the latter, they think, are caused by non-magnetic narrow corpuscular beams from the socalled 'M-regions' of Bartels (1932). Taking Huancayo ionisation chamber data from 1936-1946, Yoshida and Kondo (1954) selected days (115 in all) of SC-type magnetic storms which are associated with appreciable cosmic ray decrease ($\triangle I \geqslant 0.4\%$) as epochs and using Chree's method of superposed epochs they showed that magnetic storm recurs only over a small number of solar rotations whereas CRS continues to recur after 27 days for a much longer period even when no typical magnetic storm occurs during this period. The earlier observations of various workers who had found that CRS is sometimes associated with a typical magnetic storm and sometimes with a small magnetic disturbance was thus explained by Yoshida and Kondo was due to the fact that both magnetic storm and CRS are caused by the same agency which after some time loses its potency to cause magnetic storms but retains its effectiveness for causing CRS. Kamiya and Wada (1959) show that every solar flare which is accompanied by type IV radio outburst is followed by a CRS. However, the amplitude of CRS is indepndent of the meridian distance of radio outburst on the sun.

Latitude dependence of the amplitude of CRS has been examined by Forbush (1938), Wada (1952), Yoshida and Kamiya (1953), Glokova (1956), Kodama and Miyazaki (1957) and Brown (1959) who find that the amplitude of depression increases as the latitude increases.

McCracken has recently studied CRS in neutron component of cosmic rays in detail and his findings are :

(a) The greater the amplitude of CRS the greater its duration (period in which intensity recovers to pre-event value or settles down to a new lower level - McCracken, 1958).

(b) Quite frequently a CRS is preceded by a transient decrease which exhibits strong directional dependence (McCracken and Parsons, 1958).

(c) Onset times of CRS observed at stations situated along different longitudes are different - the difference, in some cases, amounts to several hours. (Fenton et al, 1959).

(d) At the same station the onset of CRS does not occur simultaneously in all directions. The intensity in the directions between 30^{o}-120^{o}W of the earth-sun line is the first to decrease and is the one that suffers the greatest depression. The intensity from the directions 0^{o}-90^{o}E of the earth-sun line is the last to be affected and it suffers the least depression (McCracken, 1958).

(e) The amplitude of CRS is a function of altitude and at high latitudes the amplitude increases at the rate of 12 % per 1000 meters (McCracken, 1958).

Venkatesan (1959), who analysed the data of Canadian stations from October 1956 to December 1957 for neutron and meson monitors, found that :

(a) an association (statistical) exists between CRS and c.m.p. of active solar regions. On the average, the greater the activity rating of the regions, the larger the amplitude of CRS.

(b) CRS exhibits 27 day recurrence tendency though the amplitude of recurrent decrease is very variable, being sometimes smaller than, equal to, or larger than the first observed decrease. However, very large ($\geqslant$ 9 % at Ottawa) CRS do not recur.

Murakami and Kudo (1959) have pointed out that in a CRS, low energy cosmic rays (neutrons) have earlier onset time than high energy ones (hard component). Kitamura and Kodama (1959) show that, in a CRS, low energy component (neutrons) recovers later than the high energy component (hard component). They have also studied cosmic ray energy spectrum during CRS and find that the spectrum becomes flatter while CRS is in progress; which finding is consistent with Blokh et al's (1959) observation that with increasing amplitude of CRS, the ratio of the depression amplitudes of neutron to hard component increases.

Recently Yoshida and Wada (1959) and Kondo et al (1959) have studied, in detail, the CRS associated with two severest magnetic storms of the present solar cycle; one of which took place on 13th Sept.1957 and the other on 11th Feb.1958. Their findings are :

(a) A pronounced increase was superposed on the intensity decrease associated with normal CRS. This was not a flare type increase because firstly no solar flare was observed just before or during the actual time of increases (however, flare activity was high two days prior to the commencement of CRS) and secondly a normal flare type increase is larger the higher the latitude of observing station whereas the current increases were most pronounced in lower latitudes. Also these increases could not be due to pronounced anomalous diurnal variation which appears during CRS (Sekido et al, 1952) due to their being simultaneously present at the day (Zugspitze) and the night side (Norikura) of the globe*.

(b) The intensity increases occurred almost in coincidence with the maximum depression of the geomagnetic field intensity.

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* However, Sarabhai and Palmeira (1959) have pointed out, in connection with the February event, that the increase did exhibit a longitude dependence being more pronounced in the longitude belt 0-32°E and less so in 75-115°W.

(c) The dependence upon energy of the increases was nearly the same as that of the decrease i.e. the more, the lower the mean energy of the primaries.

They (Kondo et al, 1959) conclude that these increases are caused by the lowering of the cut off rigidity during magnetic storms. Their theoretical calculations show that such a mechanism will produce greatest increase at sea level stations having rigidity of the order of 7 GV and at mountain (pressure $\simeq$ 680 gm.cm^{-2}) stations having cut-off rigidities $\simeq$ 5 GV. Increase will also depend upon the total depression of the geomagnetic field during a particular storm. The more the depression of the field, the larger the increase.

Sarabhai and Palmeira (1959), who studied the differential effects of longitude, of latitude and the northern and southern hemispheres with respect to the February 11, 1958, event in conjunction with detailed solar and terrestrial observations provided by Trotter and Roberts (1958) and Van Allen (1959), have pointed out the following salient features of the event :

(a) A transient increase precedes the main decrease by a few hours at equatorial stations (recording neutrons). At higher latitudes this phenomenon is not observed.

(b) The amplitude of the decrease is more and the minimum is reached later for low than for high energy primaries.

(c) The secondary increase superposed on normal main decrease is more prominent in low than at high latitudes (as also noted by Yoshida et al, 1959), but exhibits a strong N-S and E-W asymmetry; being very small in southern hemisphere and absent in longitudes 147°-168°E.

They thus infer, in contradiction to Yoshida and Wada (1959), that the second increase is mainly anisotropic and has an energy dependence different from the mainly isotropic decrease. They believe that these increases are caused by magnetic fields in the shock front of the moving plasmas as suggested by Dorman (1959). The latter author has also calculated the energy spectrum of particles which participated in pre-storm increase and has shown that with decreasing rigidity the amplitude of increase should increase but its duration should get diminished e.g. for particles with rigidity $\sim 10^{8}$eV/c the amplitude of the pre-storm increase would be ~ 100 % but its duration only 2 minutes.

1.72 Day to day variations of intensity

Neher and Forbush (1953) established the world-wide nature of day to day changes of intensity by showing that changes in intensity as recorded by ionisation chambers at Huancayo and Cheltenham and by a neutron monitor at Climax and changes in total ionisation at 70,000 ft. over Bismark are correlated with each other. Further Neher et al (1953) have shown that changes at high altitude over Bismark and near the geomagnetic north pole are correlated amongst themselves*. Fonger (1953) and Van Heerdan and Thambyahpillai (1955) also testify to the world-wide nature of day to day changes.

An important type of day to day change of intensity is the one which shows 27-day recurrence corresponding to the synodic period of sun's rotation about its axis** with respect to earth. The earlier work with hard component was done by a number of workers Hess et al (1936), Kolhoerster (1939), Gill (1939), Monk and Compton (1939), Forbush (1940) and Waffler (1941). Glokova (1952, 1953) who analysed the Carnegie stations' data over the period 1937-1950 has pointed out that :

(a) 27-day variation is most pronounced in years of maximum solar activity and completely absent during years of minimum solar activity; which finding tallies with those of Roka (1941), Broxon (1949), Meyer and Simpson (1954) and Venkatesan (1958).

(b) 27-day variation for hard component shows practically no difference in going from $\lambda = 0$ (Huancayo) to $\lambda = 50^{o}$ (Cheltenham).

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* However these correlated changes differ in the order of magnitude of change involved.

** More precisely this relates to the intermediate latitude region of the sun, the period of rotation of high latitude regions is 1-2 days longer.

(c) The position of maximum is stable during period of high solar activity in that the mean annual vectors of 27-day wave lie in first quadrant (1-7 days of rotation after passage of the Carrington meridian across the centre of the solar disc).

Meyer and Simpson (1954) and Simpson and Babcock (1955) have shown that peak to peak amplitude of 27-day variation associated with nucleonic component is four to five times that associated with hard component (and this relation holds throughout the solar cycle). Recently Vernov et al (1959) have shown that total component at 30 km shows 8 to 10 times the amplitude of 27-day variation compared to the intensity measured on the surface of the earth. This should be compared with Kuzmin's (1959) result that amplitude of 27-day variation decreases with increasing depth underground; amplitude at 60 m.w.e. being $\sim 1/3$ of the amplitude at 20 m.w.e. These results show that though low energy primaries are most affected by 27-day change, high energy primaries (mean energy ~ 450 GV, Kuzmin, 1959) are also influenced by it.

Close association of 27-day variation with geomagnetic activity is inferred from the works of Benkova (1944) and Afanas'yeva (1954), Sekido et al (1955), and this has been confirmed by Glokova (1956) who showed that the amplitude of 27-day variation decreases to almost half, if solar rotations during which 'effective' magnetic storms take place (i.e. those storms which reduce the intensity of hard component of cosmic rays by more than 1 %, Glokova, 1952) are excluded from the averaged material. Van Heerdan and Thambyahpillai (1955) have shown that the minimum of 27-day variation occurs 5 days earlier than maximum of K_p. Simpson (1954) and Kane (1955) have also reported a similar result.

Simpson et al (1952) believe that quasi periodic increases of intensity take place and have shown the association of the increases with c.m.p. of active solar regions and regions of green coronal emission on the sun. Simpson et al (1955) also find close association between cosmic ray increases and meridian transits of unipolar (UM) region discovered by Babcock (1955). Kodama and Murakami (1956) adduce evidence for solar emission (i.e. production) of particles at least during period of lull in solar activity*. involved in 27-day variations by studying concurrent diurnal variation. However, Van Heerdan and Thambyahpillai (1955) find that mean intensity decreases as the amplitude of 27-day variation increases and are thus led to the conclusion that 27-day variations are essentially decreases produced by a screening mechanism.

The nature of 27-day variation is an open question to-day. Because of its association with sunspot numbers, geomagnetic activity, magnetic storms and its energy dependence, many workers such as Brown (1956), Dorman (1957),

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* Their observations extend from October 1954 to July 1955.

Neher (1958) and Kuzmin (1959) believe that 27-day quasi-periodic variation belongs to the same group of phenomena as do the 11-year cyclic change and magnetic storm effects. However, one can see from the evidence presented above that such a view represents an over simplification of the picture because apparently some times the increases do take place and they do recur. Author has examined this problem in more detail.

1.8 Increases of intensity associated with solar flare

Flare type increases provide the most direct evidence of the acceleration of charged particles to cosmic ray energies either on the sun itself or in regions very close to it. The additional cosmic rays during such bursts thus constitute a special sonde for sounding conditions on the sun and in the interplanetary space and for studying the nature and the form of geomagnetic field at large distances ($\gg 1$ earth radius) from the earth. The results of four well-known early events (February 28, 1942; March 7, 1942; July 25, 1946 and November 19, 1949) have been discussed in detail by Daudin (1951), Elliot (1952), Forbush et al (1950), Biermann and Schluter (1953), Sekido and Murakami (1955) and Dorman (1957). These studies have established that the increase (which may be delayed upto an hour after the visible sighting of the solar flare) and its magnitude depends upon the mode of detection and is a function of geomagnetic latitude, longitude and the height above sea level of the observing station. None of the above four flares produced any increase at the equatorial station of Huancayo.

Assuming the additional cosmic rays to be locally generated on the sun and propagating rectilinearly outwards, Schluter (1951) and later Firor (1954), taking into account the deflection of such particles in the geomagnetic field, showed that these additional particles (if protons) will produce sizeable increases at places having local time 0900 and 0400 hours within the geomagnetic latitude 25° to 60°; the higher latitudes falling in forbidden zone*. Increases were, however, observed at Godhavn ($\lambda = 80^{\circ}$), Resolute ($\lambda = 83^{\circ}$) (Rose, 1951) and Thule ($\lambda = 89.5^{\circ}$) in July 1946 (Graham and Forbush, 1955). Kraushaar (1955) ascribed this effect to deflection by galactic field. Sekido and Murakami (1955) suggested it to result from the scattering by an 'outer' trapping field extending a little beyond the earth's orbit.

1.81 Solar flare of February 23, 1956

The solar outburst (having magnitude 3+) of February 23, 1956 was associated with the most energetic

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* Firor's calculations stopped at 10 GV and therefore there exists a blank at geomagnetic latitude below 25°. However, if higher energies are involved, as happened in the flare type increase of Feb.23, 1956, the impact zone would extend to still lower latitude, even upto equator.

solar cosmic ray event observed so far, in that the increase was registered even at equatorial stations as reported by Forbush et al (1956) and Sarabhai et al (1956). The latter authors have estimated that solar protons of 30-67.5 GV were involved in causing the observed increase. Neutron monitor at Leeds, which was in 0400 hours impact zone, recorded 4500 % increase (Marsden et al, 1956) whereas the one at Climax registered a 2000 % increase (Meyer and Simpson, 1956) even though the latter did not lie in any impact zone. Winckler et al (1956) observed a 180 % rise in neutron intensity at 10 gm.cm^{-2} over Chicago, some 15 hours after the onset of the flare; at sea level the rise of neutron intensity at that time was only 26 %. However, an EAS instrument which recorded showers produced by particles of energy $\geqslant 10^3$ GV did not register any increase (Sittkus et al, 1956).

Brunberg and Eckhartt (1956) at Stockholm ($\lambda = 58^o$) and Kuzmin et al (1956) at Yakutsk ($\lambda = 51^o$) found that north pointing telescopes recorded more particles than the south pointing ones. The latter authors interpret this to mean that solar protons did not travel in straight line orbit but suffered a deflection by a magnetic field $\sim 6x10^{-6}$ gauss before reaching the earth. Ehmert (1956) reached similar conclusion after making a detailed study of the time difference in the onset and the decay of the increases for different recording stations all over the globe. Meyer and Simpson (1956), from a study of the network of neutron monitor stations, have shown that additional solar cosmic rays had a steep momentum spectrum (power law with exponent $n \approx -7$) and that the increase decayed with time roughly as $t^{-3/2}$. They believe that a heliocentric field free cavity ($B < 10^{-6}$ gauss) of radius ~ 1.4 A.U. (1 A.U. = 1.5×10^{13}) exists. This cavity they suggest, is surrounded by a shell of finite thickness in which disordered magnetic fields ($B \approx 10^{-5}$ gauss) exist and this shell reflects back the flare particles into the field-free region. If this model is to hold, solar flares on the invisible side of the sun should also lead to increases at the earth; upto now no event of this type has been observed.

Eckhartt (1958) has pointed out that Hobart, which lay outside Firor's impact zone, recorded earlier onset of flare type increase. The particles responsible for this increase seem to have arrived from the direction of the solar beam which produced the magnetic storm two days later.

McCracken (1959) has pointed out that only the most energetic solar flares (which are also observed in white light) produce cosmic ray increases and that the rarity of cosmic ray flare effect is, at least, in part due to rarity of very energetic solar flares. However, a very energetic flare occurred on March 23, 1958 which was of Class 3^+ and was observed in white light also but did not produce any cosmic ray increase. But then this flare occurred on the eastern limb of the sun. Cocconi et al (1958) have pointed out that elongated magnetic 'tongues' extending from the vicinity of the sun serve as 'guides' for solar flare protons. So that earth will register a cosmic ray increase only if the earth, at the particular moment (when an energetic flare is observed), happens to be, 'coupled' to the flare region by such a 'tongue'. If such a condition does not hold then no sizeable flare type increase would be observed on earth even though the cosmic rays have been actually generated during the flare. They have further shown that for such a coupling to take place effectively the flare regions have to be situated on the western regions of the sun.

1.82 Effects of small solar flares

Dolbear et al (1950) and Firor (1954) have shown that small increases $\sim 1\ \%$ may occur at the time of less intense flares. Neher (1953) observed an increase of intensity during descent compared to the intensity during ascent of a balloon carrying ionisation chamber. A flare of type 1^+ had occurred one hour prior to the ascent of the flight. Corrigan et al (1958) have reported transient increases ($\sim 30\ \%$) of low energy cosmic rays that occurred on August 9, 1957 at 25,000 ft. The increases were preceded by solar flare of type 1^+ . McCracken (1958) has reported a 2 % increase at sea level of neutron intensity which was observed simultaneously at Australian and American stations on August 31, 1956. The increase was preceded by a solar flare of type 3*.

1.9 The solar daily variation

Lindholm (1928) was the first to detect the existence of cosmic ray intensity variation dependent on local solar time. However, complications arising out of meteorological effects - the nature of which was not fully known then - prevented any definite conclusions to be drawn regarding the existence of this effect. Alfven and Malmfors (1948) succeeded in circumventing these difficulties by making use of the ingenious idea of crossed-telescopes in which particles arriving from two opposite azimuths (north and south) were recorded. The difference between the variations for the two directions is then independent of any atmospheric effect, because particles coming from north and south pass through the same thickness of the atmosphere and the conditions along the paths so traversed are about the same. The fact that a finite difference exists was interpreted to mean that there exists an anisotropy of primary cosmic rays and the above authors demonstrated, from model experiments, that this anisotropy existed only for high energy primaries (comparatively, speaking) which were not subject to solar magnetic field and only weakly subject to earth's field. Similar conclusions were arrived at by Elliot and Dolbear (1951) who performed directional studies in all the four azimuths at Manchester. According to the above line of thinking, daily variation results from earth's rotation in an anisotropic flux of primary cosmic rays. Brunberg and Dattner (1954) showed that the mean energy of primaries which constitute the anisotropic flux lies within 20-40 GV.

Solar daily variation consists of two important components the diurnal variation which has a period of 24 hours, and semidiurnal variation which has a period of 12 hours. Evidence from Elliot and Dolbear's (1951) experiment in which the amplitude of the semidiurnal variation in southern direction was found to be three times that in northern direction at the same zenith angle when taken along with Nicolson and Sarabhai's (1948) theoretical calculations, prove beyond doubt that semidiurnal variation is also of extraterrestrial origin, though very little is known about its origin so far*.

Recently Elliot and Rothwell (1956) and Parsons (1957) have pointed out that their results obtained with directional telescopes during 1954 and 1955 are at variance

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* Dorman (1957) has recently hazarded an explanation as to how semidiurnal component can arise but it is not very satisfactory as he himself admits.

with the view that the daily variation arises from earth's rotation in anisotropic flux of primaries and have come to the conclusion that the cause of daily variation lies in the modulation of primaries within earth's magnetic field. They have considered only the mean energy of response instead of the integrated effect of primaries of all energies; which method is rather crude, considering that their results relate to high latitudes where particles arrive from widely different asymptotic latitudes and longitudes. Sarabhai et al (1959) in their study with directional telescopes pointing east and west at 45° to the zenith are led to believe that, apparently, there are two sources responsible for solar daily variation on individual days. They have presented evidence to indicate that on days characterised by low geomagnetic activity ($Cp \leqslant 0.5$) and high east-west assymmetry, the daily variation results are consistent with the notion of anisotropic distribution of primary cosmic rays far out in space whereas on geomagnetically disturbed days, a source localised within earth's magnetic field seems to be operative.

1.91 Energy dependence of solar daily variation

Thompson (1948) showed that the amplitude and phase of solar daily variation, for hard component, does not show any dependence on geomagnetic latitude of the place of observation. Dolbear and Elliot (1950), from vertical measurements of hard component at an altitude of 30,000 ft. exclude occurrence of solar daily variation with an amplitude greater than 1 %. Bergstrahl et al (1951) did not find any solar daily variation at 75,000 ft. greater than 1 % for total ionising component and more than 3.5 % for neutrons, which figures represent the limits of accuracy attained in each case. Firor et al (1954) found an amplitude of solar daily variation of nucleonic component, measured by neutron monitor, at Climax which was five times that found by counter telescopes (wide aperture) or ionisation chamber experiments which measure the hard component. By comparing station near equator (Huancayo) with Climax ($\lambda = 48^{o}$) they showed that the amplitude shows only a small variation over a wide spectral range, the ratio of peak to peak amplitude at $\lambda = 48^{o}$ and at $\lambda = 0^{o}$ being 1.4 ± 0.2. Kodama and Miyazaki (1957) have, however, reported a daily variation averaged over the months January and February 1957 at Antarctic, for nucleonic component, which has an amplitude a few times that observed by Mt. Norikura neutron monitor during the same period.

Lord and Schein (1950) studied solar daily variation of heavy primaries $10 \leq Z \geqslant 26$ at an altitude having pressure < 10 gm.cm^{-2} over Minneapolis ($\lambda = 55^{o}$) and got a ratio between day and night fluxes = 2.55 ± 0.26 which, within experimental error, was independent of Z in the region $10 \leqslant Z \geqslant 26$. Frior et al (1951) and Anderson et al (1953) found that the solar daily variation for heavy primaries of $Z \geq 10$ cannot have an amplitude $> 20\%$. Yngve (1953) found in the period 12 to 14 hours the flux of heavy primaries ($Z \geq 10$) was $25 \pm 8.5\%$ greater than in adjacent intervals of time at $\lambda = 55^{o}$N. Stix (1954), using proportional counters, found that the intensity is actually less by 14 to 16 % at noon compared to intensity in morning hours for primaries having $Z > 6$. Peters et al (1952) have advanced arguments to show that, if at all, solar daily variation exists for heavy primaries its amplitude could hardly exceed 10 %. However Koshiba and Schein (1956), using a technique similar to Yngve, did get a solar daily variation for primaries with $Z \geq 10$ of amplitude $34 \pm 7\%$ with maxima at 0900 hours. Thus the only definite conclusion that can be drawn is that solar daily variation of heavy primaries, if at all it exists, is not so conspicuous as reported by Lord and Schein (1950).

MacAnuff (1951) obtained solar daily variation having an amplitude of 0.05 % at 60 m.w.e. Barett et al (1952) at a depth of 1574 m.w.e. and Sherman (1954) at 60 m.w.e. could not detect any daily variation greater than 1 %. While Sandor et al (1959) report an amplitude of $0.065 \pm 0.012\%$ at 40 m.w.e. obtained with semicubic telescope, Regner (1959) observed solar daily variation of amplitude $0.12 \pm 0.001\%$ with telescopes inclined at 45^{o} to the zenith and situated underground at 30 m.w.e. (measured vertically). Kuzmin (1959) has recently made a detailed study of solar daily variation with semicubic telescopes at surface and at 7, 20 and 60 m.w.e. during 1957 and 1958, and finds the amplitude to be respectively 0.36%, 0.25%, 0.18% and 0.05% i.e. amplitude decreases with the increasing depth underground and so with increasing primary energy.

Farley and Storey (1954) found a solar daily variation of amplitude 1.4±0.25% in investigations on large atmospheric showers. Crawshaw and Elliot (1956) reported that a significant solar daily variation exists for E.A.S. of total energies 10^{16} to 10^{17} eV recorded in England. On the other hand, Greisen (1959) did not find any significant solar daily variation for shower of 10^{4} to 10^{9} particles during 1958. It is necessary to confirm beyond any doubt whether there exist any solar daily variation for high energy primaries ($\sim 10^{16}$ to 10^{17} eV), at all.

1.92 Long term changes of solar daily variation.

The solar daily variation as characterised by the amplitudes and times of maxima of diurnal and semidiurnal components of the 12 month mean daily variation of hard component undergoes large long term changes that are world-wide in character, as pointed out by Sarabhai et al (1953, 1954, 1955). Giving their results of investigation of data of continuous recording at Huancayo, Cheltenham and Christchurch for the period 1937 to 1953 they found a particularly distinct relationship between the time of maximum of the diurnal variation and the intensity of the coronal line of $\lambda = 5303$ Å (relation with sunspot number R was found to be somewhat weaker). Significant changes were observed also to take place in the semidiurnal component. Considering the daily variation as a whole, without resolving it into its harmonic components, they demonstrated an interesting sequence of changes at equatorial station of Huancayo as shown in Fig. 4. One can see that the 12 month

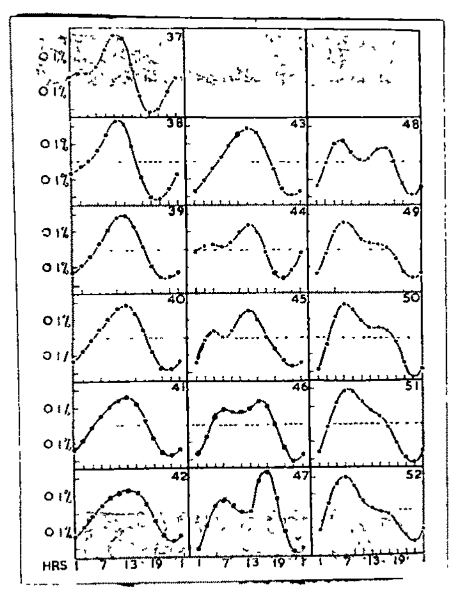

Fig. 4 - The 12 month mean daily variation of meson intensity at Huancayo during different years.

mean daily variation which exhibited 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 a clear evidence of progressive increase of early morning maximum followed by the decrease of the noon maximum. During the period 1945 to 1950 the mean annual daily variation exhibits two maxima instead of one. As can be seen only half of the cycle of change appears to have been completed in 11 years, thus indicating a 22 year cyclic change for solar daily variation. They thus arrived at the basic conclusion that the daily variation could be considered in terms of the contribution of two distinct types of variations; the 'd' or day-type which has a maximum near noon and 'n' or night type which has a maximum near 0300 hours local time. In general the 'd' and 'n' type variations are simultaneously added or attenuated. Just preceding the sunspot minimum there is a brief period when only the 'd' type variation predominates and this is immediately followed by an equally brief period when 'n' type gains preponderance. The pattern of addition and attenuation of the two types of variations thus appears to be reversed after 11 years. Sarabhai et al (1955) have, however, pointed out that the existence of 'd' and 'n' type components of solar daily variation are not quite as clearly discernible at middle latitudes (Cheltenham) as at equatorial stations (Huancayo and Ahmedabad) which feature had also been noted by Feinberg (1946).

A long term change of the phase of the diurnal component of daily variation having a period of 22 years has been reported by Thambyahpillai and Elliot (1953). This conclusion is supported by the findings of Steinmaurer and Gheri (1955) who compared data taken in groups of years over the past 22 years. They showed that during sunspot minimum in 1933 the time of maximum of diurnal component was about 0700 hours local time which was comparable to the time of maximum about 22 years later in 1953-1954, but was earlier than the time of maximum 11 years later in 1944. During some months in 1954, they observed the time of maximum of diurnal variation to occur as early as 0200 hours local time. Possener and Heerdan (1956) also found that during 1953 and 1954 the time of maximum intensity occurred during night. During this period the amplitude of the nucleonic component of cosmic rays was found to decrease to a value not significantly different from zero. Conforto and Simpson (1957) have also demonstrated a progressive shift of the time of maximum of the diurnal variation for both nucleonic component and hard component to earlier hours during 1954. Sandstrom (1955) has shown that this world-wide shift of the time of maximum of the diurnal component is independent of the direction of arrival of the primaries.

Venkatesan and Dattner (1959) showed from the data from number of stations, situated at different latitudes, that the long term changes in the amplitude of diurnal component are more closely related to geomagnetic activity than to solar activity. They also pointed out that whereas the secular changes in the mean annual vector of diurnal component are world-wide in character, that of semidiurnal component are not. Sarabhai et al (1959), on the other hand, point out that it is only meaningful to study semidiurnal component at equatorial stations where it has large amplitude. They have shown that the change in semidiurnal component at Kodaikanal ($\lambda \approx 1^{o}$) and Huancayo ($\lambda \approx -1^{o}$) are very similar from year to year. They have also shown that the time of maximum of semidiurnal component changed from 1936 to 1955 by about ten hours and thus the phase of semidiurnal component of daily variation also seems to partake in 22 year cyclic change.

1.93 Day to day changes of solar daily variation

The daily variation varies strongly from day to day and a substantial part of this variability is apparently of extraterrestrial origin (Firor et al, 1954). As such, the study of these changes is very important from the point of view of acquiring information about the mechanism causing the daily variation.

Remy and Sittkus (1955) and Firor et al (1954) have studied daily variation on groups of days. Some groups show very large amplitude of solar daily variation whereas others show negligibly small amplitudes. Further on some occasions the daily variation shows a maximum during day time whereas, on others, the maximum of daily variation occurs in the night. Sittkus (1955) found, from the analysis of ionisation chamber data, that days having large amplitudes with a maximum near noon occurred in conspicuous groups.

Though these groups showed a good 27 day recurrence tendency, they were not found to be associated with any significantly different magnetic character figure compared to the rest of the days. Sarabhai et al (1955) also noticed these features in their studies with narrow angle telescopes at Ahmedabad. On purely phenomenological basis, the latter authors classified the daily variation into three groups designated as 'd', 'n' and 's' according as the daily variation has a maximum during the day or during the night or has two maxima instead of one. They showed that daily variation of 'd' type occurred in groups and exhibits a pronounced 27 day recurrence tendency. Sarabhai et al (1958) further showed that the daily variation of 'd' type was associated with increase of mean intensity whereas that of 'n' type was linked with decrease of mean intensity; for 's' type the daily mean intensity was normal.

Sekido et al (1950, 1952) found that with increase of geomagnetic disturbance, as characterised by the character figures J.C.F. and C., the amplitude of diurnal variation increases and its phase advances; the effect being more pronounced the smaller the aperture of the counter telescope. Sandstrom (1955) also found that with increasing magnetic activity as characterised by the maximum K_p value for the day, there occurred a progressive shift of time of maximum of the diurnal component towards early hours along with increase in the amplitude of the diurnal component and this effect was more prominent for primaries arriving from vertical and from 30°S and less so for primaries recorded by counter telescopes inclined at 30° to the zenith and pointing to the northern direction. Sandstrom (1956) further demonstrated that if daily variation be regarded as arising out of 18 hour or tengential component and 12 hour or radial component of anisotropy in solar system as envisaged by Alfven (1954), then the contribution from 12 hour component increases (in negative direction) with increasing K_p whereas the 18 hour component of the anisotropy flux remains unaltered and this fact is just in accord with Alfven's theory. Firor et al (1954), who studied the relationship between solar daily variation for neutrons and the geomagnetic activity as characterised by the sun of K indices for the day, found that large amplitudes were associated with large K indices sum. However, Satyaprakash (1958) found that in 1957 there did not, apparently, exist any relationship between the parameters characterising the daily variation of nucleonic component recorded at Kodaikanal ($\lambda = +1^{\circ}$) and geomagnetic activity as indicated by C_p. This problem has been further investigated in detail, by the author in this thesis.

Yoshida and Kondo (1954), from ionisation chamber data at Huancayo for the period 1936 to 1946, demonstrated that a strong 27 day recurrence tendency exists for the amplitude of the diurnal component of daily variation which was of non-storm origin. Kane (1955) observed 27 day recurrence tendency in the amplitude of daily variation of nucleonic component of cosmic rays. Glokova (1955) found that in 1954, the year of minimum solar activity, no perceptible 27-day recurrence was exhibited by the amplitude of diurnal component of solar daily variation.

1.94 Dependence of the characteristics of solar daily variation on the geometry of the detector.

Sekido et al (1950) showed that the amplitude of diurnal variation increased from 0.19% to 0.24% when the semiaperuture of the telescope decreased from $\pm 40^{\circ}$ to $\pm 12^{\circ}$. Further (Sekido et al, 1951) they showed that the narrower the solid angle of the telescope the larger is the amplitude of semidiurnal variation. From the figure given in their paper one can easily see that the semidiurnal amplitude recorded by the narrow angle telescope ($\pm 12^{\circ}$) is $\sim$ 3 times that recorded by wider angle telescope ($\pm 40^{\circ}$) and $\sim$5 to 6 times that recorded by the omnidirectional detector. They thus recommend that for the study of semidiurnal variation, narrow angle telescopes should be used. From the published curves of Yagi and Ueno (1956) it is clear that the narrower the angle of the telescope the earlier is the time of maximum of the diurnal component. Ehmert and Sittkus (1951) also showed that the amplitude of the daily variation measured by a vertical counter telescope of a limited directional sensitivity is higher than that recorded by an ion chamber at $\lambda = 48^{\circ}$. Sarabhai et al (1955) made simultaneous measurements with the telescopes having apertures $5^{\circ} \times 38^{\circ}$ *

* $5^{\circ} \times 38^{\circ}$ is to be interpreted as : angle of opening of telescope in E-W plane = 5° and the angle of opening of the telescope in N-S plane = 38°

$10^{\circ} \times 38^{\circ}$; $30^{\circ} \times 38^{\circ}$ and omnidirectional detector. The respective amplitudes for diurnal variation were $1.21 \pm 0.15\%$; $1.15 \pm 0.08\%$; $0.68 \pm 0.05\%$ and $0.31 \pm 0.01\%$ with the time of maximum of the diurnal component occuring progressively later as the aperture of the detector decreases (latter result is opposed to Yagi and Ueno's, 1956, result). Bhavsar (1956) had earlier used an ultra-narrow angle counter telescope having an aperture of $3.6^{\circ} \times 13.4^{\circ}$ and had observed an amplitude of $2.2 \pm 0.5\%$ with diurnal maximum at noon for the period November 1952 to August 1953. Elliot and Possener (1955) however, did not observe any change in the amplitude of daily variation recorded by narrow and wide angle detectors at $\lambda = 50^{\circ}$.

Recently Brunberg (1958) has worked out in detail, the theory of the dependence of the amplitude of solar daily variation on the geometry of the telescope, taking as a basis the assumption that solar daily variation is caused by an extraterrestrial anisotropy. He points out that what we actually measure in making measurement of solar daily variation, is the ratio between the source and background intensities and not the source intensity itself. Thus if the source of daily variation were to subtend rather small solid angle at the detector, then the narrower the effective aperture of the dectector, the greater would be the magnitude of the amplitude recorded. Thus a broader angle telescope measures small amplitude because it records a higher 'background'. He has shown that if the intensity of anisotropic flux were to vary sinusoidally for a detector situated at equator, say Huancayo, then to a first approximation the amplitudes of the first, second and third harmonics, as recorded by the ionisation chamber, would be 0.72, 0.32, 0.05* of their actual values. One can see that the second and higher harmonics are most adversely affected. The corresponding reduction factors for counter telescopes of cylindrical geometry at Huancayo for first and second harmonics of solar daily variation are given in the following :

Aperture of the telescope	Reduction factors.	
	1st Harmonic	2nd Harmonic
45°	0.86	0.53
25°	0.89	0.60
15°	0.92	0.66

From the above, it is clear that the narrower the aperture of the detector, the more faithful is the reproduction of the first and particularly of the higher harmonics of the profile of extraterrestrial anisotropic flux of primaries which causes solar daily variation. This fact apart from being entirely in agreement with the experimental evidence presented above, points to the importance of the study of solar daily variation at equator with narrow angle telescopes.

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* In the calculation of these factors, allowance has been made (under certain plausible assumptions) for the fact that several processes occur in the atmosphere which have a spreading effect upon the secondaries so that a parallel beam of primaries is gradually converted into a more or less divergent beam of secondaries which are finally recorded by the detector.

1.95 Location of the source of solar daily variation and its energy spectrum.

Dorman and Feinberg (1958), have made use of extensive experimental data on the average amplitudes, $\delta N^{i}_{\lambda,f}(h_o)/N^{i}_{\lambda,f}(h_o)$, of solar diurnal variation of different components of cosmic rays recorded at different latitudes ($\lambda = 0^{o}$ to $\lambda = 80^{o}$). Further making use of the coupling coefficients W^{i}_{λ}, for these different components they utilised eq.(1.8) to determine approximately the energy spectrum of the variation of the primaries which gives rise to quiet day solar diurnal variation (as distinguished from disturbed solar diurnal variation which is observed on geomagnetically disturbed days). They showed that all data favour the spectrum :

$$\frac{\delta D(E)}{D(E)} = \begin{cases} 0 , & E < E_1 \\ a(\Phi)E^{-1}, & E > E_1 \end{cases} \quad .... \quad (1.14)$$

where

$$E_1 = \begin{cases} 7.5 \pm 0.5 GV, & \text{if } E_1 > E^{min}_{\lambda}, \\ E^{min}_{\lambda} & , \text{if } E_1 < E^{min}_{\lambda} \end{cases} \quad .... \quad (1.15)$$

'$a(\Phi)$' is known as 'power' or 'intensity' of the source of diurnal variation. They have studied the angular distribution of the power of the source in a plane perpendicular to the plane of ecliptic i.e. as a function of Φ (defined on p. 4) and they have shown that power decreases as Φ increases. Some typical values are

$$a(\Phi = 0^{\circ}) \simeq 0.17$$

$$a(\Phi = 26^{\circ}) \simeq 0.14$$

$$a(\Phi = 75^{\circ}) \simeq 0.05$$

also $a(-\Phi) = a(\Phi)$, Φ being positive for northern hemisphere and negative for southern hemisphere. This indicates that the power of the source is symmetric with respect to the plane of the ecliptic.

Knowing $\int D(E)/D(E)$, they reconstructed the trajectories of particles in the field of earth's magnetic dipole using Brunberg and Dattner's (1953) analogue results and thereby (using eqs. 1.2 and 1.3) found the effective asymptotic angles $\bar{\Psi}^{i}_{\lambda}$, $\bar{\Phi}^{i}_{\lambda}$ of the source responsible for solar diurnal variation of various secondary components (i) recorded at various latitudes (λ). They found that the effective values of $\bar{\Phi}^{i}_{\lambda}$ calculated for different components of cosmic rays varied over a large range, showing that the source of diurnal variation has considerable angular dimensions in a plane perpendicular to the plane of ecliptic. Also using the calculated values of $\bar{\Psi}^{i}_{\lambda}$ and knowing $t^{i}_{max,\lambda}$ from experimental data for ten different components, they used eq.(1.3) to calculate the effective direction ($\bar{X}^{i}_{\lambda}$) of the source of the diurnal variation with respect to earth-sun line. They found that diurnal variation in all the ten cases is caused by a source which is situated to the left of earth-sun line and its effective position with respect to earth-sun line is given by

$$\bar{X} = 82^{\circ} \pm 8^{\circ} \qquad \ldots. \quad (1.16)$$

although, due to differences in energies of primaries which produce a given secondary component (i), their observed times of maxima t^i_{max} , are scattered within ~ 4 hours i.e. ~ 60^o.

It should, however, be pointed out that by using data averaged over ten years, Dorman has failed to take account of the important aspects of the form of solar daily variation and the significant changes that take place in the form particularly at equatorial stations (Sarabhai et al, 1955). Besides, as rightly pointed out by Sarabhai and Satyaprakash (1959), the broad classification of solar daily variation into two groups : quiet period and storm time daily variation, is not enough.

1.96 Solar daily variation during magnetic storms

Sekido and Yoshida (1950) observed that the amplitude of the diurnal component increases and its time of maximum shifts to earlier hours, whenever magnetic storm occurs. The amplitude increment (Δ a) and the phase advancement (Δt_{max}) of the diurnal variation during storms was termed 'anomalous diurnal variation' by them. They also reported an intimate connection between the world-wide decrease of cosmic ray intensity (Δ I) during magnetic storm and anomalous diurnal variation. The greater the cosmic ray decrease, the larger was the amplitude increment and the more was the phase displacement. Sekido et al (1952) also showed that amplitude (a) begins to increase at the very moment when intensity (I) begins to decrease and 'a' attains its maximum value just before 'I' reaches its minimum value; the phase (t_{max}) however starts shifting to early hours only after 'a' has attained its maximum value. The simultaneity of changes in the three parameters let tham to call this phenomenon as 'cosmic ray storm'-abbreviated CRS-and they showed that CRS begins almost simultaneously with the main phase of magnetic storm. However, no correlation exists between the parameters characterising CRS and the change in the earth's horizontal component ($\triangle$ H) during magnetic storm. Also CRS is of longer duration and exhibits stronger 27-day recurrence tendency than a magnetic storm. They thus concluded that CRS and magnetic storm though independent are 'brothers' to each other and may be due to a common cuase, which they think is the solar corpuscular stream which carries frozen magnetic field.

Considering that anomalous diurnal variation arises from an anisotropy which appears during storm time, Sekido et al (1952) made a quantitative estimate of this anisotropy by taking vectorial difference between average diurnal variation prevailing two days prior to the storm (termed quiet days) and that prevailing two days after the storm (called disturbed days). They pointed out that the anomaly vector so obtained on the average, points out in a radially outward direction from the sun and undergoes a long term change from year to year in step with the 11-year cycle of solar activity distinct from long term change exhibited by quiet day diurnal vector which undergoes 22-year cyclic change as pointed out by Thambyahpillai and Elliot (1953). Yoshida and Kondo (1954) showed that storm type anisotropy shows a strong 27-day recurrence tendency which persists long after the magnetic storms have ceased to recur.

Glokova et al (1955) analysed the ionisation chamber data of Huancayo from 1937 to 1944 and selected 10 magnetic storms which were accompanied by marked variation in cosmic ray intensity ($> 1\%$) at few widely separated stations of the world and for which the amplitude of solar daily variation was quite pronounced. They found that the amplitude of both diurnal and semidiurnal components enhances and their phases shifts to earlier hours. Earlier, however, Sekido et al (1951) had shown that amplitude of semidiurnal component of solar daily variation actually reduces during magnetic storms. The author has further examined this issue in this thesis.

1.10 The Sidereal daily variation.

If cosmic rays originate outside our galaxy and are isotropic in intergalactic space then (Compton and Getting, 1935; Vallarta et al, 1939) [redacted] because of the rotation of our galaxy relative to the distant galaxies, there should exist/sidereal daily variation of cosmic rays with an amplitude of the order of 0.17% and a time of maximum of 13 to 20 hours U.T. Elliot and Dolbear (1951) however, rule out any sidereal daily variation greater than 0.02% for hard component at sea level. MacAnuff (1951) could not detect any sidereal daily variation at 60 m.w.e. underground outside the limits of experimental error ($\sim \pm 0.02\%$). Similar results have been obtained (Sherman, 1954) for a depth of 846 mw.e. with accuracy of $\pm 0.5\%$ and at 1600 m.w.e. (Barrett et al, 1954) with an accuracy of $\pm 0.7\%$. Cranshaw and Galbraith (1954) could not find any sidereal daily variation for primaries having energies $\sim 1 - 5 \times 10^{16}$ eV outside the experimental error. Crawshaw and Elliot (1956) also could not find any sidereal daily variation for primaries of 10^{16} to 10^{17} eV. Clark et al (1957) too find that no sidereal daily variation exists for high energy showers outside experimental error. Greisen (1959) also does not find any sidereal daily variation for E.A.S. caused by primaries of energy 10^{14}-10^{18}eV.

However, Sekido et al (1956, 1959) who have been making measurements with narrow angle altiazimuth telescopes (mean energy of response = 240GV) inclined at 80^{o} to the zenith (since 1954) insist that a point source of cosmic rays (angular width $\sim 5^{o}$) exists in the region of declination 0^{o} and right ascension 0530 hours; and that it undergoes regular time variations. During 1954-1955 it (the point source) gave an intensity 20% above the background intensity of cosmic rays whereas in 1957 the effect had vanished and only background prevailed. Clark and Chitnis (1959) have studied the problem of sidereal anisotropy in a detailed manner by analysing over 100,000 showers with an average size of 10^{5} particles at 28,000 meters above sea level during 1956-1958. They too did not find any evidence for a point source or sources of cosmic ray primaries in the energy range 10^{14}-10^{15} eV. It is necessary to continue such observations and see whether the point source reappears. If it does, it may provide some interesting clue to the origin of cosmic rays.

1.11 Interpretation of various variations

Though sun is known to generate, sometines, cosmic ray protons having energy as high as 60-70 GV (Sarabhai et al, 1956), yet the solar origin of cosmic rays can be conveniently ruled out because of : (a) the existence of inverse relationship between solar activity and cosmic ray intensitty and (b) the presence of the elements lithium, beryllium and boron in primary cosmic rays far in excess of their relative abundances on the sun (Noon et al, 1957). This, nevertheless does not prevent the sun from exerting a strong influence on cosmic rays. That such an influence does exist is inferred from the close correspondence between the period of cosmic ray variations and that of various solar phenomena e.g.

(i) Solar activity has a period of 11 years which period is the same as that of the long term changes in cosmic ray intensity and that of the low energy cut off in the spectrum of primaries.

(ii) Corresponding to 22 year period of

- (a) the state of magnetic polarity of bipolar sunspot,
- (b) the frequency of prominences,
- (c) the probable variation of solar diameter,

(d) diverging motion of the forming spot groups and (e) the proper motion of spots in latitude, we have the cyclic change of the same period to be found in the form of the solar daily variation at low latitudes (Sarabhai et al, 1955), in the time of maximum of the diurnal component (Thambyahpillai and Elliot, 1953) and in the time of maximum of semidiurnal component (Sarabhai et al 1959) of average annual solar daily variation.

(iii) Corresponding to the solar synodic rotation period of 27 days we have 27-day recurrence tendency present in cosmic ray intensity as well as in the amplitude of solar daily variation. Moreover, this fluctuations in cosmic rays can be linked, in many cases, to the presence of certain regions on the sun.

Various workers have, therefore, veered round to the view that the fluctuations in cosmic rays, incident on the earth, are caused by modulation processes under over-all solar control of an otherwise isotropic flux of primaries which comes from beyond the solar system. Several models have been proposed.

In 1949, Alfven made a very important suggestion that the solar corpuscular streams which are responsible for magnetic storms and aurora (see Alfven, 1946) are also capable of causing cosmic ray intensity fluctuations. Due to their large conductivity the streams would carry magnetic field (H) frozen into them from their origin, regardless of the manner in which they are produced. When viewed from the earth, the stream would appear to be electrically polarised with an electric field perpendicular to the direction of the propagation of the stream and the direction of the frozen magnetic field. Before the earth enters such a stream it would receive cosmic rays which have been accelerated by this electric field and hence an increase in cosmic ray intensity should be registered on the earth. After the stream passes over, earth would receive decelerated cosmic rays and hence a decrease of intensity would be observed. Brunberg and Dattner (1954 a) who extended Alfven's model found that if only decreases are to be produced by the above model, then there must also exist a general although weak magnetic field (H_0) between the sun and the earth outside the stream which deflects cosmic rays sufficiently to prevent the acceleration of cosmic rays by the electric field*.

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* The authors have neglected the deflection of cosmic rays within the stream itself as well as refraction effects at the edge of the stream. Swann (1954) pointed out that low energy particles would not be able to cross the stream, however, Alfven (1954b) shows that they can do so if one allows for the gradient of H in the radial direction. Dorman (1957) has further pointed out that not all low energy particles, however, can cross the stream. For a particular energy (E) of a particle only those particles which are incident on the stream at an angle greater than certain minimum angle can seep through while others would be reflected. Further this seepage will take place only for those particles which are moving from right to left (in the direction of the drift). For particles impinging on the stream from the left, a total reflection will take place for all angles of incidence.

Considering that the particles of energy $E \backsimeq 30$ GV are involved they estimate the general field (H_o) to have a magnitude $H_o \backsim 10^{-5}$ gauss in the vicinity of the earth and its direction should be the same as that of the earth's field. They show that if solar magnetic field has a magnitude $\backsim 10$ gauss (Alfven 1950, 1952) and it varies with distance (r) as r^{-n}, with $n = 2.6$, then its value at earth's orbit would be $\backsim 10^{-5}$ gauss and solar magnetic field is assumed to have the same direction as that of the earth's field.

One of the consequences of Alfven's model is that the change of energy of a cosmic ray particle passing through the electric field is independent of initial particle energy i.e. the percentage change in energy is a decreasing function of energy. One expects therefore, to find a fairly marked latitude dependence of the intensity decrease.

To explain the origin of diurnal variation of cosmic rays Brunberg and Dattner (1954a) pointed out that seen from a fixed coordinate system, the rotating sun is strongly polarised so that there would be a voltage difference between the poles and the solar equator $\backsim 10^9$ V. The combined action of an electric field produced by polarisation and the solar magnetic field will make the cosmic rays reaching the ghbourhood of the sun from the galaxy to partake in the neral rotation with the sun so that the earth will receive cess of particles from 18-hour direction, giving a l anisotropy. They show that if cosmic rays were to partake in the solar rotation completely, the resultant diurnal variation observed by stations situated at geomagnetic equator would have an amplitude ~ 0.3 - 0.4 %. Alfven (1954a), on the other hand, has indicated the possibility of an outward radial flow of cosmic rays generated in the interplanetary space round the sun. The greater the number of cosmic rays thus generated the stronger is the radial flow. Further the mechanism of generation of cosmic rays is intensely sensitive to the solar activity, being lax when activity is high and vice versa. Thus the radial anisotropy (having 12-hour direction outside geomagnetic field) undergoes an 11-year cyclic change. According to Alfven solar daily variation thus comprises of contributions from tangential and radial anisotropy of which the tangential component gives steady contribution while the contribution from the radial component varies thus leading to long term changes of the amplitude and the phase of solar daily variation. However, as pointed out by Sandstrom (1956), such a simple picture cannot explain the 22-year cyclic change of the phase of diurnal variation observed by Thambyahpillai and Elliot (1953).

Nagashima (1955) extended Alfven's ideas to explain the anomalous diurnal variation at the time of magnetic storms as observed by Sekido and Yoshida (1950). For this purpose certain simplifying assumptions were made. They are :

(a) the stream is bounded by two infinite parallel planes perpendicular to solar equatorial plane,

(b) the magnetic field (H) frozen in the stream is parallel to the boundary of the plane and moves along the stream with a velocity v. Also H is assumed to be uniform over the width of the stream though strictly speaking it is not,

(c) the magnetic field outside the stream is zero. His finding that the maximum anisotropy would be produced in the direction pointing towards the sun agrees well with the experimental determination of the direction of the storm type anisotropy by Yoshida (1955). However, as he himself points out, his theory does not explain the fine structure of effects observed during the CRS. Further Nagashima's theory cannot explain the 'n' type variations that occur on groups of days as reported by Sarabhai et al (1955). Nerurkar (1957) extended the Nagashima's theory by considering the possibility of the frozen magnetic field in the beam being derived from intense local sunspot fields rather than the general magnetic field of the sun. Consequently, the field perpendicular to the plane of the ecliptic would have a component which is either in the direction of the general solar field* or in the direction of opposed to it. Nerurkar considered both these possibilities and showed that 'n' type variations correspond to the orientation of the frozen field in a direction opposite to the solar field whereas 'd' type variations arise when the

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* The general solar field is assumed to have the same direction as that of the earth's field.

frozen field points in the direction of the solar field. Also assuming different values for the frozen magnetic fields he has derived amplitudes of diurnal variation which are consistent with the values actually observed on individual disturbed days.

However, the most complete interpretation yet offered to explain the varied aspects of cosmic ray variations was given by Dorman in 1957. He makes use of Alfven's basic concepts but in contrast to Alfven's idea of solar generation of cosmic rays, his basic postulate is that all cosmic rays (down to the particles of lowest energy) arrive from galaxy where the flux of cosmic rays is isotropically distributed in space (barring a very small ≤ 0.02 % anisotropy) and constant in time. According to him, all cosmic ray variations (excepting solar flare type increases) observed on earth, result from the modulation of primaries by solar corpuscular streams carrying magnetic fields 'frozen' into them as envisaged originally by Alfven. However, Dorman (1957) realised that apart from the electric field (produced in the stationary system of coordinates because of the motion of the corpuscular streams - having magnetic fields frozen into them - with respect to this system), the primary cosmic rays are also subjected directly to a strong influence of the magnetic field frozen into the streams, leading to the scattering of low energy primaries; a fact, the adequate importance of which, had not been realised by earlier workers.

To explain various geomagnetic and cosmic ray variations he has postulated the existence of two kinds of streams called 'streams of the first kind' and 'streams of the second kind'. The characteristic features of these are summarised in Table A below.

Table A

	Streams of the first kind	Streams of the second kind
1. Place of origin	Faculae and other high latitude formations.	Solar eruptions confined largely to the sunspot zone.
2. Velocity	$\backsim 10^8$ cm.sec^{-1}	$\gtrsim 2 \times 10^8$ cm.sec^{-1}
3. Particle density	$\backsim$ 2 corpuscles cm^{-3} at earth's orbit and $\backsim 10^5$ corpuscles cm^{-3} at their origin.	$\backsim 2 \times 10^2$ corpuscles cm^{-3} at earth's orbit and $\backsim 10^7$ corpuscles cm^{-3} at their origin.
4. Duration & mode of engulfing the earth	Persist longer so that more often they engulf the earth with lateral front.	Persist for a short time and so the probability of their impinging on the earth with leading edge is rather high.
5. Nature of magnetic storms caused	Cause storms with gradual onset which (a) have indefinite start (lasting over hours), (b) have a rather indefinite end (lasting half a day or longer), (c) in general they last longer, (d) produce a slow and smooth variations of earth's field, and (e) exhibit a rather marked recurrence tendency particularly during the period of minimum solar activity.	Cause SC-type storms which (a) have a definite and sharp commencement, (b) generally a definite end but sometimes the recovery takes one to several hours, (c) mostly they last over a few hours, (d) produce rapid oscillations of geomagnetic field which are most pronounced in the horizontal component, (e) only weak recurrence tendency exhibited, especially so is the case for great and very great storms.

	Streams of the first kind	Streams of the second kind
6. Nature of the frozen magnetic field	Mostly the general field of the sun and its direction is perpendicular to the plane of the ecliptic. Its value at earth's orbit $\backsim 10^{-5}$ gauss.	Sunspot or other local fields, the main component of which lies in the plane parallel to the plane of ecliptic but is perpendicular to the direction of motion of the stream. Its value at earth's orbit $\backsim 10^{-4}$ gauss.
7. Region in which freezing of magnetic field takes place.	Outer layers of the sun.	Solar Corona.
8. Relationship with solar activity	A weak dependence exhibited; its frequency of occurrence does not vary by more than a factor of two from period of minimum to the period of maximum of solar activity.	Exhibits a strong 11-year cycle of variation. Its frequency of occurrence may vary by a factor of twenty in the intervening period between the minimum and the maximum in solar activity.

He has presented qualitative and quantitative evidence to demonstrate that*,

(i) to a first degree of approximation the curvature of the streams, arising out of solar rotation, can be neglected,

(ii) the angular width of the streams in a plane perpendicular to the plane of the ecliptic is about 10^{o}-30^{o} and that parallel to the plane of the ecliptic is of the order of 10^{o}-15^{o},

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* Some of these facts had, earlier, been established by Alfven.

(iii) the field (H) frozen into the streams decreases as the stream progresses outwards; the radial component diminishes with the distance (r) as r^{-2} and the transverse component as r^{-1},

(iv) unless the turbulence* sets in, the direction of the field frozen into the streams would not vary greatly as the stream progresses towards the earth since the time of decay of the field is unusually long (many thousand years; Pikel'ner, 1954) which by far exceeds the time of the passage of the stream from the sun to the earth's orbit (only about a day),

(v) only those particles can cross the stream** which have a certain minimum energy (E_1) given by :

$$E_1 = \frac{300\ H\ l}{2} \qquad ...(1.18)$$

where H is the magnetic field frozen into the stream and l is the width of the stream,

(vi) a positive particle crossing the stream in the direction of the electric field, which arises out of

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* Syrovatsky (1953) has shown that the time of rendering the stream turbulent is $\sim 10^5$ sec. which is of the order of the time of passage of the stream from the sun to the earth. Thus it is not impossible that some of the streams reach the earth without being turbulent but a short distance away, most of the streams would certainly become turbulent. Turbulent streams cannot have any appreciable influence on cosmic ray variations.

** As explained on p.66, H is actually not homogeneously distributed over the width of the stream so that there exists a component in the radial direction which enables a few lower energy particles (impinging on the stream from the right) also to seep through the stream.

polarisation, always gains an energy ($\triangle E$), (regardless of the form of the trajectory of the particle inside the stream) by

$$\triangle E = 300 \frac{u}{c} H.l \quad eV \qquad \ldots(1.19)$$

where u is the velocity of propagation of the stream. Particle crossing the stream in the opposite direction will lose energy by an equal amount.

Dorman and Feinberg (1958) have shown that :

(a) quiet day diurnal variations are caused by streams of the first kind which are situated to the left or to the right of the earth. If equal number of streams be situated to the left and to the right of the earth then the variation per n pairs of streams is given by

$$\frac{\delta D(E)}{D(E)} = \begin{cases} \pm \frac{(1+\gamma)\triangle E}{E} \cdot \frac{n\delta}{\pi^2} \left(1 + \ln\frac{\pi}{\delta}\right), & \text{if } E > \sigma E_1 \\ 0, & \text{if } E < \sigma E_1 \end{cases} \qquad \ldots(1.20)$$

where E_1 is defined by eq.(1.18), δ is the width (angular) of the stream in the meridian plain, γ is the exponent of the energy spectrum of the unmodulated primaries and $\sigma \approx 1$. Positive sign refers to the contribution from the stream situated to the left of the earth and negative sign to the one situated to the right of the earth. Eq.(1.20) is similar to eq.(1.14) obtained from observational data, if we have

$$a(\Phi) = \text{power of the source} = \frac{(1+\gamma)\Delta E}{} \cdot \frac{n\,\delta}{\pi^2}\left(1 + \ln\frac{\pi}{\delta}\right) \qquad ...(1.21)$$

and $E_1 \approx 7$ GV. ...(1.22)

They have further shown that for the relation, a $(\Phi=0)=0.17$, to hold we should have $n \approx 10$ i.e. there must exist ten streams to the right and to the left of the earth. Further eq.(1.21) clearly shows that the more the number of streams the higher the power of the source. Also these streams lead to an effective source to the left (if H is directed parallel to the geomagnetic field and we are situated in the northern hemisphere) situated at an angle $\approx 90^\circ$ with respect to the earth-sun line,

(b) decrease of intensity during storms arises from the deflection of low energy primaries by the streams of the second kind sweeping the earth, whereas the diurnal effect results from the acceleration or the deceleration of unreflected primaries i.e. high energy particles*, by the same streams. This also explains why an underground detector which may not record the decrease in intensity, will record the increase in diurnal effect as observed by MacAnuff (1951),

(c) no matter whether the frozen magnetic field in

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* However, because of the seepage of low energy particles from the right of the stream, a certain specific diurnal variation would be produced in low energy region with the source located to the right of the earth-sun line.

streams of the second kind is directed along the direction of revolution of the earth round the sun (that is from east to west) or opposed to it, the amplitude of diurnal variation will increase and its time of maximum will shift to earlier hours, when such streams sweep the earth. However, in the first case (when field is directed from east to west) particles coming from southern direction would be accelerated while those coming from the northern direction will be decelerated, creating a north-south anisotropy in diurnal effect. This would give a larger diurnal effect for stations in southern hemisphere than for those in northern hemisphere. For an opposite orientation (that is from west to east) of the field, a reverse effect would be observed,

(d) correlation with magnetic activity should exist. In particular, an increase of magnetic activity must be accompanied by an increase of amplitude of diurnal variation and the shift of its time of maximum to early hours and a decrease of mean intensity.

Not every magnetic storm or disturbance should, however, have its repurcussions in cosmic rays. The magnetic storm depend on the density of the stream and its velocity. The frozen magnetic field has probably no direct influence on the disturbances in geomagnetic field while for cosmic ray perturbations it plays the main role (together with the velocity of the stream). If for instance a dense stream has weak (or strong but turbulent) magnetic field it would cause a large or even very large magnetic disturbance but no appreciable cosmic ray perturbations would be produced,

(e) 27-day quasi-periodic variations of mean intensity and the diurnal effect are due to recurrence of streams sweeping the earth. These effects would be more pronounced during the period of maximum solar activity when the frequency of emission of the streams of the second kind is very large,

(f) semidiurnal variation is caused by the stream of the second kind and as such its amplitude should fluctuate strongly with solar and magnetic activity; its amplitude being more the higher the activity,

(g) tentatively, 22 year cyclic change of the time of maximum of the diurnal component is envisaged as arising out of the modulation of cosmic ray primaries by streams of the second kind which are emitted from opposite hemispheres and pass above and below the earth.

The importance of Dorman's hypothesis lies in its ability to connect the varied aspects of the changes of solar daily variation and mean daily intensity of cosmic rays with changes in the electromagnetic state of the interplanetary space. A unified and rather consistent picture thus emerges. Nevertheless, as admitted by Dorman (1957) himself, the hypothesis requires considerable elaboration before it can be transformed into a universally accepted theory. Further as pointed out by Sarabhai and Satya Prakash (1959), Dorman's method of comparison of experimental results with his theory is not adequate since he relies chiefly on data averaged over long periods of time and he considers only the diurnal component to describe the solar daily variation. Thus he neglects the important aspects of the form of solar daily variation and the significant changes that take place in the form. The inadequacy is worst at an equatorial station like Huancayo, during 1948 to 1953 (see Sarabhai et al, 1955) when the form of solar daily variation deviates significantly from a simple diurnal variation.

Besides the above theories, there are other theories which attempt to explain the various cosmic ray variations in terms of the diffusion of primaries through interplanetary magnetic gas clouds which are heliocentric or geocentric. The main contribution to this group of theories has come from Davis (1955), Beiser (1958), Morrison (1956), Parker (1956, 1958), Nagashima (1953) and Singer (1957).

Davis (1955) showed that the 11 year cyclic change of 4 % in cosmic ray intensity as observed by Forbush (1954), could be explained in terms of a 1 % change in the radius of a field-free cavity having a mean radius of about 200 A.U. which is brought into existence by sweeping away of solar and galactic magnetic fields by ionised matter emitted from the sun. Beiser (1958) improved upon Davis' model and was able to explain, in addition, the low energy cut off in the primary energy spectrum and its appearance and disappearance as observed by Neher (1953, 1957). However, as pointed out by Chandrasekhar, the cavity which plays so important a role in the above models is not stable enough.

Morrison's (1956) basic idea involves emission of large ionised gas clouds which carry tangled magnetic field embedded in them. He envisions such clouds engulfing the earth and thus shielding it from incident galactic cosmic rays. However, as pointed out by Parker (1956), the mechanism suggested by Morrison requires certain drastic assumptions to be made regarding the cloud velocities and the magnitude of tangled magnetic fields that they carry; even then it cannot explain cases of CRS where cosmic ray intensity drops abruptly in a few hours ($\sim$ 5 hours) and then levels off and requires days and weeks to recover to predecrease level or anywhere near it. Further the rate of loss of mass by the sun, in such a picture, is grossly inconsistent with the experimental determination of this quantity by van de Hulst (1953) and Beirmann (1951). Also it requires sun to eject clouds in all directions including the polar regions. But both visual as well as magnetic observations show that violent aspects of solar activity (flares, sunspots etc.) with which we associate the emission of the clouds, do not occur near the poles of the sun (Payne et al, 1952).

Parker (1956) has proposed a mechanism which is geocentric but operates well outside the confines of the terrestrial atmosphere and the regions of dense geomagnetic field. He envisages earth capturing material from interplanetary magnetic clouds to form a nebulous geocentric barrier of chaotic magnetic fields which scatters the galactic cosmic ray flux. Commenting on the merits of this model, Parker points out that the small scale of the model vastly reduces the amount of magnetic gas that is needed, eliminates the necessity of the sun to eject clouds in directions far from its equatorial plane, reduces the characteristic time to the observed value of a few hours for augumenting the barrier and producing a CRS and readily accounts for the steady low energy cut-off in face of only sporadic solar ejection of clouds. It is also shown that the geomagnetic field is sufficiently dense to support the weight of such barrier. Thus this model suggests that :

(i) Low energy cut-off is due to scattering of low energy primaries by the barrier and the duration of such an effect is determined by the decay time of captured magnetic fields which is of the order of a few months and this also explains why the cut-off does not vary violently with day to day solar activity but does vary over a period of years with mean level of solar activity*.

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* As suggested by Singer (1958) if this explanation is correct then there should not exist any low energy cut-off beyond the extent ($\simeq 3$ earth radii) of Parker's barrier. This can be tested by means of rocket experiments which are within our reach now.

(ii) CRS is caused by fresh capture of interplanetary matter; the fraction by which the cosmic ray intensity decreases will be approximately equal to the extent to which the barrier is strengthened and the rate of decrease of intensity can be made as steep as one wants to. Following the capture of magnetic gas the cosmic ray intensity should remain depressed till the newly captured fields decay*.

(iii) Firor's (1954) conclusion that there must exist some scattering mechanism responsible for deviating the flare time cosmic rays from straight line orbit receives a logical explanation, because a geocentric barrier $\sim 10^4$ km. thick will produce a random deflection of about a radian which is of the right order of magnitude.

(iv) The geomagnetic effects are caused by two mutually compensating processes.

(a) The weight of the barrier compresses the magnetic field leading to increased intensity of the horizontal component of geomagnetic field.

(b) A non-magnetic gas cloud i.e. a gas which does not carry an internal magnetic field, if captured, would result in inflating the geomagnetic field so that the intensity of horizontal component of geomagnetic field decreases.

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* Such a mechanism, however, can explain neither the pre-storm transient decreases (McCracken, 1958) nor pre-storm increases (Sarabhai and Palmeira, 1959) nor the increase superposed on a normal CRS (Yoshida and Wada, 1959; Sarabhai and Palmeira, 1959).

Thus an ideally suitable combination of these two effects while earth is capturing new interplanetary material, can produce both a cosmic ray decrease and a magnetic storm of SC-type. The proportions of magnetic and non-magnetic gas composing the captured material determines to what extent the cosmic ray decrease will be accompanied by a magnetic storm and vice versa.

No evidence exists at present, independent of cosmic ray inferences, which could establish the geocentric distribution of magnetic proton clouds. But as suggested by Parker himself, if such a barrier exists, rocket borne spectrographs should be able to reveal a narrow absorption line (half width as small as 0.04 Å) in the vicinity of solar L_{α} line. A direct test of this kind will, therefore, be very useful.

Nagashima (1953) has proposed that a varying geoelectric field, a geocentric mechanism, can cause observed modulations of the flux of primaries. Yoshida and Kamiya (1953) have shown that such a theory explains, fairly well, the latitude and altitude dependence of world wide intensity decreases observed by many workers. However, Simpson (1954) could not explain the energy dependence of 27-day variation of cosmic ray intensity on the basis of this model. Moreover, the very existence of geoelectric field is doubtful because of the high electrical conductivity of the ionosphere and the interplanetary space. Also as pointed out by Parker (1956), the effect on primary spectrum of such a field would be to shift the energy of each incoming particle by a fixed amount whereas Meyer and Simpson (1955) think that the fluctuations in cosmic rays represent a change in the total number of incoming particles. Parker's objection is applicable to all processes which utilise the idea of deceleration of primaries by electric fields to explain the intensity decrease. It is, therefore, imperative to measure the primary spectrum during a CRS to be able to verify whether a change in the total number of particles is involved or whether deceleration effects predominate. Such measurements should now be possible by making use of artificial earth satellites.

Singer (1957) thinks that CRS, the 27-day variation and the 11-year cyclic change of cosmic ray intensity are all caused by the deceleration of primary cosmic rays in interplanetary space due to expansion of turbulent magnetic clouds (of the type proposed by Morrison) emitted by the sun. The detailed mechanism depends upon a statistical decrease of initially high tangled magnetic field and can therefore be called an 'inverse-Fermi' effect. Here the random walk of cosmic rays in the region of decreasing tangled magnetic field causes the deceleration by induced electric field. However, Parker's objection to Nagashima's hypothesis holds for the above mechanism also.

Recently Parker (1958) has shown that the hydrodynamic outflow of gas from the sun, as inferred by Biermann in his observations of comet tails, can cause a reduction of cosmic ray intensity in the inner solar system, during years of high solar activity. The computed cosmic ray energy spectrum, based on this model, of the 11-year cyclic change of cosmic ray intensity resembles very closely that observed (experimentally) on the earth. However, as pointed out by Dorman (1959), Parker has apparently underestimated the free path length of scattering of low energy particles. Dorman asserts that the length cannot be less than the distance between the elements of turbulence, whereas in Parker's theory it tends to be zero at low energies. Dorman (1959) has presented a revised version of Parker's theory in which the velocity, with which the inhomogenieties are propagated in the interplanetary medium, falls off exponentially. He also takes account of the 'inverse-Fermi' mechanism of the deceleration of particles by induced electric fields in this new theory.

Any theory which stakes its claim for a general acceptance must be able to explain the following features of cosmic ray variation in addition to other well known features.

(a) The change of the form of solar daily variation with a period of 22 years, as observed by Sarabhai et al (1955).

(b) The origin of the semidiurnal component and its relation with the diurnal component of solar daily variation as also the 22 year cyclic change of the time of maximum of semidiurnal component as observed by Sarabhai et al (1959).

(c) The nature of 27 day quasi-periodic variations which apparently do involve increases besides decreases.

(d) The variability of the relationship of the diurnal component of the solar daily variation with geomagnetic activity as reported by Parsons (1958) and Sarabhai and Satya Prakash (1959).

(e) The implication of the directional studies of Elliot and Rothwell (1956) and Parsons (1957) during 1956-1957 and of Sarabhai et al (1959) during 1956-1958, which indicates the possible presence of a non-meteorological local geocentric source of solar daily variation at certain periods.

(f) Why is a CRS some times preceded by a transient decrease and sometimes by a short lived increase and on other occasion has an increase superposed on a normal decrease?

At present no single theory adequately describes the varied experimental facts and their solar terrestrial relationships. There are indications that a combination of some of the Alfven-Dorman ideas along with the heliocentric and geocentric processes, suggested by Parker, may provide an appropriate, but by no means simple, interpretation of the complex phenomena of various cosmic ray variations.

1.12 Scope of the study of time variations of cosmic rays and the purpose of the study presented in this thesis

In the preceding pages we have seen that both solar daily variation and daily mean intensity of cosmic rays exhibit large world wide changes on a day to day as well as on a year to year basis. It has also been shown that the study of these variations holds the key to the proper understanding of various processes involved in the modulation of primary cosmic rays. This fact, in turn, brings out the importance of using primary cosmic rays as a probe for studying the electromagnetic conditions in the interplanetary medium. Before such a step is taken, it is necessary to gain a comprehensive knowledge about the varied aspects of cosmic ray variations and then form a unified picture by establishing the inter-connection between these various aspects. This entails experimentation on a large scale with different components of cosmic rays which are representative of the different bands of the primary energy spectrum. Further such observations, of necessity, have to be spread out over a fairly wide range of latitudes and longitudes and such observations have to be conducted at different altitudes and at various depths underground.

Besides one has to refine the methods of analysis of the observational data. So far it has been customary to use experimental data averaged over long intervals of time to reduce the statistical errors in the results obtained. This procedure, at best, gives only a general picture but fails to bring out the finer details of the processes involved in producing cosmic ray variations and geomagnetic disturbances.

This limitation has become particularly obvious through recent studies which have established that there exists a, so called, 'meteorology' of interplanetary space, so that the electromagnetic state of matter in the interplanetary medium varies from place to place and from time to time. The solar corpuscular streams are, presumably, instrumental in bringing about these changes. Thus an interesting possibility exists of being able to classify the different electromagnetic states of matter populating the interplanetary space, if only one could find an index which could specify the electromagnetic characteristics of these streams unambiguously. Dorman (1957) has shown in a detailed manner how the velocity, the corpuscular density, the orientation of the magnetic fields frozen into the streams and heliolatitude of emission of these streams could be related, in a rather definite way, with observable changes in cosmic ray intensity and the perturbations in the geomagnetic field. Although a considerable refinement is still needed in Dorman's hypothesis, a preliminary beginning can be made towards verifying the salient features of this model. Sarabhai and Satya Prakash (1959) have suggested that this could be done by looking at significant changes in individual bihourly intensity of cosmic rays on each day, together with the perturbations in geomagnetic field during the corresponding interval of time. They further pointed out that it is advantageous to use the data of nucleonic component of cosmic rays for such analysis because such data can be corrected for meteorological effects in an accurate way. However, very often, the standard error of an experimental determination of individual bihourly intensity on any particular day is too large to permit any valid conclusions to be drawn. As such, they suggested that the next best alternative was to average the data over a number of days grouped together on the basis of parameters defining a particular state. The parameters used were (a) Cp which represents geomagnetic disturbance on a particular day, (b) the variance for the day, which parameter represents the degree of variability of cosmic ray intensity on that day and (c) the mean intensity for the day. From the results obtained by them they believe that the above type of approach towards phenomenological classification of the various electromagnetic states of the interplanetary medium, in the vicinity of the earth, holds promise. Their analysis was confined only to the data obtained at Kodaikanal (λ = +1°, f = 147°, and h = 2343 m) during 1957. With more data available from neutron monitor stations at Ahmedabad and from the network of other neutron monitor stations operated during the last I.G.Y., an attempt has been made (in this thesis) to elaborate on some aspects of their analysis and confirm whether the results obtained by them hold on a world wide basis. In addition several other distinctive features of day to day changes in solar daily variation and daily mean intensity of cosmic rays have been brought to light. Briefly speaking, an attempt has been made to answer the following specific questions :

(a) Do there exist world wide correlated changes of the solar daily variation and the daily mean intensity of cosmic rays as has been reported by Sarabhai and Bhavsar (1958) and Sarabhai and Satya Prakash (1959)?

(b) Are there only increases or are there only decreases or are there both increases and decreases in the day to day changes in the daily mean intensity of cosmic rays?

(c) Do only the decreases or only the increases or both increases and decreases recur?

Besides the author has utilised the data from Ahmedabad and Huancayo neutron monitors to study the general features of solar daily variation and of daily mean intensity of cosmic rays during 1957 and 1958. In this connection, the following are the questions to which the author has sought to find the answers :

(a) How does the form of the mean annual solar daily variation change from 1957 to 1958 and what relationship does such a change bear with corresponding changes in the level of (i) mean annual daily intensity of cosmic rays, (ii) the mean annual geomagnetic activity and (iii) the mean annual solar activity?

(b) Is enhanced solar daily variation a world wide effect? If it is, then does there exist an index which can enable one to separate days of enhanced solar daily variation on a world wide basis?

(c) What relationship does enhanced solar daily variation bear with geomagnetic activity as represented by Cp?

(d) What is the nature of the change that semidiurnal component of solar daily variation undergoes during period of high geomagnetic activity and during magnetic storms?

Further, in June 1955 the author was asked to establish a mountain level, cosmic ray recording, station at Gulmarg ($\lambda = +25^{o}$, f = $+ 147^{o}$, h = 2740 m) in the Himalayas, as a part of the development programme of the Physical Research Laboratory, Ahmedabad. It was proposed to set up a number of narrow angle telescopes to record hard component of cosmic rays. The whole electronic equipment required for this purpose was designed by the author himself as described, in detail, in chapter II. The unit was put into continuous operation in early 1956 and was maintained by the author till early 1958. Because of a large number of difficulties e.g. snow bound conditions for about six months in a year, absence of reliable A.C. mains supply, the availability of only meagre laboratory and workshop facilities, absence of satisfactory arrangement of transport etc., the experimental programme could not be carried out on a scale originally envisaged. Only a part of the full capacity of the experimental arrangement could thus be utilised, which resulted in the statistical error of the data being rather large. This being the case, no detailed analysis, on a day to day basis, of Gulmarg data collected over a period of two years could be undertaken. Nevertheless, the data have been used for the study of certain broad features of solar daily variation in conjunction with neutron monitor data from Mt.Norikura* and hard component data(obtained with meson telescopes)** from Ahmedabad. In particular, an attempt has been made to answer the following questions :

(a) How did the power and the position of the source of diurnal component of solar daily variation change during 1956 and 1957?

(b) Does there exist a periodic annual change, of non-meteorological origin, in solar daily variation of cosmic rays as reported by Sekido and Yoshida (1950) and by Sekido and Kodama (1952) ?

(c) At the time of onset of giant solar flare of Feb.23, 1956 Gulmarg (geographic longitude = 75°E) was just entering 0900 hours impact zone. Hence an attempt has been made to see what distinctive features did the flare type increase exhibit at Gulmarg ?

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II

EXPERIMENTAL TECHNIQUES

2.1 Recording of meson component

2.11 Introduction

In 1950 a comprehensive programme of cosmic ray variation was begun by cosmic ray research group of Physical Research Laboratory, Ahmedabad. One of the chief objectives, on development side of the programme, was the establishment of sea level and mountain level cosmic ray recording stations along the 75°E meridian section and spread out over a wide range of latitudes ranging from geomagnetic equator, in South India, to as high a latitude as could be reached in the North India. In pursuance of this objective cosmic ray recording stations were first set up at Ahmedabad ($\lambda = +14°$, $f = 144°$, h = sea level),* Kodaikanal ($\lambda = +1°$, $f = 147°$, h = 2343m) and Trivandrum ($\lambda = -1°$, $f = 146°$, h = sea level). In the middle of 1955 the author was entrusted with the task of setting up a high altitude cosmic ray recording station at Gulmarg ($\lambda = 25°$, $f = 147°$, h = 2740m) in the Himalayas. To start with, it was decided to concentrate only on devising satisfactory means of

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* λ, f, h are respectively the geomagnetic latitude, geomagnetic longitude and height above sea level of the station.

recording hard component of cosmic rays by counter telescopes. To decide the geometry of counter telescopes account was taken of the work of Sekido et al (1950) who showed that the amplitude of diurnal and semidiurnal components of solar daily variation increases as the angle in the E-W plane is narrowed and of Sarabhai et al (1955) who showed that it was enough to have a semiangle of 5° in the E-W plane because any further diminution of the angle of opening in E-W plane did not significantly increase the amplitude of solar daily variation but it did adversely effect the bihourly counting rate thereby associating an increased statistical error with bihourly intensities recorded. Thus it was decided to set up a number of telescopes having a semiangle of opening of 5° in E-W plane and an adequate counting rate*. This could be achieved within limitations by using single-counter telescopes having a length of 30 cm diameter of 4 cm with end-trays separated by 40 cm. A detailed description of the arrangement of the counter telescopes is given in section 2.111 below.

Having fixed the telescope configuration, the problem arose of designing electronic circuits which could be operated on batteries since A.C. mains at Gulmarg fluctuates over wide limits (90 volts to 230 volts) and there are frequent interruptions during the course of the

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* At that time the author was not aware of the influence of the angle of opening in N-S plane on the form of solar daily variation.

day. This, in turn, required that the power consumption by valves of the circuits be kept to a bare minimum. From the list of battery operated valves, it was found that DL 67 electronic tube (manufactured by Philips Limited) was just the valve which consumed the least power on both H.T. and L.T. side and at the same time could give a performance commensurate with the requirements of the electronic circuits used for continuous recording of cosmic rays. Hence all electronic circuits, the details regarding which find place in the ensuing pages, were designed using DL67 electronic tubes. The filament of this tube requires only 13 MA of current at 1.2 volts and an H.T. as low as 22.5 volts is enough. However, pulse height and stability considerations led the author to operate these circuits from an H.T. of 90 volts. But in case of recording stage, relatively high current was required because the 'telephone-call' type mechanical recorders which were used to register cosmic ray counts, require a minimum of 15 mA to actuate them. Nevertheless the author could still economise on power consumption by using cold cathode tube type OA4G which does not require any filament current.

After completing the construction of various circuits the equipment was given a trial run for two months during which time the author satisfied himself about the proper running and stability of operation of the various circuits. The unit started operating, on regular basis, from

31st December 1955. The author shouldered the responsibility of its maintenance upto 31st January 1958.

In the earlier stages of the work, the author received generous assistance and helpful advice from Dr. U.D. Desai, the Reader in Electronics.

2.111 The layout of the apparatus

The schematic diagram of the experimental set up of telescopes having an aperture of 10°x112°* is shown in Figure 5.

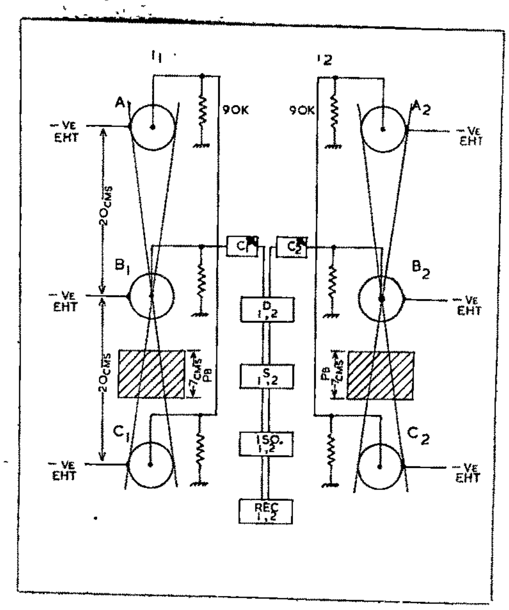

Fig. 5 - Illustrating the layout of the apparatus.

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* 10° = apex angle of the cone in E-W plane and 112° = apex angle of the cone in N-S plane.

Triple coincidence system of recording was used. Each telescope (T) consists of three one-counter trays A, B, C mounted vertically one above the other at a distance of 20 cm. from each other; the extreme trays being thus 40 cm apart. Self-quenched type counters were used. The length of each counter was 30 cm and its diameter 4 cm; the total sensitive area for each telescope being 120 cm^2. There were eight such telescopes T1, T2.....etc.). The alignment of the telescopes was such that the cross-section of the end-on position of the counters lay in the E-W plane whereas the cross-section of the broad side-on position of the counters lay in the N-S plane. The respective semiangles of the cones defined by the extreme trays in the two planes was 5° and 56°. To eliminate the soft component, 10 cm of lead absorber was interposed between middle and the bottom trays. Unscaled counting rate of each telescope was 1200 per bihour.

With a view to keeping the recording arrangement as simple as possible and to economise on power consumption the use of conventional quenching unit was dispensed with and resistance quenching system was used*. The quenching resistances also formed the grid leaks of the coincidence unit. The output pulses from the trays A_1, B_1, C_1; A_2, B_2, C_2; .... were fed to the coincidence units

* This type of arrangement was made possible by use of good quality GM counters which were prepared by the author himself. The method of preparation has been described in Sec. 2.121.

C_1^x, C_2^x, ... respectively. Output of the coincidence units were fed to level-discriminators in twos* e.g. the output of C_1^x and C_2^x was fed to $D_{1,2}$; wherefrom it passed on to the scalers $S_{1,2}$ etc. and thence, through an isolator $Iso_{1,2}$ etc. to the recorders $R_{1,2}$ etc. The dials of the mechanical recorders (the mechanical recorders were all mounted on a panel) were photographed at hourly intervals by an automatic, battery operated, photographic arrangement which makes use of a 16 mm aircraft camera. Details regarding various circuits is given in Sec. 2.3.

The inherent simplicity of the arrangement described above led to great amount of convenience in the maintenance of the unit.

2.113 Response characteristics of the telescopes

One of the principal characteristics of the counter telescope is its directional pattern, or more exactly, the function $I(\theta)$; showing the relation between the intensity of particles recorded by the given instrument and the angle (θ) between the direction of their motion and the zenith. The knowledge of $I(\theta)$, apart from aiding other calculations (e.g. the theoretical

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* The grouping of the output pulses from coincidence unit of the telescopes T_1, T_2, T_3.....etc. into pairs was undertaken to enable the author to use lesser number of recording stages with obvious economy in power consumption and electronic components. All this was achieved without imparing the efficiency of operation of the arrangement!

calculation of barometric coefficient etc.), enables one to locate the position of extraterrestrial source of various variations of cosmic rays with respect to a particular geometry of the counter telescope.

I(θ) may be calculated in many different ways as suggested by various authors e.g. Witmer and Pomerantz (1948), Newell and Pressly (1950), Blokh and Dorman (1957) and Brunberg (1958). Author has followed Newell and Pressly's method of calculation and the results for the telescope configuration used by him are indicated in Figures 6(a), 6(b) and 6(c).

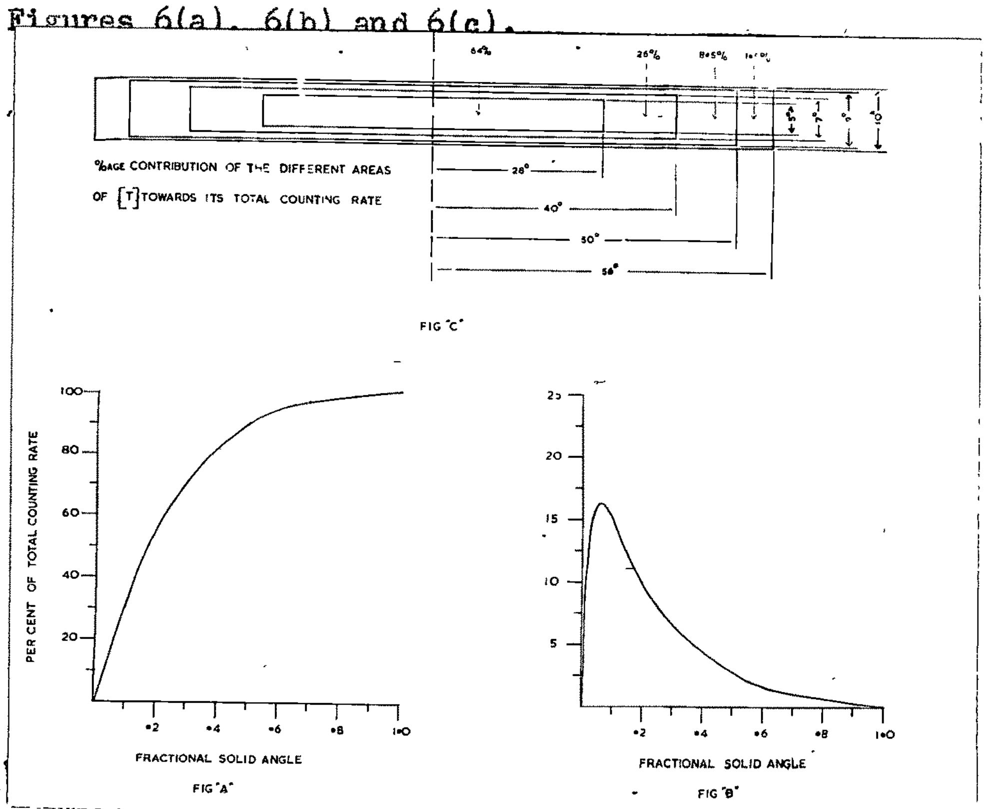

Fig. 6(a) & 6(b) give the response characteristics of the telescope.

Fig. 6(c) gives the contributions made by different arbitrary areas to the total counting rate of the telescope.

Figure 6(a) shows that 55% of particles are confined to 1/5 of the total solid angle subtended by the telescope. Figure 6(b) gives the percent of particles confined within various arbitrary fractions of the total solid angle. Figure 6(c) gives the contributions made by different arbitrary areas (defined by angles subtended by them in two mutually perpendicular planes) to the total counting rate of the telescope. Figure 6(b) would be, later, used for calculating the position of the source of diurnal component of solar daily variation from the data obtained from meson counter telescopes operated at Gulmarg during 1956 and 1957.

2.12 Self-Quenched Geiger-Muller Counter

The self-quenched type of Geiger counter is essentially a diode, filled with an inert gas like argon and a polyatomic vapour* like ethyl acetate, which operates in the region of the unstable corona discharge. The arrangement, in active state, being so sensitive that the formation of a single pair of ions anywhere within its confines is sufficient to trigger a discharge; the magnitude, duration, and general character of which are independent of the specific ionizing power of the

* For satisfactory performance the polyatomic vapour should have (i) low ionization potential compared to the monoatomic inert gas and (ii) a broad and intense ultraviolet absorption band which should enable it to dissociate rather than emit radiation when in an excited state.

ionizing particle. Montgomery (1940), Stever (1942), Wilkinson (1950) and Korff (1955) have discussed, in an exhaustive manner, the process of the development of the discharge and its quenching in a self-quenched Geiger counter.

When an ionizing particle passes through such a counter, in active state, it produces a few ion pairs in the sensitive volume of the counter. The electrons so freed trigger a discharge which spreads rapidly throughout the length of the counter. The discharge, however, lasts only a few microseconds. Soon the field conditions inside the counter are altered due to the formation of a sheath of positive space charge in the high field sensitivity region near the central wire and the discharge is extinguished. A small voltage pulse is developed, in this process, across the counter and this can be easily detected and recorded by electronic circuits.

The important requirements that such counter should meet are, that they have low operating potential, long operating range, high efficiency, stability with use and time, large pulse size and short recovery time. In practice, however, a workable compromise has to be made between these stringent requirements depending upon the purpose for which these counters are to be used. For time-variation studies the primary requirements are that the counter should have a long life and that their characteristics should not change significantly during the course of their useful life.

2.121 Preparation of self-quenched Geiger counters

A typical self-quenched Geiger counter used by the author consisted of a pyrex glass tube 30 cm long, 4 cm in diameter along the axis of which was stretched a fine tungsten wire 4 mils (1 mil = 2.5×10^{-3} cm) in diameter which serves as an anode. The cathode consisted of a cylindrical copper sheet. Thin glass sleeves were introduced at the ends to confine the sensitive area of the counter within well defined limits. The whole assembly was thoroughly baked in an oven to drive out the adsorbed gases.

The chief cause of the deterioration of the counter characteristics is often the multiple pulses which arise because of the photosensitivity of the cathode. Multiples also adversely effect the useful life of the counter. So the chief problem in producing good counters involves devising means of diminishing and if possible eliminating the photosensitivity of the cathode. If a quenching unit is used in conjunction with the counter, this problem is relegated to the background because in that case, after every discharge the voltage across the counter is automatically kept far below the threshold till the discharge is completely quenched and hence we get a single pulse in the output for every discharge. But if one decides to use resistance quenching system, as the author did, it becomes rather imperative to take special care in treating the cathode so as to reduce its photosensitivity. The author succeeded in doing this by subjecting the cathode to a chemical treatment suggested by Curran and Craggs (1949). It involved the use of three solutions. Complete details regarding the composition of these solutions together with the procedure followed is given in the appendix attached at the end of this chapter.

At the end of the desensitizing treatment the counter was washed properly and dried and then evacuated by a rotary oil pump and filled with a mixture of argon (90%) and ethyl acetate (10%) to a total pressure of 10 cm. of Hg. After allowing sufficient time for the gases to admix, the counter was tested for plateau and only those which showed a plateau of a minimum of 200 volts, were considered acceptable. They were next left for aging overnight and re-tested in the morning. Only those counters the characteristics of which remained unaltered after aging were finally accepted.

A typical counter prepared in this way had a threshold at about 1150 volts, a practically flat plateau of 200 volts, an useful life of six to eight months during which time few multiples appeared in the output. The efficiency of such counters was found to be ∽ 99.5%.

Old rejected counters need not be subjected to the desensitizing treatment again. It is enough to just refill them. At the time of refilling, the counter was merely rinsed with distilled water to rid the cathode and the walls of the counter, of decomposition products of polyatomic vapour. Also, following Shepard (1949), the central wire was heated to a dull red heat. This procedure restored most of the counters to their original characteristics.

2.13 Electronic circuits

2.131 Coincidence circuit

It is designed after the wellknown Rossi (1930) type circuit. An important property of such a circuit being that a large output pulse (positive) is obtained only when the input pulses (negative) from various (say n) channels arrive within a few microseconds of each other. Of necessity the difference in the output resulting from n-fold and (n-1)-fold coincidences has to be rather large so that it is easy to discriminate between them. The author used a triple coincidence i.e. $n = 3$, circuit shown in Figure 7. The circuit has a resolving time $\sim 7 \times 10^{-6}$ sec. and a ratio of three-fold to two-fold coincidences greater than 15.

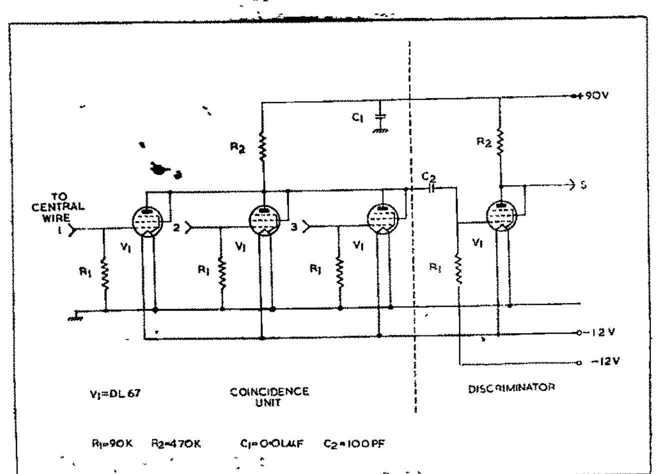

Fig. 7 - Coincidence unit.

Attached to the coincidence circuit was a 'level-discriminator' which also acted as phase inverter. The output from this stage had the same sign (negative) as that of the input pulses arriving at the grid leaks of the coincidence unit.

2.132 Scaling Circuit

It consisted of a suitable number of Eccles-Jordan type bistable multivibrators put in cascade. An ideal bistable circuit should, if possible, have a high triggering speed, a high trigger sensitivity, a low power consumption, a good stability, and a low sensitivity to extraneous interferences. All these demands, however, cannot be satisfied at the same time, as an improvement of one or more of the properties mentioned results in a deterioration of others (e.g. see the detailed analysis made by Neeteson 1956). Therefore, general rules for designing a bistable multivibrator are difficult to formulate. Many investigators e.g. Stevenson and Getting (1937), Lifschutz and Lawson (1938), Reich (1938), Higginbotham et al (1947), Fitch (1949) etc., have described varied methods of increasing the switching speed and improving the general reliability of such circuits. Ritche (1953), and Pressman (1953) have described an elegant design procedure.

Battery operated binary type scaler designed by the author is shown in Figure 8. The chief features of the circuit being very low power consumption both on H.T. and L.T. side and a tolerably good resolving time. Diode input feed to the plate circuit was used because such an arrangement improves the stability of the scaler and at the same time it also immunises the circuit to extraneous interferences.

Apart from providing a low output rate corresponding to a high input rate, the scaling circuit helps to change the random distribution of pulses into one where the different pulses are more regularly spaced; this facilitates the recording of the pulses on the output side by "telephone call" type recorders, which have a rather low resolving time (~ 0.2 sec.). As shown by Alaoglu and Smith (1938) the time interval between every r^{th} pulses will have standard deviation given by $(1-r)^{-\frac{1}{2}}$ so that as r increases the r^{th} pulse will be more regularly spaced.

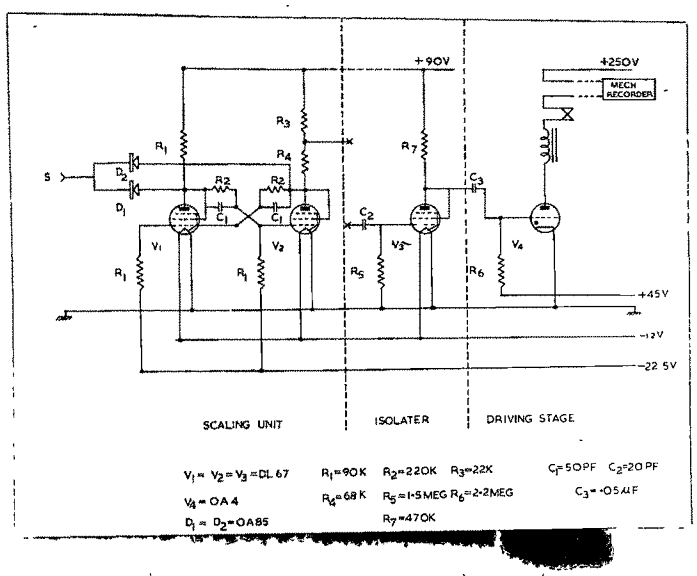

Fig. 8 - Scaling Unit.

2.133 Isolating Circuit

The output pulses of the scaler are fed to an 'Isolator' which consists of a grounded-grid triode. The necessity of using 'Isolator' arose because when the cold cathode tube of the recording stage is triggered, a continuous discharge occurs between the plate and the cathode of the tube. So that if output is fed to the recording stage straight from the last stage of the scaler, a feed back is likely to occur from the former to the latter. Isolating stage prevents this by acting as a buffer between the scaling stage and the recording stage. It presents an infinite impedance for any feed-back that might take place between the grid circuit of the cold cathode tube, and the scaling stage.

2.134 Recording Circuit

As shown in Figure 8, it consists of a cold cathode tube (type OA4-G) biased to a little below the 'break-down' point and in the plate circuit of it is put an electromechanical recorder in series with an energising relay (R). A mechanical switch (S) operated by the energising relay serves as triggering mechanism for the recorder.

The output pulses from the Isolater trigger the cold cathode tube and a current of the order of 15 m.A. flows through the plate circuit thereby energising the electromechanical recorder and the relay (R). The latter, in turn, operates the mechanical switch (S) which cuts off the H.T. connection leading to the extinction of discharge in cold cathode tube. In the meantime, the recorder has registered one count. The circuit is thus ready to receive another triggering signal. The mechanical recorders were mounted on a panel which was photographed by an automatic battery operated photographic device every hour.

2.14 Testing of the proper running of the apparatus

The routine checks for the satisfactory working of the apparatus consisted of the following tests.

(1) Tray rates of all the counter trays were taken daily to ensure that counters were working satisfactorily. Besides at the end of every month, even if the arrangement were working satisfactorily, plateau of all the counters was taken. In case of any counter failure, plateau was taken of all the counters comprising the particular telescope.

(2) Daily measurement of the following D.C. voltages:

(a) Filament voltages.

(b) Grid Bias voltages.

(c) Plate voltages.

(3) Periodic checks on the satisfactory working of mechanical recorders.

(4) Visual inspection on an oscilloscope of the shapes and the sizes of the input and output pulses from various electronic circuits.

These checks were found sufficient to obtain stream lined performance from the various constituent units of the apparatus.

2.2 Recording of Nucleonic Component

2.21 Introduction

After having come back from Gulmarg in 1958, the author undertook the responsibility of the maintonance of the Ahmedabad neutron monitor pile for the period May-December 1958, as a part of author's contribution towards the I.G.Y. effort of the Physical Research Laboratory at Ahmedabad.

The experimental arrangement of neutron monitor pile was essentially similar to that described by Chicago group and closely conformed to the specifications laid down by SCRIV for the recording of the nucleonic component during the last I.G.Y.

The entire neutron monitor pile along with associated electronic circuitary was assembled by the author's predecessor Mr. Satyaprakash Gupta. The proportional counters filled with borontriflouride (enriched with B^{10} isotope) were also prepared by Mr. Gupta according to a technique of filling developed by him in collaboration with Prof. H.V. Neher of California Institute of Technology (1957), which work was essentially an extension of Prof. Neher's earlier work (1954) in this direction.

2.22 The Neutron Detectors

The neutron component may be registered by means of proportional counters filled with boron triflouride the interaction of which with neutrons leads to the reaction:

$$B_5^{10} + {}_0n^1 \longrightarrow Li_3^7 + He_2^4 + Q_1$$

where Q_1 = the energy liberated in the reaction = 2.5MeV; about 1.6 MeV goes to α -particle and about 0.9 MeV to Li_3^7 nucleus (Veksler 1950). The two fragments travel in opposite directions and form about 80,000 ion pairs if mean-free-path is fully utilized. For a counter whose gas multiplication is unity and which has a capacity $\sim 10^{-5}$uF, the pulse developed will be approximately one microvolt. Hence a counter with gas multiplication $\sim 10^3$ (which is normally attained in practice) will develop a pulse large enough to be recorded.

Natural boron consists of a mixture of two isotopes, B_5^{10} (about 20%) and B_5^{11} (about 80%), but only B_5^{10} participates in the reaction; therefore, this mixture is normally enriched with B_5^{10} isotope (to the extent of 96%) to increase the effectiveness of the counters. The counting effectiveness is determined by the probability of neutron capture by the boron nuclei. The capture cross-section σ, over a wide range of neutron energies, is inversely proportional to their velocity and reaches its maximum value for thermal neutrons where $\sigma = 550 \times 10^{-24}$ cms^2.

The counting characteristic of a boron counter has a wide plateau (∽ 200 volts) since pulses from the α -particles are equal in value and considerably exceed the pulse size of the pulses from β -particles and other ionising particles of cosmic rays. It is important to note that, since only a single nucleus of isotope B_5^{10} is consumed for each instance of recording, the service life of the counter is practically unlimited for the recording of neutrons in cosmic rays.

The neutrons may be detected by boron-triflouride propotional counters with either the atmosphere acting as a moderator or by surrounding the counters with a moderating material like paraffin or carbon. In the first case slow neutrons (energy ∽ leV) are detected and the arrangement is called a 'slow detector', whereas in second case fast neutrons (energy ∽ 1 to 20 MeV) are recorded and the arrangement is termed a 'fast detector'.

To get a foolproof system of recording which is not affected by atmospheric or local conditions, a process called 'local generation' of neutrons is employed. In this case BF_3 counters are enveloped in a small thickness of moderator and are surrounded by 'condensing material', the whole of this assembly being shrouded by an increased thickness of moderator which serves as an outer cover. In such arrangement the detected neutrons are mainly those which are produced inside the 'condensing material' through local nuclear fission. It is found that the greater the atomic weight of the 'condensing material' the larger the number of secondary neutrons produced e.g. the ratio of neutron multiplication (mean number of neutrons emitted in low energy nuclear fission) in lead to the multiplication in graphite is about 8:1 (cf. Tongiorgi 1949, Montgomery et al 1949). So generally lead is used as condensing material with paraffin as moderator to decelerate the neutrons generated in lead. The assembly of local neutron producer (lead), a moderator (paraffin) and a neutron detector, is termed a 'neutron monitor pile'.

2.221 <u>The Neutron Monitor Pile</u>

The optimum thickness of condensing material and the moderator to be used to set up a neutron pile has been studied by several workers e.g. Tongiorgi et al (1949), Montgomery et al (1949), Cocconi et al (1950), Adams and Braddick (1951) and Simpson et al (1949, 1953).

Simpson et al have found that the optimum thickness, l_1, of moderator between lead and BF_3 counter (See Figure 9) is about 3.2 cms. the lead thickness, l_2, is taken arbitrarily as 5.1 cms. to take account of the fact that l_2 should be greater than the local transition maximum but at the same time the attenuation of 'star' producing radiation should not be large.

The paraffin surrounding the lead - paraffin - counter assembly is primarily meant for stopping extraneous disintegration neutrons produced outside the neutron pile from reaching the counters, but it also acts as a moderator and reflects back the neutrons produced in lead which tend to escape.

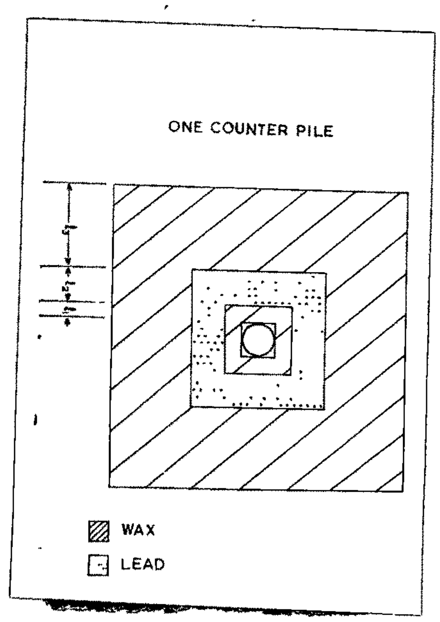

Fig. 9 - Neutron Monitor Pile.

The thickness, l_3, of this paraffin was determined empirically by the aid of a Ra-Be source placed outside the pile. The increase in l_3 for each 3.8 cms. resulted in a decrease in the count of neutrons arriving at the detector from outside by a factor of 2. The thickness $l_3 = 15.2$ cms. was selected and was entirely sufficient to assure effective slowing and scattering of the neutrons formed in lead.

2.222 Characteristic of the Neutron Monitor Pile

Though the disintegration neutrons are emitted isotropically from lead nuclei and scattered by the moderator in all directions, the high energy star producing radiation (Nucleonic Component of cosmic rays) is peaked in the vertical direction in the atmosphere (the angular distribution near sea level varying as $\cos^n\theta$, with $n \sim 4$ to 5). Thus neutron pile measurements correspond to the primary particles arriving vertically at the top of the atmosphere.

Studies (Simpson et al 1953) have shown that about 84% of recorded neutrons are formed in lead, 13% in paraffin, and only 3% make up the background of the counters and neutrons arriving at the detector from outside.

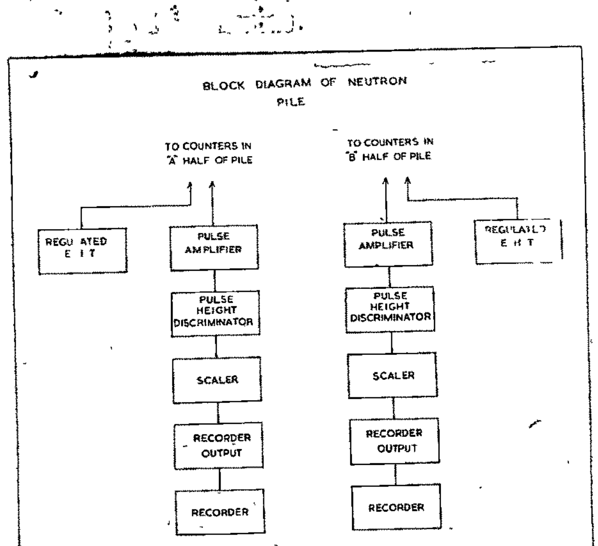

Fig. 10 - Block diagram of the pile and the recording system.

Neutron pile at Ahmedabad consists of two sections (A,B) each having three BF_3 counters and each section has an independent electric pulse recording system. The layout of the pile and the recording system is shown in Figure 10.

2.23 Electronic Circuits

All the circuitry at Ahmedabad, unlike that at Gulmarg, was operated by A.C. mains supplying 230 volts A.C. To reduce the voltage fluctuations in the mains to a bare minimum, the input to various circuits was derived from a constant voltage power transformer which was fed from the A.C. mains.

2.231 Pulse Amplifier

The function of an amplifier, used in conjunction with a boron triflouride counter is to accept and amplify the pulses produced in the counter by neutrons and by other ionizing radiations. The pulses may be of the order of a few hundred microvolts and have to be amplified to a level of a few volts so that discrimination can be made, to high degree of accuracy, between the pulses produced by the capture of neutrons by B^{10} and those produced by background radiation.

Elmore and Sands (1949) have given an exhaustive account of the theory of various types of amplifiers and the relative merits and limitations of each of them. The basic requirements of the amplifier, for our purpose, is that it be capable of handling randomly distributed pulses at a high mean rate of recurrence, it have a large signal to noise ratio and a fairly steady gain. These demands are reasonably satisfied by wideband Feedback type Amplifiers.

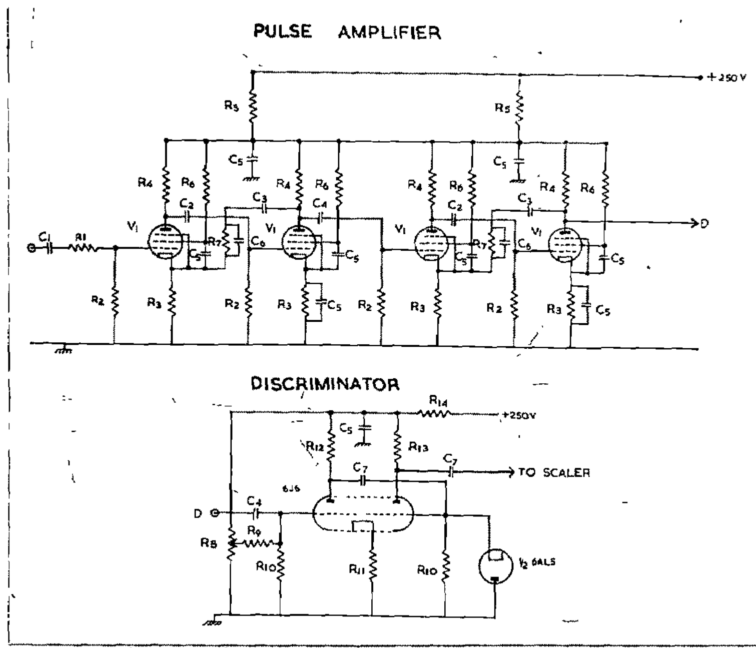

Fig. 11 - Pulse amplifier and discriminator.

The amplifier used by the author is shown in Figure 11(a). The circuit consists of two sets of two stage feedback loops, each having a gain of about 20, connected in cascade. Short time-constant RC network ($\sim 5.0 \times 10^{-6}$ sec.) was introduced between the two stages and another with about 50 microsecond for connecting the counter to the first loop of the amplifier. A small resistance of 470 ohm. was also introduced as a stopper between the grid of the first tube and the condenser feeding counter pulses to the first loop to supress parasitic oscillations. The upper and the lower half power frequency of the amplifier are 500 Kc/sec and 30 Kc/sec. respectively.

2.232 Pulse Height Discriminator

The chief requirements of such a unit are:

(i) It should be able to discriminate reliably between pulses that differ in amplitude by a small fraction of a volt and hence the amplitude at which discrimination occurs should be stable to a similar extent.

(ii) It should be capable of accepting narrow pulses, such as those produced by the pulse amplifier.

(iii) It should present a high impedence to the signal source and respond to each of the many pulses that follow each other in rapid succession.

(iv) It should not overload on a pulse of amplitude much greater than critical amplitude i.e. it should not distort large signals that it receives, nor should its operation depend upon the size of previous input pulses.

(v) It should have an easily adjustable discrimination level.

Various types of balanced pulse height discriminators which can handle pulses as large as 100 volts have been described in literature (e.g. see Elmore and Sands, 1949). These circuits have hysteresis of about 1 volt and the bias voltage is reliable to within 0.1 volt over a long interval of time. In our case, however, the requirements of the discriminator were not so stringent since it was required to handle pulses that were fairly uniform in size and hence the simple discriminator circuit as used by Simpson (1955) was found to be good enough for the purpose. An added advantage of such circuit was that whereas more refined circuits require pulses of about 20 volts, this circuit could be triggered reliably even with negative pulses of about 1 volt which, in turn, enabled the gain requirement demanded of the pulse amplifier to be reduced by a factor of 20.

The discriminator used is shown in Figure 11(b). It consists of a cathode coupled monostable multivibrator which, when triggerred remains in the unstable state for a few hundred microseconds and gives a pulse big enough to drive a scaling circuit.

2.233 <u>Scaling Circuit</u>

A high speed scaling circuit was used and is shown in Figure 12(a). Neon indicators were used for visual inspection of the proper functioning of the scaler.

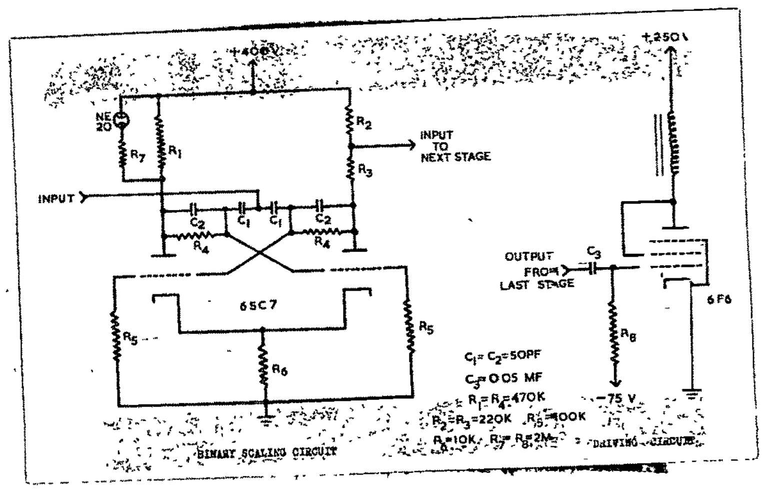

Fig. 12 - Scaling Unit.

2.234 Recording Circuit

The cascade of scaling units was followed by a recorder driving circuit as shown in Figure 12(b) alongside the scaling circuit. It consists of a power pentode biased below cut off. Pulses from one of the plates of the twin triode of the last stage of the scaling unit are fed to the grid of this tube. The tube actuates an electromechanical recorder whenever a positive pulse arrives at its grid.

2.235 Automatic Photographic Device

The raw cosmic ray data were obtained by photographing, every hour, the dials of the mechanical recorders mounted on a panel alongside which were fixed a clock and a calender. This panel formed one end of a light-proof box, blackened from inside, containing two bulbs (having proper wattage) to illuminate the panel when required. On the opposite side of the box a detachable camera was attached which took photographs of the panel, at hourly intervals, on 35 mm. film.

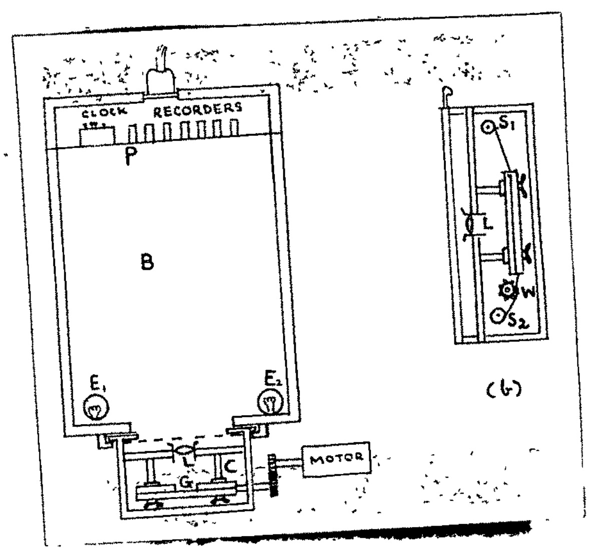

Fig. 13 - Camera Unit.

The film was moved by a sprocket attached to a shaft which protudes outside the camera and was coupled to a low speed motor which rolled the film through one frame after each exposure. This was done with the help of a relay arrangement triggerred by an electrical contact of a few seconds duration made hourly by a clock. The

Camera unit is shown in Figure 13.

Figure 14 shows the relay control circuit used for exposing and winding the film at hourly interval. It consisted of two triggerred thyratron switches working in succession.

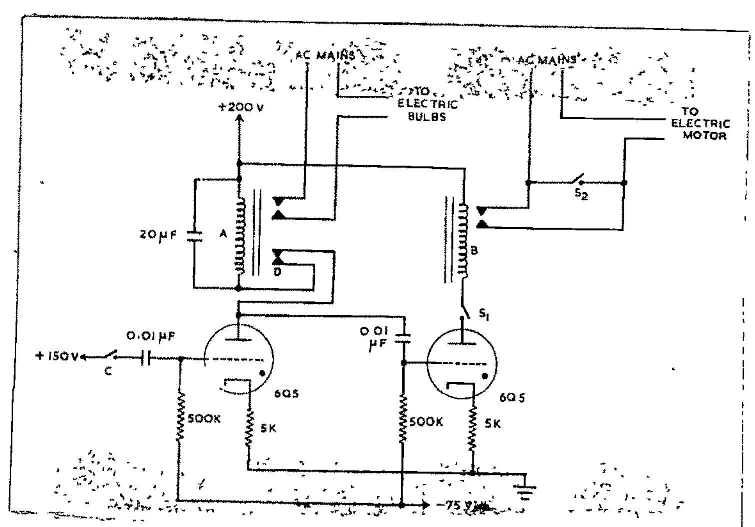

Fig. 14 - Automatic sequence control circuit.

Every hour the clock gave a positive pulse of 150 volts to the grid of the first thyratron (left) which is normally biased negative. The current passing through this thyratron energises the relay A, thereby making the bulb contact which flashes momentarily. At the same time plate circuit of this tube is made open and so its discharge is extinguished and this, in turn, 'opens' the relay(A) circuit thus switching off the lamps. The pulse from the plate of the first tube triggers the second thyratron (right) thus energising the relay B which, in turn, puts on the motor. An internal switch of the motor cuts off H.T. connection from the plate of the second tube; however, before this happens the film has moved by one frame. After these successive operations the circuit reverts to its original state.

At a time, the camera can hold 50 ft. of film. Everyday, at 9 a.m., the exposed film of the previous day is removed and developed. The readings of the dials of the mechanical recorders are then noted for odd bihours from the negative film.

2.236 Power Supplies

High Voltage Supplies. To achieve high stability in the working of electronic units and of BF_3 counters stabilisation of all D.C. voltages against line voltage fluctuations and load variations is very necessary. A complete analysis of stabilising circuits is given by Hunt and Hickman (1939) and Gilvary and Rutland (1951).

A degenrative type of regulating circuit is the most suitable for getting a close control over the output voltage, a high stabilising ratio and a low internal impedance. Figure 15 shows the high voltage supply used by the author. It consists of a half-wave rectifier, with a RC type filter, feeding about 3500 volts to the degenerative regulating network which gives a variable output in the range of 1800 to 3000 volts.

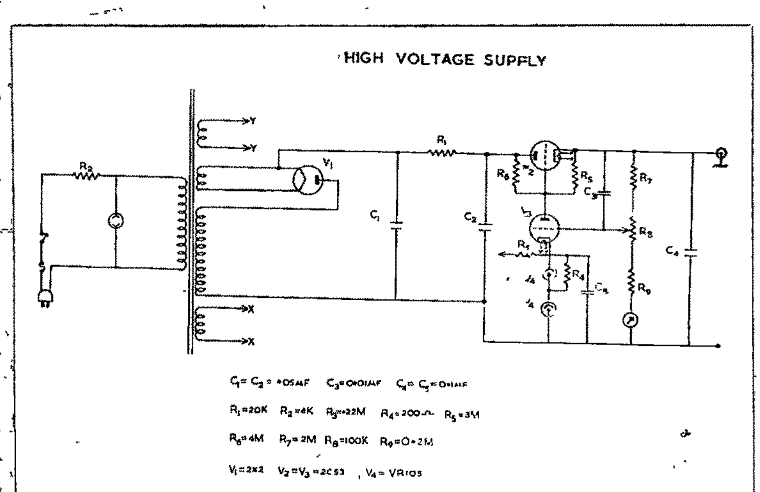

Fig. 15 - High voltage supply.

Low voltage supplies. Although the degenerative type of regulating circuit is generally used in low voltage supplies; in applications where the current load is relatively small and the variations in the load are limited, a VR tube stabilisation can be used. The maximum current which can be drawn from a VR tube regulator depends upon the maximum current which can be passed through the VR tube (which is of the order of 40 mA), the output impedance of the filter section and the variations in the load current.

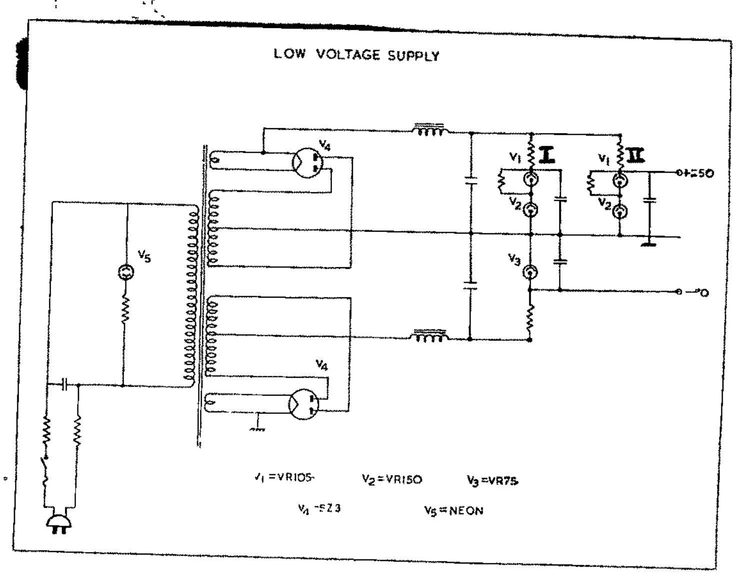

Fig. 16 - Low voltage supply.

Figure 16 shows the low voltage supply used by the author. There are two sections (I and II) of VR tube regulators, one for supplying current to the amplifier and the discriminator and the other to the scaler and the high voltage supply.

2.24 Maintenance of the neutron monitor pile

The maintenance of the neutron monitor pile involved the following routine checks:

(a) Calibration of the input pulse sensitivity of the amplifier using a special pulse generator which gave pulse ~ 1 millivolt, the shape of which was similar to the one given by BF_3 counters. Pulse repetition rates of 1 sec^{-1} to ~ 100 sec^{-1} were used for checking the performance of the scaling and the recording circuits.

(b) Every fortnight the 'plateau' was taken using a 2 mg. Ra-Be test source giving 2.7×10^4 neutrons sec^{-1}. For this purpose the test source was inserted in the two cavities specifically meant for it and the counting rate was taken. The operating voltage for the BF_3 counter was selected in the middle of the 'plateau'.

(c) During normal operation the ratio of the counting rate from A and B sections should be constant with time. Similarly, the ratio of the rates from the A and B sections for a neutron source must be constant.

From these checks and the parallel running tests (to be described in Sec. 3.1) it was possible to ascertain the proper operation of the neutron monitor pile.

2.3 APPENDIX

Chemical treatment for diminishing the photosensitivity of the cathode of GM counter

Prepare three solutions as follows:

Sol.A. 300 gm. ammonium chloride + 90 cc concentrated hydrochloric acid + 50 cc gelatin solution 0.2% by weight. These are made upto one litre in distilled water.

Sol. B. 250 gm. chromic acid + 75 cc concentrated sulphuric acid + 35 cc of Sol.A + 50 cc gelatin solution 0.2% by weight. These are made upto one litre in distilled water.

Sol. C. 250 gm. chromic acid + 75 cc concentrated sulphuric acid. These are made upto one litre in distilled water.

Procedure

1) Take 100 cc of Sol. A and heat upto 90°C. Introduce this hot solution into the counter tube and shake gently till all signs of oxidation disappear from the cathode surface. Remove the solution from the tube and rinse it thoroughly with distilled water.

2) Now introduce about 30 cc of Sol. B and shake thoroughly for about 2 minutes. Remove Sol. B and

rinse the counter thoroughly with distilled water.

3) Introduce 30 cc of Sol. C and shake the counter for one minute. Remove the solution and rinse the counter repeatedly with distilled water for ten minutes. Now put the counter for drying.

Precautions

Do not allow the Sol. A to remain in touch with the cathode for more than eight minutes, in any case.

The cathode surface gets a dull golden colour after treatment with Sol. B and a uniform matt pinkish hue after completing the treatment with Sol. C. It is probably covered with a very thin and uniform layer of oxide at this stage.

III

METHODS OF ANALYSIS

3.1 Processing the Raw Data

The raw data for any particular day is obtained by noting down the readings of the mechanical recorder, as registered on the photographic film, at odd hours : 2300 (previous day), 0100, 0300, ... 2300. Differences between these successive readings then provide the twelve bihourly observations for the day centred at the hours : 0000, 0200, ... 2200, and these may be termed :

$$C_0^i,\ C_2^i,\ \ldots\ldots\ldots,\ C_x^i,\ \ldots\ldots\ldots\ C_{22}^i \qquad \ldots(3.1)$$

where subscript 'x' refers to the hour of centering of the particular bihour and the superscript 'i' refers to the identity of the independent units of a detector e.g. two sections of the neutron pile, different meson telescopes having similar geometry, etc.

The independent units of the same detector are expected to show similar pattern of variation. This is tested by grouping the units into twos and taking the differences ΔC_x ($= C_x^1 - C_x^2$) between the bihourly counts recorded by the two units for every bihour for each pair. In ideal case no finite difference should exist between the correspondir bihours outside of the limits of statistical significance i.e.

$C_x = 0 \pm 2\sqrt{2}\,\sigma_x$ for 95.4 % of the cases; σ_x being the standard error for the bihourly counts. However, because of slight difference in geometry, the difference in the sensitivity of the recording arrangement etc. a finite difference will always exist. But then this difference must remain constant within the confidence limits i.e.

$$\Delta C_x = d \pm 2\sqrt{\sigma_1^2 + \sigma_2^2} \qquad \ldots(3.2)$$

where 'd' is the constant difference and σ_1, σ_2 are the standard errors for the bihourly counts recorded by the two units. The probability for any difference to be greater than $d \pm 2\sqrt{\sigma_1^2 + \sigma_2^2}$ is only 4.6 %.

Now if $d_1, d_2, \ldots\ldots\ldots, d_n$ be the observed differences between the two units for a continuous run of 'n' bihours, then the best estimated value ($\bar{d}$) of the constant difference 'd' in particular case would be given by :

$$\bar{d} = \frac{d_1 + d_2 + d_3 + \ldots\ldots\ldots + d_n}{n} = \frac{\sum^{n} d_n}{n} \qquad \ldots(3.3)$$

The deviations $\sum^{n} (d_n - \bar{d})$ are then found and plotted on a graph paper. Such deviations are expected to be confined within the boundary lines drawn at a distance of $+2\sqrt{\sigma_1^2 + \sigma_2^2}$ and $-2\sqrt{\sigma_1^2 + \sigma_2^2}$ about the mean $\bar{d}$; the probability for any deviations to exceed the boundary on either positive or negative side being only 2.3 %. So if the plot crosses the boundary lines on either side for a set of consecutive points for more than 2.3 % cases then one of the units is suspected of faulty operation. To locate the faulty unit the variance of the same number of bihourly values preceeding and following these bihours (36 in all, including these bihours) is calculated. The unit exhibiting the larger varianc is the faulty unit. The faulty bihourly observations for this unit are then replaced by values manipulated from the corresponding bihourly observations of the normally working unit by multiplying these values by the averaged ratio of the means obtained on 5 days of the day in question when the two units were showing normal behaviour. The data from the two units is then combined.

The various groups of twos of similar units are then intercompared by the same method and then the data, at corresponding bihours, of all the similar units are added together to give the bihourly counts for the day. This procedure finally gives us raw data in a standard form for the various detectors e.g. neutron monitor, meson telescopes of various geometries etc. The combined bihourly values are then normalised to a mean of one thousand for the whole period by multiplying each bihourly value by thousand and then dividing it by the mean of the entire period.

3.11 Corrections for meteorological effects

3.111 Correction for barometric fluctuations : The values of atmospheric pressure are read out for 0000, 0200, 0400, ..., 2200 hours from daily precision micro-barograph charts and these are expressed as deviations from the standard pressure level for the particular station. The standard pressure level for any station was determined from the average pressure over the course of a few years. The standard pressure levels for Gulmarg (λ = + 25°, f =+147°, alt. = 2740 m), Ahmedabad (λ = +14°, f = +143°, sea level) and Kodaikanal (λ = +1°, f = +147°, alt. = 2343 m) are respectively, 525 mm., 750 mm., and 570 mm.

Using the pressure deviations calculated as above, the bihourly counts were corrected for pressure fluctuations using a pressure coefficient of -0.94 % mm^{-1} in case of nucleonic component and -0.30 % mm^{-1} in case of hard component recorded at Gulmarg*.

3.112 Temperature Correction : As shown by Barkow (1917), Dines (1919), Bemmelan (1916), and Venkateswaran & Desai (1953), the amplitude of daily variation of temperature 2 km above ground, hardly amounts to a fraction of 1°C,

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* The pressure coefficient for Gulmarg was calculated from the intensity (of hard component) versus altitude curves, given by Neher (1952).

which determination itself is not outside of instrumental error. So view is taken here, following Sarabhai et al (1953), that it is meaningful to correct the daily variation of hard component* only for temperature changes upto 2 km. above ground. Beers (1944) has shown that the temperature variations at 1 km. and at 2 km. above ground have amplitudes 0.22 and 0.11 times the amplitude of variation on ground level respectively.

Dorman and Feinberg (1956) have calculated the global temperature coefficient K_i which should be used in conjunction with temperature variations at specific isobaric levels. These are summarised in the following table.

Table of Coefficients K_i

No.	1	2	3	4	5	6	7	8	9	10	11
Pressure h(mb)	1000	900	800	700	600	500	400	300	200	100	50
K_i $\%\,{}^{\circ}C^{-1} \times 10^{-3}$	20	21	22	24	25	26	28	33	38	31	23

Thus if 'a_T' °C be the amplitude of daily variation of temperature at ground level then combining the result of Beers' and of Dorman's, the temperature correction (dT) for the daily variation of temperature at Gulmarg between

* As shown in sec.1.52 the temperature correction for nucleonic component is negligible.

ground level (pressure $\backsim$ 700 mb.) and 2 km. above it (pressure $\backsim$ 500 mb.) amounts to

$$dT \approx (a_T \times 0.024 + 0.22\ a_T \times 0.025 + 0.11\ a_T \times 0.026)\ \%$$

$$\approx a_T \times 1.33 \times 0.025\ \%\ \text{(taking a mean value for } K_i = 0.025)$$

$$= a_T \times 0.033\ \% \qquad \ldots(3.4)$$

The temperature coefficient is thus - 0.03 % $^{\circ}C^{-1}$ for hard component recorded at Gulmarg.

The ground temperature values for even bihours on different days are read from the daily thermograph charts and these are expressed as deviations from the daily mean temperature. Using the temperature coefficient derived above, the data for the daily variation of hard component were corrected for the daily variation of temperature. No attempt was made to correct the daily mean intensity of the hard component for temperature effect because this requires data of temperature variations in higher isobaric levels which data were not available for Gulmarg. As such no analysis, whatsoever, has been done for the daily mean intensity of the hard component. Only daily variation of hard component, which can be corrected for temperature effect (as shown above), is studied. It must, however, be noted that the above described method of applying temperature correction to the data of solar daily variation of hard component is subject to certain uncertainties which become particularly important when the amplitude of solar daily variation is of the same order as the correction ($\sim$ 0.05-0.10 %, as shown by Maeda, 1953 and Kuzmin, 1955) arising out of the daily variation of temperature. Hence due caution has to be exercised in interpreting the results in such cases.

3.2 Determination of solar daily variation

When bihourly data, normalised as described in Sec.3.1, are corrected for pressure changes in the case of the nucleonic component and for pressure and temperature changes in the case of the hard component, as described above, they are referred to as normalised bihourly intensities corrected for meteorological effects and may be designated as : I_0, I_2, ..., I_x, ..., I_{22}. The % standard error due to statistical fluctuations in each bihourly intensity I_x is :

$$\sigma I_x = \frac{(I_x.k)^{\frac{1}{2}}}{I_x.k} . 100 = \frac{100}{(I_x.k)^{\frac{1}{2}}} \qquad ...(3.5)$$

where k is the scaling factor. The mean intensity ($\bar{I}$) for the day is then,

$$\bar{I} = \frac{I_0 + I_2 + I_4, ... + I_x + ... + I_{22}}{12} \qquad (3.6)$$

The % standard error in $\bar{I}$ is given by

$$\sigma_{\bar{I}} = \frac{\sigma_{I_x}}{(12)^{\frac{1}{2}}} \qquad \ldots(3.7)$$

The solar daily variation for any particular day is then represented by the 12 bihourly deviations :

$$(I_0 - \bar{I}),\ (I_2 - \bar{I}),\ \ldots\ldots\ (I_x - \bar{I}),\ \ldots\ldots\ (I_{22} - \bar{I}) \qquad \ldots(3.8)$$

However, in case of nucleonic component large day to day changes of intensity take place and hence the deviations representing the daily variation curve, in case of nucleonic component, should be further corrected for changes of intensity with period longer than one day. So nucleonic bihourly intensities were, in addition, subjected to the following treatment.

From each normalised and pressure corrected bihourly values the mean of 13 bihours*, comprising the particular bihour and 6 bihours on either side of it, is subtracted and this is repeated for each bihour. Let the residual bihourly

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* The method of taking moving averages over 13 bihours, to correct the solar daily variation data for day to day changes, was adopted because of convenience in calculating and as can be shown from elementary calculations it is not subject to any appreciable error.

intensities be i_0, i_2, i_4, ... i_x, ... i_{22}. Then

$$(i_0 - \bar{I}),\ (i_2 - \bar{I}),\ .....,\ (i_x - \bar{I}),\ .....\ (i_{22} - \bar{I})$$

$$= U_1 \qquad = U_2 \qquad\qquad = U_k \qquad\qquad = U_{12} \qquad ...(3.9)$$

where

$$\bar{I} = \frac{i_0 + i_2 + i_4 + ... + i_x + ... i_{22}}{12} \qquad ...(3.10)$$

with

$$\sum^{12} U_k = 0 \qquad ...(3.11)$$

U_k thus determine the solar daily variation for the day with day to day changes, largely, eliminated.

In general, because of large statistical uncertainties it is difficult to get any information about the genuine variations from the data of a single day. Hence it is customary to derive the average daily variation over a large number of days, selected and grouped according to suitable criteria. The average daily variation for a group of days, selected in this manner, is found by combining the deviations corresponding to the same bihourly interval of all the days in the group and then dividing each bihourly total by the number of days in the group.

3.3 Harmonic analysis

3.31 Expansion into Fourier series

To represent the aggregate of experimental data U_k ($k = 1, 2, \ldots\ldots 2p$) in a definite interval of time T, in the form of a Fourier's series

$$U(t) = \frac{a_o}{2} + \sum_{n=1}^{n=\infty} \left(a_n \operatorname{Cos} \frac{2\pi nt}{T} + b_n \operatorname{Sin} \frac{2\pi nt}{T}\right) \qquad \ldots(3.12)$$

we must find the Fourier coefficients a_o, a_1, b_1, ... These coefficients are expressed in terms of the integrals (where $\tau = \frac{2\pi t}{T}$)

$$a_o = \frac{1}{\pi} \int_0^{2\pi} U(\tau)\, d\tau ; \quad a_n = \frac{1}{\pi} \int_0^{2\pi} U(\tau) \operatorname{Cos} n\tau\, d\tau ;$$

$$b_n = \frac{1}{\pi} \int_0^{2\pi} U(\tau) \operatorname{Sin} n\tau\, d\tau \qquad \ldots(3.13)$$

If the U_k are given at equal intervals of time, then the Fourier's coefficients for $n < p$ are calculated from the following expressions (Bessel, 1815, formulas)

$$a_o = \frac{1}{p} \sum^{2p} U_k ; \quad a_n = \frac{1}{p} \sum^{2p} U_k \operatorname{Cos} \frac{nk\pi}{p} ;$$

$$b_n = \frac{1}{p} \sum^{2p} U_k \operatorname{Sin} \frac{nk\pi}{p} \qquad \ldots(3.14)$$

If eqs.(3.14) be substituted in eqs.(3.12), then the resultant series at $t = \frac{kT}{2p}$ takes exactly the values of the U_k, thereby satisfying the principle of least squares. Further if p = 6 i.e. U_k represent the twelve bihourly deviations characterising the solar daily variation on any particular day, then

$$a_o = 0 \qquad (\because \sum^{12} U_k = 0 \text{ from eq.3.11}) \quad .(3.15)$$

Many authors e.g. Thompson (1911), Whittaker and Robinson (1937), Henny (1941), Serebrennikov (1948), and Kane (1954), have suggested diverse methods for evaluating the Fourier's coefficients. Author has followed Kane's 12-ordinate calculation scheme, which is illustrated in the appended chart.

Eq.(3.12) can also be written in the form of the sum of individual harmonics (combining the terms of the same periods) :

$$U(t) = \sum_{n=1}^{n=\infty} r_n \operatorname{Sin}\left(\frac{2\pi nt}{T} + \Upsilon_n\right), \quad (\because a_o = 0, \text{ from eq.3.15}) \quad ...(3.16)$$

It follows from eq.(3.16) that the amplitude of the nth harmonic is

$$r_n = (a_n^2 + b_n^2)^{\frac{1}{2}} \qquad ...(3.17)$$

while the phase Ψ_n is determined from

$$\mathrm{tg}\ \Psi_n = \frac{a_n}{b_n} \quad \text{or} \quad \Psi_n = \mathrm{arctg}\left(\frac{a_n}{b_n}\right) \qquad \ldots(3.18)$$

If we denote

$$|\Psi_n| = \mathrm{arctg}\left|\frac{a_n}{b_n}\right| \qquad \ldots(3.19)$$

then the phase Ψ_n is defined in terms of $|\Psi_n|$, depending upon the sign of a_n and b_n by means of the following Table :

a_n	b_n	Ψ_n
+	+	$\|\Psi_n\|$
+	-	$\pi - \|\Psi_n\|$
-	-	$\pi + \|\Psi_n\|$
-	+	$2\pi - \|\Psi_n\|$

Again the nth harmonic given by r_n Sin $\left(\frac{2\pi t}{T} \cdot n + \Psi_n\right)$ will have the maximum amplitude r_n, when

$$\frac{2\pi t}{T} \cdot n = n \cdot \phi_n \qquad \ldots(3.20)$$

where ϕ_n is the time of maximum of nth harmonic in degrees. Thus we have

$$n \cdot \phi_n + \Upsilon_n = 90^\circ \quad \text{or} \quad n \cdot \phi_n = 90^\circ - \Upsilon_n \qquad \ldots(3.21)$$

The above table can therefore be modified to give $n.\phi_n$ directly in terms of $|\Upsilon_n|$ by subtracting Υ_n values from 90°. Modified table is given below :

a_n	b_n	$n \cdot \phi_n$
+	+	$(90^\circ - \Upsilon_n)$
+	-	$-(90^\circ - \Upsilon_n)$
-	-	$\pi + (90^\circ - \Upsilon_n)$
-	+	$(90^\circ + \Upsilon_n)$

To get the time of maximum of nth harmonic in hours one has to divide the value of ϕ_n (in degrees) by 15.

3.32 Harmonic diagram

For a clear representation and convenient study of the results obtained by harmonic analysis, wide use is made of their representation by the aid of vectors on a harmonic diagram. Such diagrams may be constructed both for the first harmonic and higher harmonics; for nth harmonic, the period of diagram would be $\frac{T}{n}$ as shown in Fig.18.

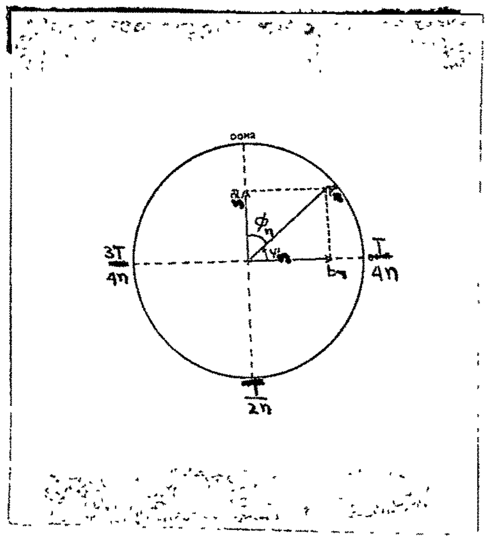

Fig.18 - The harmonic dial.

The radius vector of the points (a_n, b_n) on such a dial will be $r_n = (a_n^2 + b_n^2)^{\frac{1}{2}}$ while the angle between the b-axis and radius vector, measured counter clock-wise will be the phase, γ_n of the nth harmonic (eq.3.18). The angle between a-axis and the radius vector, measured clockwise, gives the time of maximum, ϕ_n, of the nth harmonic.

Thus if this representation be used to denote the harmonic components of the solar daily variations, then T = 24 hrs. For first harmonic or diurnal component of solar daily variation n = 1; for second harmonic or semidiurnal component of solar daily variation n = 2 and so on.

3.33 Errors in the Fourier coefficients

The standard error 'σ' of a function F (m_1, m_2, m_3, ... m_n) of m_1, m_2, m_3, ... m_n corresponding errors of which are σ_1, σ_2, σ_3, ... σ_n is given by (e.g. see Topping, 1955) :

$$\sigma^2 = \left(\frac{dF}{dm_1}\right)^2 \sigma_1^2 + \left(\frac{dF}{dm_2}\right)^2 \sigma_2^2 + \ldots\ldots + \left(\frac{dF}{dm_n}\right)^2 \sigma_n^2$$

$$\text{or } \sigma = \left\{ \sum^{n} \left(\frac{dF}{dm_n}\right)^2 \sigma_n^2 \right\}^{\frac{1}{2}} \qquad \ldots(3.22)$$

where $\frac{dF}{dm_1}$, $\frac{dF}{dm_2}$, ..., $\frac{dF}{dm_n}$, are the partial differential coefficients of F with respect to m_1, m_2, ... m_n.

Since the Fourier's coefficients are expressed by certain linear functions of U_k of the form $\Sigma \lambda_k U_k$, where λ_k are the corresponding factors of the grouping (for instance, refer to the chart showing analysis scheme), the errors of the coefficients will be determined by the quantity (using eq.3.22) :

$$\left(\sum^{k} \lambda_k^2 \cdot \sigma_k^2 \right)^{\frac{1}{2}} = \left(\sum^{k} \lambda_k^2 \right)^{\frac{1}{2}} . \qquad \ldots(3.23)$$

taking

$$\sigma_1 = \sigma_2 = \ldots\ldots\ldots = \sigma_k = \sigma \qquad \ldots(3.24)$$

where σ_k is the standard error in U_k. An elementary calculation shows that, in the scheme for 12 ordinates, we have

$$\sigma_{a_n} = \sigma_{b_n} = \frac{\sigma}{(6)^{\frac{1}{2}}} = 0.41\,\sigma \qquad \ldots(3.25)$$

Hence taking account of eqs.(3.17) and (3.18) in conjunction with eq.(3.22) we have

$$\sigma r_n = \left(\frac{a_n^2}{a_n^2 + b_n^2} \cdot \sigma_{a_n}^2 + \frac{b_n^2}{a_n^2 + b_n^2} \cdot \sigma_{b_n}^2\right)^{\frac{1}{2}}$$

$$= 0.41\,\sigma \qquad \ldots(3.26)$$

and

$$\sigma\psi_n = \frac{1}{1 + \frac{(a_n)^2}{(b_n)^2}} \left(\frac{a_n^2}{b_n^2} + \frac{a_n^2 \cdot \sigma_{b_n}^2}{b_n^4}\right)^{\frac{1}{2}}$$

$$= \frac{0.41\,\sigma}{r_n} = \frac{\sigma r_n}{r_n} \qquad \ldots(3.27)$$

σr_n, $\sigma\psi_n$, being the errors in the amplitude and phase of the nth harmonic, respectively. Thus, on the harmonic dial, when plotting the results of the harmonic analysis of the data U_k each having error σ, a circle of radius $\sigma r_n = 0.41\sigma$ (for 12-ordinate Scheme) characterising the accuracy of the given harmonic must be drawn about the point (a_n, b_n).

3.4 Method of separation of quasi-periodic variation

Small quasi-periodic variations in cosmic rays which are masked by the statistical fluctuations of individual measurements can be detected by the aid of a special averaging method, first used in the studies of geomagnetic variations by Chree (1913) and known after him as Chree's method of superposed epochs.

Suppose we single out 'n' epochs on a certain criterion and we wish to study the association of such epochs with the intensity changes in cosmic rays. To do this the values of cosmic ray intensity corresponding to the times of onset of these epochs are entered in a vertical column numbered 0. The values of the intensity for the times following the times so chosen are then entered in a sequence of columns arranged to the right of the column marked 0 and are numbered +1, +2, +3, ... etc. The data for times preceding the time 0 are entered in columns arranged to the left of the column 0 and are numbered -1, -2, -3, ... etc. In the table so obtained consisting of n rows, the mean value of the cosmic ray intensity for each column is then found and plotted on a graph against the corresponding column number. The curve so obtained very clearly brings out the relationship, if any, between the epochs used and cosmic ray intensity and at the same time, it gives the recurrence period if any recurrence tendency is present in the cosmic ray effect.

3.5 Correlation analysis

The method of correlation is a mathematical process for determining the degree of relationship between two variables, say, x and y. The relationship is characterised by a coefficient called, 'correlation coefficient'. If Δx, Δy represent the deviations from the mean of x and y over a common interval of time and if 'n' is the number of pairs, the correlation coefficient '$\gamma_{x,y}$' between x and y is given by :

$$\gamma_{x,y} = \frac{\sum^{n} xy - \frac{\sum^{n} x \sum^{n} y}{n}}{\left[\left\{\sum^{n} x^2 - \frac{(\sum^{n} x)^2}{n}\right\}\left\{\sum^{n} y^2 - \frac{(\sum^{n} y)^2}{n}\right\}\right]^{\frac{1}{2}}} \quad \ldots(3.28)$$

$$= \frac{\sum^{n} \Delta x \sum^{n} \Delta y}{\left[\sum^{n} (\Delta x)^2 \sum^{n} (\Delta y)^2\right]^{\frac{1}{2}}} \quad \ldots(3.29)$$

Any of the above two equations can be used to determine the correlation coefficient. $\gamma_{x,y}$ can be positive or negative which respectively indicates whether x and y vary in the same or in the opposite manner. $\gamma_{x,y} = 0$ would indicate that there is no relationship between x and y whatsoever.

The standard error (σ_γ) in $\gamma_{x,y}$ is given by :

$$\sigma_\gamma = \pm \frac{1 - \gamma^2_{x,y}}{(n - 1)^{\frac{1}{2}}} \qquad \ldots(3.30)$$

which shows that the larger the number of pairs 'n' and the larger the value of $|\gamma|$, the smaller would be σ_γ.

3.6 The X^2 test

To test the conformance of a series of 'n' values of I_n to the Poisson law, where the interval length is the same for all the determinations we compute,

$$X^2 = \frac{\sum^{n} (I_n - \bar{I})^2}{\bar{I}} \qquad \ldots(3.31)$$

where,

$$\bar{I} = \frac{\sum^{n} I_n}{n} \qquad \ldots(3.32)$$

Elderton (Elderton's tables of goodness of fit) has prepared a table of X^2 from which, knowing the number of degrees of freedom of 'n' measurements, one can find out the proportion of the cases 'P' in which a particular value of X^2 will be exceeded. Applying this to the case of solar daily variation where we have 12 bihourly measurements, and so the degree of freedom is 11, the probability 'P' that X^2 will exceed any specified value is given in the following Table :

Values of P :	0.5	0.1	0.05	0.01	0.001
Values of X^2:	12.90	17.28	19.68	24.73	26.22

Thus in 99.9 % of the cases X^2 should have a value ≤ 26.22, if daily variation were to be due to purely statistical fluctuations. The more the value of X^2 the greater would be the dispersion of bihourly intensities about the daily mean intensity* and hence the greater would be the amplitude of the daily variation.

3.7 Punch card system of tabulation of data

A detailed study of the various aspects of the daily variation of cosmic rays involves the determination of frequency distributions, the sorting out of days according to different criteria, evaluating the parameters of the average daily variation on groups of days thus sorted out and the determination of the time series of different parameters.

In analyses of this nature, it is convenient to use the punch card system of tabulation of data so that the

* which would be given by eq.3.22, where I_n is the bihourly intensity centred at the hour 'n'.

standard electrical sorting and tabulating machines can be used to perform these various computational operations. In the present investigation, Hollerith cards having eighty columns and ten rows were used for tabulating the primary data corrected for meteorological effects. The following information is punched on the cards :

Column No.	Information punched
1, 2	Identity numbers of the recording instrument.
3, 4	Year.
5, 6, 7	Day of the year.
8, 9	C_p
10	Number indicating whether any bihourly deviation in percent is greater than 5.0 % or less than -5.0 % for the day.
11, 12, 13	Blank.
14 to 37	The 12 bihourly deviations in percent to which 5.0 % has been added to make them all positive.
38, 39	Residue in percent to which 5.0 % has been added to make it positive.
40	Number characterising any manipulations made in bihourly intensities.
41	Number of similar units running for the day.
42	Scaling factor of the recorder.

Column No.	Information punched
43 to 46	Pressure corrected mean intensity for the day.
47 to 50	Blank.
51 to 58	a_1, b_1; a_2, b_2 the Fourier coefficients for the day in percent to which 5.0 % has been added to make them all positive.
59 to 66	r_1; ϕ_1; r_2, ϕ_2 the harmonic parameters characterising the diurnal and semidiurnal variation for the day.
67, 68	Ratio r_1/r_2.
69, 70	X^2 for the day.
71 to 80	Blank.

-:0000000:-

IV

EXPERIMENTAL RESULTS, THEIR DISCUSSION AND CONCLUSIONS

4.1 Introduction

The results presented in this chapter relate to the following :

(1) Meson data at Gulmarg ($= +25^{\circ}$, f $= +147^{\circ}$ alt. = 2740 m), obtained by the author with counter telescopes, for the period January 1956 to January 1958. Table 1 indicates the number of days of opeæatiœn of one or more counter telescopes.

Table 1

Table showing the number of days in each month for which data is available for the hard component at Gulmarg during 1956, 1957 and 1958 and for nucleonic component at Ahmedabad during 1957 and 1958.

Detector	J	F	M	A	M	J	J	A	S	O	N	D	Total No. of working days.
1 9 5 6													
Meson telescopes at Gulmarg.	26	27	31	23	23	25	24	23	28	28	29	18	305
1 9 5 7													
Meson telescopes at Gulmarg.	29	25	25	26	25	25	25	15	-	19	10	22	246
Neutron monitor at Ahmedabad.	-	-	-	-	18	26	21	21	30	24	-	-	140
1 9 5 8													
Meson telescopes at Gulmarg.	20	-	-	-	-	-	-	-	-	-	-	-	20
Neutron monitor at Ahmedabad.	-	-	-	-	25	28	28	28	26	28	29	30	222

As would be seen from the table, the data for Gulmarg meson telescopes for August, October and November 1957 are rather scanty and there are no data for the month of September 1957. This is due to the fact that from the last week of August 1957 to the first week of October 1957, the author was away from Gulmarg. In November 1957, however, there was a prolonged power failure because of the havoc wrought by a severe blizzard which uprooted many of the poles carrying power transmission lines; also the diesel engine which was normally used as a stand-by, developed mechanical trouble and could not be used. As such, no supply was available for charging the batteries which, in turn, resulted in a stand still. After about a fortnight normal conditions were restored. Various constituent units of the apparatus were then tested thoroughly and the unit was started again. By the middle of February 1958, the Gulmarg station was, temporarily, closed down and the author returned to Ahmedabad.

(2) Neutron monitor data from Ahmedabad ($\lambda = +14^{\circ}$, $f = +143^{\circ}$, sea level).* These data are available in two fairly continuous series; one extends from May 1957 to October 1957 during which period author's predecessor, Mr.Satyaprakash, was responsible for the maintenance of the neutron monitor at Ahmedabad. From October 1957 to April 1958, unfortunately, there were large number of interruptions in the working of the neutron monitor at Ahmedabad and hence the data are rather haphazard during this period. From the time, the author

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* λ, f are respectively the geomagnetic latitude and geomagnetic longitude.

undertook the responsibility of the maintenance of the neutron monitor, in late April 1958, the neutron monitor started working satisfactorily. The author laid down the responsibility of the maintenance of the neutron monitor in early 1959. Details regarding the working of the neutron monitor (both sections) during the two periods are summarised in Table 1.

(3) Neutron monitor data from Mt.Norikura (λ=+25° f = +204°, alt. = 2770 m), Huancayo (λ= -1°, f = +354°, alt. = 3400 m), Makerere (λ=-2°, f = +101°, alt. = 1196 m) and meson monitor data from Makerere and Itabashi (λ= +25°, f = +206°, sea level) were also analysed for the period July 1957 to December 1958.

The data from home stations were tested for parallel running of the similar units by the method described in Sec. 3.1. They were then corrected for atmospheric pressure and temperature changes using appropriate coefficients, described in Sec. 3.11. Because of the rather large day to day fluctuations exhibited by the nucleonic component of cosmic rays, the neutron monitor data (for home stations as well as for the other stations of the world) were further processed to rid the individual bihourly intensities, as far as possible, of the day to day changes of intensity. The method used is described in Sec. 3.2.

4.2 Study of the solar daily variation

Solar daily variation can be resolved into two harmonic waves; the first harmonic or the diurnal variation having a period of 24 hours and characterised by its amplitude r_1 and its time of maximum ϕ_1 and the second harmonic or the semidiurnal variation having a period of 12 hours and defined by its amplitude r_2 and its time of maximum ϕ_2. Thus to study the characteristics of solar daily variation averaged over a period of time or in groups classified according to some distinct criteria, it is customary to examine the averaged harmonic parameters $\bar{r}_1$, $\bar{\phi}_1$; $\bar{r}_2$, $\bar{\phi}_2$. The variability of these parameters can be studied by looking at their histograms. An alternative method of studying the solar daily variation, which has proved very useful, is to look at individual bihourly intensities as suggested by Remy and Sittkus (1955) and Sarabhai and Satyaprakash (1959).

4.21 Year to year changes in solar daily variation at low (λ = 0 to +14°) latitudes.

4.211 Annual mean solar daily variation of nucleonic component at Ahmedabad and at Huancayo :- Fig. 18a gives the annual mean solar daily variation curves for the nucleonic component at Ahmedabad for the years 1957 and 1958 - actually the periods May 1957 to October 1957 and May 1958 to December 1958 are taken to be representative of the two years respectively*. The mean parameters characterising these curves are given in Table 2. The chief features revealed by the study of this table along with the curves of figure 18a

* Strictly speaking this assumption may be questioned, but since the data in the two years roughly correspond to the same period, the chief features would not be materially affected.

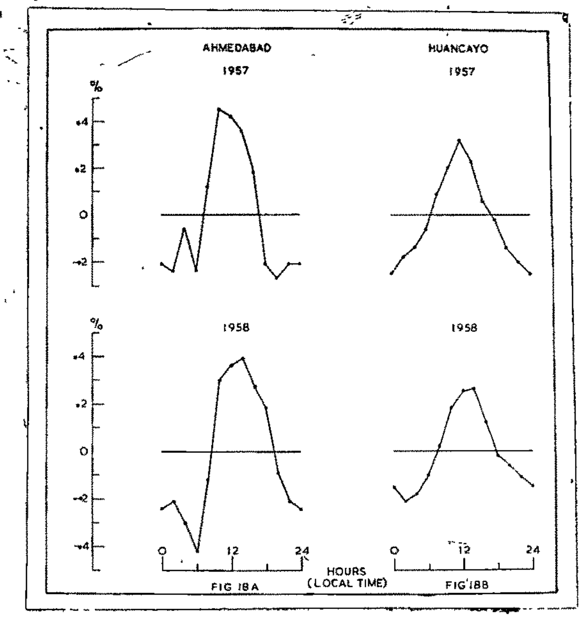

Fig. - 18a. Annual mean solar daily variation curves for the nucleonic component at Ahmedabad.

18b. Annual mean solar daily variation curves for the nucleonic component at Huancayo.

Table 2.

Table showing the parameters $\bar{r}_1$, $\bar{\phi}_1$; $\bar{r}_2$, $\bar{\phi}_2$ which characterise the diurnal and semidiurnal components of solar daily variation at Ahmedabad during 1957 and 1958. Values of annual mean C_p and relative sunspot number ($\bar{R}$) are also indicated.

Year	No. of days	$\bar{r}_1$ %	$\bar{\phi}_1$	$\bar{r}_2$ %	$2\bar{\phi}_2$	$\bar{C}_p$	$\bar{R}$
1957	140	0.38±0.03	177°	0.17±0.03	8°	0.78	153
1958	222	0.40±0.03	π+32°	0.12±0.03	22°	0.78	194

are :

(1) in both the years $\bar{r}_1$ is two to three times greater than $\bar{r}_2$ i.e. the diurnal component of solar daily variation predominates in both the years,

(2) $\bar{r}_1$ and $\bar{r}_2$ remain practically unchanged, within error, in the two years,

(3) $\bar{\phi}_1$ the time of maximum of the diurnal component becomes later by about two hours in 1958 relative to 1957,

(4) the shift to later hours of $\bar{\phi}_2$ in 1958 is rather small ($\sim$ 1/2 hour) relative to 1957.

(5) the 0600 hours negative deviation is more prominent in 1958 where it had a magnitude of $-0.45 \pm 0.06\%$ compared to 1957 where it had a magnitude of $-0.28 \pm 0.06\%$. It will be shown later that negative deviation at 0600 hours is a characteristic feature of solar daily variation at Ahmedabad.

(6) the 2000 hours negative devation has reduced in magnitude in 1958 where it had a magnitude of $-0.11 \pm 0.06\%$ compared to 1957 where it had a magnitude of $-0.31 \pm 0.06\%$. It will be shown later that this negative deviation is also associated , in a fundamental way, with the nature of the solar daily variation.

In Fig. 18b are given, for comparison sake, annual mean solar daily variation curve for nucleonic component at Huancayo for the years 1957 and 1958 - the period July 1957 to December 1957 being taken to be representative of the year 1957 and the period January 1958 to December 1958 represents the year 1958. The mean parameters of the harmonic components characterising these curves are summarised in Table 3. The study of table 3 together with

Table 3

Table showing the parameters $\bar{r}_1$, $\bar{\phi}_1$; $\bar{r}_2$, $\bar{\phi}_2$ which characterise the diurnal and semidiurnal components of solar daily variation at Huancayo during 1957 and 1958. Values of annual mean C_p and relative sunspot number ($\bar{R}$) are also indicated.

Year	No. of days.	$\bar{r}_1$ %	$\bar{\phi}_1$	$\bar{r}_2$ %	$2\bar{\phi}_2$	$\bar{C}_p$	$\bar{R}$
1957	161	0.25±0.01	$\pi+1^{\circ}$	0.04±0.01	4°	0.78	153
1958	310	0.22±0.01	$\pi+16^{\circ}$	0.06±0.01	-7°	0.78	194

the annual curves reveals the presence of a similar basic pattern of change in annual mean solar daily variation at Huancayo as has already been noted in case of Ahmedabad. Namely,

(1) the solar daily variation is predominently diurnal in character during both the years,

(2) $\bar{r}_1$ and $\bar{r}_2$ remain practically unchanged during the two years,

(3) $\bar{\phi}_1$ has shifted to later hours in 1958 relative to 1957 by about 1 hour.,

(4) the shift to later hours of $\bar{\phi}_2$ in 1958 is rather small ($\sim$ 1/2 hour) relative to 1957.

(5) the 0400 hours negative deviation is more prominent in 1958 where it had a magnitude of $-0.18\pm0.01\%$, compared to 1957 where it had a magnitude of $-0.14\pm0.01\%$,

(6) the 0000 hour negative deviation has reduced in magnitude in 1958 where it had a magnitude of $-0.15\pm0.01\%$, compared to 1957 where it had a magnitude of $-0.25\pm0.01\%$.

Thus we see that the pattern of change of annual mean solar daily variation from 1957 to 1958 is similar for the equatorial stations (Huancayo and Ahmedabad).

4.212 <u>The mode of change of the parameters $\bar{r}_1, \bar{\phi}_1$; $\bar{r}_2, \bar{\phi}_2$ of annual mean solar daily variation at Ahmedabad.</u>

We have seen above that the features of the annual mean solar daily variation at Ahmedabad and Huancayo are similar. In the following few subsections, we shall probe deeper into the nature of these annual changes with particular reference to Ahmedabad data.

Fig. 19 gives the histograms describing the frequency distribution of the parameters of the harmonic components on individual days at Ahmedabad during 1957 and 1958. In drawing ϕ_1, ϕ_2 histograms, only those days have been considered which respectively have the amplitudes of diurnal and semidiurnal components significant at 2σ level of

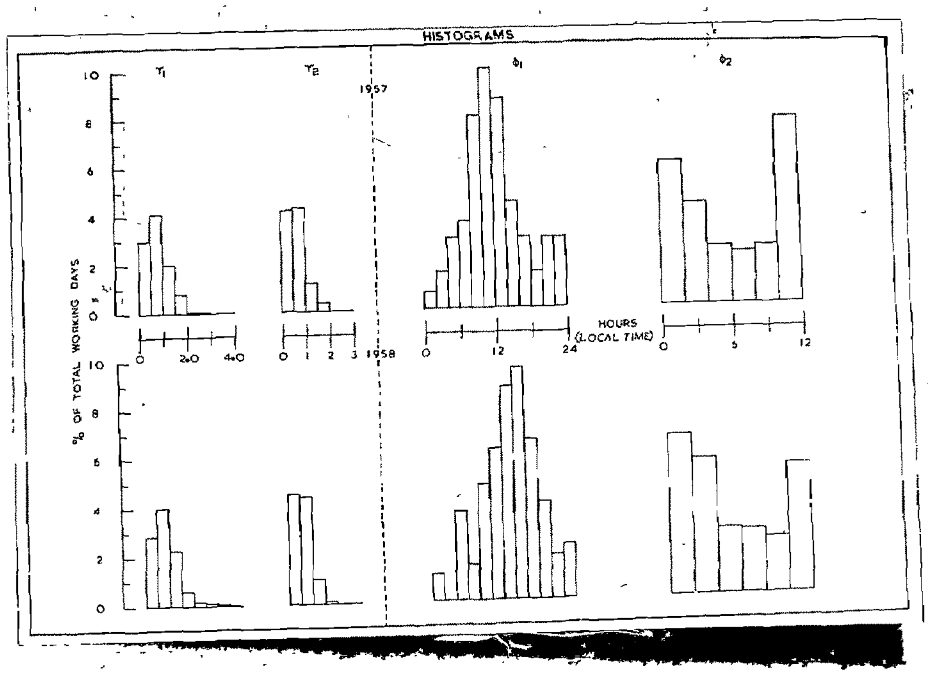

Fig. 19 - The histograms of r_1, ϕ_1, r_2 and ϕ_2 for the years 1957 and 1958 showing their distribution, on individual days, at Ahmedabad.

significance (σ = error arising out of statistical fluctuations). This is done to prevent the random errors associated with ϕ_1 and ϕ_2 (because of the finite size of the sample) from masking their real frequency distribution over different bihours.* One can clearly discern that

(1) frequency distribution for r_1 and r_2 is not significantly different during the two years;

(2) a distinct shift to later hours is evident for

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* This same procedure would be followed throughout in drawing ϕ_1 and ϕ_2 histograms.

ϕ_1 in 1958 relative to 1957; .

(3) a shift of ϕ_2 to later hours in 1958 is also seen, though this shift is not so conspicuous as for ϕ_1.

4.213 Mode of change of the annual frequency distribution of significant positive and negative bihourly deviations at Ahmedabad.

A study of this type enables one to picture the nature of the changes affecting the bihourly deviations of intensity which comprise the solar daily variation. Such changes are not brought out equally clearly by the study of mean parameters specifying the harmonic components of the mean solar daily variation.

For the purpose of this study, the bihourly deviations were first corrected for the trend of the day to day changes in daily mean intensity by the method described in Sec.3.2. A bihourly deviation Δi_x, obtained by subtracting the daily mean intensity from the bihourly intensity centred at the hour x, is considered to be significantly positive or negative according as its magnitude is greater than $+2\sigma$ or less than -2σ respectively; the standard error σ for an individual bihourly intensity at Ahmedabad being 0.9%. A significant positive deviation is designated as Δi_x^+ or x^+ and a significant negative deviation as Δi_x^- or x^-.

The frequency distribution of x^+ and x^- for 1957 and 1958 is shown in Fig. 20, the latter being shown with the ordinate reversed. The average number (in percent of total working days) of deviations of each sign, greater than 1.8% at each bihour that could occur purely due to chance is only 2.3%. Variations of intensity of the primaries with the time scale of change short compared to 24 hours, could also pollute the bihourly intensity significantly and this pollution would not be eliminated by the process of applying correction for day to day changes of intensity. However such a pollution would contribute to increasing the random fluctuations which should occur with equal probability at all bihours. We therefore take note of only those bihours for which the number of deviations significant at 2 σ level is more than three times that expected through pure chance.

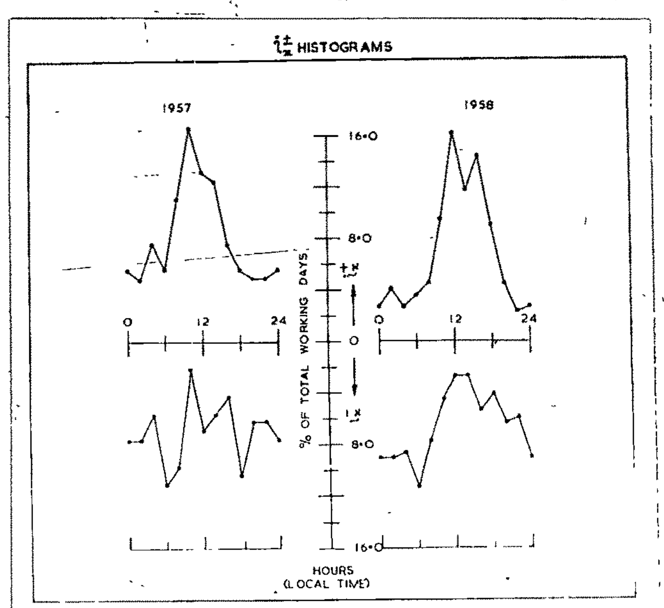

Fig. 20 - Frequency distributions of significant positive and negative bihourly deviations at Ahmedabad for the years 1957, 1958.

From the above figure, it can be seen that whereas in 1957 the frequency of occurrence of positive deviations was peaked at 1000 hours, the peak shifted to 1200 hours in 1958. Also the frequency of occurrence of negative deviations at 1800 hours has been considerably reduced in 1958 whereas that of negative deviations at 2400 hours increased relative to 1957. However the frequency of occurrence of negative de deviations at 0600 hours remains unchanged during the two years. Thus the solar daily variation in 1958 differed from that in 1957 in the sense that in the former year there took place a shift to later hours, of significant positive and evening hours negative deviations.

4.214 The mode of change of parameters characterising the annual mean solar daily variation at Ahmedabad, in relation to the geomagnetic activity.

To test whether the year to year change in solar daily variation is related, in any way, with geomagnetic activity (as represented by C_p) the two annual mean solar daily variation curves for Ahmedabad was split up into two C_p groups.

(1) Low C_p group or C_p^L group which comprises of days where $0 \leq C_p \leq 0.5$.

(2) High C_p or C_p^H group which comprises of days where $C_p \geqslant 1.0$.

The mean parameters characterising the annual mean solar daily variation associated with C_p groups along with mean C_p for the particular group are summarised in Table 4.

Table 4

Table showing characteristics of annual mean solar daily variation, at Ahmedabad, for C_p^H and C_p^L groups during 1957, 1958. Mean values of C_p and the number of days in each C_p group, during the two years, are also indicated.

C_p Group	$\bar{C}_p$	No. of days.	1957 $\bar{r}_1$ %	1957 $\bar{\phi}_1$	1957 $\bar{r}_2$ %	1957 $2\bar{\phi}_2$	$\bar{C}_p$	No. of days.	1958 $\bar{r}_1$ %	1958 $\bar{\phi}_1$	1958 $\bar{r}_2$ %	1958 $2\bar{\phi}_2$
C_p^H	1.3	44	0.34± 0.06	162°	0.15± 0.06	-62°	1.3	59	0.39± 0.05	π+44°	0.13± 0.05	39°
C_p^L	0.3	59	0.37± 0.05	161°	0.22± 0.05	22°	0.3	96	0.35± 0.04	π+35°	0.12± 0.04	48°

One can see that no significant change has taken place in the geomagnetic activity (mean) during the two years for both C_p^H and C_p^L groups. Nevertheless, in both groups (i) $\bar{\phi}_1$ has shifted to later hours in 1958 relative to 1957 and the amount of shift involved is about the same in C_p^L as well as C_p^H groups ($\sim$ four hours), (ii) shift in $\bar{\phi}_2$ is rather small ($\sim$ half hour) for C_p^L group and quite appreciable for C_p^H group ($\sim$ three and a half hours) and (iii) $\bar{r}_1$ and $\bar{r}_2$ do not exhibit any significant change. Fig. 21 gives the form of the solar daily variation for the two C_p groups during 1957 and 1958. One clearly sees that, in both the groups :

(1) The primary maximum in solar daily variation has shifted to later hours in 1958 than in 1957.

(2) The minimum at 0600 hours has deepened in 1958 than in 1957.

(3) The deviation at 2000 hours becomes less negative in 1958 compared to 1957 for C_p^L group whereas in C_p^H group it has even become positive.

These facts are similar to the ones already noted in Sec. 4.211 and suggest rather clearly that the change observed in the annual mean solar daily variation had little connection with geomagnetic activity.

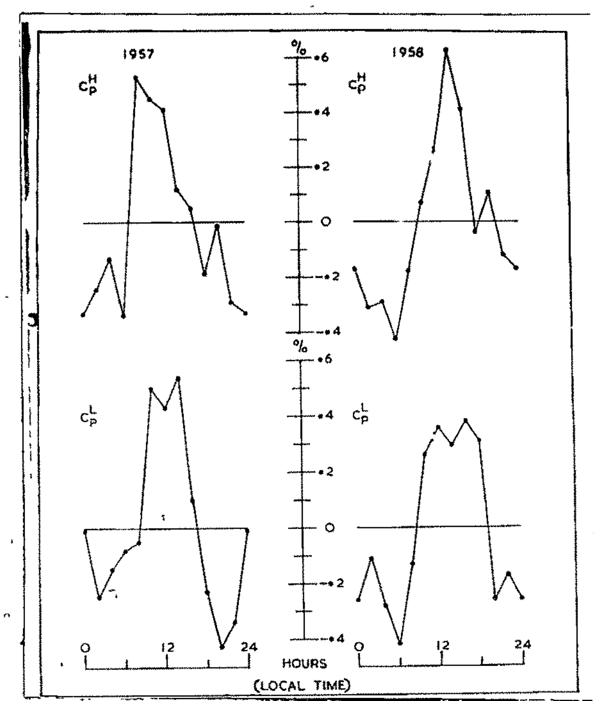

Fig. 21 - Mean solar daily variation in the low and high C_p groups during individual years 1957 and 1958.

We thus see that the basic change in annual mean solar daily variation at equatorial stations (Ahmedabad and Huancayo) involved the shift of the time of maximum of the diurnal and to some extent of semidiurnal components, of solar daily variation, towards later hours in 1958 relative to 1957. Further, detailed analysis of data at Ahmedabad carried out in the above , indicates that this change arose because of the general shift of significant positige and evening hour negative deviations towards later hours in 1958. Also this change was independent of the geomagnetic activity since it was associated with geomagnetically quiet (C_p^L group) as well as with highly disturbed (C_p^H group)days. The nature of the influence of $\overline{R}$ on the changes exhibited by the annual mean solar daily variation will be examined in the following subsection.

4.22 Year to year changes in solar daily variation at intermediate latitude ($\lambda = +25^\circ$).

4.221 Annual mean solar daily variation of hard component at Gulmarg :- Here we shall study the annual mean solar daily variation of hard component observed with counter telescopes at Gulmarg, in conjunction with hard component data available from Ahmedabad and with neutron monitor data from Mt.Norikura, during common periods.

Table 5 summarises the averaged parameters charactersing the annual mean solar daily variation at Gulmarg (hard component), Mt.Norikura (nucleonic component) and Ahmedabad (hard component) for the years 1956 and 1957; for the last two stations the annual mean harmonic parameters are also given for 1958. Also summarised therein are the annual mean value of C_p and of the relative sunspot number ($\overline{R}$). The following points stand out rather clearly.

Table 5

Table showing the parameters specifying the diurnal and the semidiurnal components of 12 month mean solar daily variation at Gulmarg (hard component), Mt.Norikura (nucleonic component) and Ahmedabad (hard component) during 1956, 1957 and 1958.

Year	$\overline{C}_p$	$\overline{R}$	Gulmarg (C.T.) $\overline{r}_1$ %	Gulmarg (C.T.) $\overline{\phi}_1$	Gulmarg (C.T.) $\overline{r}_2$ %	Gulmarg (C.T.) $2\overline{\phi}_2$	Ahmedabad (C.T.) $\overline{r}_1$ %	Ahmedabad (C.T.) $\overline{\phi}_1$	Ahmedabad (C.T.) $\overline{r}_2$ %	Ahmedabad (C.T.) $2\overline{\phi}_2$	Mt.Norikura (N.M.) $\overline{r}_1$ %	Mt.Norikura (N.M.) $\overline{\phi}_1$	Mt.Norikura (N.M.) $\overline{r}_2$ %	Mt.Norikura (N.M.) $2\overline{\phi}_2$
1956	0.75	111	0.31 ± 0.05	158°	0.09 ± 0.05	-35°	0.18 ± 0.02	161°	0.14 ± 0.02	35°	0.26 ± 0.01	$+23^\circ$	0.09 ± 0.01	69°
1957	0.78	153	0.21 ± 0.05	158°	0.06 ± 0.05	20°	0.28 ± 0.02	$+12^\circ$	0.21 ± 0.02	38°	0.26 ± 0.01	$+32^\circ$	0.09 ± 0.01	21°
1958	0.78	194	-	-	-	-	0.27 ± 0.02	$+47^\circ$	0.17 ± 0.02	39°	0.28 ± 0.01	$+33^\circ$	0.05 ± 0.01	-1°

(C.T.) - Counter telescope

(N.M.) - Neutron monitor

(1) The mean planetary index of geomagnetic disturbance ($\overline{C}_p$) has not changed significantly during all the three years.

(2) The solar activity - as given by $\overline{R}$ - rapidly increased during the three years and in 1958 it was twice as intense as in 1956.

(3) The annual mean solar daily variation observed during 1956 and 1957 with a neutron monitor and with a counter telescope has similar form for the mountain altitude stations (Mt. Norikura and Gulmarg) in the intermediate latitude ($\lambda = +25^{o}$); both being predominently diurnal in character. At low latitudes (Ahmedabad for example) however, semidiurnal variation is relatively more important in both nucleonic as well as hard component (see tables 2 and 5). In fact, in hard component at Ahmedabad, the amplitude of semidiurnal component ($\overline{r}_2$) is comparable with the amplitude of diurnal component ($\overline{r}_1$).

(4) The pattern of change of annu al mean solar daily variation is also dependent upon the latitude of the observing station. Both at Mt. Norikura and Gulmarg $\overline{r}_1, \overline{\phi}_1$; $\overline{r}_2, \overline{\phi}_2$ have not changed significantly i.e. outside twice the standard error of determination, during 1956 and 1957. At Ahmedabad however, the amplitude of both first and second harmonic components of solar daily variation increased during the same period. Also $\overline{\phi}_1$ at Ahmedabad shifted to later hours. $\overline{\phi}_2$ at Ahmedabad, however, did not exhibit any such

shift during 1956 and 1957.

From 1957 to 1958 again no change takes place between $\bar{r}_1$, $\bar{\phi}_1$; $\bar{r}_2$, $\bar{\phi}_2$ at Mt.Norikura, whereas at Ahmedabad $\bar{\phi}_1$ continues to shift to later hours from 1957 to 1958; $\bar{r}_1$, $\bar{r}_2$ and $\bar{\phi}_2$, however, do not change significantly at Ahmedabad also. As noted earlier in Sec. 4.211, the nucleonic component at Ahmedabad during 1957-1958 also behaves in a manner similar to the behaviour of hard component at Ahmedabad i.e. $\bar{r}_1$, $\bar{r}_2$ do not exhibit any change whereas $\bar{\phi}_1$ shows a distinct shift at later hours; $\bar{\phi}_2$ also seems to shift to later hours but the shift is not so conspicuous as for $\bar{\phi}_1$.

We thus see that :

(a) at the same latitude the change in the form of the solar daily variation of the hard component and the nucleonic component are similar e.g. compare changes in the mean annual solar daily variation of hard component at Gulmarg with the changes in the annual mean solar daily variation of nucleonic component at Mt.Norikura and of hard component at Ahmedabad with nucleonic component at Ahmedabad. This shows that the same mechanism causes changes in the annual mean solar daily variation of nucleonic and hard components of cosmic rays;

(b) the pattern of change of mean annual solar daily variation at $\lambda = 0^\circ$ (Huancayo) and at $\lambda = +14^\circ$ (Ahmedabad) is different from that at $\lambda = +25^\circ$ (Mt.Norikura and Gulmarg) in the sense that whereas at Ahmedabad, $\bar{\phi}_1$ shifted continuously to later hours during the three years 1956, 1957 and 1958, $\bar{\phi}_1$ at Mt.Norikura remains practically the same.

(b) suggests that there are perhaps some influences at work which lead to an observed pattern of change (of annual mean solar daily variation) at geomagnetic equator and stations closed to it ($\lambda = 0^{\circ}$ to $+14^{\circ}$) which is different from the pattern observed at intermediate latitude ($\lambda = +25^{\circ}$). This fact, in turn, requires that either the agency responsible for causing the pattern of change has its influence strictly confined to the equatorial plane or that there are certain other influences present which tend to blur the distinctness of the pattern of change at higher latitudes so that the rate of change is considerably retarded, in which case observations over a period of three years may not be enough to study the differential aspects of the nature of the agency responsible for these changes at intermediate and higher latitudes. In this connection it is interesting to note that Sarabhai et al (1955) also pointed out that the changes in the form of solar daily variation are more pronounced at the low than at high latitudes.

Further as we have already seen the solar activity increased rapidly, from 1956 to 1958 and was twice as intense in 1958 as in 1956. Corresponding to this striking change in solar activity, there is no conspicuous change in the character of solar daily variation recorded at Mt.Norikura during the same period. This shows that $\overline{R}$ cannot have direct relation with solar daily variation, at best relationship between the two can only be an indirect one.

4.222 Location of the source of mean solar diurnal variation of hard component at Gulmarg during 1956 and 1957 :- As we have already seen in the preceding chapter the annual mean solar daily variation observed at Gulmarg is predominently diurnal in character - having an amplitude of semidiurnal component less than 1/3 of the diurnal component. Now if the diurnal component arises from earth's rotation in an anisotropic flux of primaries as was initially suggested by Alfven and Malmfors (1948) and later by Elliot and Dolbear (1951), then the constancy of $\overline{\phi}_1$ at Gulmarg during 1956 and 1957 implies that the direction of the source responsible for the observed diurnal variation, with respect to the earth-sun line, remained unchanged during the two years. To find this direction we assume that the variation spectrum of the primaries (of energy E) responsible for the solar diurnal variation at Gulmarg is given by

$$\frac{\delta D(E)}{D(E)} = a(\Phi)E^{-1} \text{ for } E > E_{\lambda}^{min}, \quad \text{(see eqs.1.14, 1.15)}$$

where E_{λ}^{min} is the vertical cut off energy due to geomagnetic field (for Gulmarg $E_{\lambda}^{min} \approx 10$ GV), which spectrum was found by Dorman (1957) to hold in case of various experimental data. We further assume that $a(\Phi)$ varies with the angle Φ made by primaries - responsible for diurnal variation at Gulmarg - with the plane of the ecliptic at infinite distance ($\geqslant 10$ earth radii) from the earth, in the manner given by Dorman (1957).

Using the differential response curve for the telescope configuration used by the author and given in Fig. 6b, we determine the number of particles (in percent of total counting rate) arriving from 0^{o}, 8^{o}, 16^{o},..... 56^{o} with respect to the zenith and let these be n_0, n_8, n_{16}.... n_{56}.

The asymptotic angles ψ_E and ϕ_N are next found, through interpolation, from the curves given by Brunberg and Dattner (1954) for the particles of energies 10, 15, 20, 25.......100, 150, 200, 250, 300, 400,......1000 GV, coming from the zenith angles 0^{o}, 8^{o}, 16^{o},.....56^{o} in the north and the south directions.** For a particular energy E_1 let these be

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* We may remind here, that the semiangles of opening of the telescopes used by the author were 56^{o} in N-S plane and 5^{o} in E-W plane.

** The angle of opening in E-W plane being rather small (semiangle $=5^{o}$), we neglect its effect on the nature of solar daily variation observed by the telescope for the purpose of present calculations.

$(\Psi_E)^N_{0E_1}$, $(\Psi_E)^N_{8E_1}$, ...$(\Psi_E)^N_{56E_1}$; $(\Phi_N)^N_{0E_1}$, $(\Phi_N)^N_{8E_1}$, ...$(\Phi_N)^N_{56E_1}$, for particles reaching the telescope from the north and $(\Psi_E)^S_{0E_1}$, $(\Psi_E)^S_{8E_1}$, ...$(\Psi_E)^S_{56E_1}$; $(\Phi_N)^S_{0E_1}$, $(\Phi_N)^S_{8E_1}$,......$(\Phi_N)^S_{56E_1}$, for particles reaching the telescope from the south.

The weighted values of the asymptotic coordinates for the particles coming from the north and from the south directions are next found as follows :

$$\overline{(\Psi_E)^N_{E_1}} = \frac{n_0\,(\Psi_E)^N_{0E_1} + n_8(\Psi_E)^N_{8E_1} + \ldots + n_{56}(\Psi_E)^N_{56E_1}}{100}$$

with similar expressions for $\overline{(\Psi_E)^S_{E_1}}$, $\overline{(\Phi_N)^N_{E_1}}$, $\overline{(\Phi_N)^S_{E_1}}$.

$\overline{(\Psi_E)^N_{E_1}}$, $\overline{(\Phi_N)^N_{E_1}}$; $\overline{(\Psi_E)^S_{E_1}}$, $\overline{(\Phi_N)^S_{E_1}}$ are then representative asymptotic coordinates for the particles of energy E_1 entering the telescope from the north and from the south directions respectively. These coordinates are next converted into geographical system using the formulae given by Brunberg (1956). Let,

$\overline{\Psi}^N_{E_1}$, $\overline{\Phi}^N_{E_1}$; $\overline{\Psi}^S_{E_1}$, $\overline{\Phi}^S_{E_1}$, be the affective asymptotic coordinates, in the geographical system, for the particles reaching the telescope from the north and from the south respectively.

Now if X be the angle between the direction of the source and the sun-earth line and $t^N_{E_1}$ be the time of arrival (in hours) of the particles of energy E_1 from the source on the earth in the northern direction then

$$X = \overline{\Psi^N_{E_1}} + 15(t^N_{E_1} - 12) \text{ or } t^N_{E_1} = \frac{180^\circ + X - \overline{\Psi^N_{E_1}}}{15} \quad \ldots (4.1)$$

and for the particles reaching the telescope from the south

$$X = \overline{\Psi^S_{E_1}} + 15(t^S_{E_1} - 12) \text{ or } t^S_{E_1} = \frac{180^\circ + X - \overline{\Psi^S_{E_1}}}{15} \quad (4.2)$$

where $t^S_{E_1}$ is the time of arrival of additional particles of energy E_1 from the south.

Using eq. 1.8 the percent amplitude contributed by particles of energy E_1 coming from the north to solar daily variation is

$$r^N_{E_1} = a(\overline{\Phi^N_{E_1}})\, E_1^{-1}\, W_\lambda^{*} \quad (4.3)$$

and the percent amplitude contributed by the particles of the same energy but coming from the south is given by

$$r^S_{E_1} = a(\overline{\Phi^S_{E_1}})\, E_1^{-1}\, W_\lambda^{*} \quad (4.4)$$

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* Strictly speaking the coupling coefficient W_λ may be different for the particles coming from the vertical and those coming from the inclined direction but as a first

where W_λ is the coupling coefficient and $a(\overline{\Phi}^N_{E_1})$ and $a(\overline{\Phi}^S_{E_1})$ are the values of $a(\Phi)$ determined from the curves given by Dorman (1957), for $\Phi = \overline{\Phi}^N_{E_1}$ and for $\Phi = \overline{\Phi}^S_{E_1}$.

Having calculated, for the cosmic ray primaries in narrow energy band of mean energy E_1, the amplitudes and times of maxima $r^N_{E_1}$, $t^N_{E_1}$ and $r^S_{E_1}$, $t^S_{E_1}$ for particles reaching the telescopes from the north and the south directions respectively, we can get the resultant contribution to solar diurnal variation from the particles of energy E_1 and reaching the telescopes from the north and the south directions. Let r_{E_1}, t_{E_1} be the amplitude and the time of maximum respectively of this resultant contributory curve due to particles of energy E_1.

Similarly resultant curves may be found for particles having energies E_2, E_3,.....etc. Later all the vectors defined by r_{E_1}, t_{E_1}; r_{E_2}, t_{E_2}; r_{E_3}, t_{E_3} ......etc., can be added up vectorially and the resultant variation can be calculated. For this purpose various values of X, defining the position of the source can be assumed and that value of X for which best fit with the observed time of maximum of solar diurnal variation is obtained gives the effective direction of the source responsible for producing this observed solar diurnal variation. Using this procedure it

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cont...
approximation we have used, in the present calculations, the values of W_λ for the vertical direction. We presume that this approximation will not materially alter the basic result.

was found that

$$X = 50^{\circ} \pm 15^{\circ} \qquad \ldots\ldots \qquad \ldots\ldots \qquad (4.5)$$

gives the best fit with the time of maximum (1000 hours local time of Gulmarg) of solar diurnal variation observed at Gulmarg. The fact that X is positive implies that the source is located to the left of the earth-sun line. Further for the calculated amplitude to tally with that observed experimentally, the source is required to have power $a(\Phi = 0)$, in the equatorial plane, given by

$$a(\Phi = 0) = 0.09 \pm 0.01 \text{ GV} \qquad (4.6)$$

These values of X and $a(\Phi = 0)$ are in excellent agreement with those given for the source responsible for the solar diurnal variation of the hard component recorded at Moscow during 1956, by Dorman and Feinberg (1958). The values given by them in the figure 7 of their paper quoted above are

$$X \sim 40^{\circ} \quad \text{and} \quad a \sim 0.10 \text{ GV}.$$

In Fig. 22 we give the annual mean solar daily variation averaged over 1956 and 1957 for hard component at Gulmarg. In the same diagram is also plotted the fitted curve.

Thus we see that during 1956 and 1957 the observed solar diurnal variation at Gulmarg is satisfactorily accounted for by the variational spectrum of primaries given by eqs.(1.14 and 1.15) which spectrum was determined by Dorman and Feinberg (1958) from experimental data averaged over ten years. This fact, in turn, means that the observed solar diurnal variation at Gulmarg is also consistent with the view that the cause of this variation is the spinning of earth in an anisotropic flow of the flux of the primaries because it is on the basis of the existence of an extra-terrestrial anisotropy that we link the observed amplitude of solar diurnal variation with the variational spectrum $\delta D(E)/D(E)$ of the primaries (e.g. see Sec. 1.4).

The limitations of the present analysis are covered by the comments that we made earlier in Sec. 1.95 to the use of data averaged over a period of one year or longer when the phenomena observed show highly variable characteristics on day to day basis. However the general consistency of the results obtained by us with those obtained by Dorman and Feinberg (1958) does indicate the broad validity of considering data averaged over long periods for observations made at intermediate and high latitudes where the solar daily variation is mainly diurnal in character and exhibits less day to day changes of form than at low (equatorial) latitudes.

4.223 <u>Annual periodic changes in the solar daily variation of hard component at Gulmarg</u> :- Sekido and Yoshida (1950) found that the amplitude of the diurnal component of the solar daily variation increases in equinoxes and its time of maximum shifts to early hours. Sekido and Kodama (1952) found that the annual periodic change of solar diurnal variation certainly exists, for cosmic rays coming from the vertical direction. They based their study on the data obtained with narrow angle telescopes having an aperture of $\pm 12^{o}$ and covering the years 1949 and 1950. In their study they considered magnetically quiet days only. The curves published by them clearly show that from spring to summer there is a sudden and distinct shift to morning hours, of the time of maximum of solar diurnal variation. From then onwards the time of maximum gradually shifts to later hours.

To check whether such annual periodic variation exists for Gulmarg data (corrected for meteorological effects); the yearly data were grouped into four three monthly groups centred round equinoxes and solstices. Since the annual mean solar daily variation at Gulmarg does not undergo any change during 1956 and 1957, the corresponding groups for the two years were combined. The mean parameters $\bar{r}_1$, $\bar{\phi}_1$; $\bar{r}_2$, $\bar{\phi}_2$ characterising the solar daily variation over the three monthly epochs for hard component at Gulmarg and for the nucleonic component at Mt. Norikura are presented in Table 6. The mean values of C_p for the corresponding periods are also tabulated alongside. All available days during the three monthly period were taken into consideration. In case of Gulmarg the following points are quite obvious.

(1) $\bar{r}_1$ values in summer and winter (solstices) are nearly twice as large as those in spring and autumn (equinoxes) which fact is contrary to the observation of Sekido and Yoshida

(1950) who obtained large values of diurnal amplitude in equinoxes.

Table 6

Table showing the characteristics of the mean solar daily variation obtained by forming four three monthly groups for Gulmarg (hard component) data for 1956 and 1957.

Three monthly groups.	Season	$\bar{C}_p$	Gulmarg $\bar{r}_1$ %	$\bar{\phi}_1$	$\bar{r}_2$ %	$2\bar{\phi}_2$	Mt.Norikura $\bar{r}_1$ %	$\bar{\phi}_1$	$\bar{r}_2$ %	$2\bar{\phi}_2$
F+M+A	Sp.	0.83	0.24 ± 0.07	$\pi+12^\circ$	0.14 ± 0.07	69°	0.26 ± 0.02	$\pi+31^\circ$	0.06 ± 0.02	31°
M+J+J	Su.	0.72	0.45 ± 0.10	104°	0.07 ± 0.10	124°	0.26 ± 0.02	$\pi+37^\circ$	0.14 ± 0.02	54°
A+S+O	A.	0.73	0.22 ± 0.08	141°	0.32 ± 0.08	-85°	0.30 ± 0.02	$\pi+15^\circ$	0.08 ± 0.02	60°
N+D+J	W.	0.76	0.46 ± 0.13	$\pi+18^\circ$	0.19 ± 0.13	6°	0.23 ± 0.02	$\pi+25^\circ$	0.06 ± 0.02	0°

(2) $\bar{r}_2$ has largest value in autumn but nothing can be said about the relative changes of $\bar{r}_2$ during other three monthly period since the changes are not statistically significant.

(3) $\bar{\phi}_1$ is earliest in summer (Su.) and then gradually shifts to later hours which fact is consistent with the result obtained by Sekido and Kodama (1950) with narrow angle ($\pm 12^\circ$) telescopes at Nagoya (Japan) during 1949-1950.

(4) Maximum shift to later hours for $\bar{\phi}_2$ occurs in autumn (A.) In other groups error is rather large to permit any valid

conclusions to be drawn.

However, in case of the nucleonic component at Mt.Norikura there is, apparently, no annual periodic variation during the same period. To confirm whether this annual periodic variation was some local effect or a characteristic of the hard component, the data obtained at Ahmedabad (that have beencorrected for the fluctuations of atmospheric temperature) with counter telescopes, each having an aperture of $22^{\circ} \times 37^{\circ}$, were analysed. However, as we have already pointed out there was present a long term change in the solar daily variation observed at Ahmedabad during 1956 to 1958. To remove the influence of this long term change,(as far as possible) from the yearly data, the 12 month mean solar daily variation was first found with the beginning and the close of each 12 monthly interval shifted by one month, for the period July 1955 to June 1958. This gives the moving 12 month mean solar daily variation centred at successive months ranging from January 1956 to December 1957. The monthly data so obtained were then subtracted from the original data for the corresponding months. The residual data were then grouped together into three monthly groups and the corresponding groups for 1956 and 1957 were combined together. This then directly gives the additional diurnal and semidiurnal effects which are superposed on a supposedly constant annual mean solar daily variation to produce an annual periodic change. For Gulmarg where there is no appreciable long term change present in annual mean solar daily variation from 1956 to 1957, the annual periodic effect is found by subtracting mean annual solar daily variation data averaged over two years from the three monthly mean solar daily variation data. The parameters $\bar{r}_1^s$, $\bar{\phi}_1^s$; $\bar{r}_2^s$, $\bar{\phi}_2^s$ characterising the additional diurnal and semidiurnal effects correspondirg to the annual periodic change of solar daily variation for Gulmarg and Ahmedabad are presented in Table 7.

Table 7

Table showing the additional effects specified by $\bar{r}_1^s$, $\bar{\phi}_1^s$ and semidiurnal effects specified by $\bar{r}_2^s$, $\bar{\phi}_2^s$ for Gulmarg and Ahmedabad during 1956 and 1957.

Three monthly group	Season	C_p	Gulmarg $\bar{r}_1^s$ %	$\bar{\phi}_1^s$	$\bar{r}_2^s$ %	$2\bar{\phi}_2^s$	Ahmedabad $\bar{r}_1^s$ %	$\bar{\phi}_1^s$	$\bar{r}_2^s$ %	$2\bar{\phi}_2^s$
F+M+A	Sp.	0.83	0.15 ± 0.12	-86°	0.16 ± 0.12	94°	0.11 ± 0.04	159°	0.06 ± 0.04	50°
M+J+J	Su.	0.72	0.36 ± 0.14	69°	0.13 ± 0.14	138°	0.18 ± 0.04	28°	0.06 ± 0.04	122°
A+S+O	A.	0.73	0.08 ± 0.13	30°	0.29 ± 0.13	$\pi+84^\circ$	0.08 ± 0.04	$\pi+6^\circ$	0.14 ± 0.04	-77°
N+D+J	W	0.76	0.31 ± 0.15	$\pi+50^\circ$	0.14 ± 0.15	21°	0.17 ± 0.04	-86°	0.03 ± 0.04	71°

Also the vectors representing these additional effects are displayed on harmonic dials in Fig. 23a and 23b. A study of table 7 along with figures 23a, 23b brings out the following very interesting points.

(1) The vector representing additional diurnal effect has a maximum amplitude in summer (Su.) and in winter(W)

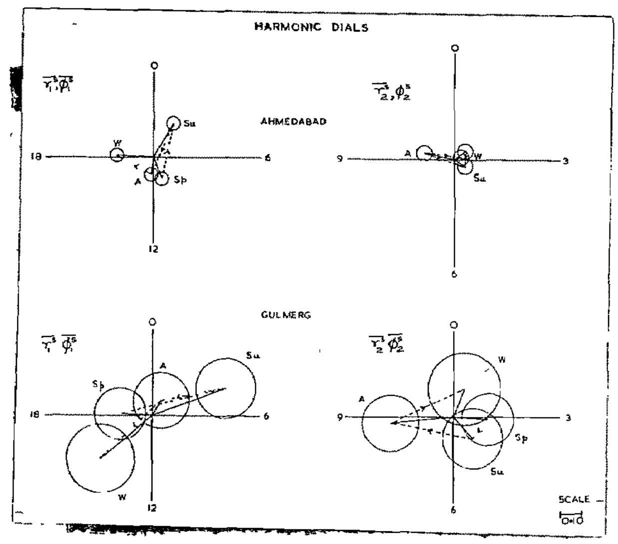

Fig. 23a - The vectors representing the additional diurnal $(\overline{r_1^S}, \overline{\phi_1^S})$ and semidiurnal $(\overline{r_2^S}, \overline{\phi_2^S})$ effects at Ahmedabad.

Fig. 23b - The vectors representing the additional diurnal $(\overline{r_1^S}, \overline{\phi_1^S})$ and semidiurnal $(\overline{r_2^S}, \overline{\phi_2^S})$ effects at Gulmarg.

both at Ahmedabad and Gulmarg and a minimum amplitude in Autumn (A) and in spring (Sp.) i.e. in equinoxes.

(2) The vectors representing additional semidiurnal effect have a maximum amplitude in autumn, at Ahmedabad as well as at Gulmarg and they are similarly aligned on the harmonic dials.

(3) The abrupt displacement of the vector representing the additional diurnal effect towards early morning hours from spring to summer is also distinctly seen for Ahmedabad as well as for Gulmarg.

(4) The magnitudes of the corresponding vectors at Ahmedabad and Gulmarg are about the same within the limits of standard error.

(5) At Gulmarg where the standard error is large, the vectors representing additional diurnal effects during Autumn and Spring (equinoxes) do not have significant amplitude. As such no comparison can be made regarding the alignment of these vectors with the corresponding ones at Ahmedabad. However, for summer and winter (solstices) the vectors representing the additional diurnal effects at Gulmarg have significant amplitudes and their alignment on the harmonic dial compares well with that of the corresponding vectors at Ahmedabad.

It must be noted that the evidence presented here for the annual periodic change in the daily variation of meson intensity is not consistent with the one reported by Sekido and Yoshida (1950) in the sense that whereas we get maximum diurnal amplitudes in solstices, the latter authors get larger values for diurnal amplitudes during equinoxes. The latter authors have not applied corrections for the daily variation of temperature to their experimental data. We have applied this correction on the basis of certain general considerations described in Sec.3.11. We also note that the amplitudes of the additional effects are rather small and as such they may as well be sensitive to corrections arising out of daily variation of temperature. Moreover the neutron monitor at Norikura, which is not subject to an atmospheric temperature effect, shows no annual periodic change of the daily variation. Thus this question requires to be studied further using high counting rate instruments. The data available therefrom should also be supplemented with regular series of radiosonde flights so that the correction for temperature effect can be applied accurately.

4.23 Relationship of solar daily variation with X^2.

As indicated in Sec.3.6, the value of X^2 determines the degree of variability of successive bihourly intensities during the day. On days on which the amplitude of solar daily variation is large, the scatter of bihourly intensities about the daily mean intensity of cosmic rays for the day would be large and this would be reflected in the value of X^2 being greater than normal. As has already been stated in Sec.3.6, the value of $X^2 \leq 26.2$ can arise due to random fluctuations in 99.9 % of the days. Hence on days for which $0 \leq X^2 \leq 27$ the amplitude of the solar daily variation would be low. On the other hand, days having high amplitude of solar daily variation may be expected to occur when $X^2 > 27$. Let such days be termed X^2_H days.

X^2 for individual days, in the years 1957 and 1958 was calculated from bihourly deviations corrected for day to day changes of daily mean intensity using eq.(3.31). Fig.24 gives the frequency distribution of X^2 at Ahmedabad and at Huancayo. The following points are quite obvious.

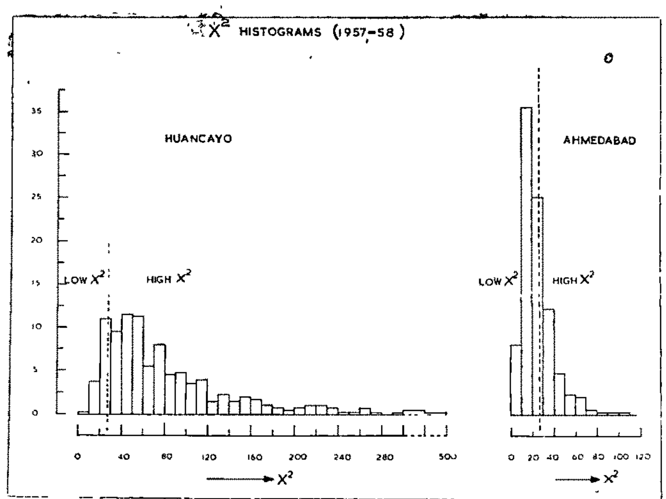

Fig. 24 - Frequency distribution of X^2 at Ahmedabad and at Huancayo during the period of common operation (1957-1958).

(1) X^2 values are spread over a greater range in Huancayo compared to the spread observed in case of Ahmedabad.

(2) There are twice as many days at Huancayo that fall into X^2_H group at Huancayo compared to the case for Ahmedabad.

The above features point to a comparatively higher variability of the solar daily variation observed at Huancayo. This is quite understandable because not only is Huancayo situated at a much higher altitude (~3400 m) compared to Ahmedabad which is situated at sea level, but also the vertical cut off rigidity at Huancayo due to geomagnetic field is less ($\sim$13 GV/c) compared to the rigidity cut off at Ahmedabad ($\sim$ 14 GV/c). These facts make Huancayo, comparatively, more sensitive to temporal changes in the primary energy spectrum. (2) can also arise because of some contribution from the following cause:

The mean bihourly counting rate of the neutron monitor at Huancayo $\sim$5000 x 64 with a standard error of 0.18% in the mean bihourly counts compared to the counting rate at Ahmedabad where on the average $\sim$1600 x 8 counts are registered per bihour with a standard error of 0.9% in mean bihourly counts. Thus days for which the $X^2 > 27$ at Huancayo may not have an amplitude of bihourly deviations large enough to give $X^2 > 27$ for the Ahmedabad instrument even if the absolute magnitude of the bihourly deviation at Huancayo and Ahmedabad is the same.

However what we want to know is that when X^2 has high value (> 27) at Ahmedabad does it have a high value at Huancayo also ? Fig. 25 shows a plot of X_H^2 values observed at Ahmedabad versus X^2 values observed at Huancayo. It is very clear from the figure that on days when there occurs a high value of X^2 (> 27) at Ahmedabad, the value of X^2 observed at Huancayo is also high; only very few points ($\sim$ 1/12 of the total points) are there for which X^2 has a high value at Ahmedabad but not at Huancayo. This fact, in turn, means that enhanced solar daily variation is a world-

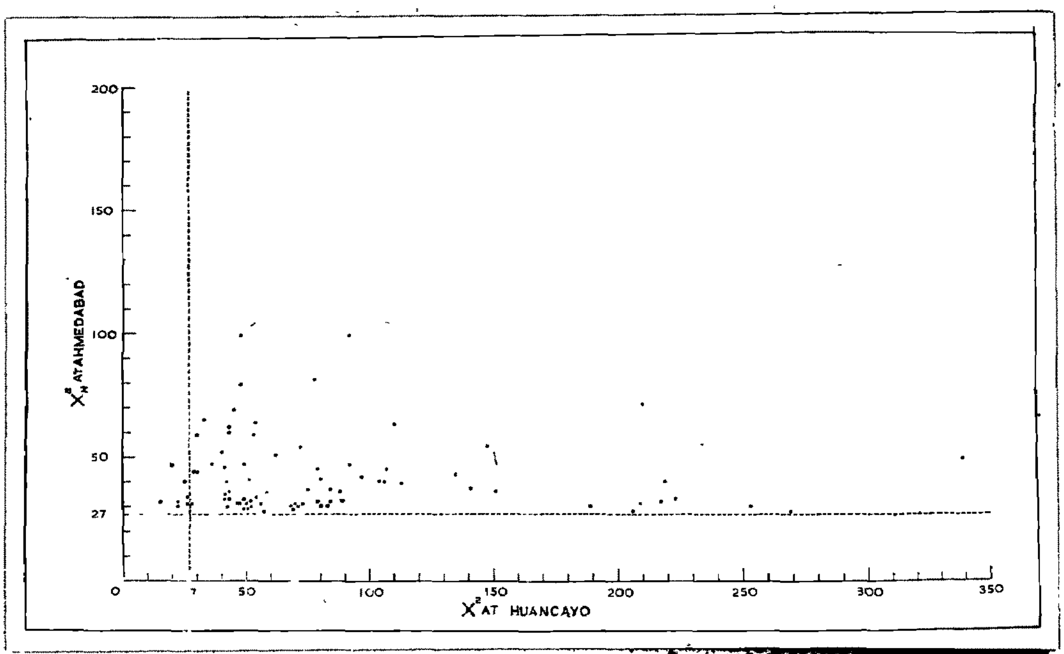

Fig. 25 - Plot of X_H^2 observed at Ahmedabad versus the values of X^2 at Huancayo.

wide phenomena . This conclusion is consistent with the observation of Sarabhai et al (1958) who showed that on days on which Sittkus observed high amplitude of solar daily variation at Freiburg, the solar daily variation observed at Amsterdam and at Ahmedabad also had high amplitudes. Fig. 26 shows the solar daily variation observed on X_H^2 days at Ahmedabad and Huancayo; striking similarity of form and high value of amplitude stand out rather clearly. Further the amplitude of solar daily variation observed at Ahmedabad is seen to be higher than that observed at Huancayo.

From the evidence presented above it is quite clear that high value of X^2 (> 27) at Ahmedabad providesus with a convenient index of picking out days on which enhanced

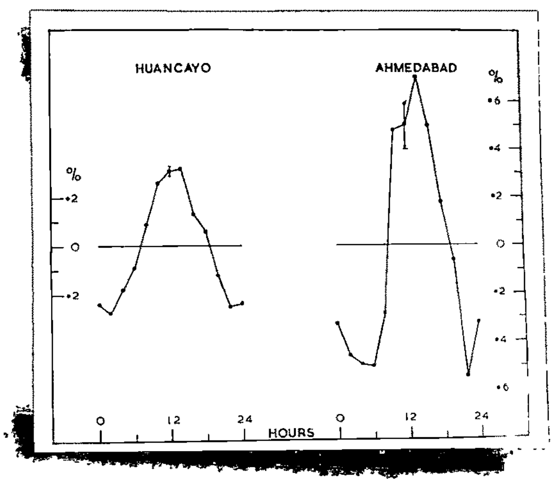

Fig. 26 - Solar daily variation observed on X_H^2 days at Ahmedabad and Huancayo.

solar daily variation occurs, on a world-wide basis.

4.24 Relationship of solar daily variation with geomagnetic activity.

As described in Sec. 1.93, Sekido et al (1950, 1952) and Sandstrom (1955) found that the amplitude of the diurnal component of solar daily variation increases and its time of maximum shifts to earlier hours. Parsons (1958), however, found that the relationship between changes in solar diurnal variation and the degree of geomagnetic activity was far from consistent. He showed that in the different relatively long term data groups, increased geomagnetic activity was associated sometimes with enhanced and sometimes with smaller mean amplitudes, sometimes with advanced phase and at other times with retarded phases. The studies made at Kodaikanal by Sastry (1959) with the hard component and by Satyaprakash (1958) with the nucleonic component also led to similar conclusions.

The analyses presented below were undertaken to study, for the nucleonic component recorded at low latitudes, the relationship between geomagnetic activity and the diurnal and semidiurnal components of the solar daily variation. For this purpose we pick out days at Ahmedabad and Huancayo for which C_p (the planetary index of geomagnetic activity) has values $0 \leq C_p \leq 0.5$ and $C_p \geqslant 1.0$. Let these groups be designated as C_p^L and C_p^H groups respectively. The latter group that represents highly disturbed geomagnetic conditions and the former group relatively normal geomagnetic conditions.

Table 8 gives the mean parameters charecterising the diurnal and the semidiurnal components of solar daily variation observed at Huancayo and at Ahmedabad along with the mean values of C_p for each group. As is clear, the parameters specifying the harmonic components for C_p^H group are not significantly different from those that characterise the two components of the solar daily variation associated with C_p^L group either at Ahmedabad or at Huancayo. This is so, despite the fact that the former group is associated with geomagnetic activity which is four times as intense as the geomagnetic activity (as indicated by the $\overline{C}_p$ values for the two groups) associated with the latter group.

To study the specific relationship between the diurnal

Table 8

Table showing the characteristics of mean solar daily variation for C_p^L and C_p^H groups for nucleonic component recorded at Ahmedabad and Huancayo during 1957 and 1958 mean values of C_p and number of days in each group are also given.

C_p Group	$\bar{C}_p$	No.of days.	Ahmedabad $\bar{r}_1$ %	$\bar{\phi}_1$	$\bar{r}_2$ %	$2\bar{\phi}_2$	No.of days.	Huancayo $\bar{r}_1$ %	$\bar{\phi}_1$	$\bar{r}_2$ %	$2\bar{\phi}_2$
C_p^H	1.28	103	0.33± 0.04	$\pi+23^\circ$	0.09± 0.04	-6°	147	0.24± 0.01	$\pi+11^\circ$	0.05± 0.01	18°
C_p^L	0.33	155	0.34± 0.03	$\pi+17^\circ$	0.16± 0.03	35°	102	0.27± 0.01	$\pi+10^\circ$	0.08± 0.01	9°

component of solar daily variation and C_p, days were picked out from among the two C_p groups which had significant diurnal component at Ahmedabad at 2σ level of significance, (σ being the standard error in r_1 on an individual day and for Ahmedabad $\sigma = 0.35\%$). Table 9 gives the mean parameters

Table 9

Table showing the characteristics of mean solar daily variation for C_p groups for days on which the diurnal component has a significant amplitude at 2σ level of significance, for nucleonic component recorded at Ahmedabad during 1957 and 1958. Mean values of C_p and the number of days in each group are also indicated.

C_p group	$\bar{C}_p$	No.of days.	$\bar{r}_1$ %	$\bar{\phi}_1$	$\bar{r}_2$ %	$2\bar{\phi}_2$
C_p^H	1.41	61	0.61±0.05	$\pi+24^\circ$	0.13±0.05	0°
C_p^L	0.28	84	0.52±0.04	$\pi+16^\circ$	0.21±0.04	28°

specifying diurnal component of solar daily variation in the two C_p groups. The table clearly shows that no significant change (at 2σ level of significance) takes place in going from C_p^L to C_p^H group for Ahmedabad,

Let us look at the problem in an other way, by examining whether there exists any distinct relationship between days on which solar daily variation has high amplitudes and the geomagnetic activity. For this purpose we pick out days for Ahmedabad and Huancayo which have high values of X^2 (>27) from among the two C_p groups. Table 10 gives the mean

Table 10

Table showing the characteristics of mean solar daily variation for C_p groups of X_H^2 days for nucleonic component recorded at Ahmedabad and Huancayo during 1957 and 1958. Mean valuesof C_p and the number of days in each group are also given.

C_p Group	$\bar{C}_p$	No. of days.	Ahmedabad $\bar{r}_1$ %	$\bar{\phi}_1$	$\bar{r}_2$ %	$2\bar{\phi}_2$	No. of days.	Huancayo $\bar{r}_1$ %	$\bar{\phi}_1$	$\bar{r}_2$ %	$2\bar{\phi}_2$
C_p^H	1.41	39	0.69 ± 0.06	$\pi + 28^\circ$	0.13 ± 0.06	-29°	35	0.30 ± 0.01	$\pi + 29^\circ$	0.04 ± 0.01	136°
C_p^L	0.28	53	0.46 ± 0.05	$\pi + 23^\circ$	0.33 ± 0.05	40°	40	0.20 ± 0.01	$\pi + 5^\circ$	0.07 ± 0.01	10°

parameters specifying the two components of solar daily variation for these groups. The following features are obvious.

(1) $\bar{r}_1$ is significantly greater ($\sim$ 1.5 times) for C_p^H group compared to C_p^L group at both Huancayo and Ahmedabad.

(2) At both Huancayo and Ahmedabad, $\bar{r}_2$ is significantly smaller ($\sim$ 1/2 to 1/3 of $\bar{r}_1$) for C_p^H group than for C_p^L group. In fact in C_p^L group for Ahmedabad $\bar{r}_2$ has a value comparable with $\bar{r}_1$.

To probe deeper into the nature of the above changes, the histograms were drawn for the parameters characterising the two components of the solar daily variation for the C_p^H and ~~AND~~ C_p^L groups for Ahmedabad and are shown in Fig. 27a. A study

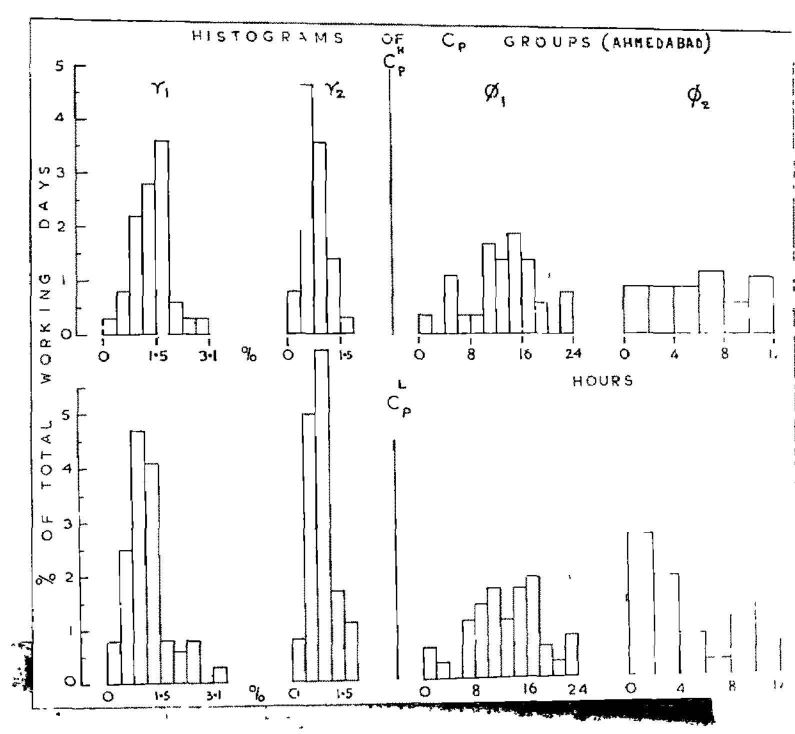

Fig. 27a - Histograms of the amplitudes of diurnal and semidiurnal components and their times of maxima for days in low and high Cp groups. The Cp groups being formed out of days on which the amplitude of solar daily variation is high (X_H^2 days).

of these histograms reveals that

(i) $\bar{r}_1$ is greater in C_p^H group because in this group there are proportionately more days having high diurnal amplitudes compared to the days in C_p^L group;

(ii) $\bar{r}_2$ is greatly reduced in C_p^H group because the variability of ϕ_2 is larger in this group in that it shows a large scatter compared to C_p^L group where it indicates a preference for early hours.

We thus see that for the days with significantly high X^2, the days having pronounced diurnal component are associated with high geomagnetic activity. Further a greater variability in the time of maximum of semidiurnal component for X_H^2 days is accompanied by increased geomagnetic activity. This latter conclusion can also be arrived at in another way which involves the study of days on which semidiurnal component is significant at 2 level. Such days were picked out from among the two C_p groups. Table 11 gives the summary of the mean parameters specifying the harmonic components of solar daily variation for the two groups at Ahmedabad. We see that the mean semidiurnal amplitude ($\bar{r}_2$) is reduced to 1/3 of its value in C_p^H group compared to its value in C_p^L group. A study of the histograms of r_2 and ϕ_2 given in Fig. 27b clearly reveals that though the range of values over which r_2 is spread in the two cases is about the same, ϕ_2 in case of C_p^H group does not show any distinct preference for any particular hour as it does in

Table 11

Table showing the characteristics of mean solar daily variation for C_p groups of days on which semidiurnal component has significant amplitude at 2σ level of significance for the nucleonic component recorded at Ahmedabad during 1957-1958. Mean values of C_p and the number of days in each group are also given.

C_p group.	$\overline{C}_p$	No. of days.	$\overline{r}_1$ %	$\overline{\varphi}_1$	$\overline{r}_2$ %	$2\overline{\varphi}_2$
C_p^H	1.31	36	0.36 ± 0.06	$\pi + 39^\circ$	0.16 ± 0.06	-30°
C_p^L	0.29	53	0.53 ± 0.05	$\pi + 6^\circ$	0.44 ± 0.05	24°

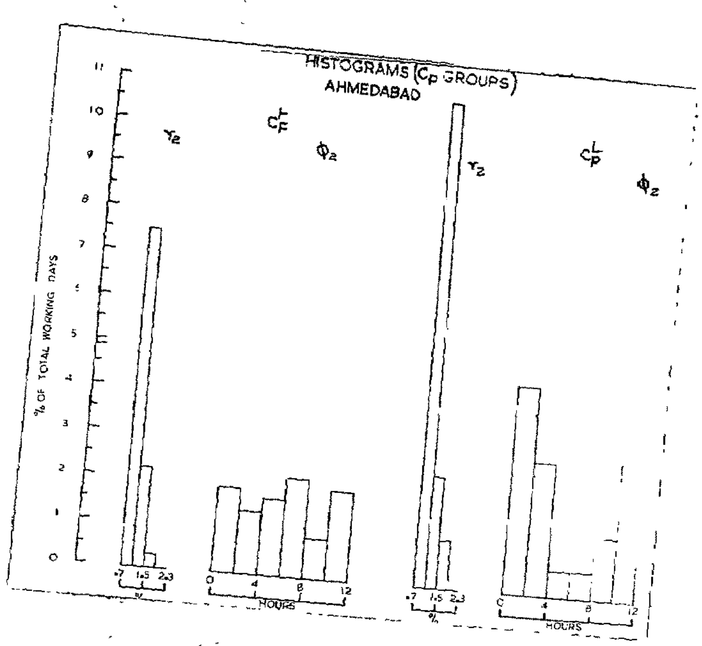

Fig. 27b - Histogram of the amplitude and the time of maximum of the semidiurnal component for days in low and high C_p groups. The C_p groups being formed out of days on which the amplitude of semidiurnal component is significant at 2σ level of significance.

case of C_p^L group where ϕ_2 is clearly peaked at early hours (midnight).

From the analysis presented above we are led to the conclusion that C_p by itself does not bear any exclusive relationship with the character of the solar daily variation. However, increased geomagnetic activity does accompany certain striking changes in the character of solar daily variation. Some of these correlated features are (a) higher values of diurnal component of solar daily variation associated with X_H^2 days are in general accompanied by increased geomagnetic activity and (b) high variability in the time of maximum for semidiurnal component seems to be accompanied by enhanced geomagnetic activity.

(a) and (b) suggest that the agent responsible for producing short term changes in the two main components of solar daily variation has the potency to cause increased geomagnetic activity but increased geomagnetic activity by itself does not have any repurcussions in the character of solar daily variation. The present position can be understood on considerations advanced by Dorman and Feinberg (1958). They have shown that short term variability in the character of solar daily variation is related to certain specific characteristics of solar corpuscular streams, these characteristics being not particularly relevent to the production of overall geomagnetic disturbance. If this be so then the characteristics of corpuscular streams must undergo long term changes to be able to explain the apparent contradiction in the experimental results obtained at different periods of time. This statement is supported by the recent finding of Sandstrom (1959) who has reported that in 1957-1958 there did not exist any distinct relationship between diurnal component of solar daily variation (of nucleonic component of cosmic rays) and K_p of the type he had earlier (Sandstrom, 1955) reported in case of hard component.

4.25 Relationship of solar daily variation with moderate magnetic storms of SC-type.

As we have already seen, the annual mean solar daily variation observed at low ($\lambda = 0^{\circ}$ to $+14^{\circ}$) and at intermediate ($\lambda = +25^{\circ}$) latitudes exhibit certain differences during 1956, 1957 and 1958. This is most clear in the pattern of change undergone by the parameters specifying the diurnal and the semidiurnal components of the solar daily variation. We examine here whether the change that occurs in the solar diurnal variation during SC-type magnetic storms also exhibits any differential features at low and intermediate latitudes. The period July 1957 to December 1958 was selected for this purpose. Firstly, because this period overlaps the one during which a different pattern of change is observed at Gulmarg and at Mt.Norikura compared to low latitude stations of Huancayo and Ahmedabad and secondly because during this period nucleonic and hard component data, of high accuracy, were available from different stations which made it easier to study the energy dependence of changes taking place during magnetic storms.

For the purpose of this analysis, we selected Huancayo and Makerere College to represent equatorial stations and Mt.Norikura and Itabashi to represent intermediate latitude stations. The details about the geographic and geomagnetic coordinates and altitude of the stations, as well as the type of detector working, etc. are summarised in Table 12.

Table 12

Table showing the situation of the stations which have been selected to represent equatorial and intermediate latitudes.

Station	Detector working	Alt. m	λ	f	Geographic longitude.	Vertical cut off rigidity GV.	Error per bi-hour(%) ±
Huancayo	NM	3400	-0.6°	353.8°	W75°20'	13.2	0.18
Makerere	NM MM	1196	-2.0°	101.4°	E32°34'	14.0	0.28 0.25
Mt.Norikura	NM	2770	25.6°	203.6°	E137°33'	10.3	0.15
Itabashi (Japan)	MM	20	25.5°	205.5°	E139°48'	10.3	0.16

NM = Neutron monitor. MM = Meson monitor.

(The information put in this table was taken from the booklet published by National Committe for I.G.Y., Science Council of Japan, Ueno Park, Tokyo)

Only moderately severe SC-type storms (i.e. those storms where the horizontal component of the geomagnetic field was disturbed by more than 25 x 10^{-4} gauss) were selected for this purpose. There were 19 such epochs during the period under study. Three groups were formed as follows.

(i) The solar daily variation in group 0 represents the mean solar daily variation during three days prior to the onset of the SC-type storms. This group is taken to represent quiet day solar daily variation. This assumption is justified because the mean K_p value for days in this group is rather small (K_p = 18).

(ii) The day of onset of the magnetic storm constitutes the epoch day in group I.

(iii) The day of maximum activity of the storm i.e. the day on which greatest value of three hour K-index occurs, forms the epoch day in group II.

The mean parameters specifying the harmonic components of solar daily variation, associated with the three groups, are summarised in Table 13. The mean values of K_p for these groups together with the ratios of disturbed day amplitude to quiet day amplitude for the diurnal $(D/Q)_{r_1}$ and for semidiurnal $(D/Q)_{r_2}$ components are also tabulated alongside. The following features are quite clear.

(1) On the day of onset of storm (group I) the amplitude of the solar diurnal variation in relation to amplitude for quiet days (group 0), increases and its time

Table 13

Table showing the characteristics of mean solar daily variation on days comprising the groups 0, I and II. Mean values of K_p and the ratio of the disturbed day amplitude to quiet day amplitude for diurnal, $(D/Q)_{r_1}$, and for semidiurnal $(D/Q)_{r_2}$ components are also given for each group.

Groups.	$\overline{K}_p$	Nucleonic Component $\overline{r}_1$ %	$\overline{\phi}_1$	$\overline{r}_2$ %	$2\overline{\phi}_2$	$(\frac{D}{Q})_{r_1}$	$(\frac{D}{Q})_{r_2}$		Hard component $\overline{r}_1$ %	$\overline{\phi}_1$	$\overline{r}_2$ %	$2\overline{\phi}_2$	$(\frac{D}{Q})_{r_1}$	$(\frac{D}{Q})_{r_2}$
Huancayo														
0	18	0.22 ± 0.01	$\pi+13^\circ$	0.07 ± 0.01	-27°									
I	41	0.27 ± 0.02	178°	0.07 ± 0.02	47°	1.23 ± 0.09	1.00 ± 0.25							
II	43	0.28 ± 0.02	169°	0.12 ± 0.02	84°	1.27 ± 0.09	1.71 ± 0.33							
Makerere								Makerere						
0	18	0.37 ± 0.02	$\pi+20^\circ$	0.30 ± 0.02	40°				0.21 ± 0.01	172°	0.11 ± 0.01	0°		
I	41	0.43 ± 0.03	151°	0.54 ± 0.03	28°	1.16 ±	1.80 ±		0.37 ± 0.02	114°	0.13 ± 0.02	1°	1.76 ± 0.13	1.18 ± 0.21
II	43	0.37 ± 0.03	157°	0.58 ± 0.03	27°	1.00 ±	1.93 ±		0.37 ± 0.02	113°	0.17 ± 0.02	3°	1.76 ± 0.13	1.55 ± 0.23
Mt.Norikura								Itabashi						
0	18	0.25 ± 0.02	$\pi+26^\circ$	0.07 ± 0.02	8°				0.16 ± 0.01	$\pi+25^\circ$	0.05 ± 0.01	-27°		
I	41	0.40 ± 0.02	$\pi+4^\circ$	0.10 ± 0.02	26°	1.60 ± 0.12	1.43 ± 0.42		0.41 ± 0.02	150°	0.21 ± 0.02	118°	2.51 ± 0.19	4.20 ± 0.89
II	43	0.34 ± 0.02	$\pi+2^\circ$	0.08 ± 0.02	61°	1.36 ± 0.11	1.14 ± 0.38		0.21 ± 0.02	157°	0.14 ± 0.02	24°	1.31 ± 0.13	2.80 ± 0.64

of maximum ($\bar{\phi}_1$) shifts to early hours at all the stations, in conformity with the experience of other workers e.g. Sekido and Yoshida (1950); Dolbear and Elliot (1951); Trumpy (1953); Firor and Fonger (1954); Yoshida and Kondo (1954) and Glokova (1955).

(2) Comparing the parameters defining the diurnal variation of hard component with those defining the diurnal variation of nucleonic component at the same latitude i.e. Makerere hard component versus Makerere nucleonic component and Itabashi hard component versus Mt.Norikura nucleonic component, we see that the percent increase in the amplitude of solar diurnal variation is more in case of hard component than in case of nucleonic component.

(3) Comparing the percent increase in the amplitude of diurnal variation of nucleonic and hard component of cosmic rays in group I we see that the percent increase for both the components of cosmic rays increases as the latitude increases. As indeed, has already been observed by Yoshida and Kamiya (1953).

(4) The amplitude of diurnal variation remains high on the day of maximum activity of the Storm.

(5) Changes in the amplitude of the semidiurnal variation are not very consistent at all the stations and the differences, in most cases, are not statistically significant. In the case of hard component at Itabashi and nucleonic component at Makerere, the amplitude increases

significantly on the day of onset (group I) and remains high on the day of maximum intensity of the storm (group II). For nucleonic component at Huancayo and hard component at Makerere $\bar{r}_2$ is significantly higher on the day of maximum activity of the storm (group II), compared to its value in group O. Whereas in case of nucleonic component at Mt.Norikura no significant change takes place, for all the groups. Also no significant change in the time of maximum is discernible for any of the stations. However, one can very definitely say that the contention of Sekido et al (1951) that the amplitude of solar semidiurnal variation gets reduced on storm days, does not hold during the period studied by the author. Further, though some stations do show increase of amplitude for semidiurnal component with increase in storm activity, the relationship is not unique. Also no significant shift to earlier hours is noticeable in the time of maximum of semidiurnal component at any of the stations. Thus we are unable to support Glokova's (1955) contention either. However, the present evidence together with the earlier results of Sekido et al and Glokova may be taken to imply that no unique and simple relationship exists between the solar semidiurnal variation and SC-type storms.

Again (2) and (3) are apparently contradictory to each other because (2) implies that the amplitude increment for diurnal component is higher, the higher the mean energy of primaries whereas (3) demands just the opposite to hold.

However, these results need not be considered mutually exclusive. As shown by Rao (1959) the variability in diurnal Variation is greater for component responding to lower mean energy of the primaries (nucleonic component). So that there is a large scatter in the times of maxima ϕ_1 (of the diurnal variation) for this component, which results in the mean amplitude $\bar{r}_1$ (of diurnal variation) being very much smaller.

Fig. 28 shows mean solar daily variation for the three groups for nucleonic and hard components recorded at

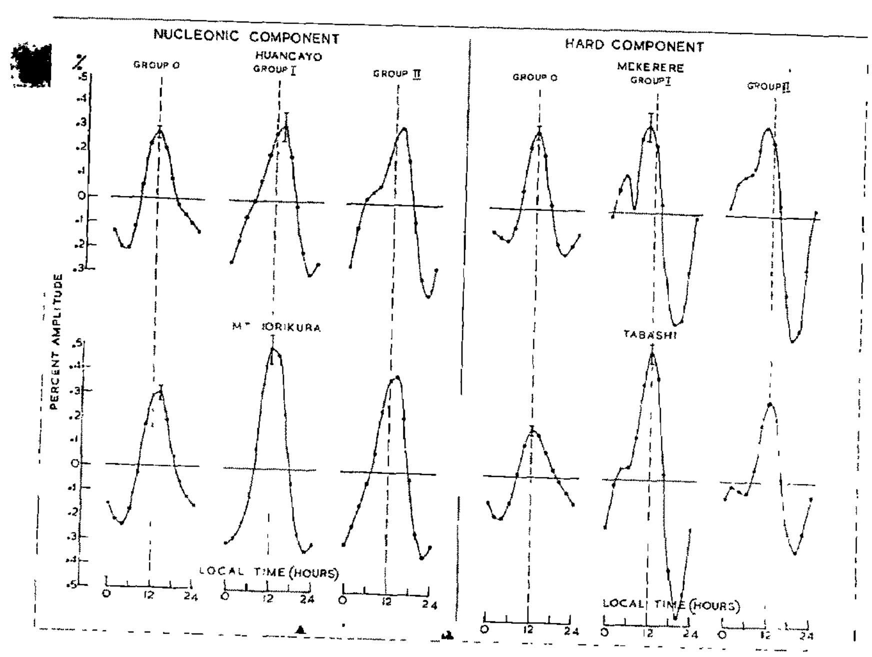

Fig. 28 - Mean solar daily variation of the nucleonic and hard components of cosmic rays for the groups 0, I, II at equatorial and intermediate latitudes.

low and intermediate latitudes. It is clear that at equatorial stations subsidiary maximum appears between 4±2 hours (L.T.) for both nucleonic and hard components on the day of onset of the storm and gains in prominence on the day of maximum activity of the storm (group II). At Mt.Norikura no evidence exists for the appearance of the subsidiary (early hour) maximum for the nucleonic component. However, at Itabashi where hard component is recorded and which is at the same latitude as Mt.Norikura, evidence points to the existence of the subsidiary (early hour) maximum. Thus the subsidiary early hour maximum seems to be associated with higher mean energy of the primaries. However we are unable to grasp the significance of the appearance of this subsidiary maximum and its apparent association with higher mean energy.

4.3 Study of daily mean intensity of cosmic rays

4.31 Correlated changes of daily mean intensity at Ahmedabad and Huancayo.

To test the world wide character of the chief features and general trend in the daily mean intensity during an extended period of time we first examine, in this section, the correlation between the daily mean intensity at Ahmedabad and that at Huancayo. Fig. 29 shows the plot of daily mean intensity at Ahmedabad (I_A) versus the daily mean intensity at Huancayo (I_H) for the common period of operation of neutron monitors at both the places. The correlation coefficient (γ_{AH}), for this common period between I_A and I_H has a value γ_{AH} = 0.7 ± 0.02. The high positive value of correlation coefficient bears testimony to the satisfactory tracking between I_A and I_H. This fact is further confirmed from Fig. 30 which represents

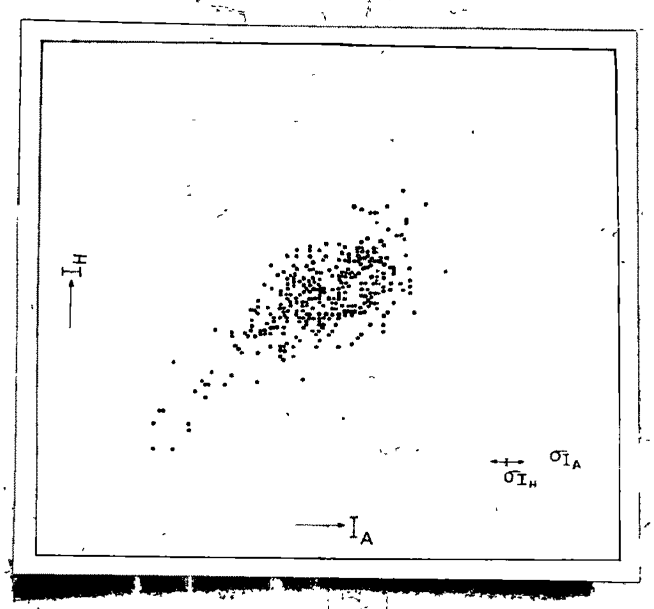

Fig. 29 - The plot of daily mean intensity at Ahmedabad (I_A) versus that at Huancayo (I_H).

a continuous plot of I_A and I_H ; alongside are also plotted the values of C_p on the corresponding days. The daily mean intensity at Mt.Norikura (I_N) measured with a neutron monitor, is also plotted on the same diagram for the sake of comparison. The similarity of prominent features and the parallelism in the general trends at the three stations is quite obvious. The latter figure also reveals that (a) rather large day to day fluctuations of intensity are present at all the three stations, (b) the amplitude of decreases during cosmic ray storms was very much less in 1958 than

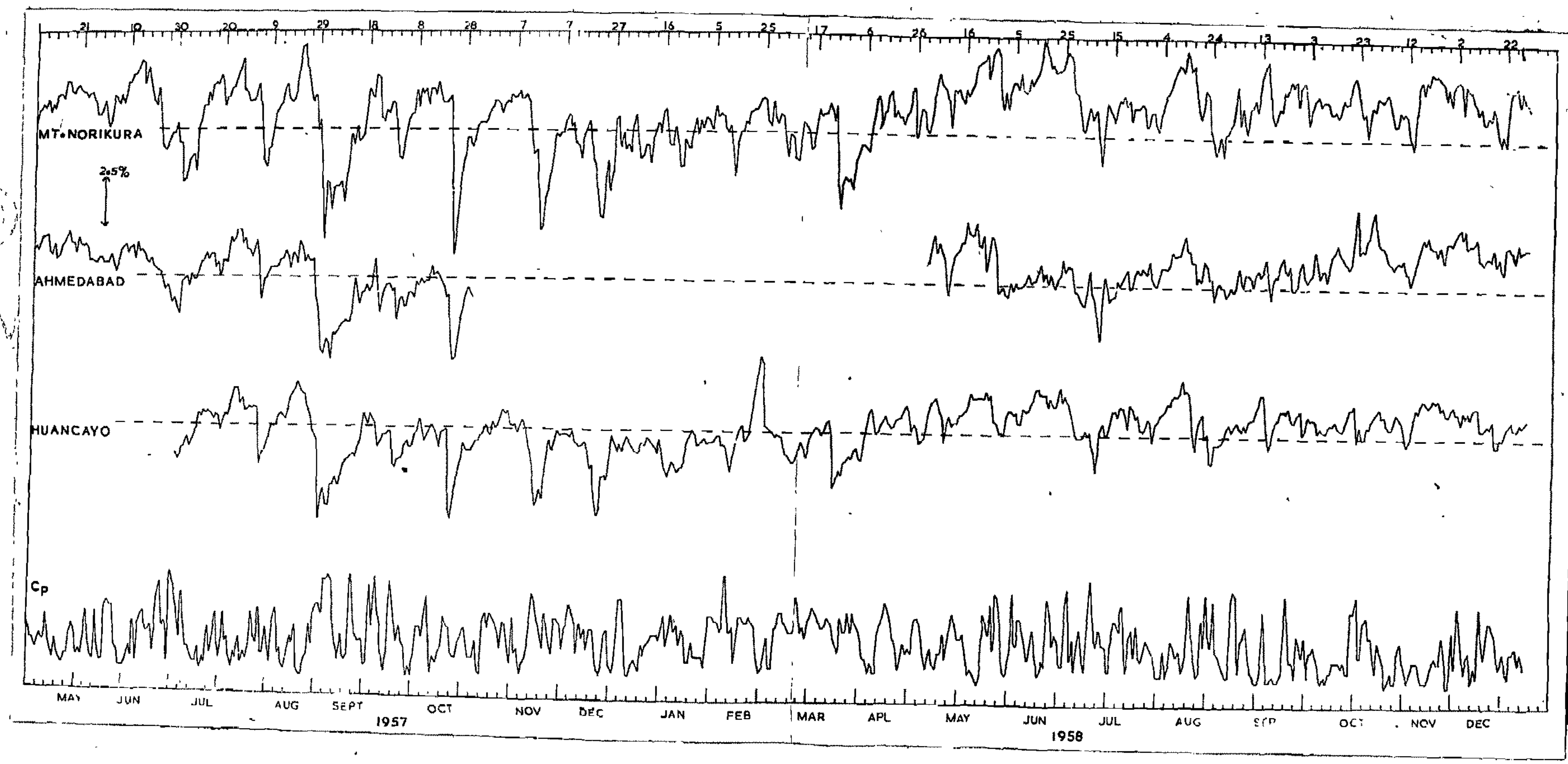

Fig. 30 - Continuous plot of the daily mean intensity at Mt. Norikura, Ahmedabad and Huancayo; alongside are also plotted the values of C_p on the corresponding days.

in 1957, and (c) the general level of daily mean intensity was higher in 1958 compared to that in 1957. This is so despite the fact that solar activity was higher in 1958 than in 1957.

However since the error involved in the determination of I_A is five times that involved in the determination of I_H, it is not possible to undertake a point to point comparison of daily mean intensity curves. Nevertheless we can undertake a study of the broad features of day to day changes in the daily mean intensity at Ahmedabad and Huancayo by considering the deviations (ΔI) of the daily mean intensity from the mean intensity for the entire period of operation at the two places.

4.32 Histograms of the deviations of daily mean intensity at Ahmedabad and Huancayo.

Since we do not have a continuous data for Ahmedabad, two groups were formed for the comparative study of the deviations (Δ I) of the daily mean intensity at Ahmedabad and Huancayo. Group I covers the period May 1957 to October 1957 and group II covers the period May 1958 to December 1958. Fig. 31 shows the histograms(for the two groups of days) grouped according to the magnitude and sign of Δ I for Ahmedabad and Huancayo. The dotted lines indicate limits of twice standard error on positive and negative side. For a deviation, due to sheer chance, to lie outside these bounding lines on either positive or negative side, the probability is only 2.3%. A glance at the figure (31) shows

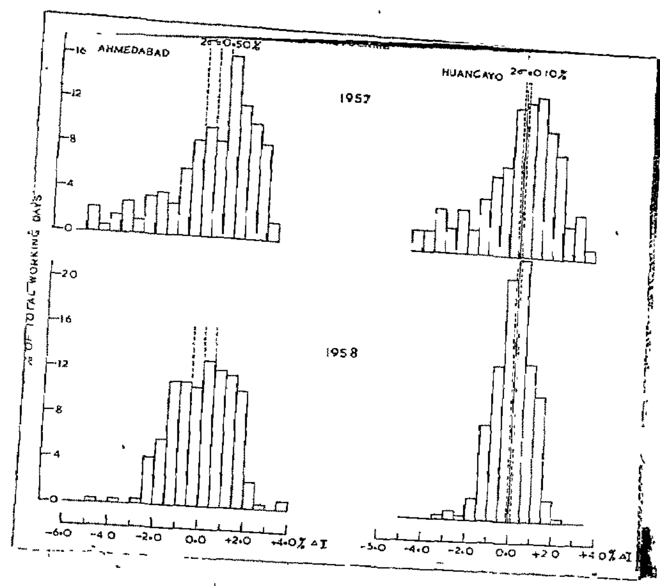

Fig. 31 - Histograms of days grouped according to the magnitude and sign of Δ I, for Ahmedabad and Huancayo.

that the number of deviations lying outside the bounding lines on both positive and negative sides are many times larger than what can be expected through chance. The difference between the histograms for 1957 and 1958 is therefore very real. The striking similarity between the histograms for Ahmedabad and Huancayo, during each year, is obvious. The chief features are (i) the histograms in 1957 (group I) at both Huancayo and Ahmedabad are skew towards negative values indicating the presence of more negative values than positive ones, and (ii) the histograms in 1958 (group II) are however almost symmetrical about the neutral line.

We have seen earlier that during the latter half of 1957 there were a large number of cosmic ray storms involving sudden and large depressions of daily mean intensity. The unsymmetrical histograms during 1957 which exhibit a bias towards the negative deviations and the more symmetrical histograms during 1958 are therefore understandable.

4.33 Representation of day to day changes of daily mean intensity at low and middle latitudes.

We have already seen in the preceding sections that the general trend as well as the prominent features involved in the day to day changes of daily mean intensity at Ahmedabad and Huancayo are similar over the common period of operation. However since the statistical error of experimental determination of daily mean intensity at Ahmedabad is much larger than that at Huancayo, we propose to use the daily mean intensity at Huancayo as being indicative of the trends and changes in the daily mean intensity of cosmic rays at low latitudes ($\lambda = 0^{\circ}$ to $+14^{\circ}$). Of course it is realised that because of altitude of Huancayo being higher ($\sim$3400 m) compared to Ahmedabad (sea level) and the vertical cut off due to geomagnetic field being lower at the former ($\sim$13 GV/c) compared to that at latter ($\sim$ 14 GV/c), Huancayo neutron monitor has a response to a somewhat lower mean energy of primaries as compared to the response of the neutron monitor at Ahmedabad. However the difference between the mean energy response of the detectors at Ahmedabad and Huancayo is insignificant compared to the difference between the mean energy of primaries arriving at the equatorial and middle ($\lambda = +50^{\circ}$) latitudes. In what follows we would, therefore, use Huancayo daily mean intensity of nucleonic component to be indicative of changes in high energy primaries (mean energy $\sim$ 40 GV) and the daily mean intensity of nucleonic component at Climax ($\lambda = +52^{\circ}$, alt. $\sim$ 3400 m) as indicative of changes in low energy part of the primary spectrum (mean energy of primaries in this case being $\sim$ 7 GV).

4.34 Elimination of the influence of long term changes from the day to day changes of intensity at low and middle latitudes.

We have already seen that the daily mean intensity of the nucleonic component besides being subject to day to day fluctuations, is also effected by CRS and other long period changes e.g. 11 year cyclic change et c. So that when it is desired to study the finer details of day to day changes of intensity, it is most desirable to remove as far as possible the influence of long term changes from the daily mean intensity. To a first approximation, the method of moving averages can be used to achieve this purpose. We took moving averages over fifteen successive days and found [redacted] the deviation (ΔI^*), for a particular day, of the daily mean intensity (I) from its moving average value (I*) centred at the same day. The deviations (ΔI^*) are therefore, largely, rid of the changes in daily mean intensity with a period longer than fifteen days. However, any change having a period of less than fifteen days would not be eliminated by such a process. Besides, the transient decreases taking place during CRS continue to show up in ΔI^*, though to a lesser extent than before. The daily mean intensity of the nucleonic component recorded at Huancayo as well as at Climax were processed as above and the deviations ΔI_H^* and ΔI_C^* - largely freed of long term changes - were obtained for the two respective places. ΔI_H^* and ΔI_C^* were then expressed in percentages by dividing these deviations by the mean over the year and multiplying the fraction by 100.

These long term corrected percent deviations would be used, in the following section, to study the correlated changes of solar daily variation and daily mean intensity of cosmic rays at low latitudes

4.4 Correlated changes of daily mean intensity and solar daily variation at low latitude stations

Sarabhai and Bhavsar (1958), from their study of hard component data obtained with narrow angle telescopes at Ahmedabad and covering the year 1956, showed that days having maximum, for solar daily variation, in the night (n-type) were associated with low mean intensity whereas those having maximum in the day time (d-type) were associated with daily mean intensity significantly above the average value for the total period of operation. They suggested that it was possible to separate epochs of high and low daily mean intensity by picking days of 'n' and 'd' type respectively. Clearly the classification is rather too broadbased, particularly in view of the fact that the time of maximum of both 'd' and 'n' type days undergoes a long term change as pointed out by the authors of the above paper, themselves. It was therefore necessary to refine the criteria still further. Sarabhai and Satyaprakash (1959) suggested that the refinement of the criteria was possible if individual bihourly intensity on a particular day were to be studied in conjunction with daily mean intensity for the day. Analysing their data obtained at Kodaikanal with a neutron monitor during 1957, they showed that there did exist correlated changes between the magnitude of the bihourly intensity centred at particular hours and the daily mean intensity. Specifically, they presented evidence which indicated that the magnitude of negative deviation at 0600 hours (L.T.) at Kodaikanal was an index of increases in daily mean intensity on a day to day basis. They demonstrated at a reasonable level of statistical significance that increasing magnitude of negative deviation at 0600 was associated with increasing daily mean intensity which, on the basis of the arguments similar to the ones first advanced by van Heerdan and Thambyahpillai (1955), means that increases of intensity are involved. Similarly they also showed that increasing magnitude of negative deviation at 2200 hours (L.T) was associated with decreasing mean intensity, which on the basis of the argument similar to the one cited above implies that negative deviation at 2200 hours is associated with decreases in daily mean intensity on a day to day basis.

In the interpretation of the variations of the intensity of cosmic rays, one of the crucial aspects, which various workers have relentlessly sought to establish is whether the variations involve only decreases or increases, or decreases as well as increases. Apart from the earlier view of Simpson et al (1952, 1955) and Kodama and Murakami (1956) who interpreted the evidence obtained by them as being indicative of the fact that increases of intensity are sometimes observed, the most prevelent view has been that only decreases of intensity take place e.g. see van Heerdan and Thambyahpillai (1955), Brown (1956), Dorman (1957) Neher (1958), Kuzmin (1959) etc.

The study presented below was undertaken with a view to confirm whether the increases of daily mean intensity associated with correlated changes of solar daily variation (as envisaged by Sarabhai et al, 1958, 1959) occur on a world-wide basis. As has been shown by us earlier (Secs. 4.21, 4.22) the changes occurring in the form of daily variation are most conspicuous at low latitudes and hence the nucleonic component data from low latitude stations of Ahmedabad, Kodaikanal, Huancayo and Makerere has been used. The analysis was confimed to the year 1958. This was done because this year was comparatively free from the disturbing influences of CRS etc. Further, since Sarabhai and Satyaprakash (1959) had indicated the particular relevance of negative deviations centred at 0600 and 2200 hours (L.T.) at Kodaikanal, we have confined our attention only to the study of negative deviations. Thus the deviations centred at 0000, 0200, 0400, 0600, 0800 and 1800, 2000, 2200 hours (local time) were considered for all the four selected stations. These deviations were next classified into three groups (I, II, III) defined by the limits : $0 > x^- \geq -\sigma$, $-\sigma > x^- \geq -3\sigma$ and $x^- < -3\sigma$, where x is the hour of centering of the bihourly deviation and σ is the standard error associated with the magnitude of the bihourly deviation. $0 > x^- \geq -\sigma$ is to be read as : the magnitude of the negative deviation centred at the hour x lies within the limits 0 to $\geq -\sigma$. The average magnitude $(\bar{x^-})$ of negative bihourly deviation centred at the hour x and confined within the limits that define the three groups (I, II, III) were then found. The mean value $(\overline{\Delta I_H^*})$ of ΔI_H^*, representing the deviations of daily mean intensity from a 15-day sliding mean,† for low latitude stations were next found separately for days in each of the three groups. Only these bihourly deviations were finally selected for each station for which a pronounced and a systematic change of $(\overline{\Delta I_H^*})$ with increasing magnitude of the negative deviation $(\bar{x}^-)$ centred at the hour x occurred. The negative bihourly deviations which were finally selected for the various stations are : 0600, 2000 hours for Ahmedabad, 0600 and 2200 for Kodaikanal, 0400, 0000 hours for Huancayo and 0400 and 1800 hours for Makerere - all hours refer to local time at respective stations.

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† For brevity ΔI_H^* would be referred to as the daily mean intensity at low latitude stations.

In Table 14 are given the average magnitudes of the negative bihourly deviations associated with 0600 hours at Ahmedabad and Kodaikanal and 0400 hours at Huancayo and Makerere corresponding to the three groups. Alongside are also tabulated the values of $\overline{\Delta I_H^*}$ obtained by averaging ΔI_H^* over the corresponding days for each station. Fig. 32 shows a plot of $\overline{\Delta I_H^*}$ versus $\bar{x}^-$ for each station. The following features are clear.

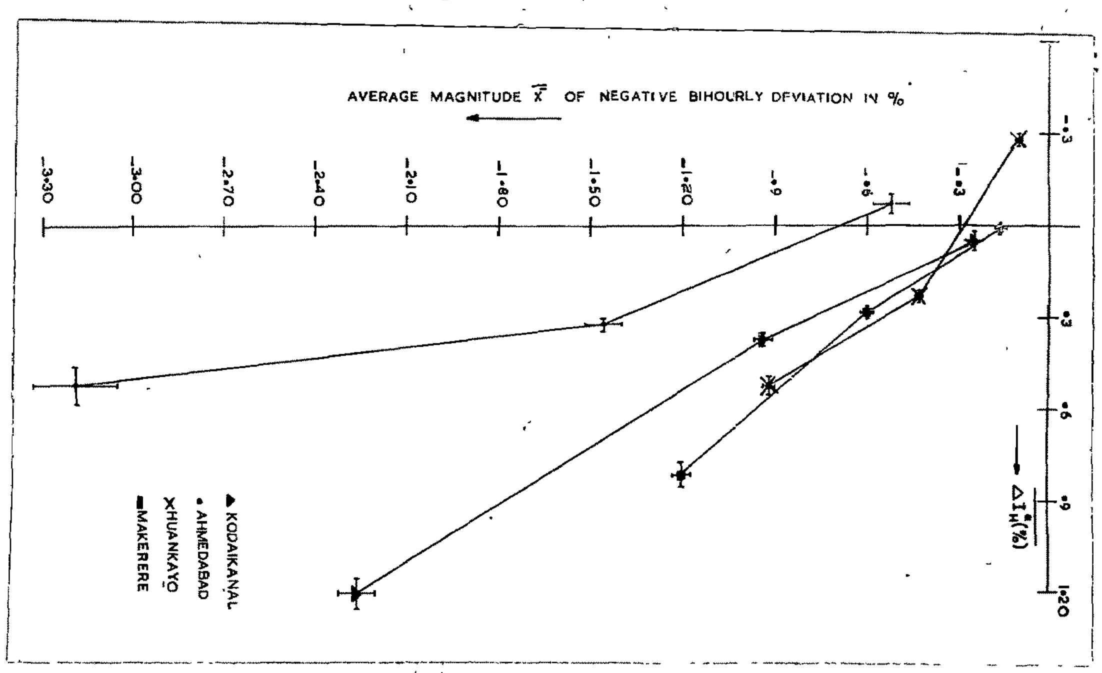

Fig. 32 - A plot of $\overline{\Delta I_H^*}$ versus the average magnitude $(\bar{x}^-)$ of negative deviation centred at 0600 hours for Ahmedabad and Kodaikanal and 0400 hours for Huancayo and Makerere.

(1) Increasing magnitude of the negative deviations centred at 'appropriate' hours for all the four stations, is accompanied by increase in the daily mean intensity.

(2) The relationship between $\overline{\Delta I_H^*}$ and $\bar{x}^-$ is not exactly linear.

Table 15

Table showing the relationship between $\overline{\Delta I_H^*}$ and increasing magnitude of negative deviation $(\overline{x}^-)$ centred at the hour 0600 for Ahmedabad, 0600 for Kodaikanal, 0400 for Huancayo, and 0400 for Makerere.

Station	Hr. of centring (L.T.)	Group III No.of days.	Group III $\overline{x}^-$ %	Group III $\overline{\Delta I_H^*}$ %	Group II No.of days	Group II $\overline{x}^-$ %	Group II $\overline{\Delta I_H^*}$ %	Group I No.of days	Group I $\overline{x}^-$ %	Group I $\overline{\Delta I_H^*}$ %
Ahmedabad	0600	10	-3.20±0.14	0.52±0.06	65	-1.46±0.06	0.32±0.02	57	-0.52±0.06	-0.07±0.03
Kodaikanal	0600	18	-2.18±0.06	1.20±0.05	77	-0.94±0.03	0.37±0.02	63	-0.25±0.03	0.05±0.03
Huancayo	0400	34	-0.92±0.02	0.52±0.03	95	-0.43±0.01	0.23±0.02	98	-0.10±0.01	-0.28±0.02
Makerere	0400	28	-1.21±0.03	0.81±0.04	112	-0.60±0.02	0.28±0.02	102	-0.16±0.02	0.01±0.02

Table 16

Table showing the relationship between $\overline{\Delta I_H^*}$ and increasing magnitude of negative deviation $(\overline{x}^-)$ centred at the hours 2000 for Ahmedabad, 2200 for Kodaikanal, 0000 for Huancayo and 1800 for Makerere.

Station	Hr. of centring (L.T.)	Group III No.of days.	Group III $\overline{x}^-$ %	Group III $\overline{\Delta I_H^*}$ %	Group II No.of days.	Group II $\overline{x}^-$ %	Group II $\overline{\Delta I_H^*}$ %	Group I No.of days.	Group I $\overline{x}^-$ %	Group I $\overline{\Delta I_H^*}$ %
Ahmedabad	2000	3	-3.43±0.26	-1.63±0.11	41	-1.61±0.07	0.08±0.03	67	-0.46±0.06	-0.05±0.03
Kodaikanal	2200	18	-1.93±0.06	-0.74±0.05	65	-0.98±0.03	-0.05±0.02	61	-0.28±0.03	-0.08±0.03
Huancayo	0000	31	-0.87±0.02	-0.91±0.03	97	-0.42±0.01	0.05±0.02	81	-0.09±0.01	0.13±0.02
Makerere	1800	16	-1.18±0.04	-1.72±0.05	99	-0.60±0.02	-0.04±0.02	91	-0.14±0.02	0.14±0.02

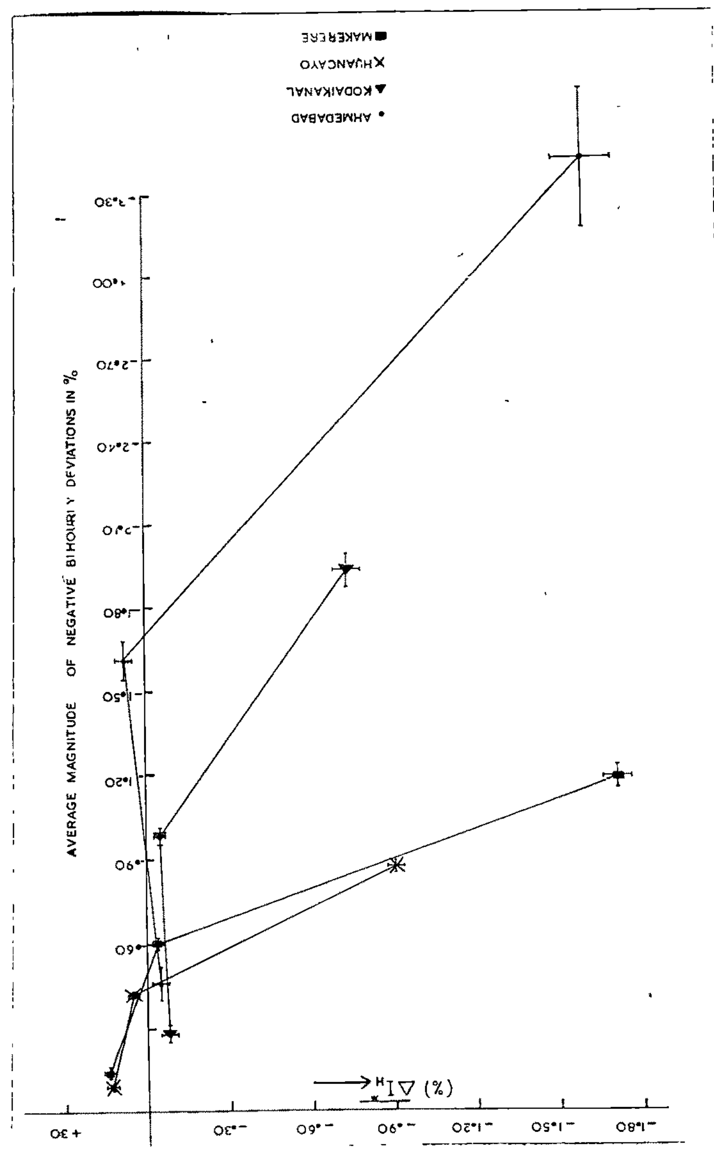

Fig. 33 - A plot of $\overline{\triangle I_H^*}$ versus the average magnitude ($\bar{x}^-$) of negative deviations centred at 2000 hours for Ahmedabad, 2200 hours for Kodaikanal, 0000 hours for Huancayo and 1800 hours for Makerere, (All hours refer to local time).

In Table 15 are given the average magnitudes ($\overline{x}^-$) of the negative bihourly deviations associated with 2000 hours at Ahmedabad, 2200 hours at Kodaikanal, 0000 hours at Huancayo and at 1800 hours at Makerere. Alongside are tabulated the values of $\overline{\Delta I_H^*}$ obtained by averaging ΔI_H^* over the corresponding days for each station. Fig. 33 shows a plot of $\overline{\Delta I_H^*}$ versus $\overline{x}^-$ for each station. The following features are seen.

(1) Increasing magnitude of the negative deviations centred at 'appropriate' hours for all the four stations is accompanied by decrease in the 'daily mean intensity'.

(2) At all the four stations the intensity changes very little in going from group I to group II and then a rather rapid fall takes place in the 'daily mean intensity', in going from group II to group III. This suggests that there is a certain threshold in the magnitude of $\overline{x}^-$ of the average negative deviations centred at the appropriate hours (for each station) upto which the daily mean intensity $\overline{\Delta I_H^*}$ does not change very much with increasing $\overline{x}^-$ but beyond the threshold, an appreciable fall in intensity takes place with further increase of $\overline{x}^-$.

We thus see that for each of the four stations selected, there are two appropriate hours, the change of magnitude of significant negative bihourly deviations centred at which is directly related to the changes in the level of daily mean intensity. For one of these hours i.e. 0600 hours at Ahmedabad, 0600 hours at Kodaikanal, 0400 hours at Huancayo and 0400 hours at Makerere, the increasing magnitude of the negative bihourly deviation is accompanied by increasing level of 'daily mean intensity.' While for the other hour i.e. 2000 hours at Ahmedabad, 2200 hours at Kodaikanal, 0000 hours at Huancayo, 1800 hours at Makerere, the increasing magnitude of the negative bihourly deviation is accompanied by decreasing level of the 'daily mean intensity.' The former appropriate hour (for each station) is, therefore, associated with day to day increases in daily mean intensity whereas the magnitude of negative bihourly deviation centred at the latter appropriate hour (for each station) is related to the day to day decreases of daily mean intensity. Further, as we shall show in the following section, the correlated changes of the form of solar daily variation (as reflected by the changes in the magnitude of negative bihourly deviation centred at appropriate hours) with changes in the level of the daily mean intensity occur at different stations mostly on same days. This fact, in turn, points to the world-wide nature of the correlated changes of the form of solar daily variation and the daily mean intensity of cosmic rays.

From the foregoing discussion it is clear that world-wide changes of intensity involving increases and decreases take place on a day to day basis. Also there exist 'appropriate' hours (L.T.) for each station, the magnitudes of negative deviations centred at which are sensitive to such increases and decreases. Further in case of decreases, there exists a certain threshold which must be exceeded by the magnitude of negative bihourly deviations centred at the appropriate hour for each station, before any noticeable change can take place in the daily mean intensity.

4.41 Solar terrestrial relationships of day to day increases and decreases.

The association of world wide day to day increases and decreases in the daily mean intensity with the magnitude of negative bihourly deviations centred at 'appropriate' hours makes it possible to separate the days on which increases and decreases occur by using the large negative b bihourly deviation centred at the 'appropriate' hours for each station. All that one has to do is to pick out days on which the magnitude of negative bihourly deviations, centred at the 'appropriate' hours, is significant at 2 level of significance. The days selected on this basis would however involve some days (precisely speaking 2.3% of the total working days) which are spurious in the sense that the larger magnitudes of the negative deviations at the 'appropriate' hours on these days, may arise due to chance alone. Table 16 gives the total epochs (during which data were available) for each station for increases and decreases during 1958. Table also gives the number of epochs to be expected out of random fluctuations of the magnitude of negative deviations centred at 'appropriate' hours for each station. It is quite obvious that total number of epochs

Table 16

Table showing the total number of epochs involving increases and decreases along with the number of events to be expected out of chance alone.

Station	Increases		Decreases	
	Total No.of epochs.	No.of epochs due to chance.	Total No.of epochs.	No. of epochs due to chance.
Ahmedabad	22	5	14	5
Kodaikanal	45	6	43	6
Huancayo	74	8	69	8
Makerere	70	8	53	8

are many times greater than those expected due to chance causes.

Fig. 34a and 34b show, on Bartel's carpets, the distribution of days on which increases and decreases respectively take place at all the four low latitude stations. A study of the two diagrams reveals that (a) increases and decreases occur on groups of days which recur and (b) increases and decreases are associated, on a world-wide basis; in the sense that, they occur within ±1 day at all the four stations, in most of the cases.

To bring out the recurrence tendency more clearly and to study other correlated changes, epochs were selected separately for increases and decreases, such that the increases or decreases were simultaneously present at, at

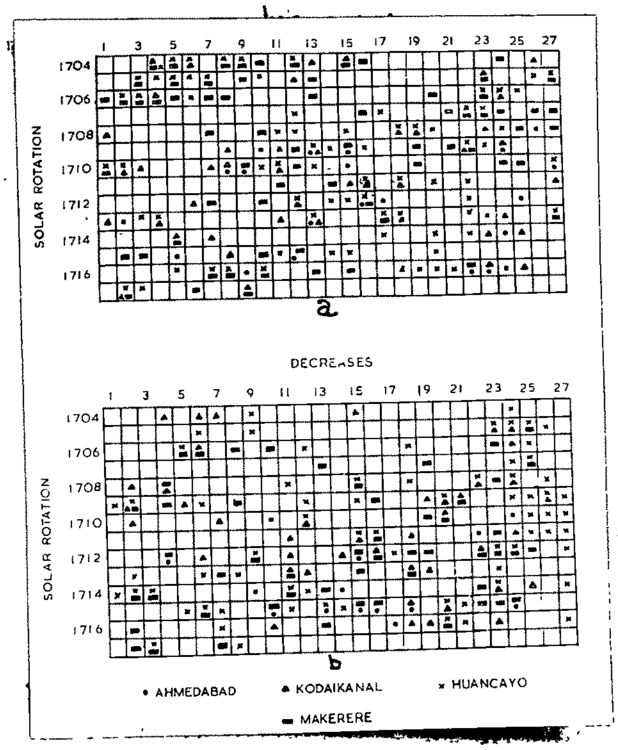

Fig. 34a - The distribution of days on which increases take place at Ahmedabad, Kodaikanal, Huancayo and at Makerere.

Fig. 34b - The distribution of days on which decreases take place at Ahmedabad, Kodaikanal, Huancayo and at Makerere.

least, two stations. Epochs selected on increases constitute group A and those selected on the basis of decreases constitute group B; there were 47 and 41 epochs in the two groups respectively. Table 17 gives the dates on which epochs corresponding to groups A and B occurred. The dates common to the two groups are marked with asterisks. We see that there are only four dates common to the two groups. This fact clearly points out that the epochs in the two groups are mutually exclusive.

These epochs were next used as 0-days for chree

Table 17

Table giving the dates on which epochs corresponding to group A (increases) and groupB(decreases) occurred.

Group A		Group B	
2-1-58	10- 6-58	17-2-58*	26- 8-58
3-1-58	11- 6-58	18-2-58	9- 9-58
4-1-58	17- 6-58	19-2-58	16- 9-58*
6-1-58	18- 6-58	26-2-58	27- 9-58
7-1-58	20- 6-58	27-2-58	28- 9-58
13-1-58	6- 7-58	14-4-58	6-10-58
28-1-58	22- 7-58*	20-4-58	18-10-58
30-1-58	24- 7-58	1-5-58	28-10-58
1-2-58	14- 8-58	8-5-58	1-11-58
17-2-58*	18- 8-58*	10-5-58	4-11-58
21-2-58	2- 9-58	15-5-58	6-11-58
23-2-58	11- 9-58	2-6-58	7-11-58
24-2-58	15- 9-58	3-6-58	9-11-58
25-2-58	16- 9-58*	8-6-58	11-11-58
16-3-58	25- 9-58	21-6-58	15-11-58
17-3-58	30- 9-58	29-6-58	8-12-58
11-4-58	3-11-58	21-7-58	18-12-58
12-4-58	25-11-58	22-7-58*	
4-5-58	26-11-58	6-8-58	
5-5-58	28-11-58	11-8-58	
26-5-58	10-12-58	17-8-58	
28-5-58	11-12-58	18-8-58*	
4-6-58	17-12-58	24-8-58	
6-6-58	24-12-58	25-8-58	

analysis of daily mean intensity at Huancayo representing low latitude station (denoted by $\triangle I_H^*$) and at Climax representing a middle latitude station (denoted by $\triangle I_C^*$). The analysis extended from -5 to +31 days and the resultant time series of $\overline{\triangle I_H^*}$, $\overline{\triangle I_C^*}$ along with those of $\bar{C}_p$ and

$-\frac{1}{I}\ \frac{d(\overline{\Delta I_H^*})}{dt}$, for the groups A and B are plotted respectively in Fig. 35a and 35b. $-\frac{1}{I}\ \frac{d(\overline{\Delta I_H^*})}{dt}$ represents the rate of change of intensity from day to day and as has been shown by Alfven (1954) the magnitude of this quantity is directly proportional to the magnitude of the electric field in the solar corpuscular stream.

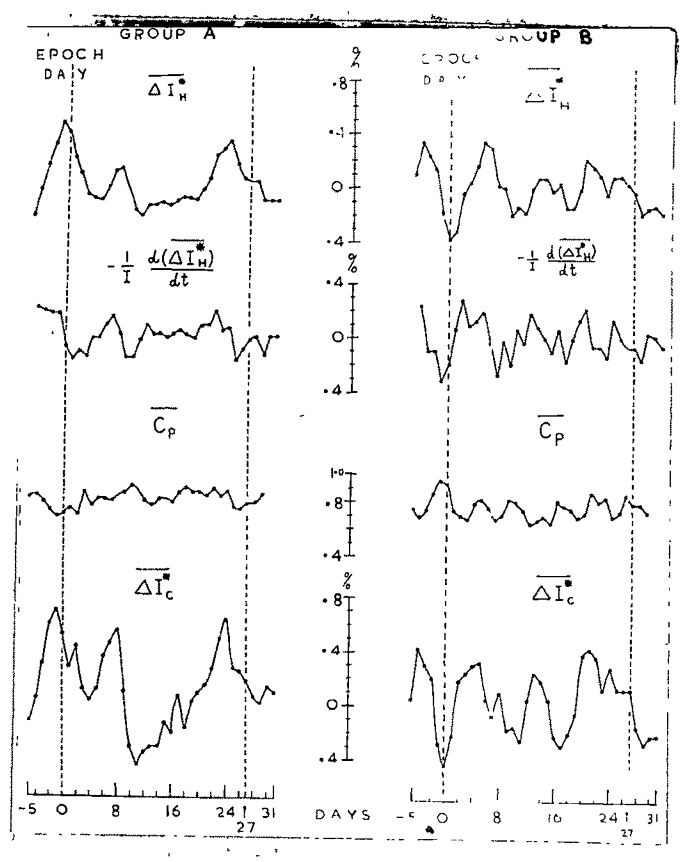

Fig. 35a. - Plot of the time series of $\overline{\Delta I_H^*}$, $\overline{\Delta I_C^*}$,
35b - $\overline{C_p}$ and $-\frac{1}{I}\ \frac{d(\overline{\Delta I_H^*})}{dt}$ for the groups A and B.

From figure 35a for increases (group A) the following features are seen.

(a) The daily mean intensity is maximum on a day prior to the epoch both at low ($\overline{\triangle I_H^*}$) and at middle latitudes ($\overline{\triangle I_C^*}$).

(b) $-\frac{1}{I}\frac{d(\overline{\triangle I_H^*})}{dt}$ is high one day prior to the epoch and is also high on the day when two subsequent pips occur in the $\overline{\triangle I_H^*}$ time series,. This suggests the association of these increases with the electric field of a solar corpuscular stream. Unfortunately, we cannot really examine the details of the implications of this suggestion e.g. fixing the direction of magnetic field frozen into the stream, the direction of the electric field etc. because of the nonavailablity of proper data which could have enabled us to unambiguiously, locate the position of the corpuscular stream with respect to the earth on the epoch day. As is clear from figure 35a the changes in C_p are not really very expressive. $C_p = 0.83$, four days prior to the epoch day and on the epoch day its value is given by $C_p = 0.69$. The latter value of C_p, perhaps, indicates that the earth is not located within the corpuscular stream on the epoch day. But it is not clear whether $C_p = 0.83$ can be considered high enough to associate it with the presence of the stream.

(c) The recurrence tendency of the increases is also obvious, the period being 25 days, This suggests that increases are related to corpuscular streams which have their origin in low heliolatitudes.

(d) A point to point comparison of the time series of

$\overline{\triangle I_H^*}$ with that of $\overline{\triangle I_C^*}$ reveals that all the features exhibited by $\overline{\triangle I_H^*}$ time series are present in $\overline{\triangle I_C^*}$ time series, only they are magnified in the latter. Ratios of 1.5 and 2.0 are obtained when the amplitudes of the primary and recurrent increases in $\overline{\triangle I_C^*}$ time series are compared with the amplitudes of the corresponding features in $\overline{\triangle I_H^*}$ time series. This fact points to the acute latitude dependence of increases.

From figure 35b for decreases (groups B) the following facts are clear.

(e) The daily mean intensity is minimum on epoch day at both low ($\overline{\triangle I_H^*}$) and middle latitude ($\overline{\triangle I^*_C}$) but is high four days prior to epoch.

(f) $-\frac{1}{I}\frac{d(\overline{\triangle I_H^*})}{dt}$ is rather high four days prior to the epoch after which it gets reduced rapidly and reaches a minimum on a day prior to the epoch day.

(g) C_p is lower (C_p = 0.58) four days prior to theepoch, after which it increases sharply and reaches a maximum value (C_p = 0.96) one day prior to the epoch. Thereafter it rapidly deminishes. Further the time series of C_p are rather zigzag.

(h) Comparing $\overline{\triangle I_H^*}$ time series with those of $\overline{\triangle I_C^*}$ time series, we see that the chief features are common to the two curves; only they are more magnified in $\overline{\triangle I_C^*}$ time series. Ratios varying from 1.0 to 2.0 are obtained when the amplitudes of the prominent depressions in $\overline{\triangle I_C^*}$ time series are compared with those in $\overline{\triangle I_H^*}$ time series. This fact is indicative of the latitude dependence of day to day decreases.

(i) Neither of the time series of $\overline{\triangle I_H^*}$, $\overline{\triangle I_C^*}$, $\bar{C}_p$, $-\frac{1}{I}\frac{d(\overline{\triangle I_H^*})}{dt}$ exhibit any distinct and smooth pattern of change at all. This fact points to the extremely disturbed geomagnetic and interplanetary conditions. Because of this reason it is not possible to determine the recurrence period, if any, for the decreases.

(e), (f) and (g) are suggestive of the fact that decreases are caused by solar corpuscular stream approaching the earth from the left of the earth-sunline. These streams actually engulf the earth (giving minimum value of $-\frac{1}{I}\frac{d(\overline{\triangle I_H^*})}{dt}$ and maximum value of C_p) a day prior (on the average) to the epoch day. On the epoch day the earth is still within the stream. Since $\overline{\triangle I_H^*}$ remains depressed for one day only, the average period for which the hard core of the stream envelopes the earth is only one day. The fact that the intensity rises rather gradually taken together with the fact that C_p falls rather rapidly, after the epoch day, indicates that the stream has associated with it a peripheral, less tenuous, portion which is spread out over a large extent. So that after the hard core of the stream passes away (after one day) the compression on the geomagnetic field is relieved, (so that C_p returns to normal value), but the bulk of low energy primaries are still kept away so that the recovery of daily mean intensity is rather slow.

We thus see that world-wide increases and decreases, observed on day to day basis, do bear a causal relationship with the solar corpuscular streams. Some evidences (see (b), (c) above) presented above seem to suggest that increases are caused by streams which originate in low heliolatitudes. Further we have seen above, that whereas increases are primarily caused by electric field, the decreases are subject to both electric field and the magnetic field frozen into the stream.* This essential difference might be related, in an important manner, with the cause of the fact that, in their association with the magnitude of negative bihourly deviations centred at appropriate hours, the decreases exhibit a prominent 'threshold' (see Fig. 34b). We are, however, unable to understand, at the moment, the fact how these increases and decreases happen to be associated with the magnitude of negative bihourly deviations centred at 'appropriate' hours. Further detailed studies are necessary, along the line suggested here, to clarify this issue.

4.5 Solar flare of February 23, 1956.

At the time of this giant flare Gulmarg was about to enter the 0900 hours impact zone. The chief features of the observed flare type increase are described in the reprint attached herewith.

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* When the earth is within the stream the influence of the frozen-in magnetic field assumes great importance.

SOLAR FLARE EFFECT ON THE COSMIC RAY MESON INTENSITY AT GULMARG

BY

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SOLAR FLARE EFFECT ON THE COSMIC RAY MESON INTENSITY AT GULMARG

COSMIC ray meson telescopes have been in operation at Gulmarg, Kashmir (altitude 9,000 ft., geomagnetic latitude 23° 5′ N.) for the last few months at the field station of the Physical Research Laboratory, Ahmedabad. Each telescope measures a triple coincidence rate of 3 G.M. counters each of length 2 ft. and diameter 1½ in. The separation between the counters and their orientation are such that the semi-angles of each telescope in the east-west and north-south planes are 5° and 56° respectively. About 8 cm. of lead are interposed in between.

On 23rd February 1956, there was a big solar flare of magnitude 3. The flare was associated with increase in cosmic ray intensity at various latitudes and numerous reports have appeared from observing stations all over the world. Sarabhai *et al.*[1] have reported an average increase of 6% at Trivandrum, Kodaikanal and Ahmedabad during the hour following the flare. At the time of the solar flare, three telescopes were in operation at Gulmarg. The rate of each telescope was only about 700 counts per hour and the standard deviation was rather large (about 4%). It was observed, however, that all the three telescopes recorded increases in cosmic ray intensity on 23rd February 1956. To reduce the statistical errors, data from the three telescopes have been combined and the hourly values for the period February 21-25 have been plotted in Fig. 1 (*a*). In spite of the large fluctuations in the ground level of cosmic ray intensity, an increase of about 10% (± 2%) is clearly seen during the interval 8 a.m. to 12 noon on 23rd February. Fig. 1 (*b*) gives the moving averages of the hourly values of cosmic ray intensity for three consecutive hourly values, the average thus centred at the middle hour. The increase on the morning of 23rd February stands out prominently in Fig. 1 (*b*). Its magnitude is about 8% (± 1%) and the hour of onset of cosmic ray increase seems to be about 10 a.m. (± 1 hr.). No corrections of any kind have been applied to the data.

The implications of increases of this type at stations in low latitudes have already been discussed by Sarabhai *et al.*[1] Forbush[2] has since reported a 18% increase of ionisation at Huancayo which is almost on the geomagnetic equator but was outside the impact zone at the time of occurrence of the flare on 23rd February 1956. He has also reported a 50% increase in ionisation at the high latitude station of Godhavn (Geomagnetic latitude 80° N.). There is, therefore, a complicated mechanism for storage and scattering of cosmic primaries

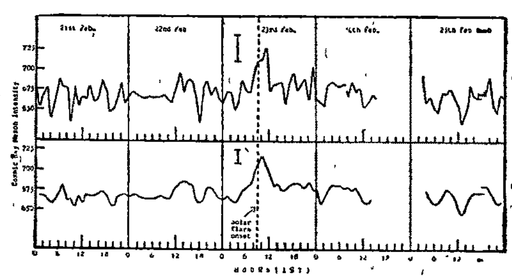

FIG. 1. Hourly values of cosmic ray meson intensity for the period 21-25 Feb. 1956.

(*a*) Actual values. (*b*) Moving averages over three consecutive hourly values.

of solar origin and the estimate of the mean energy and yield of the primaries made by Sarabhai *et al.*[1] would require re-examination.

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Physical Res. Lab., H. S. AHLUWALIA.
Ahmedabad, *February* 13, 1957.

1. Sarabhai, V., Duggal, S. P., Razdan, H. L. and Sastry, T. S. G., *Proc. Indian Acad. Sci.*, 1956, 43, 309.
2. Forbush, S., "Collection of cosmic ray, solar ionospheric and magnetic data relating to the solar cosmic ray burst of 23rd February 1956," by H. Elliot and T. Gold.

4.6 CONCLUSIONS

The principal conclusions of the present study are :

(1) The change in the annual mean solar daily variation from 1956 to 1958, at equatorial stations, involves a shift of the time of maximum of the diurnal component of solar daily variation to later hours and this change is apparently independent of geomagnetic activity and could be observed with meson telescopes as well as neutron monitors. At intermediate latitudes, however, there did not take place any noticeable year to year change during the same period.

(2) The annual mean solar diurnal variation averaged over 1956 and 1957 at Gulmarg is consistent with the view that this variation arises due to an anisotropy of the primary cosmic rays.

(3) The evidence presented by Sarabhai and Bhavsar (1958) and Sarabhai and Satyaprakash (1959) regarding the correlated changes of solar daily variation and day to day changes of daily mean intensity may now be regarded to have been confirmed, at least in the case of low latitude stations. When this evidence is taken together with the evidence presented by Simpson et al (1952, 1955), Kodama and Murakami (1956), Lockwood (1958), Yoshida and Wada (1959) and Sarabhai and Palmeira (1959), all of which favour the existence (at

some periods) of increases in cosmic ray intensity that are not related to solar flare type increases, one is led to believe that (broadly speaking) there are two types of such increases :

(a) prestorm type transient increases which may be related to the magnetic field in the shock fronts of moving plasma; and

(b) day to day increases which are related to the electric field associated with the solar corpuscular streams carrying magnetic fields frozen into them.

The increases correlated with the magnitude of negative bihourly deviations in the early morning hours which are studied in this thesis, belong to the category (b) above.

However, the magnitude of such effects is rather small and the most fruitful course of future research appears to lie in the establishment of several high counting rate instruments, operated in different parts of the globe. These should permit the study of individual small (0.2 to 0.3 %) bihourly deviations with precision. Moreover, taking into account the great variability of conditions in the interplanetary space, the data should be examined in detail for individual events and on a day to day basis rather than by averaging over a long period of time.

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