STUDIES IN COSMIC RAYS

presented

by

U. D. DESAI

for

the degree of

DOCTOR OF PHILOSOPHY

of

GUJARAT UNIVERSITY

June, 1953

PHYSICAL RESEARCH LABORATORY
AHMEDABAD.

S T A T E M E N T

1. The thesis presents the results of an intensive investigation conducted at Ahmedabad on the variations of the total, the meson and soft component, vertical intensities of cosmic rays. Omnidirectional measurements of cosmic ray intensities have been made by many workers at high latitudes, but in the present investigation directional measurement of the intensities have been carried out by counter-telescopes at a low latitude where the daily variation can be studied with advantage.

The results of the present investigation establish,

(1) The nature of daily variation of total, meson and soft-component intensity in the vertical direction. The semi-diurnal components of the intensities have been found to be highly correlated with the semi-diurnal component of the daily barometric pressure variation.

(2) The soft component variation is mostly due to meteorological effects.

(3) There is a residual extraterrestrial component of variation of mesons which is due to continuous solar emission of cosmic rays.

2. The author has included at the end of his thesis a list of 80 references to original papers published in different parts of the world. The thesis mentions the specific information derived from each of them.

PREFACE

The present thesis describes part of the investigation conducted by the Physical Research Laboratory, Ahmedabad, for studying the time-variation of the various cosmic ray components in low and middle latitudes. In particular, it deals with the results of a study made at Ahmedabad by the author during the period 1950-53 on the total, the meson, and the soft components of cosmic ray intensities.

The apparatus described in Chapter II has been developed and built up by the author. I have received assistance from Dr.Vikram A.Sarabhai and Dr.R.P.Kane in the interpretation and discussion of the data.

I am grateful to Prof.K.R.Ramanathan for his guidance and discussions on the meteorological aspect of the problem. It is a pleasure to acknowledge the co-operation I have received from my colleague Mr. S. V. Venkateswaran of the Atmospheric Physics Section in conducting the radiosonde flights mentioned in Chapter IV.

Finally, I wish to express my deep debt of gratitude to Dr.Vikram A.Sarabhai for his continuous interest and guidance throughout all the stages of this investigation.

U. D. DESAI

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FIGURES

Reprints of papers published by the author in collaboration with Dr.Vikram A.Sarabhai and Dr.R.P.Kane.

(*Reprinted from Nature, Vol.* 171, *p.* 122, *January* 17, 1953)

Daily Variation of Meson Intensity and its Possible Solar Origin

THE variation of meson intensity with solar time has been studied at Ahmedabad (mag. lat. 13° N., altitude 50 m.) and at Kodaikanal (mag. lat. 1° N., altitude 2,343 m.) with vertical triple-coincidence Geiger counter telescopes of narrow aperture with 11 cm. of lead. Observations at Ahmedabad with two similar independent telescopes extend over a period of two years, while at Kodaikanal with four independent telescopes they extend over a period of five months. Elaborate precautions were taken to keep experimental conditions very constant, and the results of independent but simultaneously operated telescopes at each place were similar. The intensity at each place was determined from hourly photographs of the mechanical recorders. For the purpose of the solar daily variation, the bi-hourly values of intensity were considered.

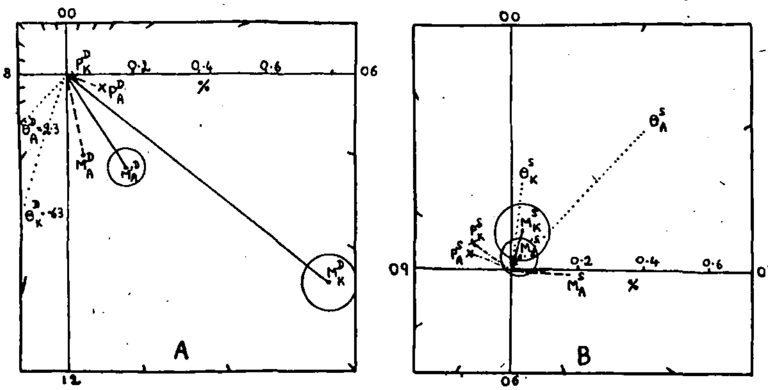
The solar daily variation of meson intensity is predominantly diurnal at Kodaikanal with an amplitude of 1·1 per cent. At Ahmedabad it has an amplitude of only 0·4 per cent with an important semidiurnal component as well. Figs. *A* and *B* show on 24-hr. and 12-hr. harmonic dials respectively the diurnal and semidiurnal harmonic components of the meson intensity M_A and M_K, the atmospheric pressure P_A and P_K and the ground temperature θ_A and θ_K at Ahmedabad and Kodaikanal. The diurnal and semidiurnal components are indicated by the additional suffixes *D* and *S* respectively.

At low latitudes the periodic daily variations of *P* and θ are larger and more pronounced than the irregular day-to-day variations which are so marked at places in high latitudes. Also, at low latitudes the daily variation of atmospheric pressure is mainly semidiurnal and that of temperature is diurnal. As a result, the semidiurnal components $P_A{}^S$ and $P_K{}^S$ are predominant, whereas $\theta_A{}^S$ and $\theta_K{}^S$ are negligible. This fortunately provides a means of studying the effect of pressure on meson intensity independently of other meteorological factors. At Ahmedabad, $M_A{}^S$ and $P_A{}^S$ have a very high correlation of $-$ 0·96, the pressure coefficient being $-$ 1·7 per cent per cm. mercury, in agreement with the mass absorption coefficient for mesons observed by other workers from day-to-day variations of intensity. At Kodaikanal, on the other hand, this correlation is only + 0·29. As, however, $M_K{}^S$ itself is only 0·12 per cent in amplitude and is not significant, this positive value might be fortuitous. The absence of the usual mass absorption coefficient indicates that during the atmospheric oscillations at Kodaikanal opposing factors act on M, and mask this absorption effect. These could be changes in heights of levels of meson formation or perhaps a density effect near these levels. An interesting feature of the present results is that, even near the equator for a high-level station, there is no marked semidiurnal variation of meson intensity positively correlated with pressure.

The atmospheric pressure plays an important part in the solar daily variation of mesons at the low-level station at Ahmedabad, but produces a negligible effect at Kodaikanal. The correlations of M_K with θ_K and of the pressure-corrected meson variation M'_A with θ_A are negligible. Ground temperature has therefore negligible effect at both places.

The curve of the residual meson variation corrected for pressure at Ahmedabad and the meson variation curve at Kodaikanal are both significant and strikingly similar. Both are diurnal with amplitude $M'_A = 0{\cdot}33 \pm 0{\cdot}06$ per cent and $M_K = 1{\cdot}1 \pm 0{\cdot}08$ per cent with maxima at 0950 and 0840 hr. local time respectively. It is unlikely that these variations are caused by a positive temperature effect such as is found by Duperier from day-to-day variations of mesons. Apart from the maxima being much earlier than the time at which a maximum of temperature in the upper atmosphere would be expected to occur, the amplitude of the diurnal temperature variation at the 200-mb. level is, on existing meteorological evidence, totally insufficient to account for a variation of meson intensity of $1{\cdot}1$ per cent as found at Kodaikanal. Variations of geomagnetic field are also not capable of explaining this variation.

There are thus grounds for believing that the observed diurnal variation of M is caused by an anisotropy of the primaries and is therefore extra-terrestrial in origin. The greatly reduced amplitude as well as a shift of maximum towards later hours at Ahmedabad when compared with Kodaikanal appears to be connected with the change of altitude between the stations. This is also seen in the ionization chamber results obtained at Huancayo as compared to the lower-level stations operated by the Carnegie Institution[1]. The amplitude of variation observed with our narrow-aperture Geiger counter-telescopes is larger than the omnidirectional ionization chamber results, as is to be expected. The increase of the percentage amplitude with elevation suggests the contribution of a larger number of low-energy particles which can make their effect felt at a high-level station but not at a sea-level station.



Amplitudes and hours of maxima in local time of harmonic components of meson intensity, atmospheric pressure and ground temperature variations. (*A*) 24-hr. harmonic dial; (*B*) 12-hr. harmonic dial

Since the variation is believed to be extra-terrestrial in origin, and the hour of maximum occurs at about the same local time during daylight hours throughout the year, a solar origin of this variation is suspected. The possibility of a part of the cosmic radiation originating from the sun, as deduced here from the nature of the residual diurnal variation of mesons, is supported by the occasional large increases in cosmic-ray intensity associated with solar flares, by recent observations associating variations of cosmic-ray neutrons with solar prominences, and by the large diurnal variation of the star intensity in the upper atmosphere reported by Lord and Schein[2]. Riddiford and Butler[3] have recently described processes by which particles from the sun can be accelerated to cosmic-ray energies. A close study of the occurrence of the hour of maximum under different conditions of observation of cosmic-ray intensity would throw a great deal of additional light on this subject. We hope to present shortly more data concerning this.

We are indebted to the Atomic Energy Commission of India for supporting this project. We are grateful to Prof. K. R. Ramanathan for many valuable discussions, particularly concerning the meteorological aspects of the problem.

V. Sarabhai
U. D. Desai
R. P. Kane

Physical Research Laboratory,
Ahmedabad, India.
May 25.

[1] Lange and Forbush, Carnegie Institution of Washington, Pub. 175 (1948).

[2] Lord and Schein, *Phys. Rev.*, **80**, 304 (1950).

[3] Riddiford and Butler, *Phil. Mag.*, **43**, 447 (1952).

Printed in Great Britain by Fisher, Knight & Co., Ltd., St. Albans.

Reprinted from the "Proceedings of the Indian Academy of Sciences," Vol. XXXVII, 1953

METEOROLOGICAL AND EXTRA-TERRESTRIAL CAUSES OF THE DAILY VARIATION OF COSMIC RAY INTENSITY

BY

V. SARABHAI, U. D. DESAI AND R. P. KANE

Reprinted from "The Proceedings of the Indian Academy of Sciences", Vol. XXXVII, No. 2, Sec. A, 1953

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By V. SARABHAI, U. D. DESAI AND R. P. KANE

(Physical Research Laboratory, Ahmedabad, India)

Received January 27, 1953

1. INTRODUCTION

IT has long been realised that a study of the solar and sidereal time daily variations of the cosmic ray intensity could give some clue to the location of regions where cosmic rays originate. However, a successful attempt to follow up this line of thought has not so far been possible due to the uncertainty in separating the variations caused by terrestrial influences from those due to an anisotropy of the primary radiation.

In investigating the time variations of cosmic rays, the ionisation chamber offers the great advantage of constancy of operation, but being an omnidirectional detector of radiation, it is hardly a satisfactory instrument for the study of an anisotropy of the primary radiation. Nevertheless, very valuable data have been collected with it. Apart from the Carnegie Institution studies made at widely separated places on the earth and reported by Lange and Forbush,[1] observations have been made, amongst others, by Hess and Grazeadei[2] at the Hafelekar, by Schonland, *et al.*,[3] at Capetown and by Hogg[4] at Canberra. Unidirectional measurements of the diurnal variation of the vertical meson intensity, performed with narrow angle geiger-counter telescopes could be more revealing than omni-directional measurements. But the only extensive data with vertically pointing telescopes comes from Duperier[5] in whose experiment the angles of the telescopes were fairly wide.

Interpretation of the ionisation chamber and Duperier's experiments has been much confused by various differing corrections for meteorological factors that have been applied, and it has not been possible finally to determine how much of the diurnal variation is due to an anisotropy of the primaries. To overcome this difficulty Alfven and Malmfors[6] and Elliot and Dolbear[7, 8] have studied the daily variation of cosmic ray intensity with telescopes pointing in the North and South directions. While the North-South daily variation difference curve is substantially independent of atmospheric effects and constitutes evidence for an anisotropy of theprimary radiation, it is difficult to interpret it further. For, an anisotropy of primaries, such as may be caused by solar emission of cosmic rays, can produce a daily variation in both North and South pointing telescopes. The difference curve in consequence reflects an arithmetic difference between the daily variations in the two directions due to anisotropic cosmic ray primaries, but does not reveal the true nature of the daily variation due to primary anisotropy in either direction.

It is felt that a satisfactory solution to the problem must begin with an understanding of the nature of terrestrial effects on the solar daily variation of cosmic ray intensity. These have then to be corrected for, leaving a residual daily variation essentially of extra-terrestrial origin. The daily variation of meteorological elements is more pronounced and regular at places in low latitudes than at high latitudes. It is particularly appropriate therefore to study the daily variation near the equator. With this in view, apparatus has been designed to carry out comparable studies of the daily variation of the total intensity as well as the meson intensity at Ahmedabad (Mag. Lat. 13° N., Alt. 50 metres) and at Kodaikanal (Mag. Lat. 1° N., Alt. 2,340 metres). As it is important to study the intensity of particles incident in a narrow cone in a fixed direction, compromise has to be made in the design of the apparatus to make the angles of the telescope narrow and still to retain an adequate counting rate for good statistics. We shall describe in this paper details of the apparatus and the results obtained during the past two years at Ahmedabad. A summary of the results obtained at both stations has already been communicated elsewhere.[9] Details of the Kodaikanal results will be presented later as soon as more significant data are available. We discuss here reasons which lead us to believe that the solar time daily variation of meson intensity corrected for barometric pressure is caused by an anisotropy of the primary radiation, probably connected with the emission of charged particles from the sun.

2. THE APPARATUS

A schematic diagram of the apparatus is given in Fig. 1.

Five trays, each with four self-quenched geiger counters connected in parallel, form three triple coincidence vertically pointing telescopes of identical dimensions. The counters have copper cathodes 30 cm. long with diameter of 4 cm. The counters are placed in the N-S direction, and each telescope subtends a semi-angle of 22° in the E-W plane and a semi-angle of 37° in the N-S plane. Since the purpose of the experiment is to measure the daily variation of cosmic ray intensity connected with the rotation of the earth, the apparatus is oriented so that the telescopes present the smaller angle in the E-W plane.

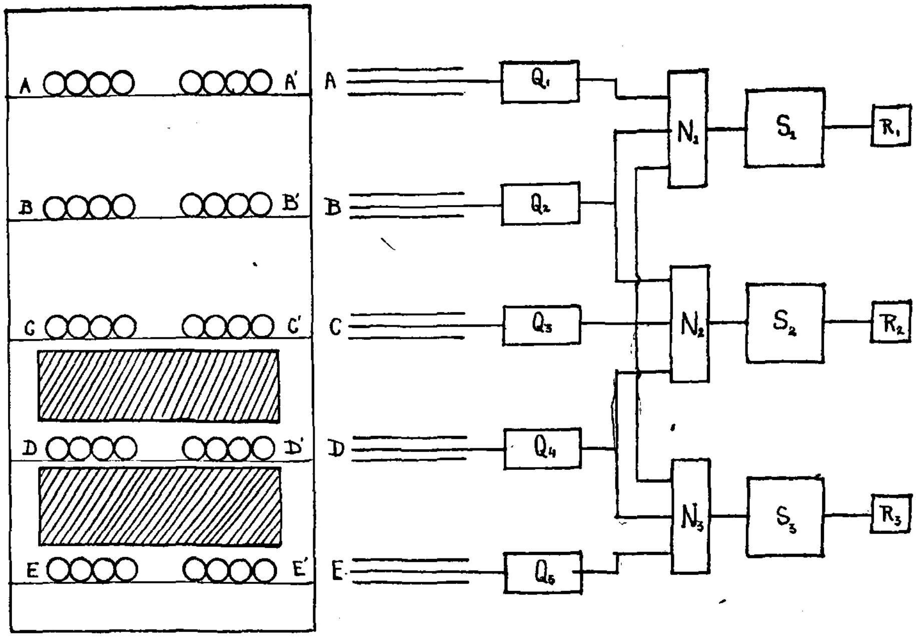

FIG. 1. Schematic diagram of apparatus showing counter trays A, B, C, D, E, A′, B′, C′, D′ and E′, quenching units Q, triple coincidence units N and scale of four units S feeding the electro-mechanical recorders R.

Lead absorbers are placed between the 3rd and 4th trays and the 4th and 5th trays. While therefore, the uppermost telescope ABC measures the total cosmic ray intensity T, the lower two telescopes BCD and CDE measure intensity that can penetrate through 7 cm. and 17 cm. of lead respectively. The soft component E is almost completely eliminated by 7 cm. of lead and is given by the difference between counting rates of telescopes ABC and BCD. The penetrating component '*m*' consisting mostly of μ-mesons is measured by the telescope CDE. The small difference between the counting rates of telescopes BCD and CDE represents the intensity of an intermediate component 'I' consisting partly of the very energetic soft component and partly of the slow meson component. Since 'I' is negligible compared to '*m*', the counting rates of telescopes BCD and CDE may be considered together to represent the meson component M, when distinction is being made only with the electronic component E.

The complete apparatus has three duplicate telescopes A′B′C′, B′C′D′ and C′D′E′ operating alongside the ones described above. These are also shown in Fig. 1. The object of providing these additional telescopes, measuring identical components of the cosmic ray intensity, is not only to improve the statistics but also to provide for continuance of data during periods when faults develop in counters or circuits connected with one or other of the telescopes.

All geiger counters are placed in a heat insulated box whose temperature is thermostatically regulated to 105° ± 2° F. Each counter tray is connected to an external electronic quenching unit which, for every discharge of one of the counters, feeds to their central wire a square negative voltage pulse of about 300 volts and 800 micro-seconds duration with a very sharp leading edge. These quenching units improve the flatness of plateau and prolong the life of self-quenched counters considerably by suppression of multiple discharges. This is important in time variation experiments where reliable operation over long periods of time is essential. The low impedence cathode-follower outputs of the quenching units are fed to fast triple coincidence units. Finally, the coincidences are scaled by a factor of 4 or 8 and recorded on telephone call registers which are automatically photographed hourly on standard 35 mm. film. All power supplies are electronically regulated to ensure stability of operation.

Hourly values of atmospheric pressure and temperature are obtained from daily charts of an accurate micro-barograph and a thermograph. Upper air meteorological data are obtained from radiosonde ascents, with I.M.D. F-type or the Vaisala type instruments, conducted by the atmospheric physics division of the laboratory under Prof. K. R. Ramanathan. Details of these experiments will be published elsewhere.

3. Analysis of Daily Variation Data

Even though the primary data for the intensity of cosmic ray components and the surface atmospheric pressure and temperature are available for hourly intervals, the analysis has been done for bihourly intervals commencing from midnight Indian Standard Time, which is 40 minutes in advance of the local time at Ahmedabad. The criterion used for elimination or inclusion of data for any particular day is the range of bihourly deviations. The data is discarded for days on which any individual bihourly value is more than 5% different from the mean for the particular day. This corresponds to a deviation exceeding three times the expected standard deviation for a bihourly value. Such cases are generally attributable to some faults either in the electronic circuits or in the counters. Cases of abnormally large daily variation in cosmic rays which may rarely occur are however also rejected on this criterion. The useful data, as presented here, extend from May 1950 to September 1952 and include about 600 days with a fairly even distribution over the four seasons.

The annual mean daily variation given by the bihourly percentage deviations from mean of the total intensity T, the meson intensity M and the electron intensity E are shown in Fig. 2. The bihourly deviations from

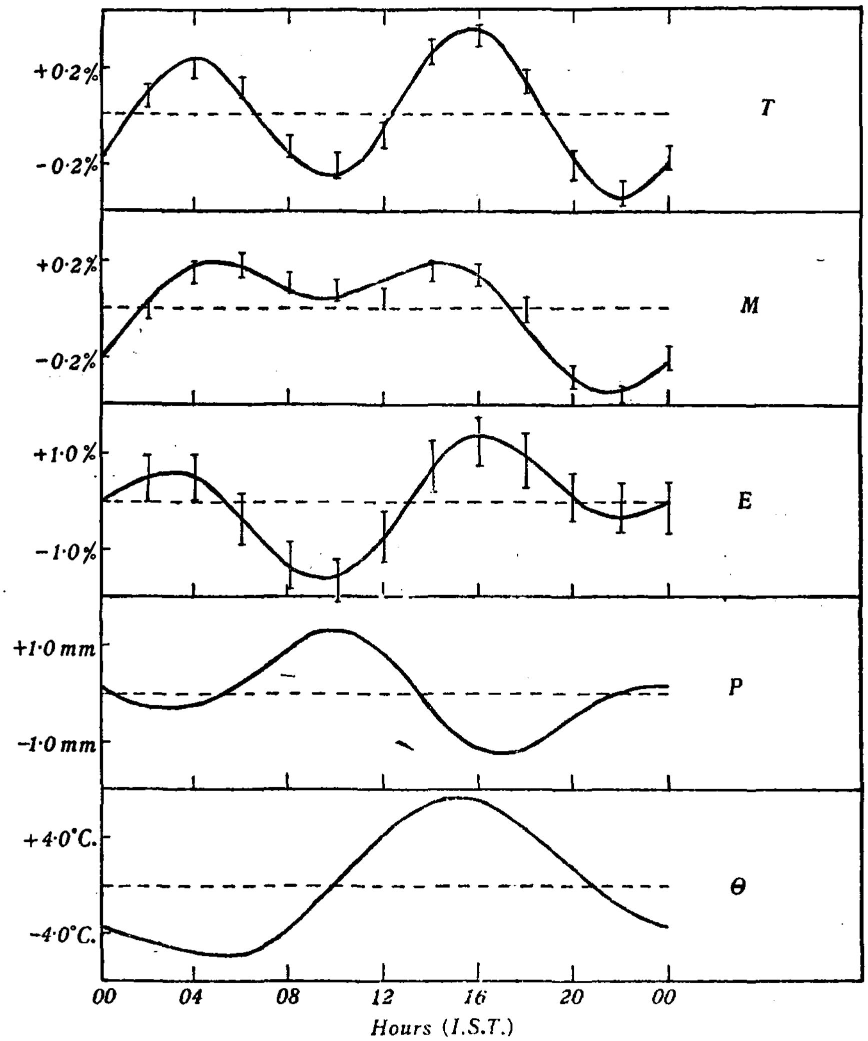

Fig. 2. The smoothened daily variation of total cosmic ray intensity T, mesons M, electrons E, barometric pressure P and surface atmospheric temperature θ. No correction has been applied to the cosmic ray values and the solid lines showing the daily variations are formed by the superposition of the diurnal and the semidiurnal components for each intensity.

mean of the atmospheric pressure P and the surface temperature θ are also shown. For the purpose of smoothening the data, moving averages over three consecutive bihourly intervals have been taken for all variates shown in the figure. The standard deviations for each bihourly value of cosmic ray intensity are also indicated.

The amplitudes and hours of maxima of the first four harmonic components of the unsmoothened daily variation of T, M, E as well as P and θ are indicated in Table I. The hour of maximum is expressed in terms of the angle in the harmonic dial representation between midnight and the vector for the particular harmonic component of the daily variation.

TABLE I

Amplitudes and hours of maxima of harmonic components of the daily variation of cosmic ray intensities and atmospheric pressure and temperature

Variate	1st Harmonic 24 hourly		2nd Harmonic 12 hourly		3rd Harmonic 8 hourly		4th Harmonic 6 hourly	
	Ampl.	Max.	Ampl.	Max.	Ampl.	Max.	Ampl.	Max.
T ..	·09%	11°	·42%	115°	·05%	−2°	·02%	29°
M ..	·22%	144°	·23%	119°	·09%	38°	·03%	108°
E ..	·80%	−61°	1·40%	112°	·30%	81°	·30%	76°
P mm. of Hg	·86	115°	·95	131°	·04	135°	·00	..
θ° C. ..	6·60	54°	1·60	64°	·50	114°	·40	−62°

It will be observed that for all variates the predominant harmonic component is either the first or the second one. In mesons and in atmospheric pressure, the two components are about equally important. For total intensity and for electrons, the second harmonic is larger than the first; but for surface temperature, the converse is true. In all cases, the third and higher harmonics are small and may be neglected. In what follows therefore, only the 24 hourly diurnal and the 12 hourly semidiurnal components are taken into consideration. In discussing these components, it is convenient to adopt a notation explained in Table II.

4. Influence of Meteorological Factors on the Daily Variation of Meson and Electron Intensities

Extensive studies have been made to relate the day-to-day variations of the cosmic ray intensity with meteorological changes in the atmosphere. Duperier[10] has shown that changes of meson intensity are connected with a mass absorption effect, an effect due to alteration of the probability of

TABLE II

Notation used for describing the amplitude and the hour of maximum of harmonic components

M^D_A = % amplitude of meson (M), diurnal variation (D) observed at Ahmedabad (A)

$M\phi^D_A$ = angle corresponding to hour of maximum of the meson (M) diurnal variation (D) observed at Ahmedabad

M^S_A = % amplitude of meson (M) semi-diurnal variation (S) observed at Ahmedabad (A)

$M\phi_A$ = angle corresponding to hour of maximum of the meson (M) semidiurnal variation (S) observed at Ahmedabad

Similarly T^D_A, E^D_A, P^D_A and θ^D_A represent the amplitudes of the diurnal variations at Ahmedabad of T, E, P and θ respectively

meson decay accompanying changes of heights of isobaric levels and an effect of the temperature or density of the atmosphere near the 100 mb. level. The physical processes responsible for the positive upper air temperature effect are not clearly understood but it should not be expected that in the daily variation the influence of these three factors on meson intensity would be identical to what is found for day-to-day variations. This is because in barometric pressure as well as in atmospheric temperature, the day-to-day changes are brought about under very different circumstances from those that produce the daily variations.

Processes responsible for day-to-day changes of barometric pressure are entirely different from those causing the dynamical periodic oscillations of the barometric pressure. The use of a barometric coefficient obtained from studies of day-to-day variations for correcting cosmic ray daily variation data in respect of the daily variation of pressure is therefore questionable. But this is exactly what has been done by most authors in the past. A better method appears to be to derive a barometric coefficient from daily variation studies for subsequent application to the same data. In doing this, we have to keep in mind available knowledge on the physical processes responsible for the daily variation of the meteorological elements and the special features of the atmospheric oscillation.

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

In the 12 hourly semidiurnal components however, the position is different. The atmospheric pressure, unlike temperature, has a very appreciable P^S component. At Ahmedabad, P^S_A is as important as P^D_A. At Kodaikanal, nearer the equator and at a higher level, P^S_K is 6 times P^D_K. As was originally pointed out by Kelvin,[26] the semidiurnal variation of pressure is due to resonance in the atmosphere which has a free period of oscillation of nearly 12 hours. Thus, even though the exciting solar force is diurnal, the semidiurnal component in pressure becomes important and is predominant at low latitudes. If attention is therefore confined only to the semidiurnal components, we have a means of studying the influence of pressure, uncontaminated with effects due to temperature variations in the atmosphere or due to an anisotropy of cosmic ray primaries.

The first two harmonic components of T, M and E along with those of P and θ are shown in Fig. 3 on 24 and 12 hourly harmonic dials. It will

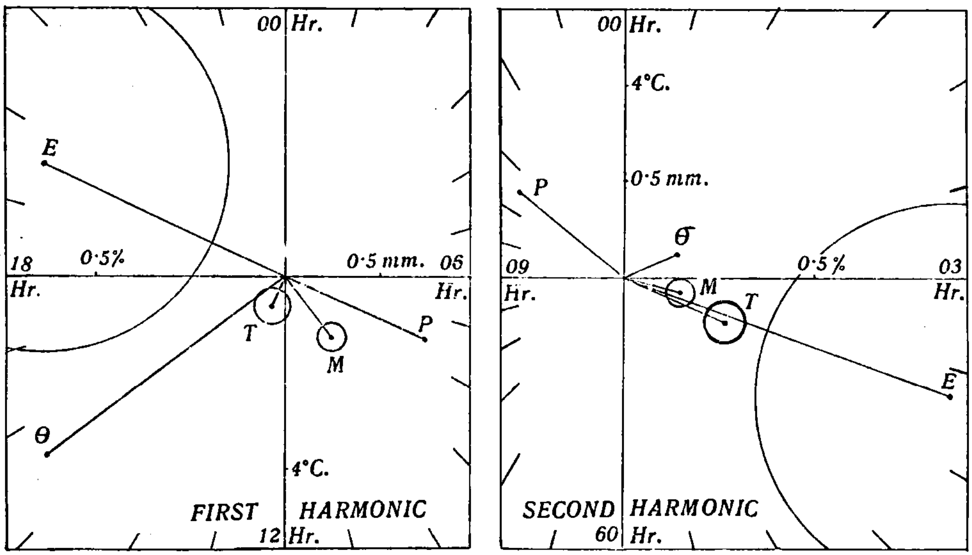

FIG. 3. Diurnal and semidiurnal harmonic dials showing amplitudes and hours of maxima of uncorrected variations.

be observed that while on the 24 hour dial, the vectors lie all around the clock, there is on the 12 hour dial a very striking grouping of the cosmic ray vectors almost completely opposite in phase with the pressure vector.

Correlation analysis of the semidiurnal vectors of cosmic ray components with atmospheric pressure give correlation coefficients and barometric coefficients as shown in Table III.

TABLE III

Correlations with barometric pressure and the barometric coefficients of the semidiurnal components of cosmic ray intensity

Cosmic ray component	Correlation coefficient with P_A^S	Barometric coefficient
T_A^S	$r_{TP}^{SS} = -\cdot 96$	$\beta_T = -4\cdot 2\%$ per cm. Hg
M_A^S	$r_{MP}^{SS} = -\cdot 98$	$\beta_M = -2\cdot 4\%$ per cm. Hg
E_A^S	$r_{EP}^{SS} = -\cdot 95$	$\beta_E = -14\cdot 0\%$ per cm. Hg

The barometric coefficient $\beta_M = -2\cdot 4\%$ per cm. Hg for mesons may be compared with the value found by other workers from day-to-day variations of cosmic ray meson intensity. Coefficients of $-3\cdot 0\%$ per cm. Hg for Huancayo and $-1\cdot 8\%$ per cm. Hg for Cheltenham, Christchurch and Godhavn have been determined and used for barometric pressure correction by Lange and Forbush[1] for the Carnegie Institution ionisation chamber data. It is not clear why at Huancayo the coefficient should be so much larger than at the other stations in spite of the shielding being the same for all instruments. Duperier's[10] barometric coefficient is $-1\cdot 50\%$ per cm. Hg and Dolbear and Elliot[11] have reported a value of $-1\cdot 88\%$ per cm. Hg obtained from the seasonal variation of intensity. These authors, by partial correlation analysis, give estimates for the three meteorological coefficients which affect meson intensity. These are shown in Table IV. Our value of the barometric coefficient for mesons is larger than the true mass absorption coefficient of Duperier but agrees well with the coefficient of Dolbear and Elliot.

It is important to examine if there is a substantial decay contribution in the semidiurnal variation. Pekeris,[12] and more lately Wilkes and Weekes[13] have examined the details of the modes of oscillation of the atmosphere. Nicholson and Sarabhai[14] have estimated the effect on meson intensity of

TABLE IV

Estimates of barometric coefficient β, true absorption coefficient μ, true decay coefficient μ' and positive temperature coefficient α for mesons

Coefficient	Duperier[10]	Dolbear and Elliot[11]
β	− 1·50%/cm. Hg*	− 1·88%/cm. Hg
μ	− 1·05%/cm. Hg	− 2·07%/cm. Hg
μ'	− 3·90%/km.	− 4·22%/km.
α	+ 0·12%/°C.	+ 0·14%/°C.

* Weighted mean for 5 periods of observations.

the semidiurnal change of height of isobaric levels due to atmospheric oscillations. For meson production near 16 km., there should be a semidiurnal oscillation of the isobaric level which would not exceed 4 metres and thus would not change significantly the contribution of the pure mass absorption effect to the barometric coefficient. There is reason to believe therefore that the barometric coefficient derived by us from the semidiurnal variation corresponds mainly to the true absorption coefficient for the meson component.

The appropriate barometric coefficients experimentally determined from semidiurnal components can be used to correct the unresolved daily variations of T, M and E for the barometric daily variation. Smoothened bihourly values of the barometric pressure corrected variations designated as T′, M′ and E′ are shown in Fig. 4. The harmonic components of these are indicated in Fig. 5.

It will be noticed that T′ and M′ are left with a residual diurnal variation of amplitude ·33 ± ·05% and ·35 ± ·04% respectively and hour of maximum near 0900 hours I.S.T. E′ on the other hand has no significant variation exceeding the standard deviation of the individual bihourly points. This indicates that the daily variation of the electron component at sea level can be explained almost completely by a mass absorption effect connected with the barometric variation.

Duperier[15] has corrected the daily variation of mesons for a decay effect due to an estimated diurnal change of height of about 50 metres in the isobaric levels near 16 km. in consequence of a diurnal heating of the atmosphere. The process has been considered to be analogous to the seasonal variation of meson intensity where, during summer, the general expansion

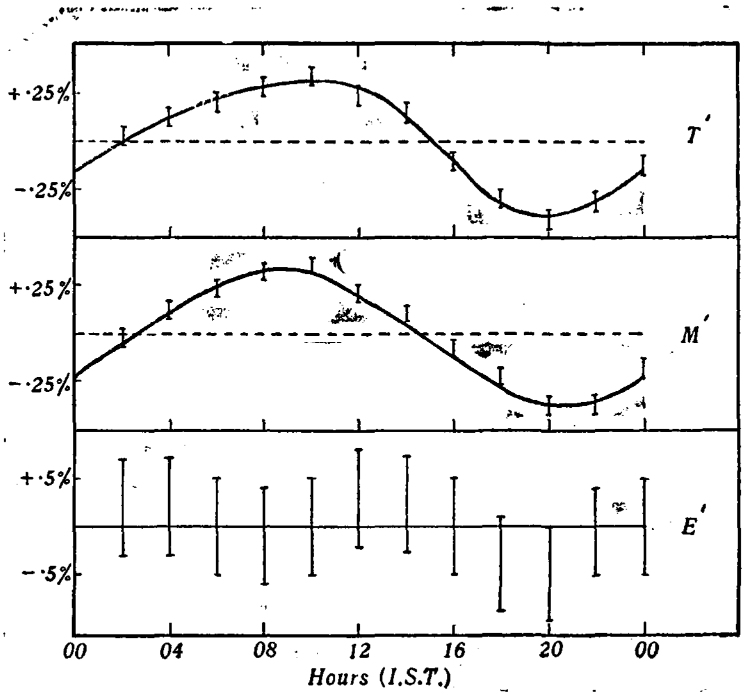

FIG. 4. The daily variation of total cosmic ray intensity, mesons and electrons, each corrected for barometric pressure.

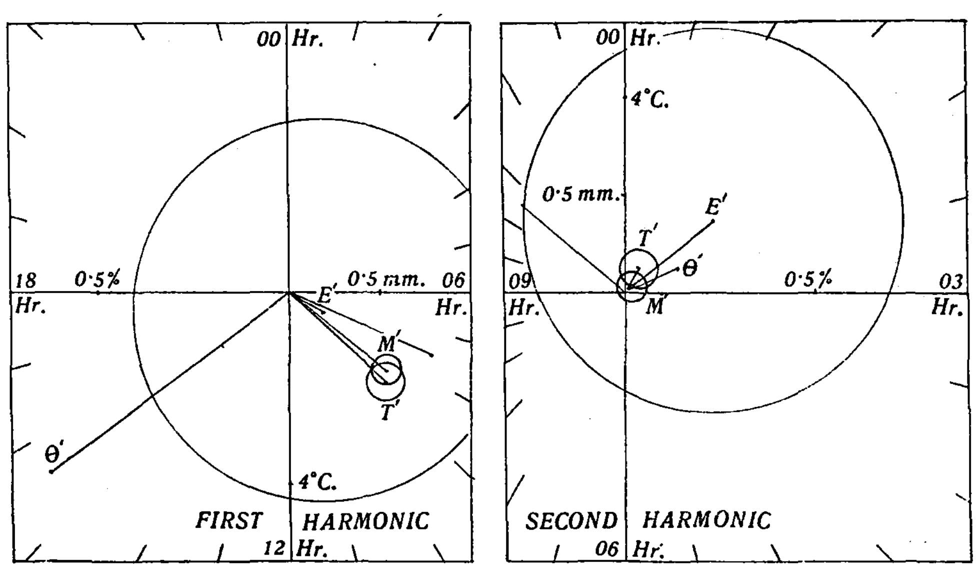

FIG. 5. Diurnal and semidiurnal harmonic dials showing amplitudes and hours of maxima of cosmic ray daily variations corrected for barometric pressure.

of the atmosphere produces a decrease of meson intensity. Dolbear and Elliot[11] have suggested a further correction for a diurnal positive temperature effect similar to the one demonstrated by Duperier[11] for day-to-day changes. The contribution of both these factors to the daily variation of mesons would depend on the magnitude of the diurnal temperature change at different levels in the atmosphere and particularly near the tropopause.

All available meteorological evidence goes to show that the daily variation of air temperature gets rapidly attenuated going upwards from ground, and becomes negligible beyond 2 km. above the surface of the earth. It may again become important in the ozone ultraviolet absorption region, well above the tropical tropopause. Duperier,[10] and Elliot and Dolbear[8] have based their arguments on radiosonde data obtained by the Meteorological Office, London, at Larkhill (100 km. S-W of London) and Downham Market (75 km. N-E of London). The interpretation of the data is however very suspect and Kay[16] has critically examined it to come to the conclusion that much of the apparent diurnal variation of temperature in the lower atmosphere is spurious and caused by inadequate radiation shielding of the thermal element. Flights have been made in India to test whether there is a diurnal variation in low latitudes. It has been tentatively found in ascents made with Vaisala instruments at Ahmedabad that there is no significant diurnal increase of temperature near the tropopause. There is ozone above 100 mb. but the heating effect due to absorption of solar radiation is considered to be of significance only at much higher levels.

An examination of Fig. 5 reveals that the barometric pressure corrected vectors for total intensity and mesons on the 24 hourly dial are both significant and are negligibly correlated with the surface atmospheric temperature. If the heating in the upper atmosphere were to take place from lower levels, the maximum temperature would occur at a later hour than the surface temperature and the correlation with T′ and M′ would be almost zero. For heating of the layers of air near 16 km. from above, the maximum temperature may occur nearer noon, but even so the correlation between the diurnal vectors for T′ and M′ and a temperature vector at noon would be quite low.

One is finally led to conclude that the atmospheric temperature has little or no part to play in producing the daily variation of meson intensity corrected suitably for barometric pressure.

5. THE BAROMETRIC PRESSURE CORRECTED MESON DIURNAL VARIATION

Having eliminated meteorological effects, it is necessary to consider possible geomagnetic and helio-magnetic influences on the residual daily variation of mesons. Janossy[17] has suggested the possibility of a diurnal variation of cosmic rays at latitudes beyond 40° due to the helio-magnetic field. Dwight[18] has worked out detailed implications, but this theory can be safely excluded in view, amongst other things, of the evidence from several quarters concerning the non-existence of an appreciable general helio-magnetic field at the present time. Vallarta and Godart[19] have discussed the influence in low latitudes of ionospheric current systems responsible for the geomagnetic diurnal variation. While the latter alters fundamentally in character with latitude, Thompson[20] has shown that the meson variation has similar features over a wide range of latitudes. It appears therefore that the barometric pressure corrected variation of mesons is of extra-terrestrial origin and is connected with an anisotropy of the primary radiation. Taking into consideration the occurrence of the maximum of the diurnal variation at about the same period of the day according to local time at widely separated places on the earth, it is reasonable to conclude that the anisotropy is caused by the solar emission of cosmic rays.

Duperier[15] has indeed made a similar suggestion by a consideration of the seasonal change of amplitude of the meson diurnal variation corrected for barometric pressure and decay coefficient. As however, the application of the decay effect is questionable for reasons mentioned earlier, the close agreement between the ratio of summer and winter diurnal amplitudes with what would be expected due to change of the solar zenith distance at the two periods may be fortuitous.

6. The Effects of Cosmic Rays from the Sun

The sun is known to emit corpuscular streams which take about 23 hours to travel to the earth and produce geomagnetic and auroral activity. It is also known to emit during some intense solar flares, moderate and low energy cosmic ray particles which travel with a velocity not very different from that of light and produce measurable effects at sea level on the cosmic ray neutron and charged particle intensity. The magnitude of the effect has a marked longitude dependence, and no effects have been observed at equatorial stations. Increases in neutron intensity reported by Simpson, *et al.*,[21] and charged particle intensity reported by Neher and Forbush[22] have been associated with the central meridian passage of active regions on the solar disc. These demonstrate the emission of more energetic particles from the sun which make their effects felt even at Huancayo on the geomagnetic equator. The present association of the meson diurnal variation with an anisotropy due to solar cosmic rays shows that the sun is a continuous emitter of cosmic radiation. Unlike the bursts of radiation following the observation of flares, this continuous emission is energetic enough to cause measurable effects in the charged particle intensity at sea level at all latitudes.

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

An important question arises about the observed hour of maximum $M\phi^D$ of the meson diurnal variation. For high energy particles from the sun which are not appreciably deflected by the geomagnetic field, one should expect the maximum to occur at noon local time. For less energetic positive primaries the maximum will be shifted to earlier hours, and for less energetic negative primaries to later hours. There is a divergence amongst the reported results of various workers concerning the precise hour of maximum. It varies in extreme cases from 0800 hours to 1600 hours. A great deal of this divergence is perhaps due to differences in methods of correcting for meteorological effects.

Hogg[23] has compared on a harmonic dial the diurnal vectors for meson dialy variation observed by various workers at different places. For Canberra data, a vector has been given for barometric pressure corrected meson variation as well as for one which has, in addition, been corrected for a temperature effect. There is a considerable difference between the amplitude and the hour of maximum of the resultant variation in the two cases. Forbush,[24] for Cheltenham data, has shown how the uncorrected meson diurnal vector at 1400 hours shifts to 1100 or 1000 hours according to the magnitude of the barometric coefficient which is applied for correction.

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

An important point that arises now concerns the relationship that can exist between the amplitude and the hour of maximum of the diurnal variation. The amplitude should be controlled, among other things, by the cut off in the solar cosmic ray energy spectrum either by geomagnetic blocking or atmospheric absorption. The mean energy of the allowed radiation determines the bending in the geomagnetic field and hence the hour of maximum of the diurnal amplitude. When changes in amplitude of the diurnal variation are due to alteration of the cut off energy, a change in the hour of maximum may also be expected. This consideration requires a revision of the past analysis made for detecting a sidereal time variation in cosmic rays from the seasonal change of the diurnal variation on lines suggested by Thompson.[25]

Due to bending of the trajectories of cosmic rays from the sun, there is every reason to expect a diurnal variation of intensity in both the North and the South pointing telescopes of Alfven and Malmfors,[6] and Elliot and Dolbear.[8] On account of the asymmetry of the geomagnetic field with respect to the earth's axis of rotation, the two telescopes may exhibit with respect to each other, a small shift of phase of the measured diurnal variation. Just as an East-pointing telescope would have an earlier maximum than a West-pointing telescope, a North pointing telescope in England should have an earlier maximum than one pointing to the South. This is what Dolbear and Elliot have found. While qualitatively the explanation is attractive, it remains to be seen whether it would hold quantitatively.

Elliot and Dolbear[8] have made the very significant observation that during days of increased geomagnetic activity, the diurnal variations in both N and S directions are enhanced, and the N-S difference changes from being a semidiurnal to a diurnal curve. Since it is known that geomagnetic disturbances are associated with solar corpuscular streams, it would appear that when there is increased activity of the solar M-regions, there is also increased cosmic ray emission from the sun. The radical change in the nature of the difference curve during magnetically disturbed days supports the view that it has no special physical significance apart from being the arithmetic difference of the diurnal variations in the two directions.

Recently, two of us (V. Sarabhai and R. P. Kane) have demonstrated large and long-term world-wide changes in the amplitude and the hour of maximum of the meson diurnal variation. These changes, at least during years of low solar activity, are well correlated with relative sunspot number and the American magnetic character figure. There is therefore good reason to believe that continuous emission of cosmic rays from the sun is an important cause for the diurnal variation of meson intensity. However, there are a number of points about the diurnal variation which are still to be cleared up. Perhaps the most important, concern the dependence of amplitude and hour of maximum of the diurnal variation on latitude, elevation and seasons. Our understanding of the problem is very much confused by the complex trajectories of charged particles from the sun. The very considerable deflection of cosmic rays from the sun is demonstrated by the occurrence both on the sunlit and the dark hemispheres of the abnormal increases of cosmic ray intensity associated with flares. It would be very valuable if the rather complicated problem of the effect of the geomagnetic field on non-isotropic cosmic ray primaries from the sun is tackled not only for a static case, but when the field wobbles with respect to the sun on account of the rotation of the earth.

We are indebted to Prof. K. R. Ramanathan for many valuable discussions. We wish to thank the Atomic Energy Commission of India for financial support given for our investigations and the India Meteorological Department for the supply of radiosonde instruments. We also owe our thanks to Mr. K. A. Gidwani for computational assistance.

SUMMARY

The daily variations of total cosmic ray intensity and the intensities of meson and electron components have been studied at Ahmedabad with vertical geiger counter telescopes. The influence of meteorological factors on these variations has been examined, and it has been found that appropriate barometric coefficients for correcting the cosmic ray intensities can be obtained from a consideration of the semidiurnal components of the variations. The barometric coefficients for the three intensities are

$\beta_T = -4 \cdot 2\%$ per cm. Hg, $\beta_M = -2 \cdot 4\%$ per cm. Hg,

$\beta_E = -14 \cdot 0\%$ per cm. Hg.

The cosmic ray intensity variations are corrected with the appropriate coefficients for the daily variation of barometric pressure. No significant variation is then left in the electron intensity, implying that variations of this component are mostly caused by the mass absorption effect with a variation of barometric pressure. In total intensity and in meson intensity, on the other hand, there is a significant residual variation of about ·3% in amplitude. This is mainly diurnal in character with a maximum at 0900 hours I.S.T.

Reasons are given for concluding that the meson residual variation is not primarily caused by either the diurnal variation of temperature in the atmosphere or of geomagnetic elements. It is finally concluded that the bulk of the meson residual diurnal variation is extra-terrestrial in origin and is caused by continuous solar emission of cosmic ray particles. This conclusion is discussed in terms of the interpretation of omnidirectional and unidirectional measurements of the diurnal variation by other workers. A connection between changes in the amplitude and the hour of maximum of the diurnal variation has been suggested.

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1. INTRODUCTION

Ever since the experiments of Hess and Kolhorster[1] proved conclusively that cosmic rays were to be traced to an extra-terrestrial source, the question of their origin has become a subject of much speculation and research. It was realized that to obtain an answer to the problem the most direct approach is to measure the intensity of radiation as a function of time and find out whether any variations exist apart from statistical fluctuations. There are several kinds of variations which might be expected. Variations with a period of a solar day, and with seasons might be expected to arise from the rotation of the earth and its motion around the sun. A diurnal variation of intensity according to sidereal time, if present, would have a bearing on the galactic origin of cosmic rays whereas a periodicity of 27 days (average rotation period of the sun) can arise from its direct solar origin or a geomagnetic or a heliomagnetic effect. Non-periodic variations can also yield some information about the origin of cosmic rays.

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

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

1.1 Variations due to Atmospheric effects :-

In 1928, Myssowsky and Tuwim[2] found that the day-to-day variations in ground level pressure are negatively correlated with the variations of the daily mean values of cosmic ray intensity. Initially this 'barometric effect' was ascribed to the changes in the mass absorption suffered by cosmic rays in their passage through the atmosphere. The pressure coefficients for the total intensity as well as the meson intensity have been obtained by several observers, though the values obtained by them do not agree very well. As pointed out by Duperier[3] this may be due to the fact that the overall pressure coefficient reflects not only the mass absorption effect but also includes an effedt due to change in the path-length, which would alter the probability of μ-meson decay and produce a variation analogous to the

I 1

seasonal variation interpreted by Blackett[4] and discussed in detail at a later stage. To find the height of the layer where most of the mesons are produced, Duperier investigated the partial correlations of day-to-day changes of cosmic ray intensity (I) with the corresponding changes of the heights (H) of isobaric levels in the atmosphere and of the barometric pressure (B) measured at the ground level. He found that the value of the partial correlation, $r_{IH.B}$, between I and H at constant barometric pressure B, was maximum for 16.1 km height which was the highest level upto which data were available from balloon ascents. This height corresponds approximately to the 100 mb. pressure level. For the two coefficients μ (due to mass absorption effect) and μ' (due to changes in the height of the isobaric level) he obtained the values 2.28% per cm.Hg and 5.4% per km. respectively.

The above constants were obtained from the records of telescopes without any absorber. Experiments with 25 cm. of lead absorber were also conducted and correlation analysis carried out as before. The partial correlation $r_{IH.B}$ increases upto the height corresponding to 200 mb. level but decreases rapidly for heights between 200 and 100 mb. Duperier[5] has interpreted this as indicating that the variation in meson intensity cannot completely be explained by the two factors mentioned above. The additional factor that he introduced is the density of the air at the level of meson formation. Duperier has computed the partial correlation coefficients

I 1

between the cosmic ray intensity 'I' and atmospheric temperature 'T' which determines the density of air at any particular level. The partial correlation is +0.68 for temperature corresponding to air between 200 and 100 mb. levels. The temperature coefficient obtained in this way is +.12% per °C. This positive temperature effect indicates that the number of mesons at sea level increases as the density of air at the 200-100 mb. level decreases. Duperier interprets this as being due to the competitive processes of nuclear capture of π-mesons and of π-μ decay. An appreciable proportion of the meson intensity at sea level is due to μ mesons formed by the decay of the π meson component created at the top of the atmosphere. The π mesons which have a strong nuclear interaction, are also captured in nuclear collisions. If the density of matter increases at the level where π decays into μ, the probability for collisions increases and so the ground level meson intensity decreases. Quantitative considerations yield a much lower value of this effect than what is observed and so there remains some doubt as to whether the interpretation put forward by Duperier is correct.

1.2 Negative temperature effect :-

Several investigators have reported negative correlation between cosmic ray intensity and ground level temperature. Blackett[4] in 1938 pointed out that this temperature effect can be explained on the basis of the instability of mesons.

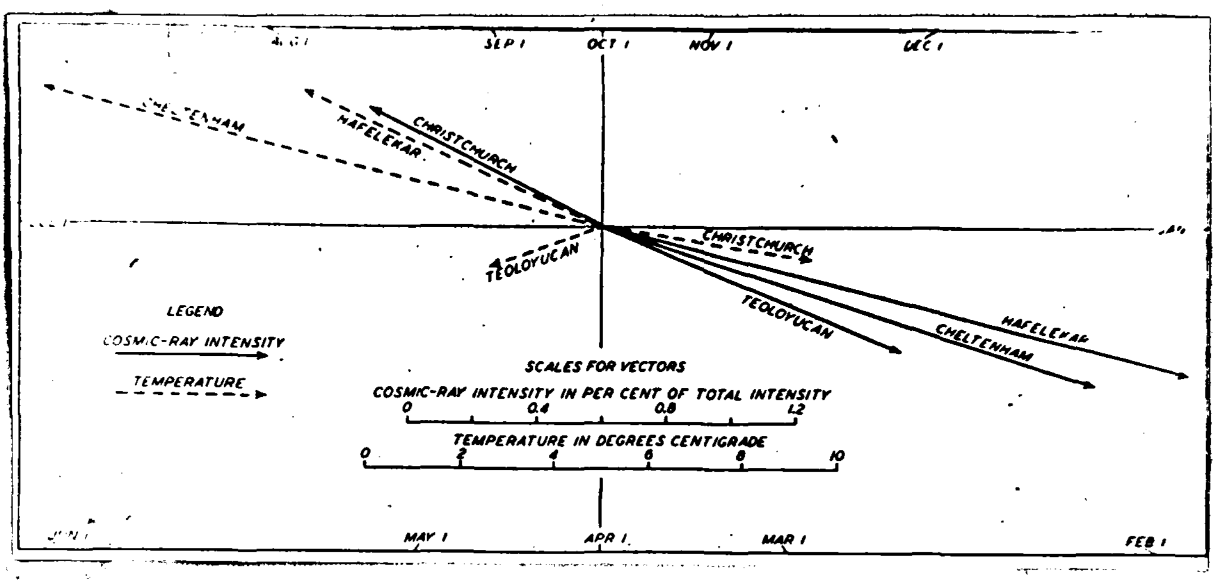
The general warming of the atmosphere increases the height of the isobaric levels where mesons are produced. This increases the decay probability and thereby decreases the meson intensity.

According to Blackett's calculations, assuming an average mean life time $\tau = 2.7 \times 10^{-6}$ Sec. for μ mesons, and an average life range as 32 km., the value of the temperature coefficient β comes out to be -0.2% per °C. The value of the coefficient as observed experimentally by Compton and Turner from seasonal changes in -0.16% per °C.

Hess has observed that the temperature coefficient is subject to a regular seasonal variation, the coefficient in winter being twice as large as in summer. If Blackett's interpretation of the effect has to be retained, it should be concluded that the ground level temperature is a very inadequate parameter for the temperature conditions of the whole vertical column of air. The magnitude of the temperature coefficient should be found not from ground-level temperatures alone but by taking into account temperatures at higher levels also. Barnóthy and Fórro[7] have explained the variation of the sign and magnitude of the temperature effect in shower-intensity on the basis that the daily temperature is limited to a height of 2 km. from the ground. Blackett[4] has predicted a latitude dependence of the temperature coefficient. At low latitudes, the incoming radiation is more energetic than at high latitudes and thus in the former case mesons of greater energy and of a longer mean effective life-time are involved. Due to this, the temperature coefficient near the equator should be lower than at high latitudes.

1.3 The Seasonal Variation :-

A seasonal variation of the cosmic ray intensity was established as early as 1939 from the studies of Hess[8], Compton and Turner[9], Gill[10] and Forbush[11]. Forbush has analysed ionisation chamber data of Cheltenham, Christchurch, Huancayo and Teoloyucan. After deducting a 12-month-wave from the data at each place except at Huancayo where a wave does not exist, the residual variations at any two places were found to be highly correlated. This clearly showed that major non-periodic changes in the cosmic ray intensity were world-wide in character. The amplitudes and the time of maxima of the 12-monthly waves at different stations are shown in the harmonic dial taken from the original paper.



The 12-monthly wave in the cosmic ray intensity at different stations (except at Teoloyucan) is 180° out of phase with the 12-month wave in temperature at each station. Christchurch and Cheltenham, having similar elevation and geomagnetic latitude, show the same ratio of amplitude of the above two variates. For other stations it is quite different. This indicates that the variations in cosmic rays in general are not closely connected with ground temperature. Forbush[11] suggests that the seasonal variation of distribution of air-density with height in the earth's atmosphere may be better correlated with the 12-monthly wave in cosmic ray intensity.

From the amplitude of the effect observed, Forbush[11] suggests that the solar magnetic moment may be an alternative possible cause for the seasonal variation of cosmic ray intensity. Vallarta and Godart[12] have also ascribed ~~that~~ the seasonal variation to the solar magnetic field. However, these calculations according to the above suggestion do not agree well with the experiments of Forbush[11]. Hence the interpretation has received little support. The analysis of recent data obtained at Manchester by Elliot and Dolbear[13] for north and south pointing telescopes shows a definite decrease of intensity in mid-summer amounting to about 2%. The monthly means of cosmic ray intensity, after correcting for barometric coefficient show a high correlation (0.94) with the height of the 100 mb. level. The decay coefficient is found to be -3.55 % per km. which differs significantly from the value -5.70% per km. obtained from day-to-day changes of I and H. Small but significant differences in the shape of their annual variation curves have also been pointed out by these authors. They therefore conclude that the positive temperature effect reported by Duperier may be responsible for the minor discrepancies.

1.4 Variations associated with Geomagnetic and solar activity.

The observations of Messerschmidt (1935)[14] showed a decrease of about 1.0% in the cosmic ray intensity during a magnetic storm. Steinmaurer and Graziadei[15] (1935) found an average decrease of 0.3% for 17 magnetic storms.

The world-wide nature of irregular variations was established from the results of Cheltenham, Huyancayo, Christchurch, Teoloyucan (reported by Forbush[11]) and Hafelekar (reported by Hess and Demmelmair[16]). The storm of 1937 was accompanied by a decrease of intensity of about 4% at widely separated stations (Forbush). A decrease of about 6% in 1938 has been reported by Forbush and there appears to be good correlation between 'H' (the horizontal component of earth's magnetic field) and variations of cosmic ray intensity. However the violent storm of August 1937 was found to be ineffective as far as variations in cosmic ray intensity are concerned. During a storm, 'H' decreases suddenly and comes back to the original value very slowly. Hogg[17] has shown that the changes in intensity, ...

associated with magnetic storms, are initially invariably of a decreasing nature and are broadly of the same character as the changes in 'H'. It is also found that the cosmic ray changes especially when they are large, are delayed by a few hours relative to the large change of 'H'.

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

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

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

(1) The variations are not always world-wide.

(2) The maximum of cosmic ray intensity and the solar flares occur at an interval of about an hour.

(3) The effect is greatly reduced at lower latitudes and is not observed at geomagnetic equator, suggesting that the primaries responsible for these variations have momenta less than 10 BeV/c.

Ehmert[27] has put forward an explanation for the above effects. He suggested that the particles from the sun are accelerated by the betatron action of the changing magnetic field of a growing sunspot. This was proposed by Swann[28] as early as 1933. The accelerating electric field, as suggested by Menzel and Salisbury[29] are due to movements of low-frequency electromagnetic waves generated by fluctu-actions of the sunspot magnetic field due to turbulence in the solar atmosphere.

Forbush, Gill and Vallarta[30] have examined the mechanism of emission of cosmic rays from the sun during occurrences of solar flares. They suggest that the bi-polar field of a sunspot group may reduce the solar field to allow comparatively low-energy particles to be emitted from the surface of the sun.

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

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

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

1.5 Daily variation :-

Periodic variations of cosmic ray intensity according to local solar time have been investigated under different atmospheric conditions and for places differing in latitude and longitude. A summary of the work done upto 1947 has been given by Nicolson and Sarabhai[35]. The following tables include additional data from work published subsequently. The notations used are :-

λ = geomagnetic latitude of the station,

h = altitude of station in metres above sea level,

ϕ = angle of cone of measured radiation (classified in general as wide and narrow),

θ = inclination of axis of observed cone to the vertical,

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

S;-S imply that the maximum of the variation is displaced by less than one hour from

	the maximum (minimum) of the semi-diurnal pressure variation.
I.C.;G.C.	indicate use of ionization chamber; Geiger counter apparatus.
B.; E.T.;I.T.	indicate correction for barometer effect; external temperature effect; internal temperature effect.

Table 1 [illegible] Variation of [illegible] intensity

Observer		h	Apparatus	θ	[illegible]	Duration of experiments.	Corrections	Results.	
								[illegible]	[illegible]
[illegible]	([illegible])	2.5[illegible] [illegible]	I. C.	0	0	3 months.	[illegible]ne	(.5, 13h)	
			w[illegible]e						
[illegible]	([illegible])	500 m.	I. C	0	0	10 days	[illegible] T.		−(.0e, 4.5[illegible])
Pe[illegible]	([illegible])	[illegible]° [illegible]	wide						
[illegible] and		1[illegible] [illegible]	[illegible]	0	0	2 months	[illegible]	(.[illegible],1[illegible])	
[illegible]orro	([illegible])	[illegible]° [illegible]	wide						
[illegible]orstar	([illegible])	0 m.	[illegible] C.	45° [illegible] 45° [illegible] 45° [illegible] 45° [illegible]	0	[illegible] months	None	Results not Fourier analysed. Appreciable variation with θ. Time of maximum [illegible] to 15h.	
		52° [illegible]							
[illegible] and		0 m.	[illegible] C.	30° [illegible] 30° [illegible] [illegible]° [illegible] [illegible]° [illegible]	0	2½ years	[illegible]	(.12,13h) (.0[illegible],13h) (.1[illegible],13h) (.17,19h)	
[illegible]ford	([illegible])	5[illegible]° [illegible]	narrow						
[illegible]ara[illegible]	(1945)	900 m	[illegible] C.	0	0	15 days	[illegible]one	(.3,14.5h)	
		3° [illegible]	wide						
[illegible]uperier	(1945)	0 m	C. C.	0	0	3 years	None [illegible] T.	(.25,17h) (.22,17h)	−(.12,0[illegible])
		54° [illegible]	wide						
[illegible]lliot and									
[illegible]lbear	(1950)	0 m	C. C.	45° [illegible] 45° [illegible] 45° [illegible] 45° [illegible]	0	1 year	None	(.1[illegible],1[illegible]) (.30,1[illegible]) (.2[illegible],13h) (.15,17h)	−(.04,03h) −(.1[illegible],0[illegible])
		57° N	wide						

Table 1.(contd.) (ii) Variation of total meson [illegible]

Observer	h	Apparatus	θ	Absorber	Duration of experiments	[illegible]	Results [illegible]	[illegible]
[illegible], [illegible]ennett & [illegible]rns (1932)	3900 m. 39° N.	I. C. wide	0	2.5 cm. [illegible] plus 5.0 cm. [illegible]	10 days.	[illegible]	(.8, [illegible]	
[illegible]lin (1932)	2500-5500 m.	I. C.	0	10 cm. [illegible]	3 weeks.	[illegible]		(.78,11 [illegible])
[illegible] (1940)	2° N.	wide						
[illegible]inmaurer (1935)	590 m. 47° N.	I. C. wide	0	10 cm. Pb.	9 months	[illegible]	(.2[illegible]) (.25,12[illegible])	
[illegible] and [illegible]ziedel (1936)	2300 m. 47° N	I. C. wide	0	10 cm. Pb.	3 years.	[illegible]	(.2[illegible],11[illegible])	(.52,[illegible])
[illegible] (1936)	150 m 52° N	I. C.	0	12 cm. [illegible]	1[illegible] days	[illegible]	(.1[illegible],[illegible])	
[illegible]rush (1937)	7[illegible] m. [illegible]° N	I. C. wide	0	12 cm. Pb.	273 days	[illegible]	(.17,11h)	([illegible])
[illegible]holand, [illegible]elatisky [illegible]aukell (1937)	1[illegible] m. 32° [illegible]	I. C. wide	0	12 cm. Pb.	3 years	[illegible]	([illegible],10h) ([illegible]) (.2[illegible],1[illegible])	
[illegible]ompson (1938)	0 m; 40-55° N; 25-40° N; 10-25° N; 10°[illegible]; 10-25° [illegible]; 25-40° [illegible]	I. C. wide	0	12 cm. Pb.	11 months in all	[illegible]	(.13,1[illegible]h) (.[illegible],1[illegible]h) (.2[illegible],1[illegible]) (.[illegible],1[illegible]) (.21,1[illegible].5h) (.17,1[illegible]h)	
[illegible] and [illegible] (1947)	760 m. 1[illegible]° [illegible]	I. C. wide	0	12 cm. Pb.	4 years	None	(.2[illegible],1[illegible]) -(.1[illegible],[illegible]h)	
[illegible] (1953)								
[illegible] (1935-40)	[illegible] m. 45° [illegible]	I. C. wide	0	10 cm. Pb.	5 years	[illegible] 1, 2,	(.2[illegible],11.5h) (.2[illegible],14.[illegible]h) (.15,11.[illegible]h)-([illegible],03h)	
[illegible] & [illegible] (1948), [illegible]	3[illegible] m. 1° [illegible]	I. C. wide	0	10.7 cm. Pb.	8 years	[illegible]	(.16,15.[illegible]h)-(.05,02h)	
[illegible]	[illegible]						(.15,15.[illegible])-(.02,1.5h)	
[illegible]	[illegible]						(.08,15.[illegible])-(.01,[illegible]h)	
[illegible]	[illegible]							
[illegible] (1952)	[illegible] 3° [illegible]	[illegible] narrow	0	8 cm. [illegible]	12 days	None		(1.0,10.5h)

(iii) Variation of [illegible] meson intensity.

[illegible] and [illegible] (1[illegible])	1[illegible] m. 4[illegible]° N	[illegible] narrow	0 / 53°	[illegible]	4 months / 3 [illegible]	[illegible]	Reversal of phase of variation [illegible] θ increasing from 0 to 5[illegible]. (.16,1[illegible])
[illegible] (1[illegible])	[illegible]	[illegible] narrow	0	40 m. [illegible]	15 months	None	
Macanul[illegible] ([illegible])	[illegible]	[illegible]	[illegible]	[illegible] depth [illegible]	1 year	None	(.05 10h)

(iv) [illegible] of [illegible] intensity

[illegible] and [illegible] (1[illegible])	1[illegible] 4[illegible]° N	[illegible]	0	[illegible]	12 months	[illegible]	(.61,1[illegible]h)

1.5.1 The diurnal variation :-

It can be seen from Table 1 that the diurnal variation has an amplitude of about .2 % at places in the temperate zone. However, the phase seems to vary widely from station to station and is different for stations on the same latitude. Even allowing for the fact that the different workers have applied different corrections to their data, the results are difficult to understand. The only definite conclusion that can be drawn about the diurnal variation is that the maximum occurs sometime during the sunlit hours and the minimum during the dark hours.

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

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

In most attempts at explaining the diurnal variation, the changes in the phase of the variation from station to station are neglected. The diurnal variation is assumed to have a maximum at about midday. As an example, Vallarta and Godart[40] have suggested that such a variation can be produced at high latitudes by a heliomagnetic field and at low latitudes by variations of the geomagnetic field. Obviously, this explanation cannot account for the changes in phase of the diurnal variation for stations on the same latitude. Moreover, Malmfors has shown that the results he has obtained with Alfven in Stockholm are not compatible with this explanation. His results are particularly interesting because they cannot be explained by meteorological effects. As Malmfors suggests, the results may be due to small disturbances in the isotropy of the primary radiation.

The results obtained recently by Elliot and Dolbear[41] with directional counter telescopes show a marked difference between the diurnal variation for cosmic rays coming in the north and south directions. The hour of maximum for the former is shifted earlier by about 2 hrs. The two telescopes are inclined to the vertical at 45°. Since the latitude of Manchester is 53°N, the north telescope is pointing approximately to a fixed direction in space, whereas the south telescope sweeps across the sky in the equatorial plane of the earth. The atmospheric effects for both the telescopes are alike since the particles from both the north and south have travelled the same amount of the atmosphere under approximately similar conditions. It is in this connection important to bear in mind that if the anisotropy of primaries such as may be caused by solar emission of cosmic rays, can produce a daily variation in both North and south pointing telescopes; the difference curve reflects only an arithmetic difference between the daily variation in the two directions. It does not reveal the true nature of the variation due to primary anisotropy in either direction.

1.5.2 The semi-diurnal variation :-

As is evident from Table 1, the nature of the semi-diurnal variation, like the diurnal variation, differs from place to place and is different for different cosmic ray components. Amongst the results that may be considered to

~~the~~ be statistically significant are firstly those of Rau[41] which were obtained from two ionization chambers suspended in a narrow vertical fissure of rock, 40 metres under the surface of Lake Constance. The variation is purely semi-diurnal with an amplitude of about .16% and phase almost coinciding with that of the semi-diurnal variation of daily barometric pressure. In Rau's experiment, the variation measured was only of mesons which could penetrate through 50 metres of water equivalent (including the atmosphere) and hence had an initial energy greater than 10^{10}eV. Moreover, the solid angle was narrow because of the presence of fissures in the rock. The intensity measured was thus almost vertical and was unaffected by magnetic variations.

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

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

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

Table 2.

H(km.)		0	10	20	30	40	50
H(km.)	= 0	.010	.012	.012	+.002	-.086	-.272
	= 50	.003	.003	.003	-.001	-.023	-.072

H(km.)		60	70	80.	90	100
H(km.)	= 0	-.490	-.510	-.60	-1.05	-2.22
	= 50	-.129	-.135	-.16	-0.28	-0.59

The positive or negative correlation with the semi-diurnal component of ground pressure can therefore be explained by assuming the meson-formation layer to be either above or below 30 km. respectively. Nicolson and Sarabhai have shown that the positive pressure effect in Rau's results can be explained by assuming that the mesons are formed at an average height of about 65 km. above ground. Above the nodal surface at 30 km. the amplitude of the pressure variation increases rapidly and attains at about 70 km., a value of the right order to explain the ground variation of meson intensity. However, the portion of atmosphere left above 70 km. is only 1/8000 th of the whole atmosphere. The primary radiation has therefore to traverse only this much mass before it produces the secondary meson component. Such an assumption leads to an abnormally high value for the cross-section of meson formation, if the primary radiation is supposed to be composed of protons. Even for heavy nuclei in the primary radiation, such as are found by Freier[44] et.al. the discrepancy would not be removed.

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

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

1.8 True and apparent sidereal daily variation of cosmic ray intensity :-

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

Hogg's analysis of available cosmic ray data of a number of authors fails to disclose any true sidereal effect of significant magnitude. However Elliot and Dolbear claim that strong evidence exists for a sidereal time daily variation of amplitude about .02 % and with a time of maximum at about 0500 hours sidereal time. In view of conflicting views on this important question it is necessary to examine the validity of some of the assumptions that have been made in deriving a sidereal time daily variation of cosmic rays. We shall revert to this at a later stage.

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

2. STATEMENT OF THE PROBLEM :-

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

(1) Dependence of the daily variation on the latitude and altitude of the station. The semi-diurnal component of the daily variation of atmospheric pressure is expected to produce variations in the meson intensity. The amplitude

of the pressure variation increases rapidly for decreasing latitude. On the other hand, the day-to-day changes in barometric pressure are more prominent in higher latitudes as compared to the tropics. A study of the day-to-day variations would therefore be more revealing in higher latitudes whereas a study of the daily variation would be more reliable and conclusive in lower latitudes. Also, the amplitude of the variation of cosmic ray intensity is more pronounced at higher altitudes. A study of the variation at mountain stations and at low latitudes is, therefore, desirable.

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

(3) Dependence upon the angle of incidence :— The phase and amplitude of the daily variation are dependent upon the angle of incidence of the observed particles with

respect to the zenith. Measurement of the intensities within restricted angle is, therefore, expected to bring out more clearly the amplitude and phase of the true variation. It is desirable, therefore, to use counter telescopes (with narrow angles) instead of ionization chambers which measure intensity from all directions.

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

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

Three units of this apparatus were constructed and installed. One is at the Solar Physics Observatory, Kodaikanal (mag. lat. 1°N, alt. 7688 ft.), another is at Ahmedabad (mag. lat. 13°N, alt. 180 ft.) and a third recently installed at Trivandrum (8° 31' N, 77° 00' E).

2. THE APPARATUS

Section I of this chapter deals with the experimental arrangement. Section II gives a detailed account of the Geiger-counters and allied electronic units.

2.1 Experimental arrangement :-

Fig. 1 is a block diagram of the experimental arrangement used for measuring the total intensity (T) and the intensity of the meson component (M) of the cosmic radiation at Ahmedabad.

Counter trays A, B, C, D, and E are placed one below another with a separation of 20 cms. A',B',C',D', D', E' are

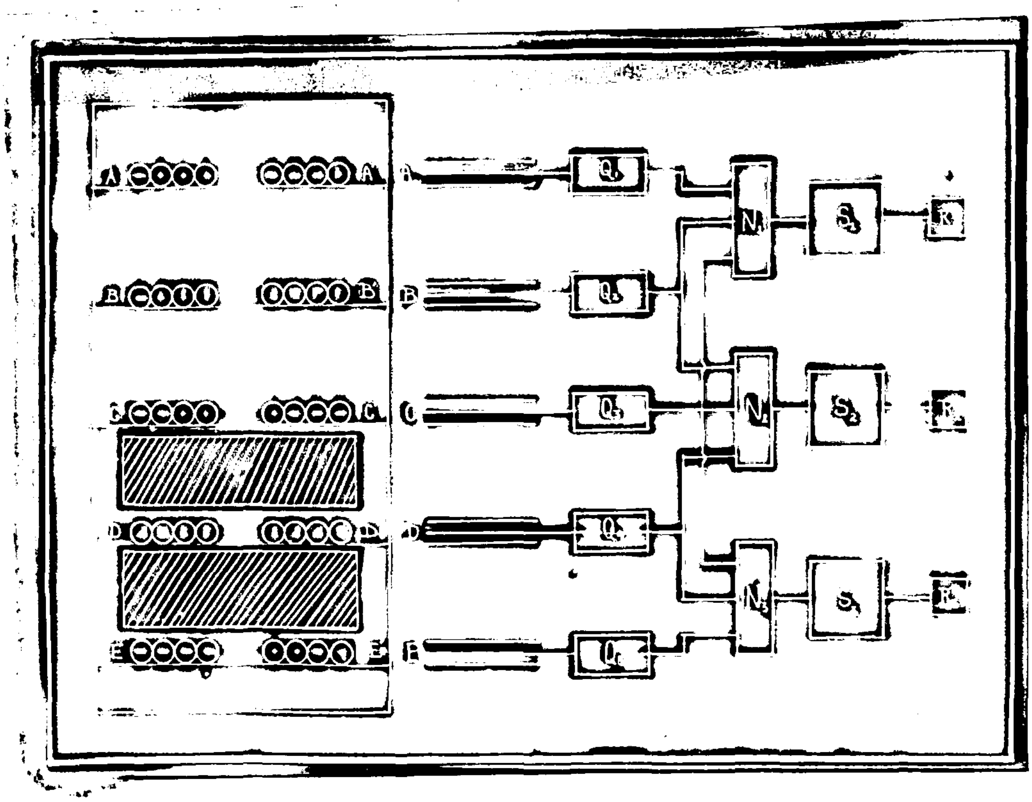


Fig. 2.1 - Experimental arrangements

similar trays. 8 cms. of lead is kept between trays C and D and C' and D'. Between trays D and E and D' and E' 18 cms. of lead are kept. Triple coincidences (ABC), (BCD), (CDE) and (A'B'C'), (B'C'D'), and (C'D'E') are measured. The rates (ABC) and (A'B'C') indicate the total cosmic ray intensity. The counting rates (BCD) and (B'C'D') measure that component of the cosmic radiation which can penetrate 8 cms. of lead. This would consist mostly of μ mesons and some energetic electronic component. The rates (CDE) and (C'D'E') measure a still harder component consisting mostly of mesons which can penetrate 18 cms. of lead. All the telescopes are oriented vertically and subtend the same solid angle. The trays are put in a thermostatically controlled box at a temperature of $105^{\circ} \pm 2^{\circ}$F.

The simultaneously running of two similar telescopes served the following purposes :-

(1) When counters which fail are replaced by new ones, the counting rate alters due to slight deviations either in the geometry of the telescope or the characteristics of the counters. This altered rate can be standardised by the uninterrupted rate of the duplicate unit.

(2) Genuine variations which occur in cosmic ray intensity are confirmed if they are equally reflected in the counting rates of both the units.

(3) The probable error in individual readings is reduced by the duplication of the measurements.

It has been shown by Greisen[48] that for the directional measurement of the cosmic ray intensity, it is desirable to have a high number of coincidences. The multiple coincidence of several trays can be effected either by a single particle passing through all of them or by time-associated particles such as are found in showers. There can also be a contribution of chance-coincidences due to the finite resolving-time of the coincidence unit. The contribution of showers can be greatly reduced by taking triple coincidences instead of double coincidences. The contribution due to chance coincidences is a function of the number of trays, the individual counting rates of the trays and the various resolving times of the elements of the coincidence unit. It is shown by Karl Eckart and Francis R. Shonka[49] that if N_1, N_2, N_3 are the individual rates of three trays and T_1, T_2, T_3 are the resolving-times of the three elements of the coincidence circuit, the contribution A_{123} due to chance coincidence is given by

$$A_{123} = N_1 N_2 N_3 (T_1 T_2 + T_2 T_3 + T_3 T_1) .$$

In the present experimental set-up the contribution of showers and chance coincidences to the total triple coincidence rate is 0.6 % . This was determined in the laboratory by shifting laterally the central tray of the triple coincidence telescope so that a single particle cannot register a coincidence in all the three trays.

Each counter tray consists of four self-quenched counters. The anodes of all of them are connected together to a common quenching unit. The total sensitive area of a representative tray is approximately 500 sq. cms. The counter trays are so arranged that the axis of the counters are pointing in the North-South direction. By putting the counters in the above way, we get a smaller semi-angle of the telescopes in the East-West as compared to that in the North-South direction. The semi-angle of the telescope in the East-West direction is 22° and that in the North-South is 37°. As has been shown in the Introduction, this set-up is advantageous for the study of the solar time daily variation of cosmic ray intensity.

The quenching unit furnishes a sharp index-pulse for every cosmic ray particle passing through the particular tray to which it is attached. These pulses are fed to the coincidence unit whose output is fed to the scaler which drives the electro-mechanical recorder. The readings indicated by the mechanical recorders are photographed automatically every hour.

Though the counting rates of the telescopes are not high, scalers have been used for the following reasons.

(1) The telephone type electro-mechanical recorders work reliably only for a finite number of counters, because of the wear on the brass ratchet. The life of the mechanical recorder is enhanced by the scaling-down of the counting rates.

(2) The use of a scaler reduces the loss of counts of successive coincidences in a time interval shorter than the resolving time of the recorder. Since the initial coincidence rate has a random distributeon, there is a certain probability for the events to occur with a very small interval of time. On the other hand if such a distribution is fed to a scaler, the output rate will not have the same random distribution. Events separated by a very small time interval will be reduced as the scaling factor is increased. Leon ALOGLU and Nicolas M.Smith Jr.[50] have given an exact analysis of the statistical theory of counting with the help of scaling circuits. If the scaling factor is increased sufficiently, one can almost get rid of the random distribution of the counts. In the present investigation a factor of four for scaling has been selected. In other units built by the author for similar apparatus at Kodaikanal and Trivandrum, a factor of eight for scaling has been used.

2.2 Counters

Geiger counters are diodes filled with gases like hydrogen or argon and working in the region of unstable corona discharge. There are two types of such counters. The essential mechanism governing the "break down" of both these types is the same. But their quenching actions are different. In the non-self-quenched-counter, the quenching action is done <u>externally</u>, either by a high series resistance or an electronic quenching device. In the self-quenched type, quenching is effected by the presence of suitable additional organic vapour introduced into it. More recently, in the place of organic gases, halogens are also being used successfully as quenching agents.

The electrode system of a geiger counter consists usually of a cylindrical cathode and a concentric wire forming the anode. When an ionising radiation traverses the gas in the counter it produces some ion pairs in it. The ions are collected by the electrodes due the action of the electric field. If the field is not intense, multiplication of the ions by collision with other gas molecules does not occur and only the ions created by the initial event, get collected. If the voltage applied to the electrodes is raised, the electrons liberated during initial ionisation get sufficient energy, while moving towards the anode, to produce further ions by collisions with the neutral gas molecules. There is then a Townsend avalanche for every initial ion. The total charge collected at the electrode is in consequence multiplied, the multiplication factor depending upon the applied voltage, the geometry of the electrode and the pressure and nature of the gases used in the counter. A linear relation between the charge collected and the ions created initially holds good only over a finite range of voltages. When the voltage is raised further, the multiplication factor for different ionising events does not remain constant and we get what is known as 'the region of limited proportionality'. In the regions of 'proportionality' and 'limited proportionality' the discharge spreads only over a limited length of the anode. Under conditions usually encountered, the discharge consisting of Townsend avalanches has a lateral spread of the order of 0.1 mm. and reaches its full development in about 10^{-5} sec. When the voltage is further raised, a number of photons are generated in avalanches and these trigger other avalanches, resulting finally in the discharge spreading along the whole of the counter. Due to this complete spread the output pulses have the same magnitude irrespective of the initial ionisation. The voltage at which the output pulses all become equal, in spite of differences in the initial ionisation, is known as threshold voltage of the geiger region. The amplification in this region is of the order of 10^9. The general behaviour of the counter in different regions of amplification is shown in the figure 2.2 as given by Friedman[51].

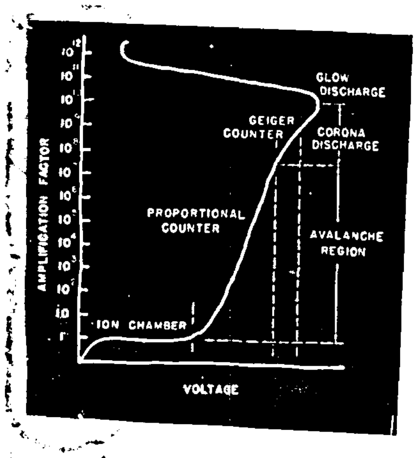


fig 2.2

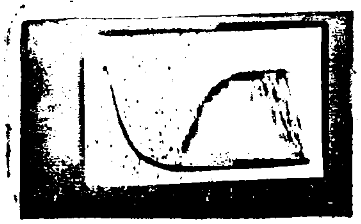
In what follows, an account is given of the spreading of the discharge along the counter and the mechanism of the quenching action for both types of the counters.

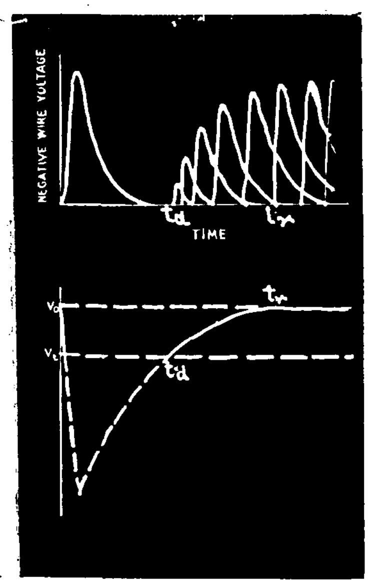
For a cylindrical form of the cathode, the field distribution is given by the following expression.

$$E_r = \frac{V}{r \log_e \frac{a}{b}}$$

It is clearly seen that the field is most intense near the anode. The development of the initial Townsend avalanches takes place very near the anode. The photons generated in these avalanches initiate new avalanches. If the gas is transparent to the photons, photoelectrons are ejected from the cathode. This happens in the case of non-self-quenched counters where the gas has low absorption coefficient for photons. In the case of self-quenched counters, the quenching vapour has a high absorption coefficient for photons, and then the photons are absorbed by the vapour and the breeding of the avalanche occurs very near the anode. This view of the mechanism of breeding has been confirmed by the experiments of Greiner[52] and of Stever[53]. Hartog[54] has studied the mechanism of discharge with a high speed triggered oscilloscope by irradiating a counter with ionising radiation travelling radially across different portions of its sensitive volume. He has found that the speed of spread of the discharge, under conditions usually encountered, is about 10 cms. per microsecond. Alder[55] Huber[56], Metzger[57] and Wilkinson[58] have attempted qualitative explanation of the development of the spread.

The discharge spreads along the anode and builds up till the density of the positive ion sheath (which is confined to a region very near the anode) is sufficient to lower the field below the threshold value. During the time electrons get collected at the anode, the positive ion sheath does not move appreciably because of the very low mobility of the positive ions. But as the positive ion sheath moves towards the cathode the field near the central wire starts rising. When the sheath reaches a critical radial distance, the field attains a value which is appropriate to the threshold of the geiger region. The pulses developing at this value of the field are smaller than normal. When the positive ion sheath just reaches the cathode, the original field is restored. The time that the positive ion sheath takes to go to the critical radial distance is known as the dead-time of the counter. The time it takes to go to the cathode from this critical radial distance is known as the recovery-time. An oscillographic study of the breeding and the movement of the positive ion sheath has been done by Stever[59] and Von Hartog[60] and others. The following is a representative record of the studies which give information regarding the nature of the positive ion sheath.





If the sheath consists of argon ions, when it reaches the cathode, the following phenomena occurs. The positive ions get neutralised by ejecting electrons from the cathode and thereby attain an excited state. When they return to the ground state, they emit photons which emit photoelectrons from the cathode. These photoelectrons breed new avalanches and the discharge continues. For the termination of the initial discharge, the new electrons ejected by the photons should not be allowed to breed avalanches. This can be done by lowering, below threshold, the voltage across the counter. The lowering can be achieved by introducing a high resistance in the counter circuit which gives a voltage drop due to a large enough discharge current of the counter. Because of the low discharge current, the resistance must be high to get a large enough voltage drop. This high value of resistance gives a very high recovery time. This limits the resolving time of the counter. The voltage can be lowered by the use of an electronic unit. The use of the quenching unit enables one to get quenching action with a very small and well defined resolving time. The nature of the pulses obtained, both for resistance and for electronic quenching is shown in the figure below : 2·3

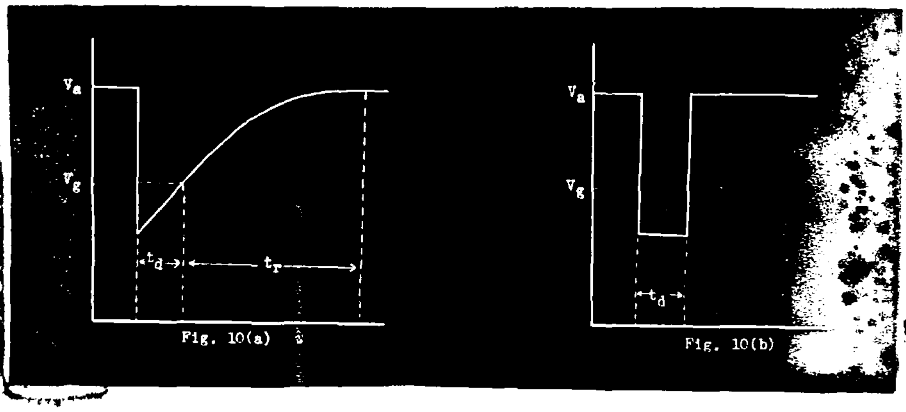


fig 2·3

The phenomenon of internal quenching action due to the presence of organic vapour was first reported by Trost[61].

Korff and Present[62] gave a qualitative explanation for the same which is as follows : as the positive ion sheath moves towards the cathode, the argon ions undergo a large number of impacts (10^5) with the molecules of the organic vapour. The ionisation potential of the organic molecules being lower than that of argon, charge-exchange phenomena takes place and when the sheath reaches the cathode, it consists mostly of positive ions of organic molecules. When the sheath is at a distance of 10^{-12} cms. from the cathode it ejects electrons from the cathode and thereby gets excited. The life-time of the excited state of these molecules is nearly 10^{-13} sec. and so before they reach the cathode (for which it would take 10^{-12} sec.) they would dissociate. Thus instead of giving photons as is done by the argon ions, the excited ions of organic vapour dissociate. Since in every discharge a finite number of molecules of organic vapour dissociate in this way a self-quenched counter deteriorates with use.

In the above discussion, we have briefly surveyed the working of the counter and its quenching mechanism. The important characteristics of a counter are

(1) The starting voltage or the threshold voltage for the geiger region.

(2) The plateau - or the voltage range above threshold for which the counting rate is substantially independent of the operating voltage.

(3) The slope of the plateau which indicates the extent to which a counter has a geiger region.

(4) The useful life of the counter expressed in terms of the number of counts registered after which the plateau deteriorates to such an extent that the counter can no longer be relied upon.

(5) The efficiency of the counter determined by the probability of getting a discharge when an ionising radiation passes through its sensitive volume. This is dependent upon the formation of at least one ion pair in the counter gas.

Preliminary investigations were carried out during the present study to make counters of high efficiency, low threshold potential and a flat plateau extending over 200 to 300 volts. It was empirically found by the author that the ratio of the length to the diameter of the counter should be at least six to get a flat plateau. Counters having cathode diameters of 1.5 to 2 cms. were prepared giving 400 to 500 volts plateau. These small counters were however not used for the present investigation. The disadvantage of using small counters lies in the fact that a large number of them have to be used to make a tray of large sensitive area. This increases the probability of failure and thereby causes interruptions in the operation of the apparatus. With counters of 4 cms. diameter and 30 cms. long which were used for the present investigation, we get a plateau of 250 volts.

The dependence of the starting potential as well as plateau on the total pressure of the gas mixture and the partial pressure of the constituent gases was studied by Mr. P. D. Bhavsar of this laboratory. The following diagrams give the results of his study.

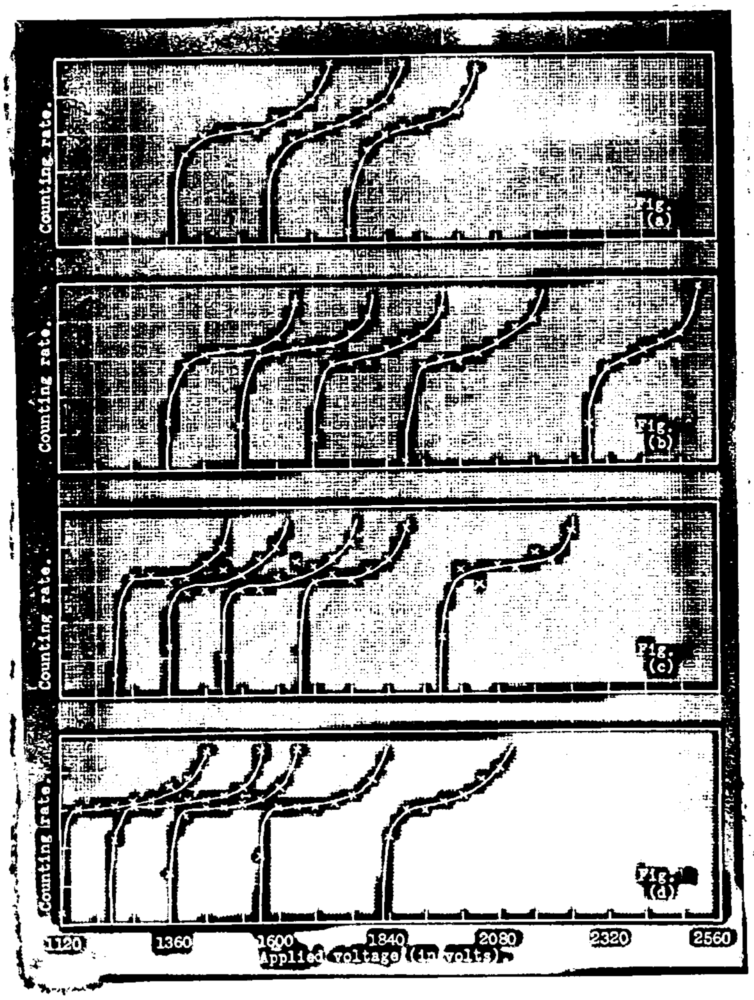


Fig. 2.4

Plateau charecteristics curve for Geiger counters filled with different percentage mixtures of ethyl acetate and argon at different total pressures.

(a) For ethyl acetate 25%, argon 75 %.

(b) For ethyl acetate 20%, argon 80%.

(c) For ethyl acetate 15%, argon 85%.

(d) For ethyl acetate 10% argon 90%.

From the above curves we see that the extent of the plateau-region depends upon the percentage of the quenching vapour used and the total pressure of the gas mixture. The threshold voltage increases as the percentage of the quenching vapour as well as the totàl pressure increases. The following table gives the dependence of the extent of plateau on the percentage of quenching vapour and the total pressure.

Table 2.1 - Plateau ranges for different percentage and total pressure.

Total pressure. \ Percentage of vapour	25 %.	20 %.	15 %.	10 %.
20 cm.	-	40 V.	64 V.	80 V.
15 cm.	-	48 V.	80 V.	120 V.
12 cm.	56 V.	48 V.	80 V.	120 V.
10 cm.	64 V.	80 V.	80 V.	160 V.
8 cm.	104 V.	120 V.	128 V.	160 V.

It is seen that by reduction of total pressure and the partial pressure of the quenching vapour, the plateau increases. In consideration of the efficiency of the counter the above two parameters cannot be reduced indefinitely. The total pressure of the mixture used is 10 cms. the pressure ratio of argon to ethyl acetate being 9:1. The starting potential of the counter lies between 1200 to 1300 volts. Generally the plateau is about 250 volts. The efficiency is about 99.98 %.

It is found that after some use the plateau characteristic of a counter changes. The rise in the slope of the plateau was investigated by the present author. It is found to be due to the multiple spurious discharges along with the genuine ones. The number of these spurious discharges increases as the operating voltage is increased. The development of such spurious discharges may be caused by improper quenching action due to dissociation of some molecules of the quenching vapour after every discharge. The following figure reproduced from Freidman's paper gives the behaviour of a counter when spurious discharges have started to develop.

Mainly by suppressing spurious discharges, an electronic quenching unit is found to improve the plateau of the counter (Elliot). The life of the counter is also prolonged as the spread of the discharge along the counter is reduced. It has already been mentioned that the speed of the spread of the discharge is 10 cms. per microsecond. If the quenching pulse is applied to the counter within a time of the order of a microsecond, the discharge cannot spread more than 20 cms.(10 cms. in either direction of initiation) along the wire.

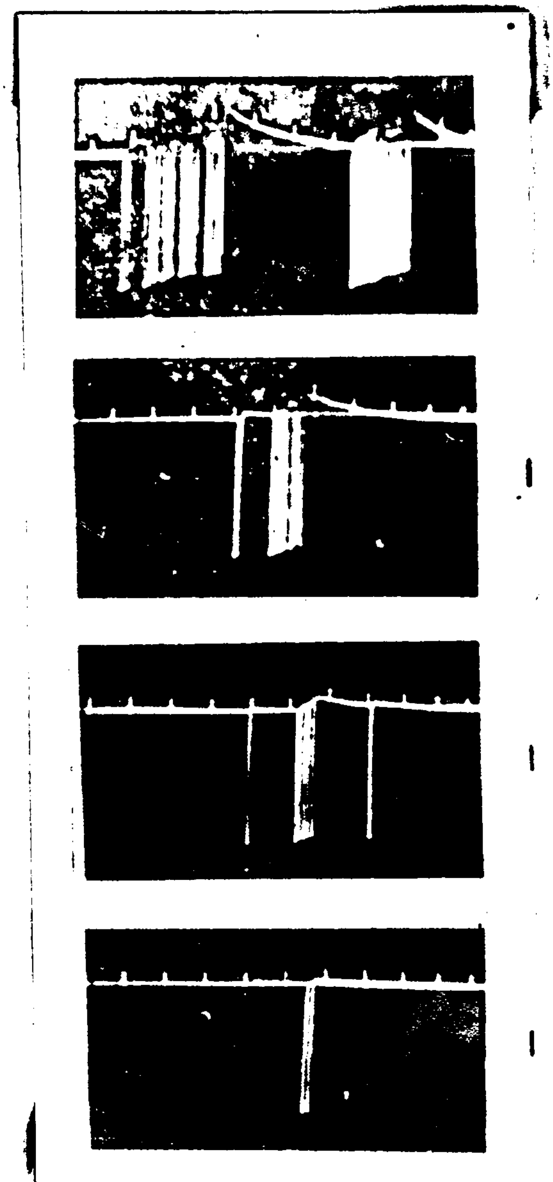


fig 2.5

Development of spurious pulses at high over voltages.

If the discharge spread is reduced in this way, the number of dissociating molecules decrease and the life of the counter is prolonged.

II

2.2.2 Preparation of counters.

A typical counter used for the present investigation is shown in the following figure 2.6

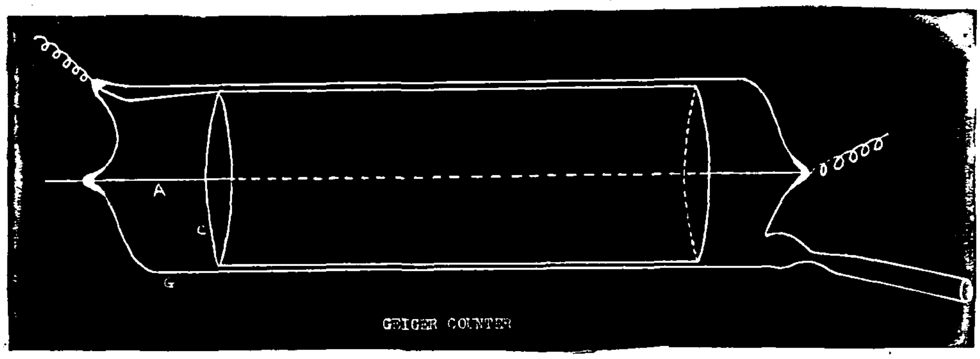


fig 2.6

It has a copper cathode and a tungsten anode in a pyrex glass tubing. The diameter of the cathode is 3.5 cms. and 4 mill tungsten wire is used as the anode. The cathode is made from 0.15 mm. copper sheet. The sheet is rolled to remove irregularities and then shaped into a cylindrical form to be put into the envelope. Thick tungsten wire is silver-soldered to the sheet for the external cathode connection to be taken out. This wire is fused into the envelope as shown in the figure. This holds the cylinder regidly in the envelope. The anode is heated red-hot and stretched to remove irregularities and then fused into the pyrex envelope at the two ends. As shown in the diagram, thick tungsten is spot welded to the thin anode wire at the end B. Copper wire is then silver-soldered to it for external electrical connection.

After having sealed the electrode-assembly in the envelope in the above manner, the counter is cleaned and washed thoroughly by the use of a washing system as shown in figure (2.7).

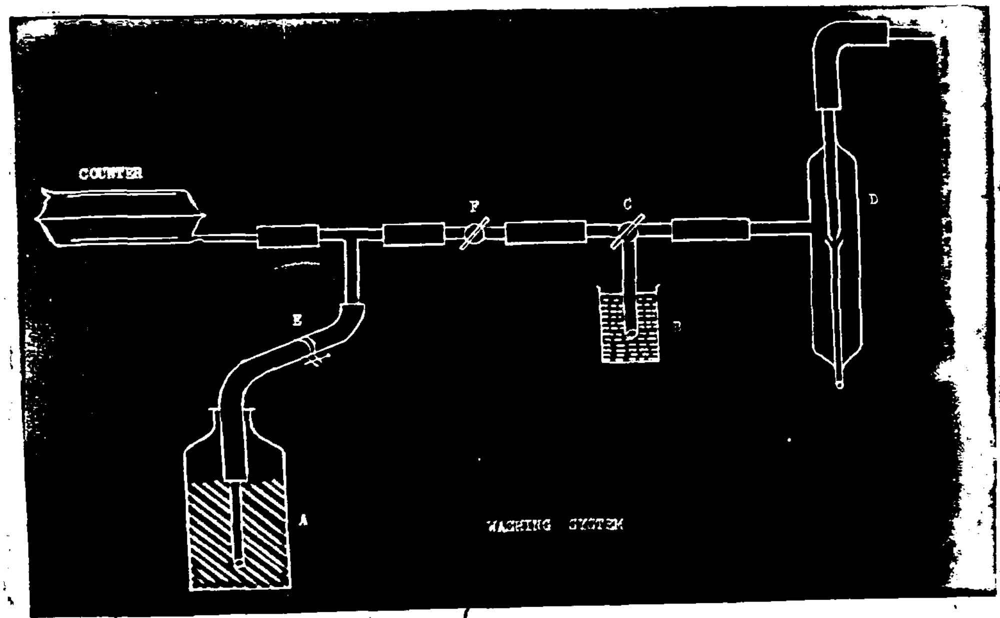


fig 2.7

The procedure consists initially of cleaning with a solution of nitric acid and distilled water by proper manipulation of the cocks of the washing system. Then the counter is repeatedly washed with distilled water. The counter is dried with a filter pump and then connected to a vacuum pump through a tube containing $CaCl_2$.

After the above procedure of cleaning, the counter is connected to a filling system illustrated in figure (2.8).

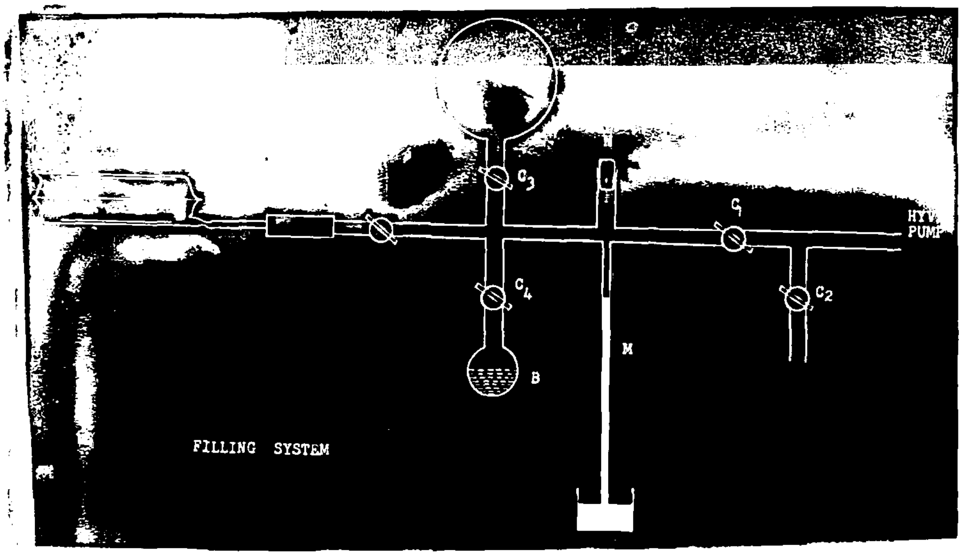


fig 2.8

A flask A having a capacity of 2 litres is first filled with 99% pure argon. P_2O_5 removes traces of water vapour. The quenching vapour is introduced with the help of a small bent glass tubing in the vacuum of the mercury manometer (M). The filling system along with the counter is then connected through a cock C_1 to a Cenco hyvac pump. After evacuation, the pump is tested by means of a high frequency probe unit. The counter is first filled with the quenching vapour and then with argon. Their partial pressures have a ratio of 1:9 and the total pressure of the gas is 10 cms.

The testing of the counter is done both with the resistance quenching using a one megohm resistance as well as on an oscilloscope. With normal cosmic ray intensity the counting rate of the counter is taken for a range of applied voltages. If a flat plateau region of 250 volts is obtained the counter is sealed.

For some time there was a scarcity of pyrex tubing of proper diameter and wall-thickness in this country. During this period, all-metal counters were developed and prepared by the author. Both brass as well as copper tubings have been utilised. Brass tubing were found to give better performance. The use of "Araldite" for sealing the metal assembly was suggested by Dr.Amaldi. The plateau of all metal counters are superior to those of pyrex glass ones. The cause of this may lie in the perfect geometry that can be had in the metal counters and the good polish that can be given to the cathode surface. All metal counters are superior to glass counters in another way too. Because of photoelectric effect on the cathodes of glass counters, it is desirable to protect them from light. In all metal counters there is no possibility of light affecting the cylinder. Metal counters have been used successfully in this laboratory.

The counter is 'aged' before it is used in cosmic ray telescopes. The aging of the counter is done by applying the working voltage continuously for three or four days and testing the plateau. If no appreciable change in the original characteristics is found the counter is taken for a routine work.

2.3 Quenching Unit

It has been shown in the discussion of the plateau of the counter that, after some use, the slope of the plateau changes because of a multiple of spurious pulses developing along with genuine ones. This may be looked upon as a case of improper internal quenching action. An improvement in the plateau can be had by the use of an external quenching unit. For this purpose the quenching unit has to lower the voltage across the counter below the threshold by feeding to the counter a negative voltage-pulse of well defined duration and magnitude. A number of electronic circuits have been devised for quenching a counter discharge. A monostable multivibrator circuit gives a negative voltage pulse which is used for the present quenching unit.

The broad negative voltage pulse which is used to quench the discharge, cannot by itself be used for fast coincidence work. Its edges are therefore differentiated and a sharp negative index pulse is generated from the leading edge for the coincidence measurements.

The sensitiveness of the unit is such that the pulses developed at the threshold voltage are adequate to trigger it. The quenching pulse is of 350 volts.

The above mentioned properties are obtained by the use of the following circuit. For the electronic design the book on " Wave-forms[63]" and "Principles of Radar[64]" of the M.I.T. series were consulted.

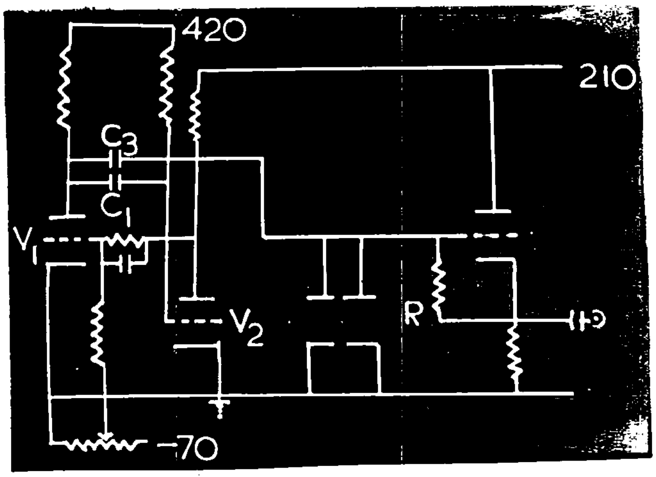


fig 2.9

As shown in the figure the above circuit consists of one-shot multivibrator, a differentiating net-work with a positive pulse clipping diode, and a cathode follower.

A 6SN7 high g_m twin triodeis used for the mono-stable multivibrator. In the stable state, tube V_1 is non-conducting and V_2 is conducting. This is so because of the D.C. - A.C. coupling between the plates and the grids and the steady potential to which the grids are returned. When a negative pulse is applied to the plate of V_1, it is fed to the grid of V_2 through the condensers C_1. This negative pulse is amplified by V_2 giving a positive pulse on its plate. This positive pulse raises the grid voltage of V_1 thereby making it conducting. The process is a regenerative one and in a very small interval of time of the order of one microsecond after the injection of the triggering event, V_1 becomes fully conducting while V_2 is taken into the cut off region. The grid potential of V_2 starts rising exponentially and when it reaches the cut off voltage, the tube V_2 starts conducting and a sudden switching to the initial stage occurs. During this process of double switching, a negative square voltage pulse is generated at the anode of V_1. The duration of this pulse is determined by the time taken by the grid of V_2 to come to the cut off value of voltage.

The following points of a one shot multivibrator are worth noting. The grid of the conducting tube is returned to the plate side instead of the ground as is usually done in such circuits (Elliot[65]). The advantage of the return of the grid to the H.T. side is to achieve stability of the duration of the rectangular pulse by increasing the slope of the exponential of the grid return at the moment of pick-off. The plate of the non-conducting tube is returned to a higher potential while that of the conducting one is returned to a lower one. This is done to improve the shape of the wave-form and to have low constant current drainage of the power supply. Across the D.C. coupling, resistance between the plate of V_2 and the grid of V_1, a condenser has been put to achieve a very fast initial triggering action. It is this fast switching that defines the width of the index pulse, and limits the discharge along the counter.

The differentiating network R_3C_3 gives two sharp pulses, one negative and the other positive, due to differentiation at the leading and the trailing edges of the quenching pulse. The diode by-passes the delayed positive pulse and at the grid of the cathode-follower only the sharp negative pulse is applied. A time-constant of the order of 5 microseconds of the network R_3C_3 enables the generation of a sharp index-pulse whose width is less than one microsecond. In the cathode follower circuit the grid leak is returned to the cathode of the valve. This increases the input impedance of the cathode follower. With the cathode follower we have a very low output impedance. This is advantageous when the pulse has to be fed to several units through shielded cable.

2.4 Coincidence Unit

The index pulses in the output of the quenching unit are fed to the multiple coincidence unit. The coincidence unit used for the present investigation is of the usual Rossi[66] type. The circuit diagram is as follows :-

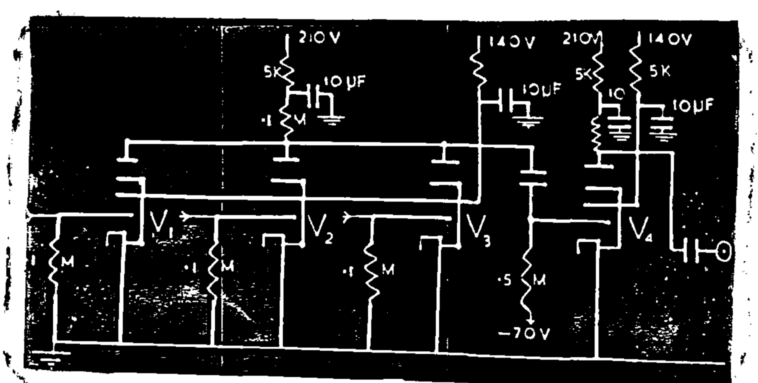


fig 2.10

In the above circuit, the circuit parameters and the signal strength applied to the grid are so arranged that when all the grids get a negative pulse simultaneously, the current through the common plate load resistance R_1 is cut off. Even if the signal is not applied to one of the grids, the current through R_1 does not appreciably differ from what it is when all the tubes are conducting. This physically means that the tubes act as perfect switches without any internal impedance and having a very high resolution time. The above discussion gives two design criteria for a multiple coincidence arrangement.

(1) High resolution time, and

(2) The ratio of the sizes of the pulses due to complete coincidence of N to the partial coincidence of (N - 1) events should be very high.

The coincidence circuit designed by the present author utilises a 50 μF grid coupling condenser and a 0.1 meg. grid leak resistance giving a time constant of the order of 1 microsecond. Actual value of the resolving time determined experimentally from the chance coincidence rate comes out to be .

To get a higher discrimination between the total and partial coincidences, sharp cut-off pentodes are used. To eliminate small pulses due to partial coincidences a level selector valve has been utilised. The bias of this valve is so arranged that it is insensitive to the small pulses generated by the partial coincidences.

2.5 Scaling Circuit

The circuit for the scaling down of the counting rate is based on the usual high vacuum Eccales-Jordan type of trigger circuit. The thyratron type scalers developed by Wynn Williams[67] have many limitations. In this the resolving time is limited by the deionisation time of the thyratron. With recent thyratrons a resolving time of the order of 50 microsecond can be had. The vacuum tube trigger circuit having two stable states has been developed from the basic Eccale-Jordan trigger circuits by many investigators[68]. Reich[69] and others have designed circuits utilising pentodes to get triggering sensitiveness for one type of pulses only. Approximate analysis of the time of switching and the general response characteristic of the trigger circuit to the triggering pulses has been given by Buys in "Nucleonics", Vol.3, No.5.

Following is the circuit diagram of the scale-of-four unit with the power-stage used to drive the mechanical recorder.

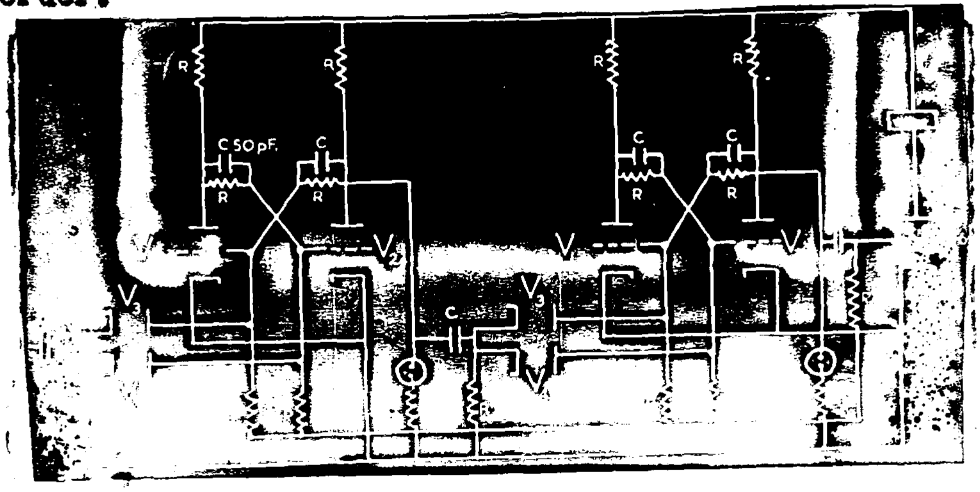


fig 2.11

The above unit consists of two scale-of-two units put in cascade. Any number of such stages can be put in cascade to get a higher scaling factor.

The basic scale-of-two circuit is a slight modification of a multivibrator circuit so as to have two stable stages. The plate of V_1 is connected to the grid of V_2 by D.C. coupling. The plate of V_2 is also connected to the grid of V_1 in a same way. Small "speeding" up condensers are put across the connecting resistances. The coupling double diode (V_3, V_4) is used for injecting the pulses. On account of this the pulse is applied only to the grid of the conducting tube.

When V_1 is conducting and V_2 is cutoff, the plate of V_1 is at a lower potential than that of V_2 while the grid of V_1 is at a higher potential than the grid of V_2. When a negative pulse is applied to the input, it is fed to the grid of V_1 because V_3 is conducting and V_4 is non-conducting. Due to this negative pulse the circuit triggers and V_2 becomes conducting and V_1 stops conducting. When another negative pulse is fed to it, it is now applied to the grid of V_2 by the diode V_4 and the circuit reverts to the original state. During this process of double change-over due to two negative pulses a step-voltage function is generated at the plate of V_1 which on differentiation gives positive and negative pulses. If negative pulses are fed in sequence to the circuit, one gets positive and negative pulses in succession. By selecting pulses of one polarity, we get a scaling factor of two.

A slightly modified circuit without diode coupling has been designed by the author. This has a very low power consumption. This is suitable where a high scaling factor is of importante. Units with scaling factors of 2^{10} i.e. 1024 have been prepared by the author and are found to be very stable in operation.

In both types of scalers neons have been used as indicators. Some trouble was experienced in the reliable working of the unit because of photoelectric effect on neons. The trouble was overcome by the use of proper limiting resistances so that the indicator circuit did not load the scale of two unit to which it is coupled.

The resolving time of these scalers is of the order of 15 microseconds. The electromechanical recorder for registration of counts is driven by a biased power amplifier. A negative bias of 70 volts applied to the control grid of the 6F6 tube keeps it non-conducting except when a positive pulse from scaler is applied to it.

2.6 Power Supplies

To achieve high stability in the working of the electronic units and the counters all D.C. voltages were stabilised against line voltage fluctuations and against load fluctuations.

The two parameters that can specify the working of the regulating network as far as line and load variations are concerned are the stabilising ratio (S_o) and the internal resistance (R) of the regulating unit. Hunt and Hickman[70] introduced these terms. Givary and Ruthland[71] have modified the method of analysis of regulating circuits as put forward by Hunt and Hickman. According to them four parameters are necessary for complete specification of a regulating network. These parameters are defined as

(1) Stabilising ratio $S = \left.\frac{e_i}{e_o}\right|_{i_o = o}$

(2) Internal resistance $R = -\left.\frac{e_o}{i_o}\right|_{e_i = o}$

Where e_o = output voltage fluctuations

i_o = output current fluctuations

e_i = input voltage fluctuations

i_i = input current fluctuations

(3) Shunt conductance for open output = $\frac{1}{q}$

where $q = \left.\frac{e_i}{i_i}\right|_{i_o = o}$.

(4) Shunt conductance for short circuited output = $\frac{1}{p}$

where $p = \left.\frac{e_i}{i_i - i_o}\right|_{e_o = o}$

Hunt and Hickman give complete analysis of the different types of regulating units. The following table summarises the different types of regulating circuits along with their properties.

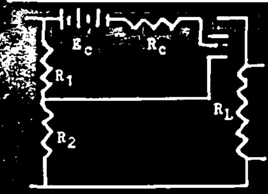
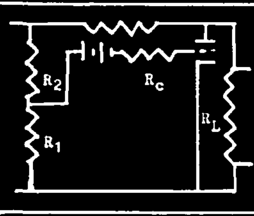
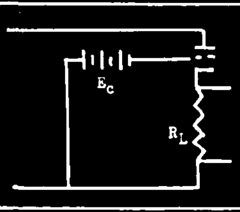
			CHARACTERISTICS	
		OUTPUT VOLTAGE CONTROL	$\frac{dE_o}{dE_i}\Big\vert_{R_L=k}$	$\frac{dR_L}{dE_o}\Big\vert_{E_i=k}$
	Mu BRIDGE	NOT READILY CONTROLLED	$\frac{dE_o}{dE_i}=0$ over a range of Constant 'μ'	NO STABILISATION
	g_m BRIDGE	LIMITED CONTROL	$\frac{dE_o}{dE_i}=0$ over a range of Constant g_m	NO STABILISATION
	DEGENERATIVE	VARIABLE E_c CAN BE USED FOR CONTROL	$\frac{dE_o}{dE_i}=\frac{R_L}{R_p+R_L(1+\mu)}$	$\frac{dR_L}{dE_o}=\frac{R_p(E_c+E_i)}{[R_p+R_L(1+\mu)]^2}$

Table 2.2

From the above table we see that the degenarative type of regulating circuit is the most suitable for getting a close control over the output, a sufficiently high stabilising ratio, and low internal impedance. A detailed discussion on the working of the degenerative type of regulating network is given in the book "Electronic Instruments[72]" (M.I.T. series). The following is a summary of their discussion.

The unit is divided in four basic elements as shown in the following diagram.

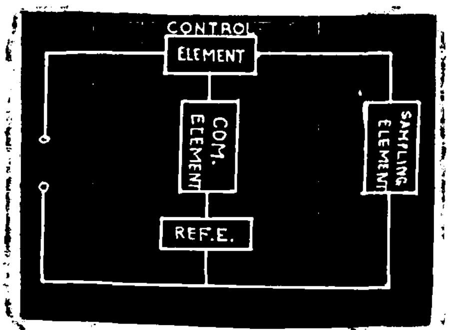


fig 2.12

The smpling circuit develops the error-voltage function. This is compared and modified with respect to a reference element by the comparison circuit, and fed to the control element which compensates for the change that developes the error-voltage function.

Normally the sampling element is a resistive network. A fraction of the output voltage variation is taken by the help of a tapping on this bleeder. A neon glow tube serves as a reference element. The stability of operation achieved by the use of a neon glow tube is not inferior to what can be achieved by the use of standard voltage regulator glow-gap tubes like VR75 or VR150. The comparison circuits being a high gain D.C. amplifier amplifies the erfor voltage function. An analysis of the regulating network shows that the stabilising property is greatly dependent upon the voltage gain of this amplifier. To achieve high gain the author has used "starvation type" amplifier circuits. The control element in the present design is a high g_m beam power tube. Newer types of tubes 6AS7-G giving heavy current at low voltage drop are not available in this country but a 6L6 type tube gives good performance.

To achieve simultaneously different voltages, separate regulating units are utilised along with the same filtered D.C. output. For low bias-voltage supply, stabilQ-volt or VR75 type tubes have been utilised.

The circuit of the complete power supply unit for low voltage as well as high voltage is given below :

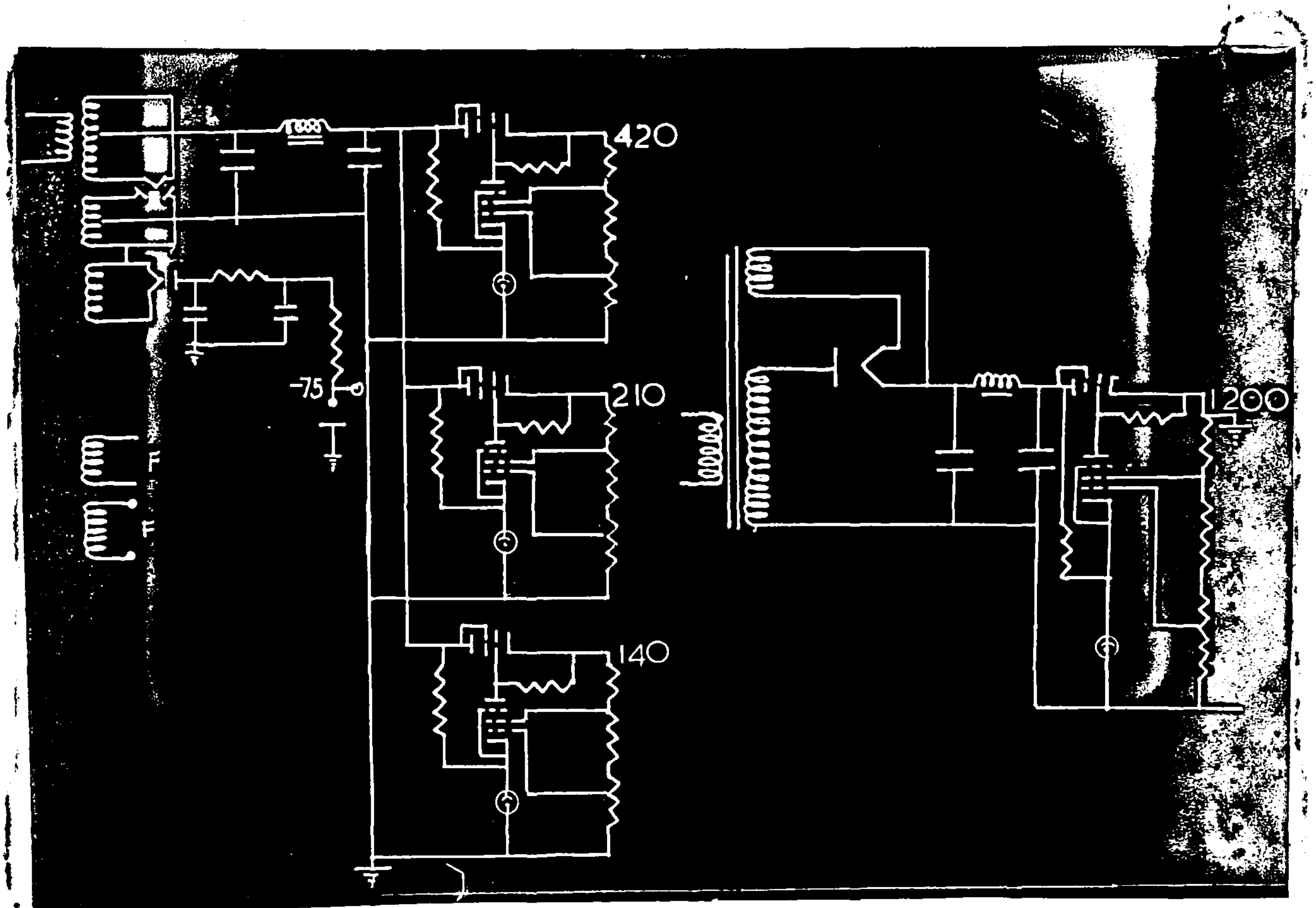


fig 2·13

The following table indicates the stabilising property of the power supply.

Input A.C. volts	Output D.C. volts
250	300
230	300
210	300
190	300
170	300
150	300
140	300
130	298

2.7 Automatic Photographic Device

Telephone-call type recorders are mounted on a panel along with a clock and a calander. This panel is kept exposed to a camera in a completly enclosed box. The following diagram gives the plan and the section of the camera unit and one representative photographic record.

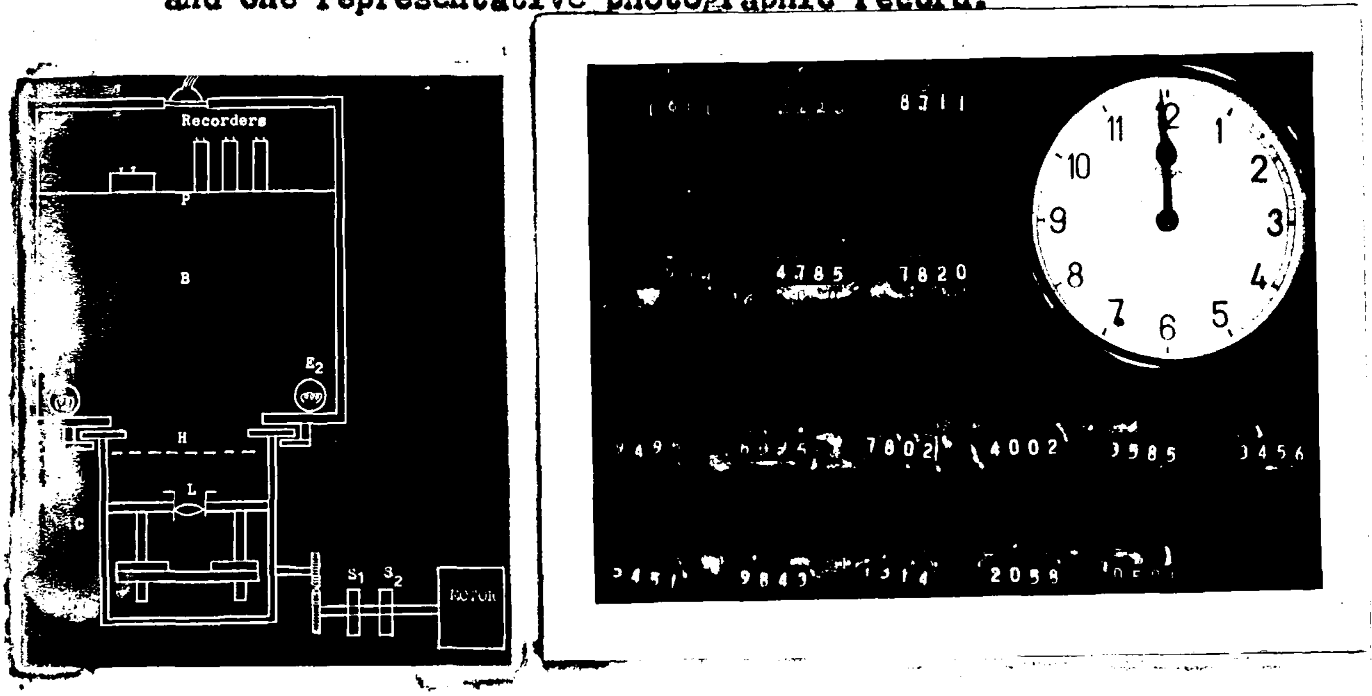


fig 2.14

The camera is of the fixed focus type utilising a lens of short focal length. There are two spools and a sprocket to move the 35 mm film. The sprocket is coupled to a gear-down motor to drive the film. The loading capacity of the camera is nearly 30 ft. of standard 35 mm film.

The automatic sequence of working of the unit is as follows. Every hour an electrical contact is made on the clock. First the bulbs are flashed and then the film winding motor is made to run one complete revolution of its geared shaft. This moves the film by one frame.

The control unit for the flash of the bulb and the start of the motor is given below :

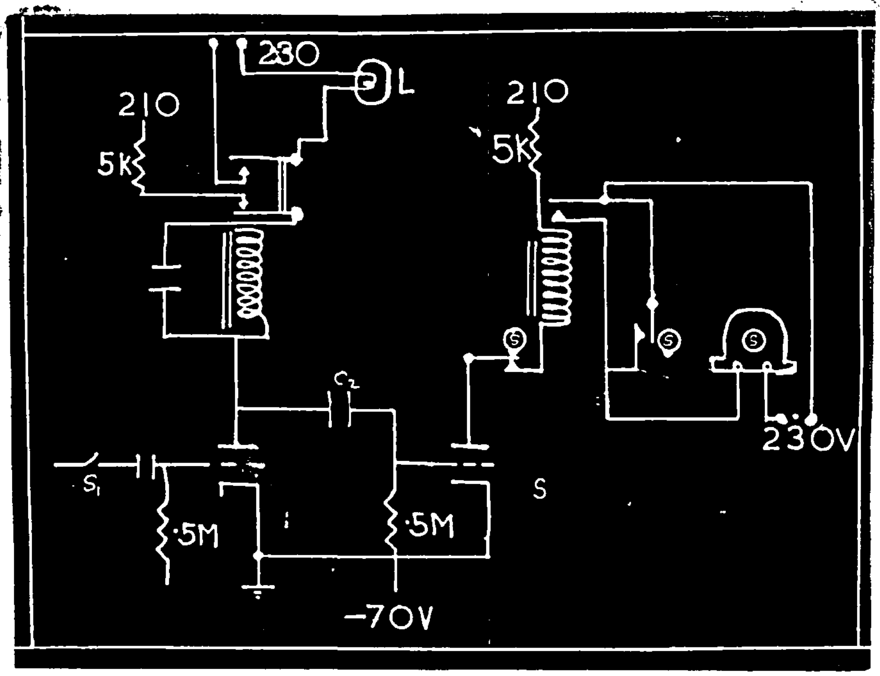


fig 2.15

The unit consists of two triggered switches working in succession. The first one controls the flashing of the ~~bulb~~ lamp and the next starts the motor and keeps the parallel switch of the motor on for some time. When the contact S_1 is closed by the arms of the clock-work, the positive pulse is applied to the grid of the tube T_1 which is normally at -70 volts. The plate circuit of the thyratron T_1 contains the relay and the contact controlled by the relay. When T_1 fires, the relay is energised. Due to this the switch for the ~~bulb~~ lamp is ~~made~~ on for a short interval of time. When the relay is energised the contact in series with the plate circuit is made off and so the thyratron extinguishes and the grid again gets control. When the thyratron extinguishes the positive pulse is developed on the plate which is applied through a condenser C_2 to the grid of another switching thyratron T_2 whose grid is also kept at -70 volts. The tube T_2 fires due to positive pulse. The relay in the plate of T_2 is energised and it keeps on the parallel switch of the motor on for some time. Due to this the motor starts and after some time the plate return switch of thyratron T_2 is made off while the main switch for the motor is made on due to rotation of the shaft of the motor. When the motor completes one revolution it again puts on the plate circuit and puts off the main motor switch. In this way the initial condition is attained for a fresh exposure.

PRESENTATION OF DATA

Section I of the present chapter is devoted to a description of the methods adopted in the present investigation for the representation and the analysis of the data. The analysed data are presented in section II.

3.1 Methods of analysis of data

3.1.1 Tabulation of primary data :-

The hourly photographic records give the counts of the mechanical recorders corresponding to the various cosmic ray telescopes for the hours 0100, 0200, 0300..........2400 I.S.T. Even though data for the intensities of cosmic ray components and the ground atmospheric pressure and temperature are available for hourly intervals, the analysis has been done for bi-hourly intervals commencing from midnight I.S.T., which is forty minutes in advance of the local time of Ahmedabad. For the purpose of studying daily variation curve, the use of bi-hourly values is advantageous as without much loss of accuracy, it helps to reduce the statistical fluctuations because of the doubling of the number of counts for each reading. Readings for 0100,0300,0500,......2300 hrs. are tabulated and the differences between consecutive readings represent the twelve bi-hourly mean rates centred at 0200, 0400........2400 hours I.S.T. In addition the daily average bi-hourly rate centred at 1300 hours is calculated from the difference between the readings at 0100 hours on consecutive days.

The values of atmospheric pressure and temperature are obtained from the daily chart of an accurate micro-barograph and thermograph. Upper air meteorological data are obtained from radiosonde ascents with I.M.D. F-type or Vaisala type instrument conducted by Mr.Venkateswaran in collaboration with the author. Details of the collection of meteorological data are given in the following chapter.

The data sheet of a day consists of twelve bi-hourly rates for each cosmic ray telescope and corresponding records of values of ground level pressure and atmospheric temperature. The deviations from the mean bi-hourly rate of the day for all the variates are then calculated. The criterion used for the elimination or inclusion of the data for any particular day is the range of bi-hourly deviations. The data is discarded for days on which any individual bi-hourly value is more than 5 % different from the mean for the particular day. This corresponds to a deviation exceeding three times the expected standard deviation for a bi-hourly value. Such cases are generally attributable to some faults either in the electronic circuits or in the counters. Cases of abnormally large daily variation in cosmic rays which may rarely occur are however also rejected on this criterion. The useful data as presented here extends from May 1950 to Feb. 1953. The rates of the telescopes ABC and A'B'C' are designated as T and T'. Similarly M_1 and M_1', M_2 and M_2' represent those of BCD and B'C'D', and of CDE and C'D'E' respectively.

Daily Variation :-

Generally, in the data of any one day, the random statistical fluctuations predominate over the genuine periodic variations. To get a significant daily variation curve, rates corresponding to the same bi-hourly interval of different days of a month are added up. The twelve values of C_1, C_2, ...C_{12} for 0200, 0400, 0600,.......2400 hours for each coincidence rate are evaluated. The average for each such set is taken to find out the deviations which are expressed as percentages. The monthly average values of the variates were used for the seasonal variation in the daily variation. All the monthly values are superposed to obtain an average daily variation curve for the year.

If distinction is to be made only between the soft component which is absorbed by 7 cms. of lead and the hard component which can penetrate the same thickness, we can superimposed M_1 and M_2 to get the mean curve M for the meson intensity.

3.1.2 (A) Correlation Analysis

The correlation coefficient between two variates gives a measure of the degree of relationship between them. In the case of two variates, when a linear relationship between them is assumed, the following formula gives the correlation coefficient between them.

$$r_{xy} = \frac{\Sigma(xy)}{N\sigma_x\sigma_y}$$

The numerator is the summation of the product of corresponding deviations from mean of the two variates totalling (N) in number. The denominator consists of the product of the standard deviation of each variate as defined below.

$$\sigma_x = \left\{(x_1^2 + x_2^2 + \cdots + x_n^2)/n\right\}^{\frac{1}{2}} = \left\{\frac{\Sigma(x^2)}{n}\right\}^{\frac{1}{2}}$$

The relationship between x and y, the two variates, is given by the following "regression equation"

$$x = b_{xy}\, y$$

$$\text{Where } b_{xy} = r\frac{\sigma_x}{\sigma_y}$$

If there are more than two variates, the partial correlation coefficient between the variates gives the degree of relationship between any two of the variates, others remaining constant. The following formula gives the partial correlation coefficient between x and y for constant z.

$$r_{xy.z} = \frac{r_{xy} - r_{xz} \cdot r_{yz}}{(1-r^2_{xz})^{\frac{1}{2}} \, (1-r^2_{yz})^{\frac{1}{2}}}$$

The regression equation of x and y and z. gives the amount of variation of x which is associated with the variation of y, z remaining constant, plus the variation of x which is due to the variation in z, y remaining constant. It has the following form

$$x = b_{xy.z}\, y + b_{xz.y}\, z$$

$$\text{Where } b_{xy.z} = r_{xy.z} \frac{\sigma_x (1-r^2_{xz})^{\frac{1}{2}}}{\sigma_y (1-r^2_{yz})^{\frac{1}{2}}}$$

The above analysis of the partial correlation coefficient can be extended for any number of variates. The constants of the regression equation are statistically termed as the regression coefficients between the respective variates.

3.1.2 (B) <u>Harmonic analysis</u> :-

For an elucidation of a periodic variation and its relationship with other factors, it is often very useful to analyse the curve harmonically. The primary variation connected with the earth's rotation is brought out in the harmonic components of 24 hourly and 12 hourly periods. The magnitude of the amplitude of these two harmonics in comparison to those of higher ones indicate the presence of disturbing factors.

The method of resolving a certain continuous periodic function into its harmonics have been treated rigorously in various text-books. One can get the amplitudes and the phase angles of the harmonics in terms of 12 equally spaced values of the variates as are obtained in the present investigation. The data is tabulated in the following way to find out the constants.

<u>Harmonic analysis of 12 bi-hourly values.</u>

(U_0 to U_6) ... ...
(U_{11} to U_7) ... ...

Sums (V_0 to V_6) ... ...
Diffs. (W_1 to W_5) ... ...

(V_0 to V_3) ... ... (W_1 to W_3) ... ...
(V_6 to V_4) ... ... (W_5 to W_4) ... ...

Sums (P_0 to P_3) ... ... Sums (R_1 to R_3) ... ...
Diffs.(Q_0 to Q_2) ... ... Diffs. (S_1 to S_2) ... ...

P_1= , P_2= , Q_2= , R_1= , Q_1= , R_2= , S_1= , S_2= ,
H_1= , H_2= , L_2= , M_1= , L_1= , M_2= , N_1= , N_2= ,

½ above line 0.866 x above line

Cont...

	P_0=	, P_1=	Q_0=	, L_1=	P_0=	, H_1=
	P_2=	P_3=	L_2=		P_3=	H_2=
Sum of 1st col.	....		....		....	
Sum of 2nd col.	....		....		....	
Sum	....= $12A_0$		....= $6A_1$			
Diff.	....= $12A_6$		....= $6A_5$		....= $6A_4$	

	P_0=	P_3=	M_1=	M_2=
	H_1=	H_2=	R_3=	
Sum of 1st col.	....		....	
Sum of 2nd col.	....		....	
Sum			....= $6B_1$	
Diff.	....= $6A_2$		....= $6B_5$	

	Q_0=	N_1=	R_1=
	Q_2=	N_2=	R_3=
Sum		...= $6B_2$	
Diff.	...= $6A_3$	...=$6B_4$	...= $6B_3$

The values U_0, U_1, U_2,........U_{11} represent the 12 bi-hourly values centred at 0000, 0200, 0400........2200 hours respectively. As a result of manipulation we get the original variation expressed as

$$x = A_0 + (A_1 \sin\theta + B_1 \cos\theta) + (A_2 \sin 2\theta + B_2 \sin(2\theta)) + A_3 \sin 3\theta + B_3 \cos 3\theta) + \cdots$$

The sine and cosine terms for similar periods can be combined together to give

$$x = A_0 + r_1 \sin(\theta + \phi_1) + r_2 \sin(2\theta + \phi_2) + r_3 \sin(3\theta + \phi_3) \cdots$$

Where $r_n = \sqrt{A_n^2 + B_n^2}$ & $\phi_n = \tan^{-1} \frac{A_n}{B_n}$

Since the initial variation curve is obtained by taking deviations from mean it does not contain a constant term i.e. $A_0 = 0$. r_1 and ϕ_1 represent the amplitude and the phase of the fundamental harmonic, the period of the fundamental in the present case being a day, that is 24 hours. r_2 and ϕ_2 give the corresponding parameters for the second harmonic having a period of 12 hours. r_3, ϕ_3 and r_4, ϕ_4 are the corresponding parameters for the third and the fourth harmonics. The angle ψ corresponding to the time of maximum of the amplitude of the harmonic component is obtained in the following way.

$$\psi = 90^\circ - \phi$$

3.1.3 (C) Harmonic Dials

The harmonic dial method as suggested by Bartels and extensively used by Forbush, Thomson and others to study variations of geophysical and geomagnetic elements has been used for the present investigation.

In this the vector denoting the amplitude and the hour of maximum of a harmonic coefficient is represented on a dial, similar to the face of a clock. The length of the vector is proportional to the amplitude and the angle which the vector makes with respect to the positive y axis is proportional to the hour of maximum. On a 24 hourly dial a clockwise rotation of 15^{0} corresponds to one hour but on a 12 hourly dial on which the semi-diurnal component is shown, a clockwise rotation of 30^{0} corresponds to an hour.

Study of the harmonic dial reveals mixed periodicities of different periods which may be superimposed on the daily variation.

3.2 Experimental Results

3.2.1 Period of experimentation :-

The experiment at Ahmedabad was started towards the end of 1950. Except for interruptions due to experimental failures it has run more or less continuously since that time. As duplicate sets of telescopes were being operated, the available data on some days refer to more than one telescope. In such cases the data have been taken as having been furnished by twice the number of days. Table 3.1 indicates the days of observation for telescopes with no lead, with 8 cms. of lead and with 15 cms. of lead measuring respectively the total cosmic ray intensity T, the meson intensity M_1 and the hard meson intensity M_2.

Table 1 — Periods of observations for the Total intensity T, Meson intensity M_1 and Hard Meson intensity M_2.

	Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
T	1950					17	17	9	8		20	23	22
	1951	28	25	15	19	11	8			20	31	10	
	1952	22	5	26	35	41	46						
	Total days.	50	30	41	54	69	71	9	8	20	51	33	22
M_1	1950					9	19	11	3			23	9
	1951	28	25	15	20	9	10		9	27	32	14	
	1952	44	4	19	36	40	46	25		74	36	41	91
	1953	58	46										
	Total days.	130	75	34	56	58	75	36	12	101	68	78	100
M_2	1950					8	12	11	6		20	21	22
	1951	28	25	15	22	15	10			22	20	10	7
	1952	54	6	20	27	34	41	16					
	Total days	82	31	35	49	57	63	27	6	22	40	31	29

It will be noticed that the telescopes registering the total intensity T, were discontinued from the middle of 1952. This was done because it was realised by then that the soft component intensity was mainly governed by atmospheric effects and for the purpose of interpretation of the daily variation in terms of an anisotropy of the primary radiation, it was preferable to confine one-self to the meson intensity variations. Prior to June 1952, the meson intensity was registered under 8 cms. of lead absorber as well as 15 cms. of lead. The difference in counting rates under these two conditions was negligible ($M_1/M_2 = 0.92$), indicating a small contribution of very high energy electrons and slow mesons. The statistics of the difference curve between M_1 and M_2 was in consequence so poor that interpretation was rendered impossible. The daily variation curves for the days on which data is available for both M_1 and M_2, exhibit a correlation of +0.927 between the two variates. Hence from June 1952 onwards the lead aborbers in M_2 were reduced in order that M_2 like M_1, should also register cosmic ray intensity under 8 cms. of lead. Thus during the later period of the experiment four similar telescopes have been in operation with the same amount of lead in each of them.

3.2.2 <u>The annual mean daily variation</u> :-

The annual mean values expressed in percentages for the bi-hourly deviation for T, and M obtained by superimposing all useful data is presented in Table 3.2. The component which is absorbed by lead constitutes the soft component. This is composed of electrons and some low energy mesons. The daily variation of this component designated E, can be obtained by subtracting the variation of 'M' from that of 'T'. This is also shown in Table 2. Even though both the daily variations of 'T' and 'M' are statistically significant, the variation of E is not significant to the same degree.

Table 2 — Final values of the percentage deviations from mean of the total cosmic ray intensity T, meson intensity M, the electron component E = T - M and the meteorological elements P (atmospheric pressure in mm.Hg.) and θ-(ground temperature in °C.).

Hour.	T 0.08	M 0.05	E	P	θ
00	-0.13	-0.18	0.12	0.22	-3.2
02	0.24	0.25	0.19	-0.20	-4.4
04	0.37	0.23	1.12	-0.43	-5.3
06	0.14	0.25	-0.43	0.10	-6.1
08	-0.09	0.26	-1.92	1.14	-5.0
10	-0.53	-0.16	-2.48	+1.69	-0.6
12	-0.17	0.13	-1.74	1.07	4.7
14	0.19	0.08	0.75	-0.46	7.0
16	0.56	0.19	2.48	-1.45	7.3
18	0.13	-0.03	0.99	-1.41	5.4
20	-0.24	-0.46	0.93	-0.53	0.8
22	-0.48	-0.56	-0.06	0.23	-1.7

The nature of variations is better revealed by figure 3.1. The bi-hourly values of the deviations, expressed in percentages are shown with their probable errors. For comparison, the annual mean daily variation of barometric pressure P and ground atmospheric temperature θ are also shown in fig. 3.1

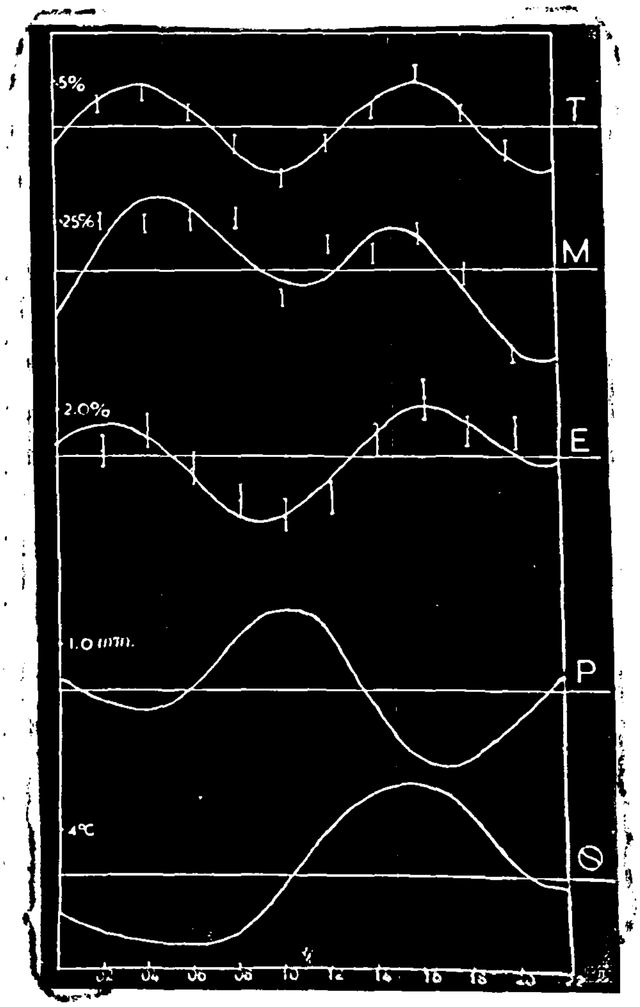


Fig. 3.1 Daily variation curves for the total intensity T, meson intensity M, electron component E, ground pressure P, and ground temperature θ.

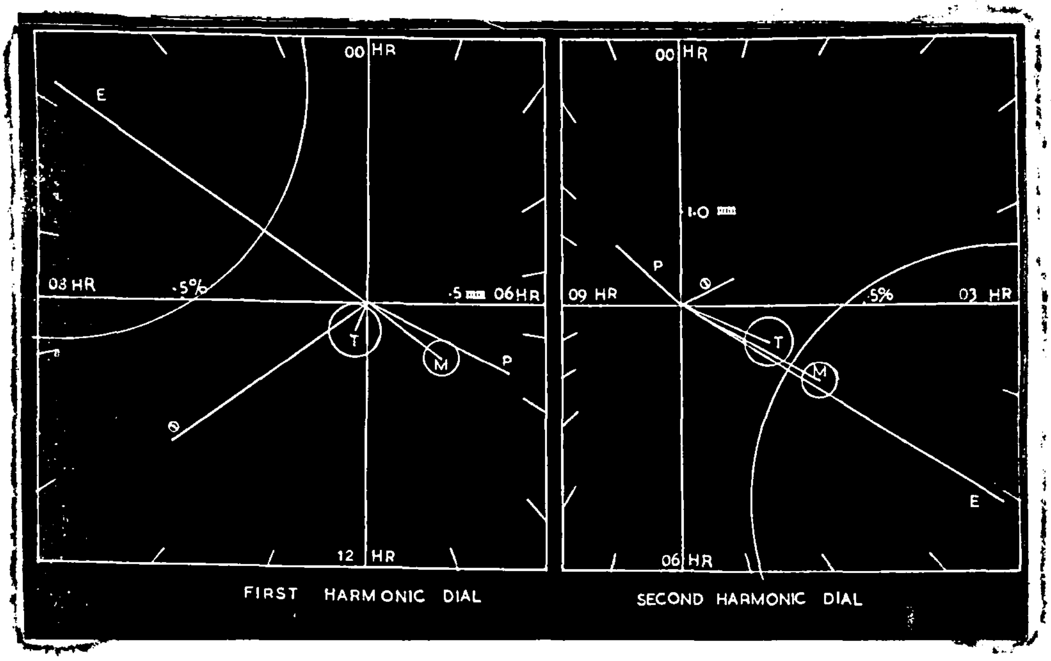


Fig. 3.1.1

Harmonic dials for T, M, E, P, θ.

The daily variations of T, M, E, P and θ have been harmonically analysed. The harmonic constants for the first six harmonics are presented in Table 3. The amplitudes for the first two harmonics along with their respective hours of maxima are indicated in terms of the angle with respect to the positive y axis, made by the vector representing the particular component on the harmonic dials.

It will be observed that for all variates the predominent harmonic component is either the first or the second one. In meson and in atmospheric pressure, the two components are about equally important. For total intensity and for electrons, the second harmonic is larger than the first, but temperature at ground level shows a predominent first harmonic. In all cases, the third and higher harmonics are small and may be neglected.

3.2.3 Annual curves of the daily variation of M :-

Table 4 indicates monthly mean, bi-hourly deviations of the meson intensity M. For this purpose all available data for either M_1 or M_2 refering to any particular month have been used irrespective of the year in which the observations were made. Also indicated in the Table are rows showing the number of days for which the data is available for each month, the mean bi-hourly rate for each month, and the probable error for the same value. It will be noticed that the mean bi-hourly rates for individual months varies from month to month. Apart from seasonal variation of the intensity of

Table 3.3

Variate	1st harmonic		2nd harmonic		3rd harmonic		4th harmonic		5th harmonic		6th harmonic	
	Ampl.	Max.	Ampl.	Max.	Ampl.	Max.	Ampl.	Max.	Ampl.	Max.	Ampl.	Max.
T	0.08	$\pi+23^{\circ}$	0.43	117°	0.06	-2°	0.03	105°	0.03	169°	0.05	
M	0.25	125°	0.26	112°	0.08	37°	0.07	55°	0.08	$\pi+12^{\circ}$	0.03	
E	1.29	-57°	1.36	122°	0.27	-77°	0.31	$\pi+32^{\circ}$	0.21	36°	0.17	
P mm. Hg	0.86	115°	0.97	-49°	0.05	133°	0.01	$\pi+77^{\circ}$	0.02	163°	0.06	
θ °C.	6.53	$\pi+55^{\circ}$	1.58	64°	0.44	114°	0.41	-62°	0.03	90°	0.15	

Amplitudes and hours of maxima of harmonic components of the daily variation of cosmic ray intensities and atmospheric pressure and temperature

Table 3.4.

Meson Intensity

Hrs.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept	Oct.	Nov.	Dec.
00	0.01	0.30	-0.34	0.13	-0.07	-0.08	-0.07	-0.04	-0.90	-0.22	0.07	-0.49
02	0.21	0.32	0.12	0.27	0.47	0.56	0.56	0.21	-1.00	0.12	0.45	0.63
04	0.11	0.42	0.34	0.00	0.60	0.76	1.01	0.69	-0.45	-0.04	0.30	0.26
06	-0.03	-0.14	0.11	-0.02	0.38	0.80	0.75	-0.53	-0.09	0.15	0.31	0.61
08	0.17	-0.27	0.09	-0.01	0.02	1.06	1.02	0.14	0.27	0.08	-0.12	0.58
10	-0.19	-0.60	0.13	-0.19	-0.63	-0.61	0.38	-0.69	0.59	-0.62	-0.05	0.13
12	0.36	0.10	0.56	0.32	0.13	-0.58	-0.81	-0.62	0.53	-0.58	0.22	0.39
14	0.16	0.16	-0.27	-0.11	0.34	-0.52	-0.86	0.48	0.48	0.15	0.15	0.28
16	0.43	0.33	0.06	0.08	0.23	0.05	-0.33	0.71	1.13	0.25	-0.10	-0.27
18	0.05	0.02	0.04	0.00	-0.08	-0.07	-0.15	0.33	0.49	0.40	-0.17	-0.58
20	-0.71	0.06	-0.44	-0.08	-0.60	-0.49	-0.92	-0.51	-0.37	0.17	-0.51	-0.88
22	-0.57	-0.66	-0.41	-0.38	-0.79	-0.91	-0.54	-0.27	-0.68	0.15	-0.57	-0.67
Mean bi-hourly value.	748	620	827	939	820	759	640	730	817	838	764	1156
No.of days.	212	106	69	105	115	138	63	18	123	108	109	129
Standard deviation	0.12	0.19	0.21	0.16	0.16	0.15	0.25	0.43	0.15	0.17	0.17	0.13

M, the changes are mainly due to alterations in the sensitive areas of the telescopes from time to time. Since in the present investigation no study was being made of the seasonal variation of the day-to-day average cosmic ray intensity, no attempt has been made to apply a correction for the changes of sensitive area of the telescopes. Unfortunately during all three years of operation there is very scanty data for the month of August. The probable errors of the bi-hourly percentage deviations are therefore quite large for this month.

In order to ascertain the nature of changes that take place in the daily variation of M, the monthly mean variation have been harmonically analysed. The constant for the first and second harmonic component are indicated in Table 5 for each month. It will be noticed that there is a considerable change in the daily variation from month to month. We shall discuss at a later stage further implications of this.

3.2.4 Year to year changes in the daily variation of M :-

Table 6 indicates the mean annual variation for the twelve months ending 30th June 1951 and 30th June 1952 respectively for M.

Since the individual variates are subject to random fluctuations a smoothening has been adopted by taking moving average over three consecutive bi-hourly periods.

Table 3.5

Harmonic constants for meson intensities

Harmonic constants	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
r_1	0.23	0.09	0.28	0.05	0.25	0.60	0.83	0.16	0.86	0.22	0.26	0.65
ψ_1	154°	152°	143°	113°	104°	78°	80°	-71°	72°	-47°	96°	117°
r_2	0.34	0.39	0.13	0.14	0.52	0.54	0.36	0.51	0.23	0.30	0.28	0.25
ψ_2	53°	93°	102°	70°	91°	151°	170°	111°	168°	160°	78°	82°

r_1 = First harmonic amplitude.

ψ_1 = Hour of maximum for first harmonic expressed in terms of angle.

r_2 = Second harmonic amplitude.

ψ_2 = Hour of maximum for second harmonic expressed in terms of angle.

Table 3·6

Variations for M for the years 1950-51 and 1951-52.

Hours	1950-51	1951-52
00	-0.11	-0.19
02	0.10	-0.09
04	0.22	-0.07
06	0.18	-0.01
08	0.08	-0.04
10	-0.04	0.00
12	-0.10	0.10
14	-0.04	0.30
16	0.06	0.28
18	0.04	0.10
20	-0.13	-0.17
22	-0.24	-0.21

Fig.3·2 illustrates this variation. It will be noticed that there is an indication of achange during the two years. This aspect is discussed later.

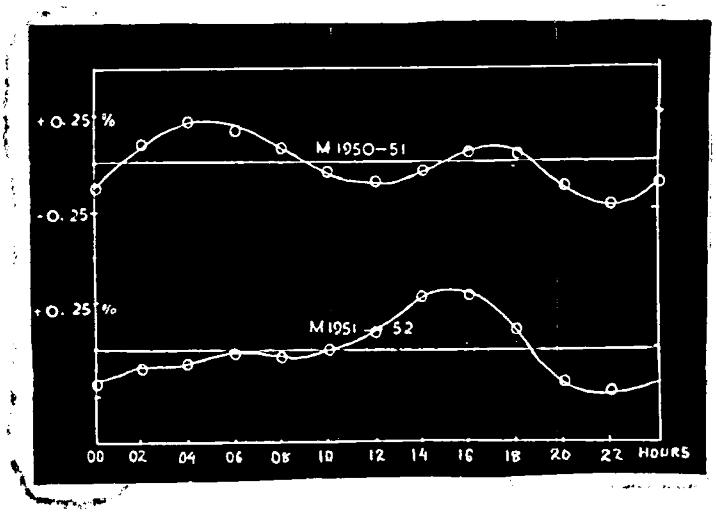


Fig. 3.2

Annual variation of M.

IV DAILY VARIATIONS OF BAROMETRIC PRESSURE AND ATMOSPHERIC TEMPERATURE

Section I of the present chapter presents data for ground level temperature and barometric pressure. Section II deals with investigation of the upper air conditions.

4.1

4.1.1. Daily variation of ground level temperature :-

The annual mean bi-hourly ground level temperature at Ahmedabad obtained from the daily thermograms is presented in Table 2 on page 73. The daily variation of ground level temperature is predominantly diurnal. The harmonic constants given in Table 3, page 76 also clearly indicate that harmonics higher than the first are insignificant. The amplitude of the diurnal component is 6.5°C while the hour when it reaches the maximum is at about 16 hrs.

The diurnal variation of the ground level temperature is due to heat exchange between the ground and the lower atmosphere. The variations of temperature due to this exchange is confined only to the lower regions of the atmosphere. This is illustrated in the next section from the radiosonde records.

4.1.2. Pressure variations :-

The annual mean bi-hourly ground level pressure, obtained from the daily charts of a microbarograph for the year 1951 and 1952 is given in Table 2 on page 73. The harmonic constants for the daily ground level pressure are given in Table 3 on page 76. It shows that the first as well as the second harmonics are equally important.

The first harmonic of the pressure variation can be mostly explained as due to the changes in temperature of the lower atmosphere. The second harmonic with a period of 12 hours is due to atmospheric oscillations. Kelvin had suggested that the atmosphere has a free period of oscillation of about 12 hours. The solar driving force has a period of 24 hours, but the oscillation of the atmosphere with 12 hourly period is built up by resonance. Systematic movements of the isobaric pressure levels occur because of these oscillations. In the present investigation such effects reflecting the overall movement of the whole atmosphere are important.

In low latitudes, the day-to-day pressure variations and fluctuations are less important than daily changes. The daily microbarograph shows a two humped curve. This predominance of regular variation over irregular fluctuation is favourable for a study of the meteorological factors effecting the daily variation of cosmic ray intensity.

To study the variability of the diurnal and semi-diurnal components of daily pressure variation over the whole year, monthly average values for the daily variations of pressure are tabulated in Table 4.1. These are harmonically analysed and the constants of the fundamental and the second harmonics are tabulated in Table 4.2. The curves of the figure 4.0 show the variations of amplitudes and hours of maxima for both the harmonics over the year.

Table 4.1

Monthly average values of the daily pressure variation
(mm. Hg)

Hrs.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
00	0.00	0.20	0.20	0.30	0.30	0.70	0.60	0.40	0.20	0.00	0.10	0.10
02	-0.30	-0.30	-0.30	-0.20	-0.10	0.30	0.10	-0.20	-0.30	-0.40	-0.40	-0.40
04	-0.60	-0.70	-0.70	-0.50	-0.10	0.10	-0.20	-0.40	-0.40	-0.50	-0.60	-0.70
06	-0.20	-0.20	-0.10	0.30	0.70	0.60	0.10	-0.10	0.30	0.30	-0.10	-0.20
08	0.90	1.00	0.90	1.40	1.70	1.30	0.80	0.90	1.40	1.30	1.10	1.00
10	2.00	1.00	1.90	2.00	1.90	1.40	1.00	1.20	1.70	1.70	1.80	1.80
12	1.20	1.30	1.70	1.40	1.10	0.80	0.80	0.90	1.10	0.90	0.90	1.00
14	-0.60	-0.40	-0.30	-0.20	-0.40	-0.50	-0.30	-0.20	-0.40	-0.70	-0.70	-0.70
16	-1.40	-1.50	-1.40	-1.60	-1.70	-1.70	-1.20	-1.10	-1.50	-1.50	-1.40	-1.40
18	-1.10	-1.20	-1.40	-1.80	-2.00	-2.00	-1.50	-1.40	-1.50	-1.30	-1.00	-1.00
20	-0.20	-0.40	-0.60	-0.90	-1.10	-0.90	-0.60	-0.60	-0.70	-0.30	-0.10	-1.10
22	0.30	0.20	0.20	0.00	-0.10	0.20	0.40	0.60	0.20	0.40	0.30	0.50

Table 4.2

Harmonic constants for pressure variation

Harmonic constants	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
r_1	7.3	7.7	8.8	11.0	13.7	11.9	7.0	6.5	9.9	8.3	6.8	6.2
τ_1	126°	125°	120°	121°	110°	95°	97°	110°	116°	114°	120°	121°
r_2	11.4	10.7	11.2	10.7	10.7	8.9	8.1	9.1	9.7	10.2	10.3	11.0
τ_2	-48°	-47°	-41°	-42°	-52°	-37°	-33°	-39°	-51°	-60°	-59°	-57°

r_1 = First harmonic amplitude.

τ_1 = Hour of maximum for first harmonic expressed in terms of angle.

r_2 = Second harmonic amplitude.

τ_2 = Hour of maximum for second harmonic expressed in terms of angle.

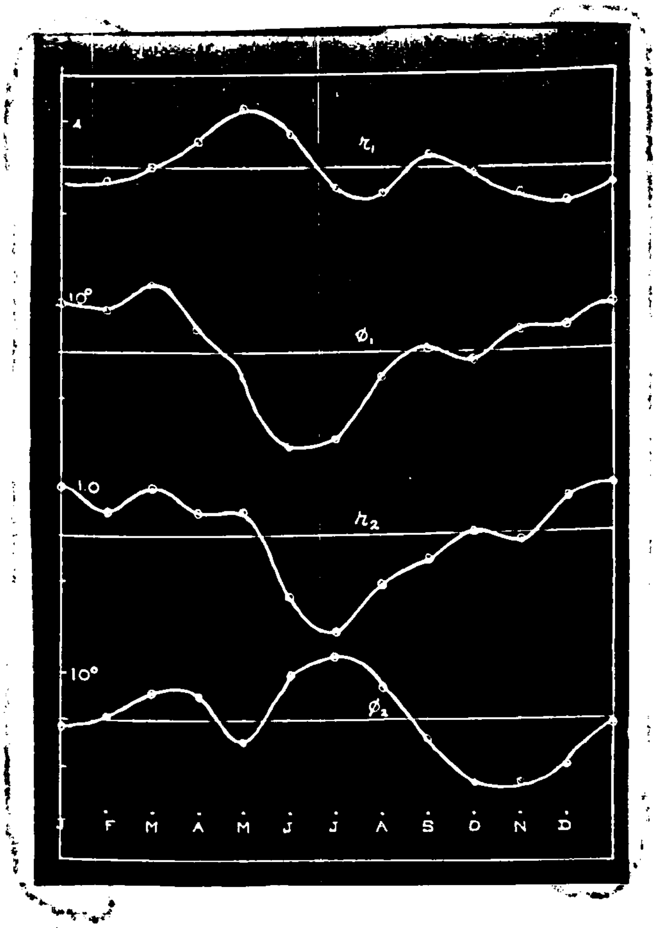


Fig. 4.7 - The annual variation of the harmonic constants of the ground level barometric pressure.

The amplitude of the first harmonic attains a maximum in May and a secondary maximum is also shown in Spetember, in August and December the amplitude of the diurnal variation is minimum. The minimum of the phase occurs in June-July.

The seasonal change of the diurnal variation of pressure is primarily governed by the change in the diurnal heating of the lower atmosphere. The blanketting of the ground by clouds during the monsoon months of July and August produces deviations from a regular seasonal pattern which may otherwise ~~ordinarily~~ be expected.

4.2 Upper air investigation.

A radiosonde consists of a meteorograph linked to a radio-transmitter. A meteorograph is an assembly of sensitive elements which measure desired atmospheric parameters. The information obtained by these elements is broadcast to the field station receiver by the transmitter.

The parameters commonly measured by a radiosonde are atmospheric pressure, temperature and relative humidity. An aneroid capsule (some times more ~~small~~ than one in combination) is used almost universally as a pressure-sensitive element. Either a bi-metal strip or a thermistor measures temperature. The relative humidity is measured in a radiosonde by (1) the psychrometric method or (2) from the measurement of changes of either the physical or the electrical properties of hyroscopic substances.

The radiosondes developed by various countries for routine aerological soundings differ mostly in their modes of transmission of the meteorological message. The French, the Swiss, and the Indian instruments use the chronometric method. In the Indian F-type instrument, for instance, the measuring elements are made to actuate pointers which contact a helically-wound silver spiral on a rotating drum once during every complete revolution of the latter. The displacements of these pointers with reference to two other fixed pointers are calibrated and used as measures of meteorological quantities. In the Kew radiosonde of Britain the elements vary inductances in an audio-frequency oscillator which modulates a fixed carrier-frequency of 27.5 Mc/S. A blocking oscillator in the American radiosonde has its repetition frequency altered by resistors controlled by the meteorological units. The Finnish instrument of Vilhelo Vaisala is an interesting type in which changes of meteorological elements are converted into changes of radio frequency. This instrument with which the soundings were made is described in greater detail in the sequel.

Proper co-ordination of aerological observation requires comparative tests from actual soundings of the different radiosondes. Painter (weather 1950, 5, 307 ~~Meteorological Magazine~~) has described the results of such tests conducted by the International Meteorological Organisation at Switzerland.

Fig. 4.1 drawn from soundings made at Ahmedabad compares the Finnish instrument with the F-type instrument used in India. The author has worked with both these types. The Indian instrument was on loan from the India Meteorological Department. A Vaisala receiver was acquired by the Physical Research Laboratory and calibrated sondes imported from the manufacturers. In all about 120 successful soundings were made with the Finnish instrument. Of these thirtyfive were swarmed into a period of thirteen days in April 1952. Most of them attained appreciable altitudes. Interesting features of these ascents are presented and discussed.

<u>The Finnish (Vaisala) Radiosonde</u> :-

Complete details of the Finnish radiosonde and the ground equipment have been given by Vaisala in his 'Handbook of Sounding'. The radiosonde has a triode oscillator with a frequency range of approximately 24-26 Mc/S. The tank circuit of this oscillator is provided with a rotatory switch operated by a wind-mill turning in the slip-stream of the ascending balloon. This switch connects in sequence five different condensers and in consequence the radiosonde oscillator has five different transmission-frequencies. All the condensers are of the parallel-plate type. Three of them are variable, the variation being effected by the motion of the movable plate by the corresponding meteorological unit.

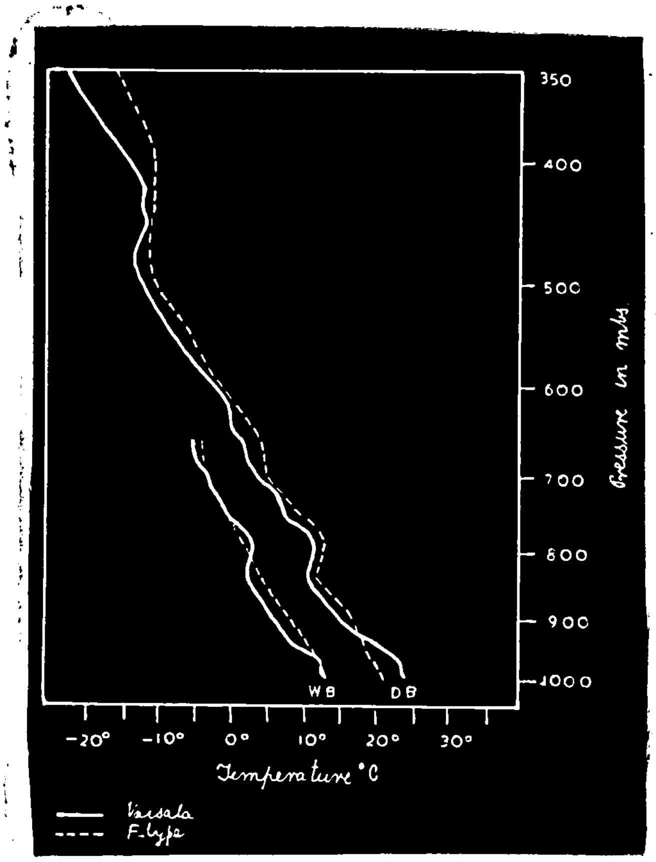


Fig. 4.1 - Comparison of the F-type and the Vaisala radiosondes

The two constant condensers have their values so adjusted that their corresponding frequencies are on either side of the transmission-range.

The ground equipment is a six-valve super heterodyne set. By means of a semi-circular tuning condenser, convenniently operated by hand, the local oscillator of this set is made to beat with the transmissions of the air-borne radiosonde. The beats are audible as fast, short squeaks at five different positions of the tuner. By pressing a stylus attached to the tuner, these five positions are punched on a recording paper clipped on a clock-driven drum.

Fig.4.2 is a reproduction of the "radiogram" obtained at Ahmedabad on 18-4-52. The dotted curves corresponding to pressure (P), temperature (T) and humidity (H) are shown along with the parallel curves obtained for the constant condensers (K) and (k). Figures on the right hand side of the record give the time in minutes after the release of the radiosonde, checked with reference to a standard clock.

Sounding of 18-4-52 :-

Described below are a few salient points associated with a particular soundings selected from our collection :-

The sounding taken on 18-4-52 appears to be one of the highest ascents ever made in this country . The radiosonde was held in position in a cage and the transmitter-battery kept safe from tilting so that reliable measurement

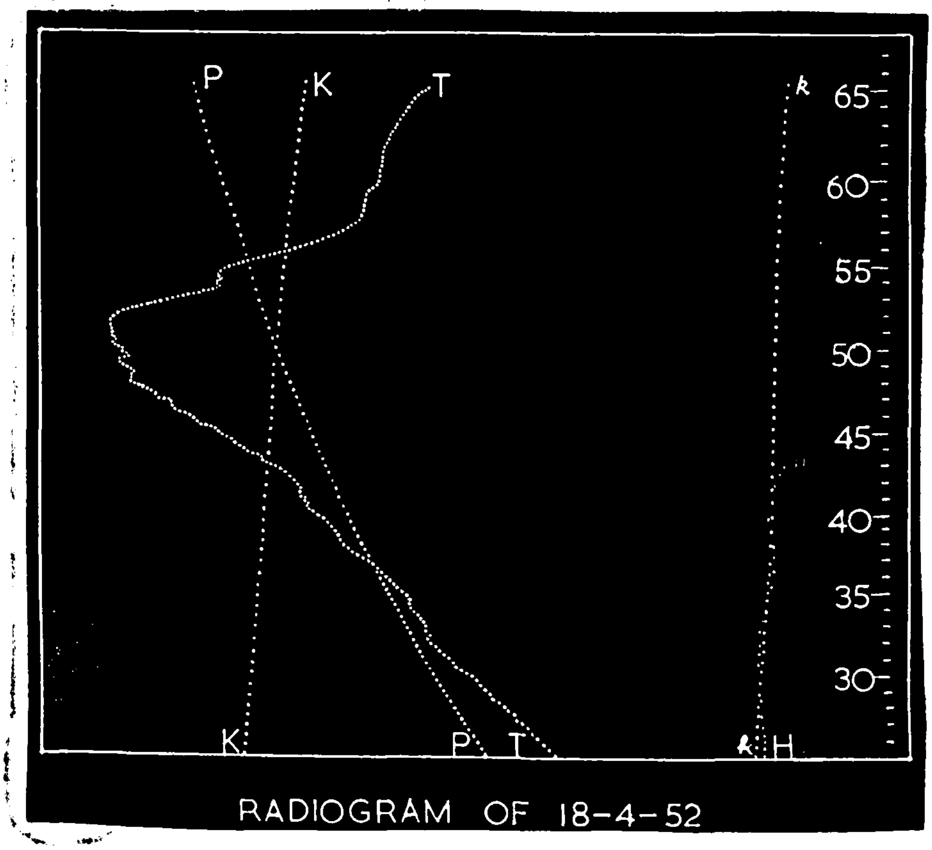


Fig. 4.2 - Radiogram of 18-4-52.

of temperature and pressure could be obtained during the ascent of the instrument till the burst of the balloon and also during its subsequent fall. Since no parachute was attached, however, the ascent and the descent took place at appreciably different speeds.

A portion of the radiogram of this sounding has already been presented in Fig.4.2. Fig.4.3 gives the height-temperature diagram evaluated from this radiogram. On the same figure is also plotted the smoothed-out time-height curve of the balloon used (Darex). Temperatures measured during the ascent of the instrument are marked with dotted circles, and those obtained during its descent by dotted triangles.

Since the sounding was made in the afternoon (1450 hrs.) upper-level temperatures can be subject to considerable radiation-error. Vaisala has described a method of correcting for this error on the following main assumptions :-

(1) Below 500 mbs. it is negligible.

(2) Above 500 mbs. and below 200 mbs. it increases linearly.

(3) Above 200 mbs. its value at any level is a function of certain instrumental constants (which can be measured in the laboratory) and on the instantaneous values of the height-angle of the Sun and the rate of ascent of the balloon. The dotted curve in the diagram, running

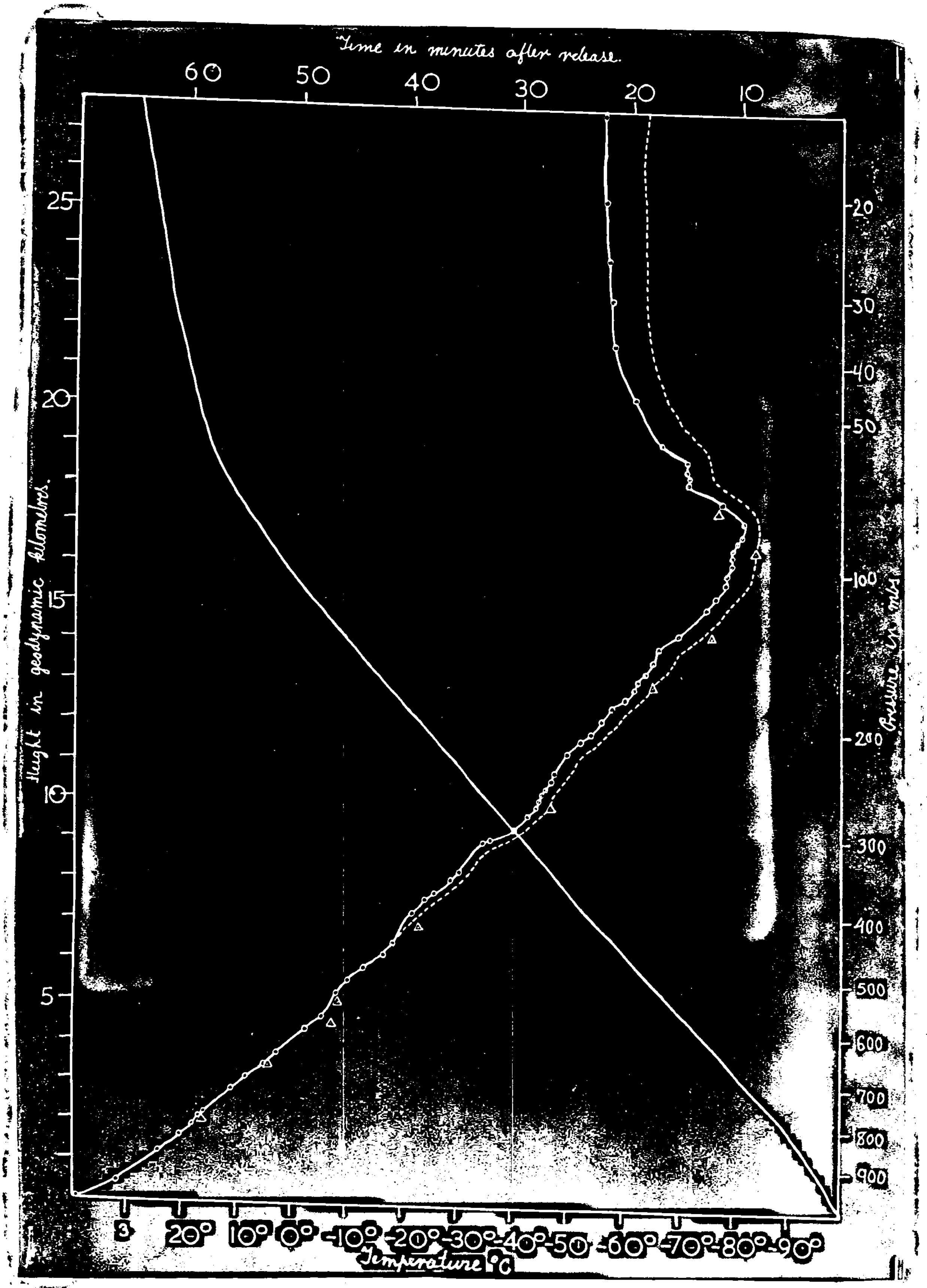


Fig. 4.3 - Height temperature diagram

alongside the curve of measured temperatures gives, according to Vaisala, the correct temperatures at the appropriate levels. Differences between the measured and the corrected values are seen to be of the order of 3°C at 200 mbs. and 8°C at 15 mbs. Other features of interest are :-

(1) Temperatures obtained at a particular level during the ascent and the descent of the radiosonde are different. This can be explained by (a) thermometric lag and (b) differences in radiation errors.

In the atmosphere in which temperature decreases with height, the indicated temperature will be, due to thermometric lag, higher than the actual temperature during the ascent and lower during the descent. This lag will increase with reduced air-density, so that the difference between the indicated temperatures will also increase with height. This is actually varified in Fig. 3. In this instance, however, the rates of ascent and descent are very different as stated earlier. The effective lags are also naturally different.

Some of the observed difference of temperature is also due to the difference in the magnitudes of the radiation error inherent in the two measurements. The amount of solar radiation falling on the instrument is smaller at the later time of the descent, while the ventilation given to it is greater. Thus the involved radiation error is smaller during the descent. It is an interesting coincidence that Vaisala's corrected temperature curve falls roughly along points obtained during the descent.

(2) The rate of ascent of the balloon increases abruptly at the stratosphere. Part of this increase is probably artificial and is the result of pressure and temperature errors reflected in the computed values of height. However it may be noted that the decrease of kinematic viscosity in the stratosphere (the appropriate value of it is the eddy-viscosity in the troposphere and the much smaller molecular viscosity in the stratosphere) can bring about such an increase.

<u>Temperature structure of the lower atmosphere</u>

One of the commendable features of the Vaisala radiosonde is the fine grained continuity of the measurements that can be made with it. This enables with it the investigation of certain problems of peculiar meteorological interest.

Fig. ~~is drawn from three soundings taken on a clear, summer day at Ahmedabad.~~ Fig.4.4 is the average of all the available observations in the month of April. These figures illustrate the typical nature of diurnal variation of temperature that is generally noticed in the surface layers of the atmosphere. In the afternoon intense insolation of the ground produces a shallow layer (approximately 200 metres in thickness) of super-adiabatic lapse-rate. Turbulent transfer

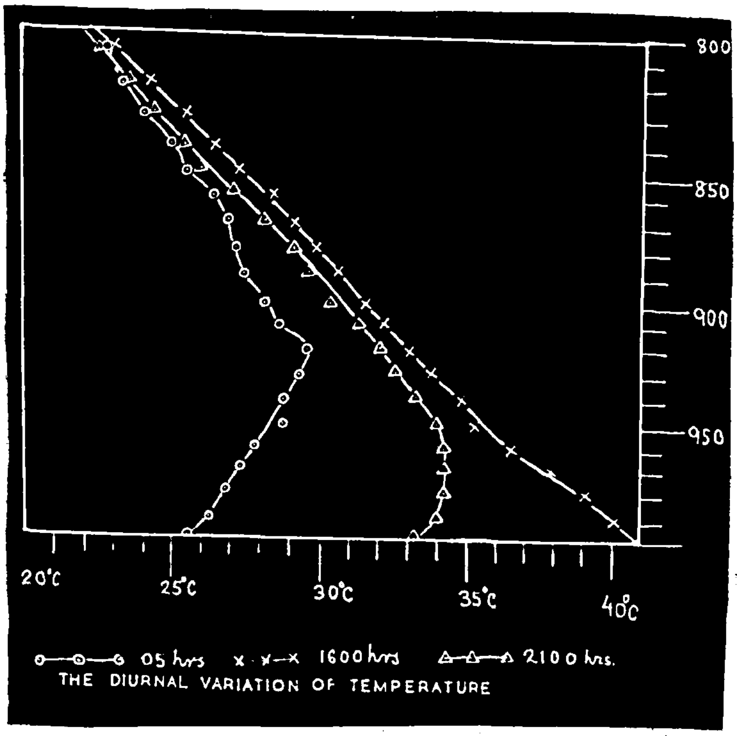


Fig. 4.4 Diurnal variation of temperature

of heat, however, tends to destroy this unstable condition. By evening a weak inversion starts to form at the surface. Helped by radiational cooling at night, this inversion builds up to a depth of 300 to 400 metres just before sunrise. It is subsequently "burnt off" due to heating from the bottom. It can be seen from the figures that the difference between afternoon and morning temperatures, which represent approximately the amplitude of the diurnal variation; decreases rapidly with height and vanishes nearly at 800 mbs. (2 kms).

The diurnal variation of temperature in the upper troposphere.

In connection with the present cosmic ray study the nature of the diurnal variation of temperature in the upper troposphere and the lower stratosphere was investigated. With a view to examine this question about 35 serial ascents were spaced in a period of 13 days in the month of April, 1952. Three ascents were made in a day, one just prior to sunrise ((0500 hrs.), one well after sunset (2100 hrs.) and one at the time of maximum temperature at the ground (1500 hrs.). Fairly the same type of surface weather persisted throughout the period.

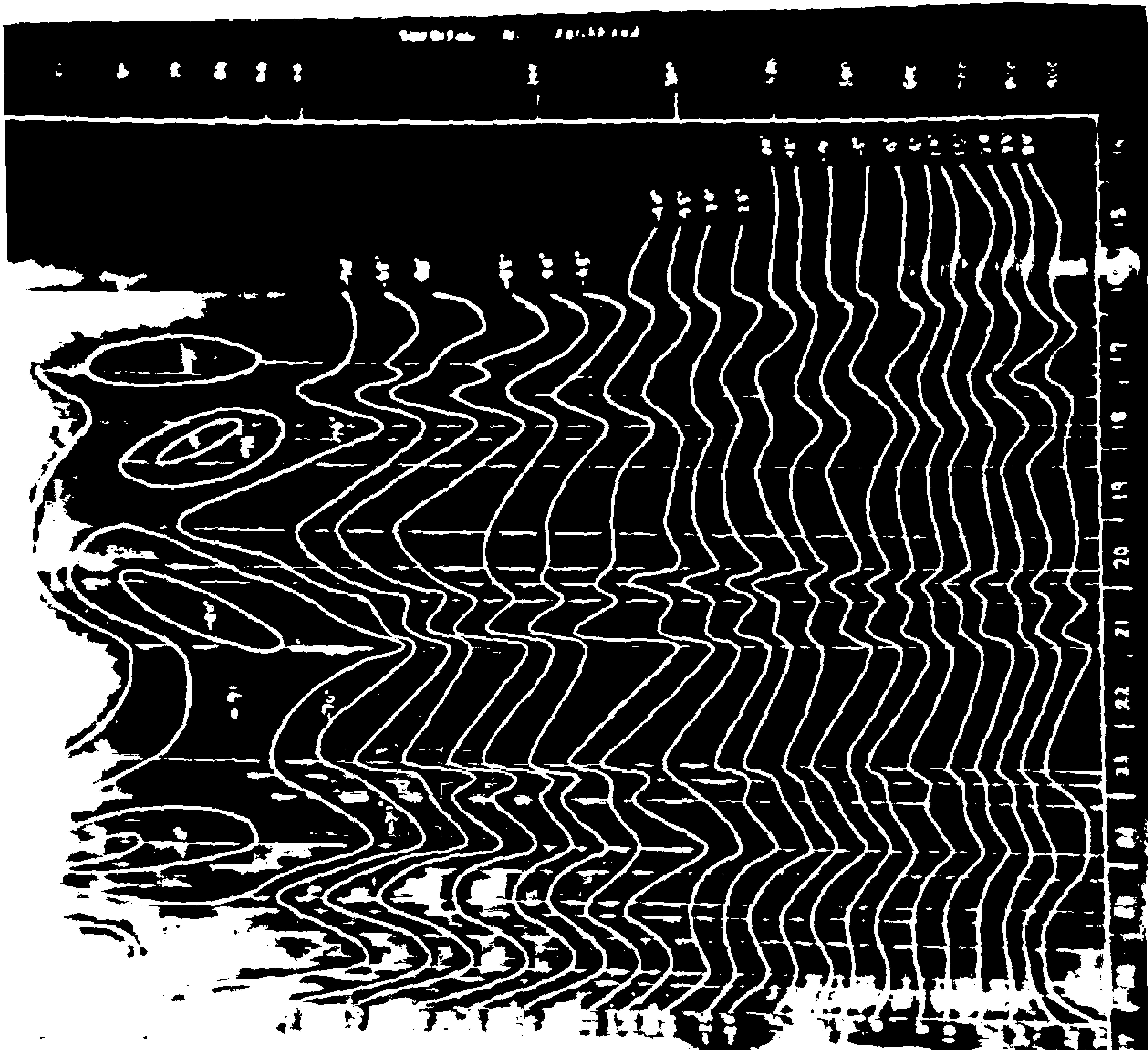
The results of these ascents are summarised in Fig. 4·5 and Table I and II.

Fig. on page 96A

Fig. is a time-section of the ascents. The time-axis runs from right to left. Each day is marked by its appropriate date. The ordinates give the pressure levels. Each ascent is represented by a vertical line erected at the correct time and rising upto its ceiling-height. The smoothed lines in the figure are the isotherms drawn at intervals of 5°C. A scrutiny of this diagram appears to suggest that the day-to-day variations of the temperature in the upper atmosphere are much more pronounced than what are observed in the surface layers. The shapes of the isotherms make it reasonable to say that there are damped temperature waves with a period of approximately three to four days at these heights. The amplitudes of these waves increase rapidly in the region of 200 mbs. There is also some evidence for the transport of very cold (-80°C) pools of air near the tropopause in the form of large sized eddies.

(Table I on page 96 B)

Table II is prepared to bring out the observed nature of the diurnal variation of temperature at the upper levels. For each isobaric surface, the measured differences between the morning and the afternoon temperatures, (T_m - T_a), the afternoon and the evening temperatures, (T_a - T_e), and the evening and the next morning temperatures are presented in this table. The means of these differences as well as their standard deviations are also given. Much weight, however, cannot be attached to these values as a very large



[illegible]	18	15	20	05	17	21	25	13	[illegible]	[illegible]	05	18	23	05	10	[illegible]	[illegible]	[illegible]	[illegible]	20	[illegible]	[illegible]	[illegible]
[illegible]	18.0	[illegible]	[illegible]	25.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25.0	[illegible]	38.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27.0	29.0	[illegible]	24.5	[illegible]	27.3	30.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	10.9	[illegible]	43.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10.3	10.3	[illegible]	[illegible]	20.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	13.7	[illegible]	11.3	[illegible]	[illegible]	[illegible]	[illegible]	12.0	13.6	[illegible]	10.3	14.7	12.6	13.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1.3	2.3	[illegible]	[illegible]	3.3	[illegible]	3.7	[illegible]	2.5	3.2	2.0	[illegible]	[illegible]	[illegible]	2.1	[illegible]	7.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-7.0	[illegible]	[illegible]	-11.5	-7.5	-10.0	[illegible]	[illegible]	2.2	[illegible]	[illegible]	[illegible]	- 7.7	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-22.7	-18.3	[illegible]	-19.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-31.5	-31.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-33.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-38.0	[illegible]	-37.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		-51.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-47.0	[illegible]	-43.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]		-59.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]				[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]				[illegible]		[illegible]		-78.0	[illegible]	[illegible]				[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]						[illegible]		[illegible]			[illegible]	[illegible]				[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]
[illegible]								[illegible]									[illegible]	[illegible]		[illegible]			

Temperatures in °C at specified isobaric levels obtained from the aerial ascents ma[illegible]

[illegible]			900 mb			800 mb			700 mb			600 mb		
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0.3		[illegible]	[illegible]		4.0	-0.6		3.7	-1.3		1.7	-0.8	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-4.7	-4.0	[illegible]	-4.7	-4.0	4.0	-4.1	-4.7	-4.3	-3.0
[illegible]	7.0	4.9	4.0	-4.0	9.7	-4.7	-4.5	3.6	-1.0	-1.4	[illegible]	-3.7	-4.7	3.0
[illegible]	4.0	[illegible]	-4.5	1.7	-4.0	-4.1	6.0	4.1	-4.4	1.9	4.0	[illegible]	4.1	4.3
[illegible]		-4.7	[illegible]		[illegible]	[illegible]		-4.3	3.0		-1.8	[illegible]		-1.7
[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	-4.9		4.5	4.0		4.0	4.0	
[illegible]	[illegible]			[illegible]		[illegible]	-3.0		[illegible]	[illegible]		-4.8	-4.0	
[illegible]	[illegible]	[illegible]	-1.3	[illegible]	[illegible]	-4.6	1.0	-4.4	-4.3	-4.1	-4.4	-1.0	4.4	-4.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.4	4.0	-4.8	[illegible]	-4.3	-4.4	3.9	-4.0	-4.4	1.3
[illegible]	[illegible]	-4.2	1.6	[illegible]	4.2	4.3	-4.0	[illegible]	4.5	4.0	4.3	4.0	[illegible]	-0.8
[illegible]	[illegible]	[illegible]	[illegible]	4.0	3.0	3.0	9.7	4.3	2.2	1.9	[illegible]	3.3	1.9	3.3

[illegible]			300 mb.			250 mb			200 mb
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0.0		2.2	-0.4		3.5	-0.3		3.6
[illegible]	-0.8	-3.4	-4.3	0.0	-3.5	-1.7	-2.4	-2.5	-4.2
[illegible]	-0.3	6.1	-3.0	1.0	6.6	-1.0	-5.8	6.7	-2.8
[illegible]	8.7	1.7	-4.0	8.0	0.0	-2.8	-3.0	9.7	-4.5
[illegible]		-2.4	6.8		-4.0	5.1		-4.9	10.2
[illegible]	-0.3		2.3	-0.2		6.7	-1.5		6.2
[illegible]	-4.0			-1.2			-5.6		
[illegible]	1.7	-5.5	1.3	2.2	[illegible]	0.3	6.4	-0.2	-4.0
[illegible]	-4.4	1.5	-2.9	1.6	1.6	-2.7	-4.1	1.0	-2.6
[illegible]	-4.7	-0.3	0.0	0.90	-0.7	1.8	-1.5	-1.1	1.7
[illegible]	3.4	0.2	3.1	0.7	1.6	3.6	3.6	0.3	2.3

[illegible] passing at specified isobaric level.

number of observations are not available.

The available results point out that significant and regular diurnal variation of temperature occurs only in the turbulent, surface layer of the atmosphere (upto 800 mbs). We have already discussed the nature of these variations. In the higher levels though large changes of temperatures are measured by the radiosondes in the course of a day, these variations are not shown to be statistically significant.

Many workers have attempted to detect the magnitude of the diurnal variation of temperature in the upper troposphere and the lower stratosphere by analysis of a large number of radiosonde ascents. Recently Kay[75] has discussed the results of approximately 11000 ascents made in the course of four years at four stations in England. His main results are (1) the temperature differences indicated by ascents just before sunrise and immediately after sunset are small. The magnitude obtained for the nocturnal cooling is about 0.5 K which is of the same order of magnitude as the theoretical value obtained by Gowan and Penndorf on the assumption of radiative equilibrium at these levels, (2) the mean midday-midnight temperature differences are much higher. The diurnal range varies with the seasons at the same level and is inversely proportional to pres_sure at different levels. At 100 mbs. the daily amplitude is $3^{o}K$ in summer and $2^{o}K$ in winter. At 50 mbs. the amplitudes are doubled, (3) a sudden increase of temperature is observed just after sunrise . A similar fall follows sunset, (4) differences between day-time observations placed symmetrically about the noon are small. They indicate a maximum rise of 0.5 K in the afternoon consistent with the magnitude of the cooling at night at these levels. It has been shown by Kay that most of these results are explicable as caused primarily by inherent errors in radiosonde measurements.

Such errors can be casual or systematic. Casual errors arise due to strict intercomparability between instruments and the inevitable random-sampling of the non-uniform conditions in the upper atmosphere. They may be effectively smoothed out by consideration of a large number of ascents. The most serious systematic errors are (1) errors in pressure-measurements which are of the order of ±5 mb. at 25-35 kms. and (2) errors in temperature measurements mostly caused by the direct irradiation of the thermometric element by sunlight. The latter error is attempted to be minimised in radiosondes by providing properly-designed radiation-shields and having measuring units of high reflectivity and low heat-capacity values. But a correct evaluation and removal of this error is difficult. Scaling experiments in which the thermometric elements have progressively graded physical properties have been suggested . Brasefield has experimentally studied the dependence of the radiation shields and the thermal and optical properties of the measuring units. More recently suggestions of indirect methods of temperature determination as from sonic velocity or α-ray absorption measurements have also been made.

With our present state of knowledge obtained from aerological ascents, it appears difficult to say whether there is diurnal variation of temperature in the upper atmosphere between the top of the lower layer penetrated by daily tubulence and the upper levels ordinarily reached by sounding balloons.

V. DISCUSSION

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

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

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

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

$$\delta I = \beta_1 \delta \beta + \beta_2 \delta H + \beta_3 \delta T$$

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

It is difficult to draw conclusions about the effects of meteorological factors on cosmic ray intensity by comparison of the daily variation curves of Fig. 3·1. Solar radiation and gravitational forces are the most important causes for the daily variations observed in geophysical elements. These variations, as well as one that could be caused in meson intensity by an anisotropy of the primaries of solar origin, would have a predominent 24 hourly diurnal component. Therefore it is not clear how much of the M^D variation is connected with P^D and θ^D or a hypothetical upper air diurnal temperature variation, and how much is due to primaries of solar origin.

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

The first two harmonic components of T, M and E along with P and θ are shown in Fig.3.11 on 24 hourly and 12 hourly harmonic dials. It will be observed that while in the 24 hourly dial, the vectors lie all around the clock, there is on the 12 hourly dial a very striking grouping of the cosmic ray vectors almost completely opposite in phase with the pressure vector. This clearly shows that high negative correlation exists between cosmic ray components and the pressure.

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

Cosmic ray component.	Correlation coefficient with P^S_A	Barometric coefficient.
T^S_A	$r^{SS}_{TP} = -0.97$	$\beta_T = -4.3\%$ per cm.Hg
M^S_A	$r^{SS}_{MP} = -0.95$	$\beta_m = -2.5\%$ per cm.Hg
E^S_A	$r^{SS}_{EP} = -0.98$	$\beta_E = -14.1\%$ per cm.Hg

Table 5.1

The barometric coefficient $\beta_m = -2.5$ % per cm. Hg for mesons may be compared with the value found by other workers from day-to-day variations of cosmic ray meson intensity. Coefficients of - 3.0 % per cm. Hg for Huancayo and - 1.8 % per cm. Hg for Cheltenham, Christchurch and Godhavn have been determined and used for barometric pressure correction by Lange and Forbush for the Carnegie Institution ionisation chamber data. It is not clear why at Huancayo the coefficient could be so much larger than at the other stations in spite of the shielding being the same for all the instruments. Duperier's barometric coefficient is -1.5 % cm. Hg and Dolbear and Elliot have reported a value of - 1.88 % cm.Hg obtained from seasonal variation of intensity. These authors by partial correlation analysis, give estimates for the three meteorological coefficients which affect meson intensity. These are shown in Table 5·2. Our value of the barometric coefficient for mesons is larger than the true mass absorption coefficient of Duperier but agrees well with the coefficient of Dolbear and Elliot.

Table 5·2

Coefficient	Duperier	Dolbear and Elliot
β	- 1.50%/cm.Hg*	- 1.88 % /cm.Hg
μ	- 1.05%/cm.Hg	- 2.07 % /cm.Hg
μ'	- 3.90% /km.	- 4.22 % /km.
α	0.12 % /°C.	0.14 % /°C

* Weighted mean for 5 periods of observations.

It is important to examine if there is a substential decay contribution in the semi-diurnal variation. Pekeris and more lately Wilkes and Weekes have examined the details of the modes of oscillation of the atmosphere. Nicolson and Sarabhai have estimated the effect on meson intensity of the semi-diurnal change of height of isobaric levels due to atmospheric oscillations. For meson production near 16 km. there should be a semi-diurnal oscillation for the isobaric level which would not exceed 4 metres and thus would not change significantly the contribution of the pure mass absorption effect to the barometric coefficient.

V 5.1

Finally, we have to consider a possible contribution from a positive temperature effect. The results of our upper air meteorological investigations have shown that in the atmosphere near the 100 mb. level, the main changes of temperature are not diurnal but of irregular day-to-day character. When data are averaged over an extended period, the latter fluctuations are expected to be smoothened out. Since the amplitude of the diurnal temperature variation near the tropopause is not significant, we are lead to believe that the barometric effect derived by us from the semi-diurnal variation corresponds mainly to the true absorption coefficient for the meson component.

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

(1) A daily variation will not in general have only the diurnal harmonic component even though it is characterised by one maximum and one minimum in 24 hours. The variation would rarely be perfectly sinusoidal, and depending on the extent to which its from differs from this type, higher harmonics would be present. In particular, if due to

anisotropic primaries, there is an increase in intensity produced only during the day, but at night the intensity is constant, we would get an appreciable $^{*}M^S$ with maximum almost coinciding with that of M^D. We can refer to this semi-diurnal component $^{*}M^S$ as a shadow component of the main diurnal component M^D. When M^D has an hour of maximum near 1030 hours $^{*}M^S$ would also be highly correlated with P^S and would tend to reduce the effective barometric effect.

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

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

5.1.2 <u>The barometric coefficient for the soft component</u> :

Reference to Table 5·1 indicates that the soft component E has a barometric coefficient - 14·1 % per cm.Hg. This is considerably more than the coefficient for mesons, as is to be expected from the additional radiative loss that an electron can suffer at high energies and which predominates over the collision loss, suffered by both electrons and mesons.

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

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

(2) the decay of μ mesons.

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

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

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

$$\frac{4Z^2}{137} \cdot r_0^2 \cdot \log(183 Z^{-\frac{1}{3}}) \text{ where } r_0 = \frac{e^2}{m_e C^2}$$

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

$$l = \left\{ \frac{4NZ^2}{137} r_1^2 \log 183 Z^{-\frac{1}{3}} \right\}^{-1}$$

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

Substance	air	H_2O	Al	Fe	Pb.
l in cm	34200	43.4	9.80	1.84	0.525
W_c in Mev.	103.0	114.6	55.56	25.88	6.927

V 5.2

When energies of the particles are expressed in terms of their critical energies in a particular substance, and lengths in terms of the radiation length in the same substance, the numerical results of the cascade theory are applicable to all substances. Values of $N_{(W\ t)}$ as calculated by Bhabha and Chakrabarty, for selected energies and depths of absorber are given below in the Table 5.3. The energy is expressed in this table in terms of a variable Y defined by $Y = \log (W/W_c)$.

Table 5.3. Values of N for different values of Y and t

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

It can be seen from the above table 5.3 that the number of particles first increases with depth, attains a maximum at a particular value of 't' and then decreases for greater thickness of the absorber. The apparent pressure coefficient would in consequence be positive at the start, become equal to zero at the maximum of shower growth and then would reverse in sign. Physically this implies that for showers, both regenerative as well as attenuative processes are operative, and the experimental value for the pressure coefficient would depend on the location of the point of observation with respect to the development of the shower. If the soft component is measured by differential absorption as in the present case there would be a large proportion of low energy component representing the end of the shower. Hence the barometric coefficient should be greater than what is found in experiments where the soft component is studied by measurement of showers with atleast two time associated particles. Table 5·4 indicates the experimentally observed coefficients.

5.2 The barometric pressure corrected variations

The appropriate barometric coefficients experimentally determined from semi-diurnal components can be used to correct the daily variations of T, M and E for the barometric daily variation. Smoothened bi-hourly values of the barometric pressure corrected variations designated by T', M' and E' are shown in figure 5·1. The harmonic component of these are indicated in Table 5·4 and presented on harmonic dials in Fig.. 5·2

Table 5.4 (p.111)

Pressure coefficients obtained for the soft component by various investigators.

Author	Method of observation	Duration	Absorber	Type of variation	Pressure coeff.
Barnothy & Forro	Showers	1 year	-	Day-to-day	-.42% per cm. Hg
Stevenson & Johnson	"	4 weeks	12 cms.Pb	"	-5.5% per cm.Hg.
Froman & Starms	"	140 days	-	Daily	- " "

Table 5.4

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

Variate	1st Harmonic 24 hourly		2nd Harmonic 12 hourly	
	Ampl.	Max.	Ampl.	Max.
T'	0.37	117°	0.11	42°
M'	0.42	120°	0.08	12°
E'	0.18	4°	0.23	35°

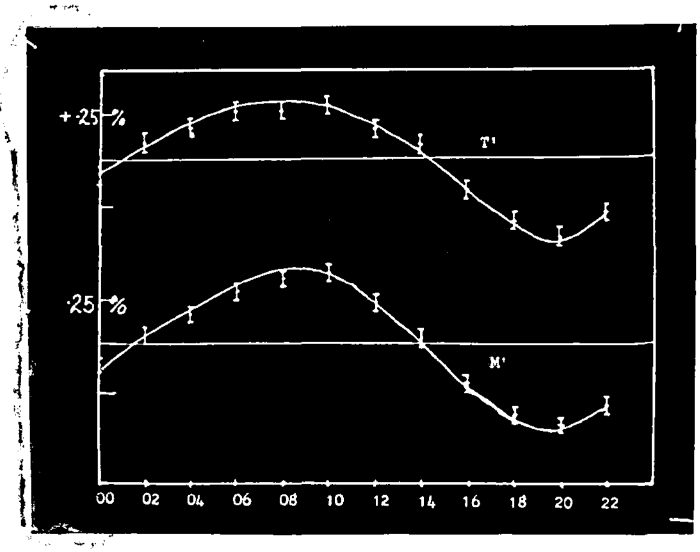


fig 5·1

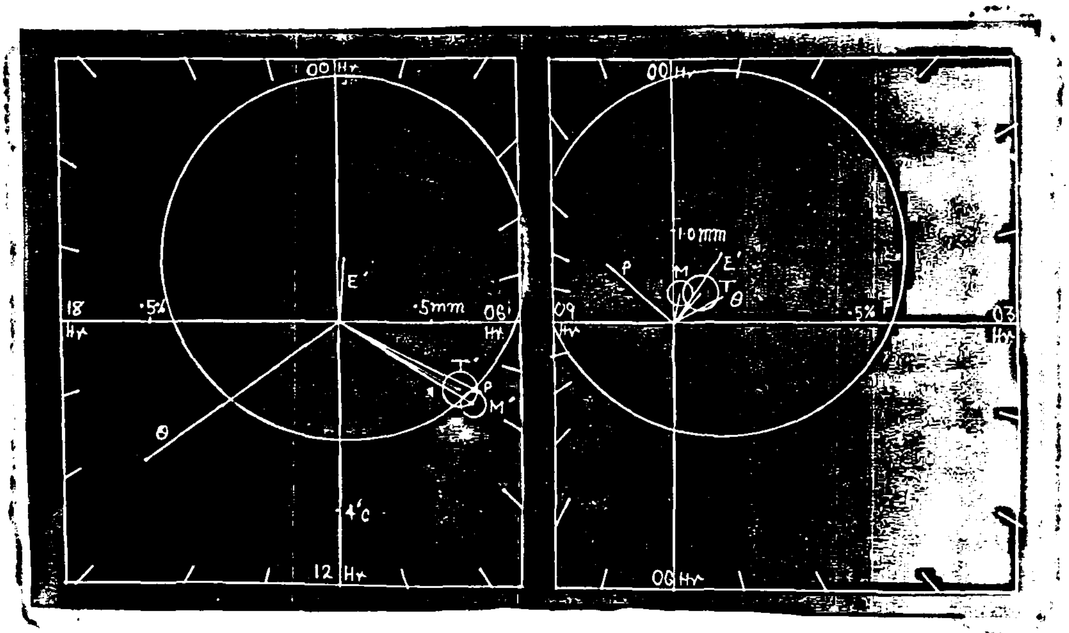


Fig. 5.2

Harmonic dials of F' and M'.

It will be noticed that T' and M' are left with a residual diurnal variation of amplitude 0·37±·06 and 0·42±0·4 respectively, and hour of maximum near 0900 hours I.S.T. E' on the other hand has no significant variation exceeing the standard deviation of the individual bi-hourly points. This indicates that the daily variation of the electron component at sea level can be explained almost completly by a mass absorption effect connected with the barometric variation.

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

An examination of Fig.5·2 reveals that the barometric pressure corrected vectors for total intensity and mesons on the 24 hourly dial are both significant and are negligibly correlated with surface atmospheric temperature. If the heating in the upper atmosphere were to take place from lower levels, the maximum temperature would occur at a later hour than the surface temperature and the correlation with T' and M' would be almost zero. For heating of the layers of air near 16 km. from above, the maximum temperature may occur nearer noon, but even so the correlation between the diurnal vectors for T' amd M' and a temperature vector at noon would be quite low. One is therefore led to conclude that the atmospheric temperature has little or no part to play in producing the daily variation of meson intensity corrected suitably for barometric pressure.

Having eleminated meteorological effects, it is necessary to consider possible geomagnetic and heliomagnetic influences on the residual daily variation of mesons. Janossy has suggested the possibility of a diurnal variation of cosmic rays at latitudes beyond 40° due to the helio-magnetic field. Dwight[78] has worked out detailed implications but this' theory can be safely excluded in view, amongst other things, of the evidence from several quarters concerning the non-existence of an appreciable general helio-magnetic field at the present time. Vallarta and Godart have discussed the influence in low latitudes of an ionospheric current system responsible for the geomagnetic diurnal variation. While the latter alters fundamentally in character with latitude, Thompson[71] has shown that the meson variation has similar features over a wide range of latitudes. It appears therefore that the barometric pressure corrected variation of mesons is of extraterrestrial origin and is connected with an anisotropy of the primary radiation.

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

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

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

The curve of residual meson variation corrected for pressure at Ahmedabad and the meson variation curve at Kodaikanal are both significant and strikingly similar. Both are diurnal with amplitude $M'_A = 0.42$ per cent and $M'_k = 1.10$ per cent with maxima at 0950 and 0840 hours local time respectively. The increase of the percentage amplitude with elevation suggest the contribution of a larger number of low-energy particles which can make their effect felt at a high-level station but not at a sea level station.

Taking into consideration the occurrence of the maximum of the diurnal variation at about the same period of the day according to local time at widely separated places on the earth, it is reasonable to conclude that the anisotropy is caused by the solar emission of cosmic rays. Duperier[80] has indeed made a similar suggestion by a consideration of the seasonal change of amplitude of the meson diurnal variation corrected for barometric pressure and decay coefficient. As however, the application of the decay effect is questionable for reasons mentioned earlier, the close agreement between the ratio of summer and winter diurnal amplitudes with what would be expected due to change of the solar zenith distance at the two periods may be fortuitous.

5.3 The hour of maximum of the diurnal variation :

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

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

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

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

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

The principal features that emerge from this analysis are :-

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

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

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

5.4 <u>The effect of cosmic rays from the sun</u> :-

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

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

Elliot and Dolbear[76] have made a very significant observation that during days of increased geomagnetic activity the diurnal variations in both North and South directions are enhanced, and the N-S difference changes from being a semidiurnal to a diurnal curve. Since it is known that geomagnetic disturbances are associated with solar corpuscular streams, it would appear that when there is increased activity of the solar M-regions, there is also increased cosmic ray emission from the sun. The radical change in the nature of the difference curve during magnetically disturbed days supports the view that it has no special physical significance apart from being the arithmetic difference of the diurnal variation in the two directions.

5.5 Year to year change of diurnal variation.

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

Longtime worldwide changes of the diurnal variation have been demonstrated by Sarabhai and Kane from Carnegie Institution data. They have derived time series which demonstrate changes of 30 to 40 per cent in the diurnal amplitude and significant shift of the hour of maximum. In years of low solar activity, these series appear to be well correlated

With relative sunspot number R and the American Magnetic Character figure C_A. It is likely that the change of form of the daily variation that is indicated in our data is genuine and part of it is representative of long-term worldwide changes.

5.6 The annual change of diurnal variation :-

In the introductory chapter, the significance of the annual change of diurnal variation has been discussed from the stand point of the solar origin of cosmic rays and a possible sidereal time daily variation of intensity. Most analysis in the past have been done by a study of the annual movement of the tip of the solar diurnal vector on 1 24 hourly harmonic dial using the methodology suggested by Thompson. Since we now realise that the hour of maximum intensity is controlled by the geomagnetic bending of trejectories of solar particles, and is therefore expected to undergo a change with an alteration of the solar zenith distance at different times of the year, the situation is more complicated than was visualised by Thompson. Our knowledge about the geomagnetic effect on solar cosmic rays is very limited. It appears that without it, an interpretation of the combined effect of the annual change of amplitude and hour of maximum on a harmonic dial can hardly be attempted. We therefore propose here to deal with the two effects separately.

For the purpose of an accurate study of the month to month or annual changes..

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

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

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

V 5.6

Table 5.6

First harmonic constants for pressure-corrected meson intensity.

	J	F	M	A	M	J	J	A	S	O	N	D
M^{D}	0.27	0.33	0.44	0.50	0.76	0.97	0.54	0.48	0.44	0.25	0.64	0.62
$M\phi^{B}$	132°	126°	126°	112°	94°	84°	85°	176°	176°	181°	115°	125°

M^{D} = Amplitude of the diurnal component for pressure-corrected meson intensity.

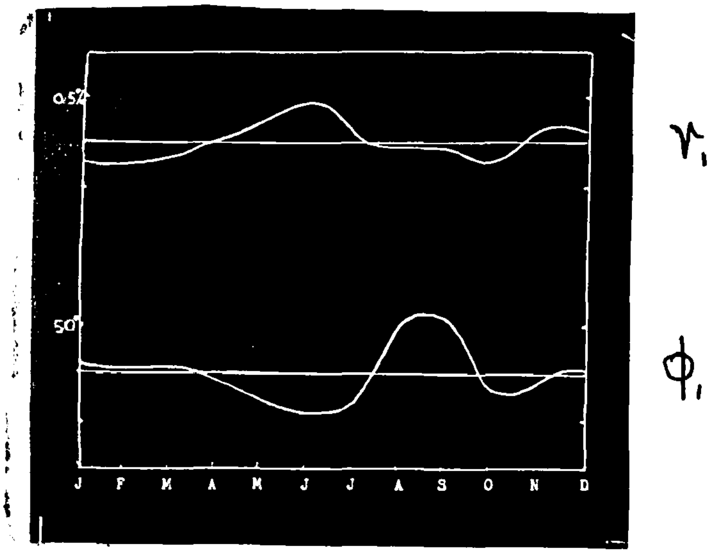


Fig. 5.3

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

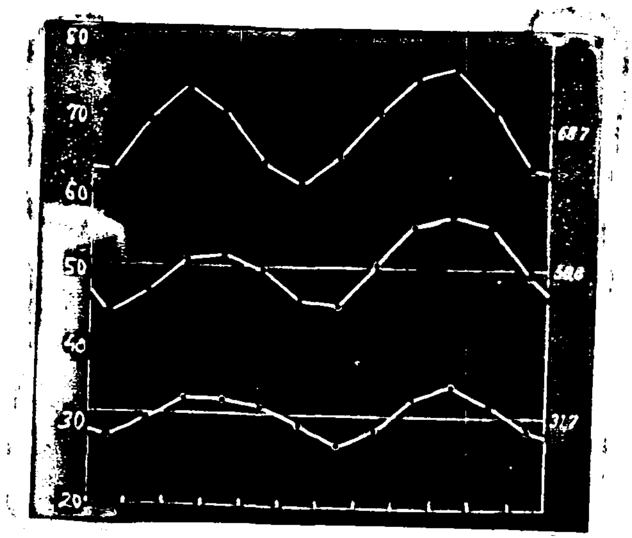


Fig. 5·4

The annual variation of the magnetic activity in years of high, medium and low activity.

change curve and the strong maximum in the $M\phi^D$ change curve during this period has any relation to the abnormal weather conditions found in July and September.

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

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

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

(2) two maxima coinciding with solstices ;

the latter could probably be produced by regions of cosmic ray activity confined to a narrow equatorial belt on the sun.

The annual change of diurnal variation of mesons studied by Duperier with counter telescopes exhibits a maximum amplitude in the summer, just as is found by us at Ahmedabad. In the absence of details of his data, we are unable to check the existence of a variation with maxima in the solstices.

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

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

VI CONCLUSION

6.1

The daily variations of total cosmic ray intensity T, meson intensity M and the soft component intensity E possess important diurnal as well as semi-diurnal components. The latter, in each case are highly correlated with the semi-diurnal component of pressure.

The barometric pressure coefficients obtained from the semi-diurnal components are $\beta_T = -4.3$ % per cm. Hg for the total, $\beta_M = -2.5$ % per cm.Hg for the meson intensity and $\beta_E = -14.1$ % per cm.Hg for the soft component.

The barometric coefficients for mesons applicable to daily variation appears to correspond to the pure mass absorption coefficient determined by other workers by studying the day-to-day variation. This, as well as consideration of the daily variation of meteorological elements at different levels of the atmosphere leads us to conclude that changes of heights of the meson fomation layer and of density of the atmosphere near it, do not contribute significantly to the effect of the daily variation of air mass on meson intensity.

The higher value of β_E obtained by us compared to values of other workers who have studied the electronic component by measurement of showers, appears to be due to our differential absorption measurement of 'E' being influence by a less energetic soft component which can no longer produced multiplicative cascade showers.

Compared to Ahmedabad results, the Kodaikanal studies have shown a daily variation of mesons which is mainly diurnal in character. This variation is negligibly correlated with barometric pressure variations.

The atmospheric pressure plays an important part in the solar daily variation of mesons at the low level station at Ahmedabad but produces a negligible effect at Kodaikanal. The correlations of M_k with Θ_k and of the pressure corrected meson variation M'_A with Θ_A are negligible. Ground temperature has therefore negligible effect at both places.

The curve of the residual meson variation corrected for pressure at Ahmedabad and the meson variation curve at Kodaikanal are both significant and strikingly similar. Both are diurnal with amplitude $M'_A = 0.45 \pm 0.06$ per cent and $M_k = 1.1 \pm 0.08$ per cent with maximum at 0850 and 0840 hrs. local time respectively.

VI

Our results concerning the meson intensity can be compared to those obtained at Hafelekar (geomag. lat. 47°N, alt.2300 m.), Huancayo (geomag. lat. 1°S, alt.3350 m.), Christchurch (geomag. lat.49°S, alt. 8 m.), Cheltenham (geomag.lat. 50°N, alt.72 m.) and Godhavn (geomag. lat. 80°N, alt. 9 m.), where the measurements were made with ionisation chamber and showed a predominently diurnal trend in the daily variation. Fig.6·1 (p.132) gives the harmonic dial for the first harmonic of the variations of the meson intensity at these places together with the first harmonic of the residual variations obtained by us at Kodaikanal and Ahmedabad.

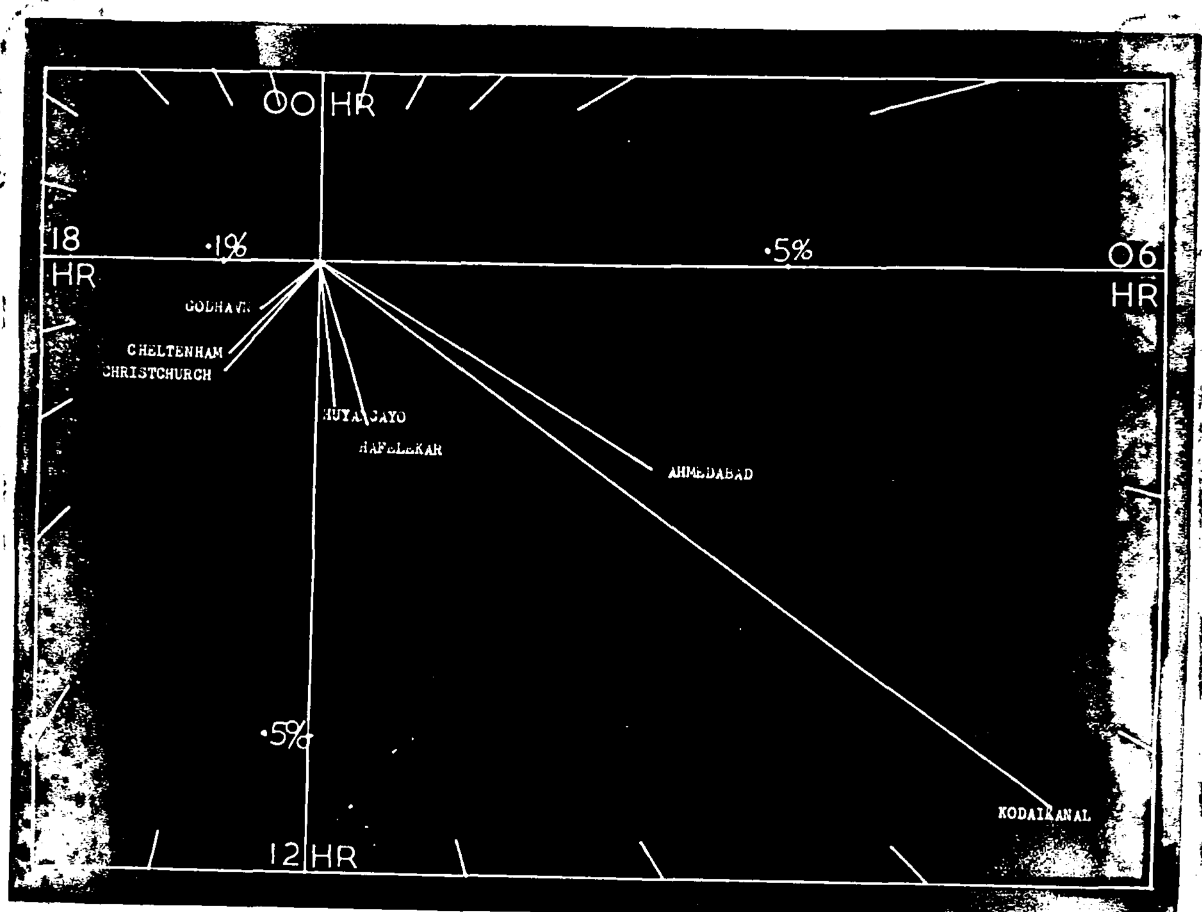


fig 6·1

V

The pronounced residual diurnal variation which remains after correcting for the meteorological elements near the ground, is unlikely to be caused by meteorological changes in the upper atmosphere which have a totally in sufficient amplitude of diurnal variation according to existing meteorological knowledge. The diurnal changes in geomagnetic elements are also unlikely to cause the residual variation. The nature of the magnetic variations changes radically with latitude whereas the diurnal variation of cosmic ray intensity has a similar form at places as far separated as Kodaikanal, Ahmedabad, Hafelekar, Huancayo, Christchurch, Cheltenhm and Godhavn. ?

The increase in the percentage amplitude of the residual diurnal variation of the total and the meson intensities in going from Ahmedabad to Kodaikanal is most probably an effect of altitude rather than changes of latitude. This is in agreement with the increase of amplitude found at the two high level stations of Hafelekar and Huancayo as compared to the low level stations of Christchurch, Cheltenham and Godhavn.

The lower percentage amplitude of the diurnal variation observed with ionisation chambers at Huancayo, Christchurch, Cheltenham and Godhavn as compared to the percentage amplitude found with vertically pointing counter telescopes at Kodaikanal and Ahmedabad must be attributed to the difference in the apparatus. Ionisation chambers which can register intensity from all directions of the sky are expected to reveal a lower amplitude of the variation than telescopes measuring intensity coming through a restricted solid angle from the vertical. This is particularly true for variations of non-meteorological origin due to anisotropy in space of the primary cosmic radiation.

The dependence of the residual diurnal variation on local time, its low correlation with terrestrial meteorological and magnetic elements, and the increase of its percentage amplitude with elevation, lead one to believe that the variation may be connected with a direct emission of moderate and low energy cosmic rays from the sun.

The view that the pressure corrected diurnal variation of mesons is a sensitive index of continuous solar emission of cosmic rays, is supported by the following further experimental facts:

(1) Long term changes in the nature of the diurnal variation of mesons, recorded by the Carnegie stations, have been found by Sarabhai and Kane to be worldwide in character. These changes follow broadly the pattern of the solar cycle. There is also some indication from our own studies, though not significant, that the daily variation and altered during the past two years. The annual change of the daily variation has a maximum of amplitude coinciding with the sun's zenith distance at Ahmedabad reaching a minimum in June-July. The hour of maximum also simultaneously advances to an earlier

time, as we should expect, if the atmospheric absorption of solar cosmic rays is a minimum in summer and the mean energy of the solar radiation that is measured also reaches a minimum. Duperier with counter telescopes reports a maximum of the amplitude of the daily variation in summer in agreement with our results. It is not clear yet why ionisation chamber data of the Carnegie Institution appear to be at varience with our findings, and those of Duperier on this subject. Simpson et.al. have established a connection between the central maridian passage of solar prominences and variations of neutron intensity. Neher and Forbush have pointed out correlations between these variations and cosmic ray intensity at both high and low latitudes.

Several instances have been reported of occasional large increase of cosmic ray intensity associated with solar flares. These further demonstrate that charged particles of cosmic ray energies can be ejected from the sun.

Present knowledge concerning the relationship of the amplitude and the hour of maximum of the diurnal variation caused by particles from the sun leads us to discard the current procedure for studying the annual change of the daily variation and also the view of the possible contribution of a sidereal time variation. Tentatively it is suggested that it might be more revealing to examine separately the annual changes in amplitude and hour of maximum respectively. The author's data are not yet extensive enough to yield significant results, but point the way towards further experimentatiôn and analysis for understanding this puzzling and important problem. Work is continuing now with this aim.

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