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

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.

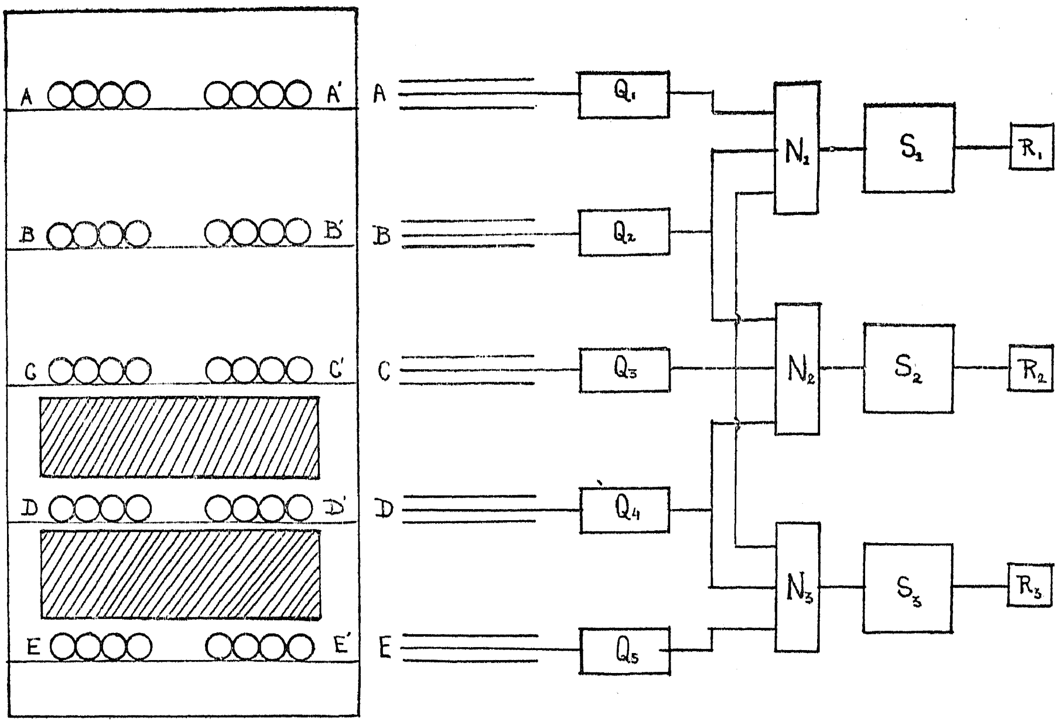

FIG. 1. Schematic diagram of apparatus showing counter trays A, B, C, D, E, A′, B′, C′, D′ and E′, quenching units Q, triple coincidence units N and scale of four units S feeding the electro-mechanical recorders R.

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

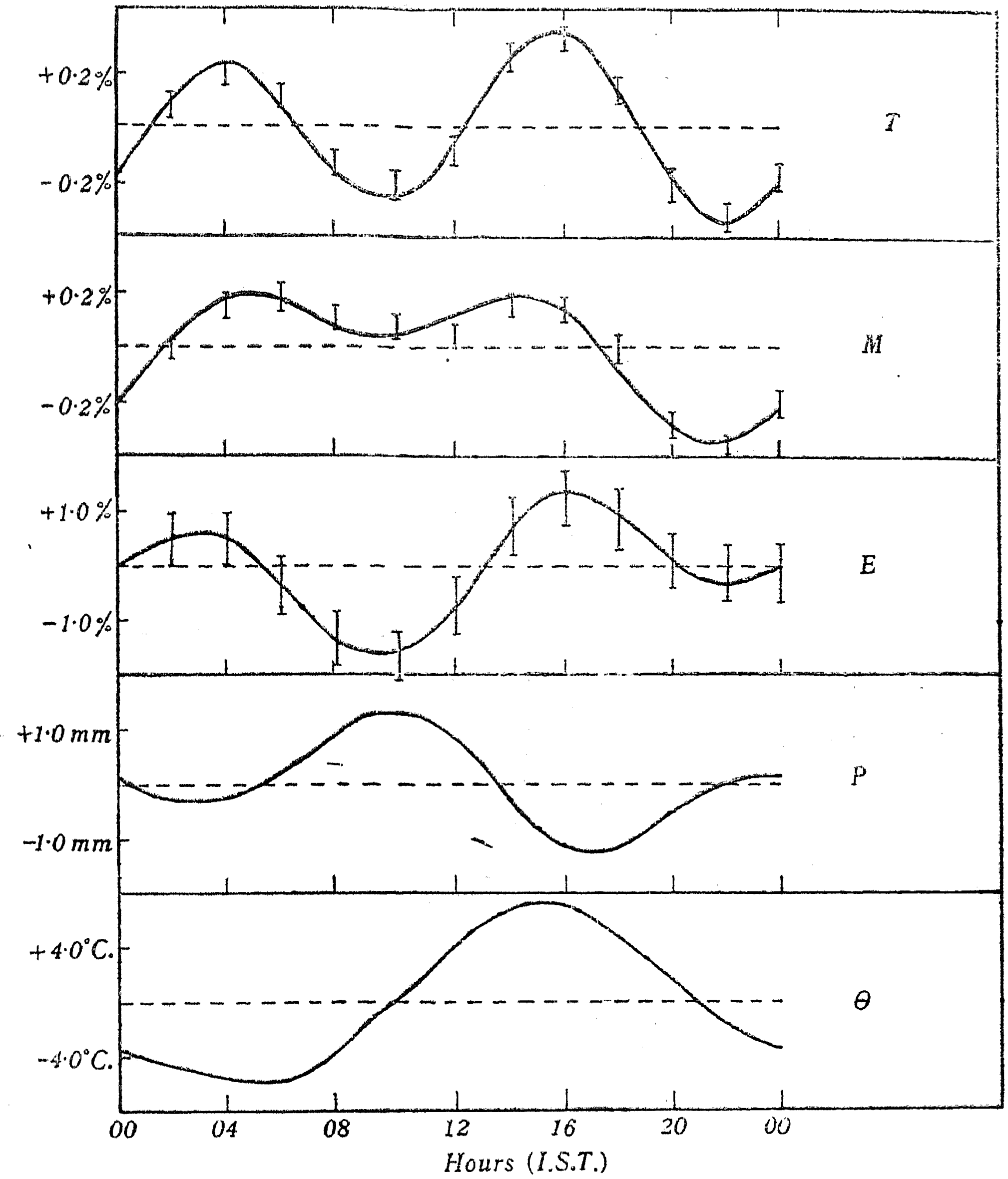

FIG. 2. The smoothened daily variation of total cosmic ray intensity T, mesons M, electrons E, barometric pressure P and surface atmospheric temperature θ. No correction has been applied to the cosmic ray values and the solid lines showing the daily variations are formed by the superposition of the diurnal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

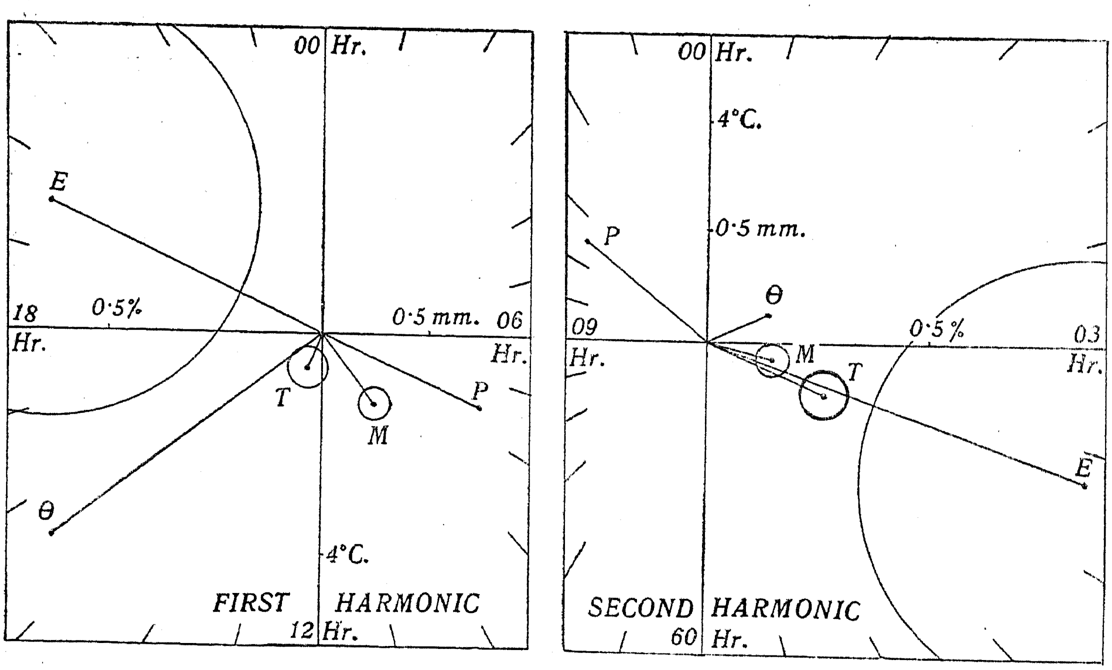

FIG. 3. Diurnal and semidiurnal harmonic dials showing amplitudes and hours of maxima of uncorrected variations.

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^S_A	Barometric coefficient
T^S_A	r^{SS}_{TP} — ·96	β_T = — 4·2% per cm. Hg
M^S_A	r^{SS}_{MP} — ·98	β_M = — 2·4% per cm. Hg
E^S_A	r^{SS}_{EP} — ·95	β_E = — 14·0% 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

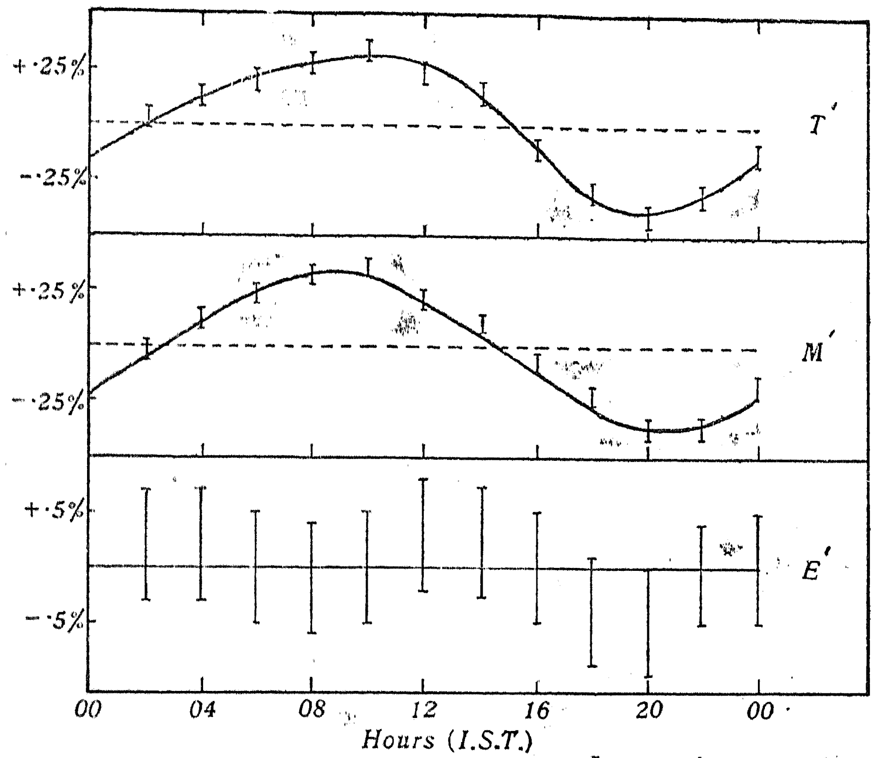

FIG. 4. The daily variation of total cosmic ray intensity, mesons and electrons, each corrected for barometric pressure.

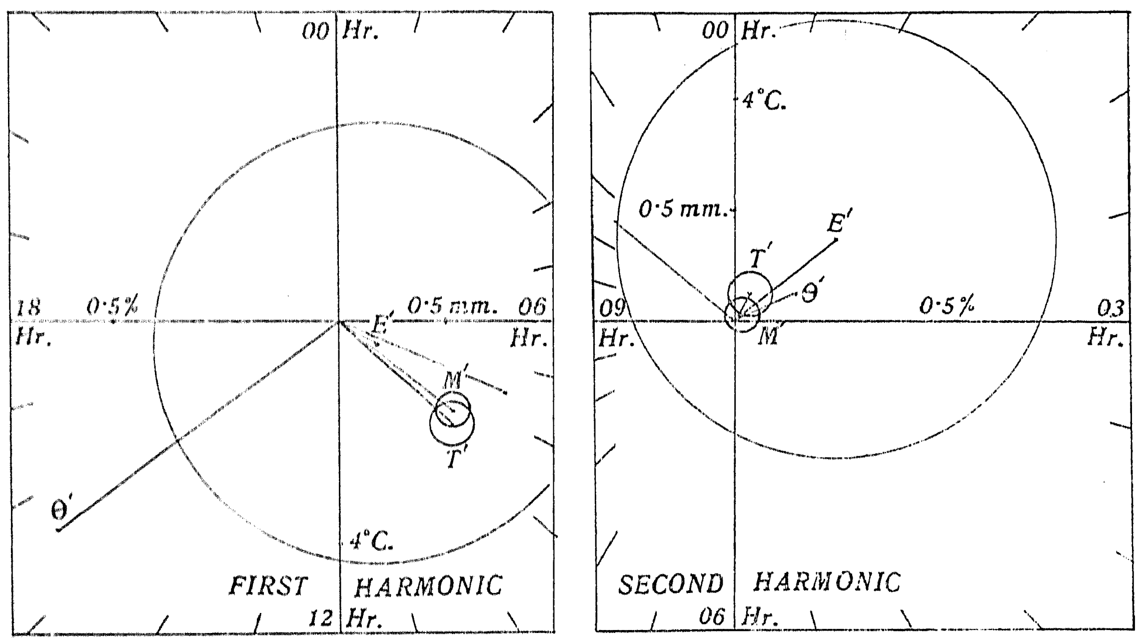

FIG. 5. Diurnal and semidiurnal harmonic dials showing amplitudes and hours of maxima of cosmic ray daily variations corrected for barometric pressure.

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.

References

1. Lange and Forbush .. Carnegie Institution of Washington Publication, 1948, 175.
2. Hess and Grazeadei .. *Terr. Mag. Atmos. Elec.*, 1936, **41**, 9.
3. Schonland, Delatizky and Gaskell *Ibid.*, 1937, **42**, 137.
4. Hogg .. *Memoirs of the Commonwealth Observatory*, Canberra, 1949, No. 10.
5. Duperier .. *Proc. Phys. Soc.*, 1945, **57**, 468.
6. Alfven and Malmfors .. *Ark. Mat. Astr. Fys.*, 1943, **29**, No. 24.
7. Elliot and Dolbear .. *Proc. Phys. Soc.*, 1950, **63 A**, 137.
8. ———— .. *J. Atmos. Terr. Phys.*, 1951, **1**, 205.
9. Sarabhai, Desai and Kane .. *Nature*, 1953, **171**, 122.
10. Duperier .. *Proc. Phys. Soc.*, 1949, **62 A**, 684.
11. Dolbear and Elliot .. *J. Atmos. Terr. Phys.*, 1951, **1**, 215.
12. Pekeris .. *Proc. Roy. Soc.*, 1939, **171 A**, 631.
13. Wilkes and Weekes .. *Ibid.*, 1949, **192 A**, 80.
14. Nicolson and Sarabhai .. *Proc. Phys. Soc.*, 1948, **60**, 509.
15. Duperier .. *Nature*, London, 1946, **158**, 196.
16. Kay .. *Quart. J. R. Met. Soc.*, 1951, **77**, 427. *Ibid.*, 1952, **78**, 279.
17. Janossy .. *Z. Phys.*, 1937, **104**, 430.
18. Dwight .. *Phys. Rev.*, 1950, **78**, 40.
19. Vallarta and Goddart .. *Rev. Mod. Phys.*, 1939, **11**, 180.
20. Thompson .. *Phys. Rev.*, 1938, **54**, 93.
21. Simpson, Fonger and Wilcox .. *Ibid.*, 1952, **85**, 366.
22. Neher and Forbush .. *Ibid.*, 1952, **87**. 889.
23. Hogg .. *J. Atoms. Terr. Phys.*, 1951, **1**, 114.
24. Forbush .. *Terr. Mag. Atmos. Elec.*, 1937, **42**, 1.
25. Thompson .. *Phys. Rev.*, 1939, **55**, 11.
26. Kelvin .. *Proc. Roy. Soc.*, Edinb., **1882**, **11**, 396.