SHORT- AND LONG-TIME VARIATIONS IN ATMOSPHERIC ELECTRIC FIELD AND POINT-DISCHARGE CURRENTS

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By

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CERTIFICATE

Certified that the thesis entitled 'Short- and long-time variations in atmospheric electric field and point-discharge currents', which is being submitted by Mr. Adarsh Kumar Kamra, for the award of the degree of Doctor of Philosophy, in Physics, of the University of Roorkee, is a record of his own work, carried out under my guidance and supervision. The matter reported in this thesis has not been submitted for the award of any other degree of any University.

This is, further to certify that he has worked for a period of more than two years to prepare this thesis.

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INTRODUCTION

The subject of Atmospheric Electricity deals with the electrical processes occurring in the region, in between earth and the upper atmosphere. The spectacular natural manifestation of lightning discharge was, obviously, the first to attract the attention of scientists, such as Franklin, Dalibar and Lomonosov, in the middle of 18th century. Lemonnier[1], however, was the first to notice the electric phenomena in the atmosphere in the absence of clouds and thereafter the clouds and thunderstorms were regarded as to be simply field-distorting agencies in the atmosphere. Since then, in this long period of more than two centuries, over-growing efforts have been made to better understand the physical and mathematical picture of the phenomena, both in fair and disturbed weather conditions. Experimental techniques have been improved and observations have been extended to larger breadths of space and time, but whereas we have collected much of factual knowledge, our understanding of the basic physical processes behind them, has not gone up in that ratio.

CONDUCTIVITY OF THE ATMOSPHERE

Conductivity of the atmosphere, which was first discovered by Coulomb[2] is now a well established fact. It is firmly believed that ionisation of the air occurs due to the radioactive radiations from the radioactive materials in the earth and air and also due to the cosmic radiations coming from outside the terrestrial atmosphere. While cosmic radiations ionise the air at all levels of the atmosphere, the ionisation due to radioactive radiations from earth is confined to the lower altitudes and on land surfaces only. At oceans and poles covered with thick layers of ice, cosmic radiations are the only dominant source of ionisation and their intensity of action increases with altitude.

These radiations strip-off negative electrons from neutral molecules leaving away positive nuclei. In the regions of the atmosphere, we are concerned with, free electrons can not exist and soon they attach themselves with the neutral molecules, making a cluster type of charged particle, known as ion. These negatively and positively charged 'small ions' are largely responsible for the conductivity of the atmosphere. At land stations, these small ions attach themselves with still greater neutral particles, such as condensation nuclei or pollution particles and form the so-called 'large ions'. Broadly speaking, all the atmospheric ions have been grouped into three categories with respect to their sizes i.e. small ions, intermediate ions and large ions, their ionic mobilities lying in the range of 1-2, 10^{-1} - 10^{-2} and 10^{-3} - 10^{-4} cm^2/V-sec. respectively. Physically speaking the essence of small ions is their charge while charge on large ions is only incidental.

The small ions are destroyed by recombination with ions of opposite sign and being attached to much larger neutral molecules. The equilibrium equation for small ions may be written as below:

$$\frac{dn}{dt} = q - \alpha n^2 - \beta n N \qquad .. \quad (1)$$

where n is the number of small ions, q the rate of ion production, α the coefficient of recombination, β the coefficient of attachment, and N the number of nuclei and large ions of opposite sign. Here it has been assumed that coefficient of attachment and coefficient of recombination with large ions of opposite signs, are nearly equal.

The number of large nuclei and ions of opposite sign N is very small compared to number of small ions of opposite sign n, over the sea, so that eq.(1) becomes

$$q - \alpha n^2 = 0$$

or

$$n = \left(\frac{q}{\alpha}\right)^{1/2} \qquad .. \quad (2)$$

On the other hand, over land, n is very small compared to N, and thus

$$q - \beta n N = 0$$

or

$$n = \frac{q}{\beta N} \qquad .. \quad (3)$$

Now, we know that conductivity of atmosphere λ, is represented by

$$\lambda = n e k \qquad .. (4)$$

where n, e and k represent the number, charge and mobility of small ions respectively.

From equations (3) and (4), we see that

$$\lambda = \frac{1}{N} \qquad .. (5)$$

and since the potential gradient is given by

$$E = \frac{i}{\lambda} \qquad .. (6)$$

where i is the air-earth current, we have

$$E = i N \qquad .. (7)$$

Thus, if the air-earth current is constant, the potential gradient is proportional to the number of nuclei.

Diurnal and seasonal variations of conductivity of the atmosphere are influenced by the corresponding changes in the ionisation intensity and pollution concentration. Conductivity is more in night and becomes less in the day time due to increased pollution in the atmosphere. Again, due to the same reason, conductivity is more in summer than in winter. Conductivity increases with altitude, nearly exponentially, which may, obviously, be expected due to increased ionisation activity and less pollution density at higher altitudes.

The effect of pollution of the atmosphere may be estimated from the fact that about half of the columnar resistance i.e. resistance of 1 cm^2 cross-section of the column of the atmosphere between the earth and the ionosphere, which has been measured to be of the order of 10^{21} ohms, is attributed to the lowest 2 kms of the atmosphere. Relatively speaking, the earth is a very good conductor, with respect to air since the conductivity of sea water is 14 orders of magnitude greater than that of air and the conductivity of ground is 10 to 11 orders of magnitude greater than that of air. Ionosphere too is about 10 times more conducting than the lower layers of the atmosphere so that we can draw the picture of the atmosphere, as consisting of two spherical conducting shells - earth and ionosphere - with a dielectric air of varying conductivity in between them.

VERTICAL ELECTRIC FIELD AND AIR-EARTH CONDUCTION CURRENT

To understand the various aspects of atmospheric electricity, earth and the ionosphere are considered as two plates of a spherical condenser, the later having positive charge and the former negative. The charge leaks through the conductive air, giving positive charge to the earth. Gish[3] estimated this leakage current to be of the order of 1800 amp.

over the whole earth surface, and the resistance of the atmosphere to be 200 ohms, so that the potential difference between the two plates of the condenser amounts to be 360,000 volts. The values are, however, very approximate and may be considered only from the point of view of orders of the magnitude.

The value of potential gradients over the land surface varies very much with space and time. We shall discuss these variations in detail in Chapter II. Here it shall be sufficient to mention that the value of potential gradient at sea surfaces is of the order of 100 V/m and it decreases with altitude, while at land, its value depends upon the amount of pollution in air, e.g. the mean value of potential gradient at Kew is 363 V/m.

As a consequence of the conductivity of the atmosphere and the potential gradients, present therein, a conduction current flows from upper atmosphere to earth. In fair weather conditions, the negative ions move upward and positive ions downward so that earth is continuously charged with positive charge. The current density may be represented by

$$i = (\lambda_1 + \lambda_2) E = \lambda E \qquad .. (8)$$

where E is the field, λ_1 and λ_2 are positive and negative conductivities and λ is the total conductivity. Over the oceans, the mean value of conduction current in fair weather is 3.2×10^{-16} A/cm^2, while over land, it generally varies from 1×10^{-16} to 4×10^{-16} A/cm^2.

The value of air-earth conduction current over oceans, as well as over land shows diurnal variations which are nearly mirror image of the diurnal variation of potential gradients, though with less range of variation. The conduction current remains constant with altitude.

It should be noted here that in the study of atmospheric electricity , the conduction current is considered to be more fundamental than potential gradient. It is because of the fact that it depends upon the total potential difference between the earth and the ionosphere and the columnar resistance of the atmosphere. The local potential gradient and the conductivity has little effect on it and therefore it is less subject to variations arising out of local conditions. The local conductivity affects conduction current only to the extent, that it changes the columnar resistance. Thus, in studies of the world-wide nature of atmospheric electricity, conduction current can give better uniformity to results.

Due to the uneven distribution of space-charge in the atmosphere and high turbulent diffusion coefficient k, one more current, diffusion current i_d , also manifests itself in the atmosphere and is given by

$$i_d = -k \frac{\partial \rho}{\partial z} \qquad .. (9)$$

where ρ is the space-charge density.

Also, due to the heating of the earth surface, convection current i_k flows,

$$i_k = \rho v \qquad .. (10)$$

where v is the velocity of convective transport of space charge.

Thus, the total current in fine weather may be represented by

$$I = i + i_d + i_k = E - k \frac{\partial \rho}{\partial s} + \rho v \qquad .. (11)$$

The magnitudes of vertical components of i_d and i_k are, of course, very small compared to i.

THE MAINTENANCE OF EARTH'S CHARGE

It is clear from the direction of flow of conduction current in fair weather that it brings positive charge to earth which shall, eventually, neutralise the bound negative charge of the earth. Calculations for Kew show that the positive charge reaching 1 m^2 of earth shall neutralise its negative charge in a period of about 48 minutes. This time reduces to about 6 minutes only for sea surfaces.

But inspite of it, the negative charge of the earth maintains and remains more or less constant. The fact automatically suggests that an equal amount of negative charge should simultaneously be supplied to earth, through some other part of the earth.

To explain the nature of this 'supply current', different theories have been put forward in which the source of supply current has varied from terrestrial to extraterrestrial one. However, the theory, proposed by Wilson[4], has found the common support and explains nearly all the electrical manifestations of the atmosphere. Wilson considers the source of supply current to be in thunderstorms. In those regions of the earth which are disturbed by thunderstorms, the charge can be carried to and from the earth through following means :

i) Conduction current,
ii) Point-discharge currents,
iii) Precipitation current and
iv) Lightning discharges.

Although, it is very difficult to have an estimate of the net balance of charge on the earth, arising out of the contributions made by these four different agencies, yet attempts have been made for some areas of the earth and of the earth as a whole too. The results, expectedly, differ very much. As an example, we give data of Wormell[5] for 1 km^2 of area of Cambridge as below:

Conduction current	+ 60 C
Point-discharge currents	-100 C
Precipitation current	+ 20 C
Lightning current	- 20 C
Total	- 40 C/km^2 year.

Making measurements above thunderstorms, Gish and Wait[6] have found the average current of the right sign to be 0.3 - 0.6 amp. per thunderstorm cell. Now to compensate the total conduction current of 1800 amp. in fine weather, the above rate of current from thunderstorm, needs about 3000 - 6000 thunderstorm cells over the whole earth. Brooks[7] estimates about 1800 thundery situations operating over earth every time. Considering the each thunderstorm to consist of about 2-3 cells, the numbers may be considered comparable. The data is very rough and large deviations have been reported in some cases.

From the above theory, it is clear that the potential difference between the earth and ionosphere and thus potential gradient, if columnar resistance remains constant, should be maximum when the thunderstorm activity is maximum. It has been found to be really so. The diurnal variation of area covered by thunderstorms over the land areas of the earth reported by Whipple and Scrase[8], is similar to the diurnal variation of potential gradient over sea. The percentage variation about their mean values and the positions of maxima and minima are in close agreement in the cases. The theory has been confirmed by other observations too.

Thus, the total electrical picture of the atmosphere may be visualised in two regions, one is the region of 'generation' or disturbed weather zone and the other the region of 'consumption' or fair weather zone. The two regions are just two components of a circuit and a full knowledge of both together is necessary to understand the electrical processes in atmosphere.

UNITARY VARIATION AND FIELD MEASUREMENTS OVER OCEANS

The proposed theory of maintenance of earths charge suggests that the potential gradient at earth surface should vary, if columnar resistance remains constant, according to the change in potential of upper atmosphere. The condition of constant columnar resistance is nearly satisfied over oceans where there is no pollution. Mauchly[9], first showed by the results of 'Carnegie' that potential gradient at ocean shows a single periodic diurnal variation with its minimum at 4.00 GMT and maximum at 19.00 GMT. This has further been confirmed by measurements on the 'Horizon' by Ruttenberg and Holzer[10]. Measurements at poles where earth is covered with thick sheets of snow, and thus no question of pollution arises, also show similar single periodic variation when they are adjusted on GMT scale. This variation of potential gradient depicts the 'basic state' of atmospheric electricity and is given the name of 'Unitary Variation'.

An interesting result was given by Paramonoff[11] who collected data from 60 continental non-polar stations and arranged their potential gradient variations according to GMT. The mean variation of these stations which clearly neutralises the local time variations of individual stations, was found to be in agreement with the unitary variation over oceans. That means that unitary variation is also a component of the diurnal variation of land areas.

EXCHANGE LAYER AND FIELD MEASUREMENTS AT MOUNTAINS

Due to heating of earth surface , convection currents are set in the atmosphere which result in vertical mixing of surface air, as a result of which ions, nuclei, dust etc. is carried up and dispersed in upper layers. This unstable atmospheric stratification and corresponding rearrangement of the air layers gives rise to the phenomena of vertical atmospheric mass 'austausch'. The actual vertical depth of 'austausch' is governed by local circumstances, temperature, wind etc. The region, under the effect of the austausch effect is known as exchange layer and sometimes it penetrates upto 2-3 kms. However, its depth is generally extended upto the altitude of temperature inversion.

Although it is purely a meteorological phenomenon, the exchange layer plays a very important role in governing the electrical manifestations of the lower atmosphere at land stations. The value of potential gradient and its daily and seasonal variations at land stations, are greatly affected by the depth of the exchange layer and its variation with time. The significance of the predominant role of the exchange layer to affect the electrical processes lies in the fact that besides changing the local conductivity, it sometimes also alters the columnar resistance of the atmosphere.

Interesting results have been given by some of experiments done on the tops of mountains. Israël, et al.[18], in their measurements of potential gradient at Zugspitze(2960 m) Jungfraujoch (3470 m), found that its nature of daily variation resembles to that of ocean in autumn and to that of land stations in summer. The results can easily be understood in terms of exchange layer. In summer, the depth of exchange layer extends upto the top of the mountains while in autumn, the exchang layer remains confined to the altitudes lower than the stations. Israël[13] also found similar variation of potential gradient at Jungfraujoch (3470 m) and Sonnblick (3100 m), about 400 km apart. However, Ohkawati[14] working at Mt. Hiei (860 m), relatively low altitude, finds the nature of potential gradient to be similar to that of land stations in all seasons which indicates the penetration of mountain's top by exchange layer in all seasons. Sagalyn and Faucher[15] measured electrical conductivity and large ion content in and above the exchange layer, with the help of an aeroplane. They found an irregular distribution of large ions inside exchange layer and a decrease of number of large ions above it.

The effect of exchange layer on potential gradient expresses its existence very nicely in the measurements of altitude variation of potential gradient and conductivity, by Venkiteshwaran[16], Venkiteshwaran and Huddar[17], Koenigsfeld[18] and Stergis et al.[19].

SPACE CHARGES IN FAIR AND DISTURBED WEATHER

The density of space charge is represented by the difference of positive and negative ions in a unit volume.

Its average value at land amounts to about 60 e cm^{-3}. The cause of space charge may be wide-spread or purely local. Among many processes which may produce space charge; electrode effect, point discharge, lightning, blowing dust, blowing snow, industrial works, splashing of rain, break-down of insulations, petrol engines, smoke plums and house-hold fires, are some of them.

The space charge of the atmosphere has very significant effects in atmospheric electricity in both-fair and disturbed weathers. Convection theory of charge electrification in clouds, proposed by Vonnegut[20], is totally based on the nature and magnitude of atmospheric space charge. Measurements of Mühleisen[21] and Whitlock and Chalmers[22] show that fair weather variations in potential gradient at land are caused by the presence of space-charge pockets. While the later has calculated the size and height of space-charge pockets from measurements by two field-mills at a distance apart, the former has made measurements at the sources of space charge origin. A knowledge of effective area of space charges which shall depend upon the relaxation time of the atmosphere, can give us dimensions and dynamics of these space-charge pockets and also of the air masses.

Chalmers[23] observed negative fields in mist and fog at places downwind the overhead electric power transmission lines and attributed it to the insulation breakdowns in high humidity. Mühleisen[24] found negative space charges in fog and positive at the time of sunrise. Adkins[25] reports large variations in space charge densities in fair weather and negative space charges of upto $-600\ e\ cm^{-3}$ in mist, though with positive potential gradients.

The simultaneous measurements of potential gradient, current density, ion concentration and space charge density at land and sea, by Mühleisen[26], indicate the presence of electrode effect. Crozier[27] finds positive space charges of upto $4000\ e\ cm^{-3}$ for wind speeds below 1 m/sec., upto a layer of height, 50 cm from ground. Brasefield[28] has reported potential gradient fluctuations at different heights due to space charges produced by motor engines.

It is a general practice in atmospheric electricity that the total potential difference between the earth and the upper 'equalising layer' is calculated from the air-earth current measurements at ground, taking the assumption that value of the air-earth current remains constant with height. The measurement of Sagalyn and Faucher[15] however, contradict the feasibility of the assumption in the lower layers of atmosphere. In their experiments, they found that vertical transfer of space charge by turbulent diffusion in the lower layers of the atmosphere causes a convection current in addition to the usual conduction current. Supposing there is an excess of positive space charge near the earth, then the convection current shall carry the positive ions in upward direction i.e. opposite to that carried by fair weather conduction current. The magnitude of the convection current may sometimes be equal to that of conduction current. Thus, if the conduction current is to be the same at all levels, its magnitude in the lower layers must exceed that of the convection current, to nullify it. Therefore, the measurements of air earth current at ground cannot give the true absolute value of conduction current. Kraakevik[29] also noticed presence of convection of positive charge upto a level of 15 m. Potential gradient variations of Law[30] also need the presence of a convection current of the order of the conduction current, to be explained.

Recently, Bent and Hutchinson[31] have measured space charges at 1 m, 2 m and 19 m levels and found that space-charge concentrations range in between $\pm$ 400 e cm^{-3}. There was no appreciable difference in their measurements at 1 m and 2 m but space charge density at 19 m was found to be much more than at 1 m and of the same sign as the potential gradient. Possible explanation of these space charges has been given in the phenomenon of electrode effect. They also observed negative space charge in and after the mist. Simultaneous measurements of some meteorological elements in their experiments and the similarity of the patterns of space-charge records to those of convection cells, gives some clue about the cause and transportation of space charge.

Bent et al.[32] has found space charge during a thunderstorm and attribute its cause to point discharge, produced by some nearby trees in high electric fields. The presence of negative space charge at 1 m and 2 m over the melting snow, even when wind speeds were as high as 10 m/sec. has been noticed by Bent and Hutchinson[33], which indicate the production of charge to be close to the earth surface.

Kawano[34] has calculated theoretically, the relation between field and the space charge near the ground, taking into account the effect of eddy diffusion. From their calculations of vertical distribution of space charge in the exchange layer, they have also estimated the height of exchange layer with the help of the data observed by them.

Israël[35] has studied short term fluctuations i.e. electrical agitation of the atmospheric electrical elements and their variations with time. These fluctuations are found to be due to the space-charge transportation by turbulent cells in the atmosphere.

POINT DISCHARGE FROM NATURAL AND ARTIFICIAL POINTS IN THE ATMOSPHERE

Direct and indirect measurements have now well confirmed the fact that thunderstorms and clouds can be treated as electrical dipoles with positive polarity i.e. positive charge upward and negative downward, and a positive charge pocket at the bottom. The electrical fields inside these clouds are very large, compared to fair weather fields and when they become too great, lightning discharge takes place and it destroyes the electrical moment of the clouds. The electrical charges are again generated and electrical moment is built up. The generation of charges may be explained in both-warm and cold clouds- by different mechanisms which have been discussed critically by Kamra ~~and Varshneya~~[36] elsewhere and shall not be given here.

Electrical fields at earth surface under thunderstorms and clouds, are very large and vary very frequently from positive to negative and vice-versa. The electrical fields, especially in the neighbourhood of sharp points raised above the earth surface, become extraordinary high and as a result, air round these points is ionised by ionisation due to collision. The ions of the sign of the potential gradient are attracted towards the point and give rise to a current through the point. The magnitude of this current is controlled by electrical field and wind speed.

The phenomenon of point discharge may occur at erected metallic points as well as at trees and other sharp points raised above the earth surface. Milner and Chalmers[37] and Chalmers[38,39] have measured point-discharge currents through trees and studied their characteristics in charging and discharging processes. It is found that trees do not behave as simple resistive points but act as a parallel resistance-capacitance circuits with a time constant of about 90 seconds.

To start point discharge, a certain critical field value is needed below which no point discharge occurs. The value of this critical field depends upon the height of the point, shape of the point and distance between the neighbouring points. It also differs slightly for the two different signs of the field. The justification for the variation of critical potentials may be sought out by considering the concentration of lines of force at the points and the corresponding acceleration in velocity of atmospheric ions round the point.

Once the point discharge has started, its magnitude and sign is determined by field strength and wind speed at that place. In our observations of point-discharge current through a sharp artificial point, we add an additional factor of rate of change of electrical field-changes, to determine the both-magnitude and sign-of point-discharge current. We differentiate between slow and fast field-changes for this phenomenon. By fast field-changes we mean, the changes caused due to lightning discharges.

PRESENT RESEARCH PROJECT

We have seen that meteorological conditions of the atmosphere have their large effects in modifying the value and mode of variations of the atmospheric electric elements. The development of exchange layer, which is purely a meteorological manifestation of the lower atmosphere, becomes governing factor of the electrical elements at land stations and oftentimes its effect completely overshadows the effects due to variations in potential of the ionosphere.

Potential gradient is one of the main electrical parameters which undergoes large short-, and long-time variations due to these local meteorological conditions. Behind these variations of potential gradient lies their cause of variations to be in changes of conductivity of the atmosphere. This change of conductivity, as we have seen, again depends upon space charge and nuclei content of the atmosphere. Whatsoever be the cause of origin of the space charge and atmospheric nuclei, one thing is very obvious that their transportation in the atmosphere must be affected by wind. Thus, the distribution of space charge and nuclei and therefore, potential gradient and its variation should have correlationship with the wind speed. The study of this correlation has been one of our problems in the present research project. We have studied the effect of wind on the diurnal and seasonal variations of potential gradient and also on the electrical agitation of potential gradient.

The following meteorological and electrical parameters have been recorded in our laboratory:

i) Potential gradient at earth surface,

ii) Point-discharge current from an isolated sharp point,

iii) Wind speed,

iv) Atmospheric temperature, and

v) Atmospheric relative humidity.

First three parameters have been recorded over a span of one full year (May 1966 to April 1967) while the last two have been recorded for four months only (January to May 1967).

The effect of wind speed on point-discharge currents has been our second problem of study in this project. Besides studying the slow changes of potential gradient and corresponding point-discharge currents, their simultaneous values, along with wind speed, in very rapid field-changes have also been studied. In the study of point-discharge currents in those rapid changes which are caused by lightning discharges, a new phenomenon of 'excess point-discharge' current has been discovered. The phenomena has been given a theoretical explanation.

The summary of the chapters is given below:

Chapter I: First chapter gives the constructional details of the apparatus used to record the five parameters, mentioned above.

Chapter II: In this chapter, diurnal and seasonal variations of potential gradient and the effect of wind on them, has been studied.

Chapter III: In this chapter, diurnal and seasonal variations of electrical agitation of potential gradient and the effect of wind on them, has been studied.

Chapter IV: This chapter gives the record of potential gradient during a solar eclipse.

Chapter V: The effect of wind on point-discharge currents-both positive and negative-during slow field changes has been studied in this chapter. The results have been compared with those of other workers.

Chapter VI: A new phenomenon of 'excess point-discharge current' during very rapid field-changes, caused by lightning discharges has been reported in this chapter. Its theoretical explanation has been given and the experimental and theoretical values have been compared.

CHAPTER I

I N S T R U M E N T S

This chapter describes the apparatus which has been used in the present research project to record the atmospheric electrical and meteorological parameters, mentioned previously. The details are given below:

1.1 INSTRUMENTS FOR ATMOSPHERIC ELECTRIC POTENTIAL GRADIENTS

(i) Principle of the Apparatus

For measurement of potential gradients at the earth's surface, there are two main types of methods in use. In the first type, the potential of two such points is measured which are at different heights in the same vertical line, and one of them is usually earthed. Radio-active collector, water-droper and fuse are generally used as potential equalisers in this type. The slow response and the distortion of field due to ionic sluggishness produced in the atmosphere, demerits this method to be desirable in general.

In the second type of method, bound charge at an isolated area of the earth's surface is measured with the help of different field machines. The bound charge, being proportional to the electric field, gives the value of potential gradients directly. These field-machines which are based on the principle of Wilson's[40] test-plate method can further be divided, on the basis of their nature of outputs in two categories:

1. D.C. field-machines, and
2. A.C. field-machines.

In D.C. field-machines a conductor is first earthed and exposed to electric field so that a charge, proportional to the electric field, is induced in it. Then the earth connection is broken; the conductor is brought under a shield and discharged through a resistance. The conductor is returned to its original position and the process is repeated again and again so that a continuous sequence of unidirectional electrical pulses is obtained. From this, the potential gradient can be measured either in the form of 'current' through a low resistance or 'voltage' across a high resistance.

This method was first used by Russeltvedt[41] and since then, has been developed by Workman and Holzer[42], Cotte[43], Chalmers[44], Vonnegut et al.[45] and Kamra and Varshneya[46].

In a.c. field-machines the conductor (usually called 'stator' in this case) is kept fixed and earthed through a high impedance. This 'stator' is alternately exposed to and shielded from the electric field by a 'rotor' moving above the stator with a constant frequency. As a result an alternating potential proportional to the field, is developed across the high impedance. This alternating potential is amplified with a tuned amplifier, rectified and recorded.

This type, of course, needs an additional arrangement to know the direction of the field. Amongst others who used a.c. type of field-machines are -Harnwell and Van Voorhis[47], Macky[48], Van Atta et al.[49], Gunn[50], Smith[51], Mapleson and Whitlock[52] etc. Most of them used different electronic or mechanical devices to find out the sign of the field , which have been summarised in the last reference and by Chalmers[53].

(ii) The Agrimeter

The agrimeter, constructed by us, to measure the potential gradients, is a d.c. type of field-machine and is an improvement , from the point of view of output magnitude of the signal, over those previously used by different workers. It has advantage over the conventional 'field-mills' in the sense that it gives d.c. output and thus needs no additional rectifier or phase-discriminating device. The instrument is capable of operating with stout type of recording device without loosing any necessary details.

A schematic diagram of the apparatus is shown in fig.1. Eight silvered copper plates P of dimensions 28x3x0.3 cm. are fixed at equal distances on the rim of two perspex discs (D_1 and D_2) of radius 12 cm. and thickness

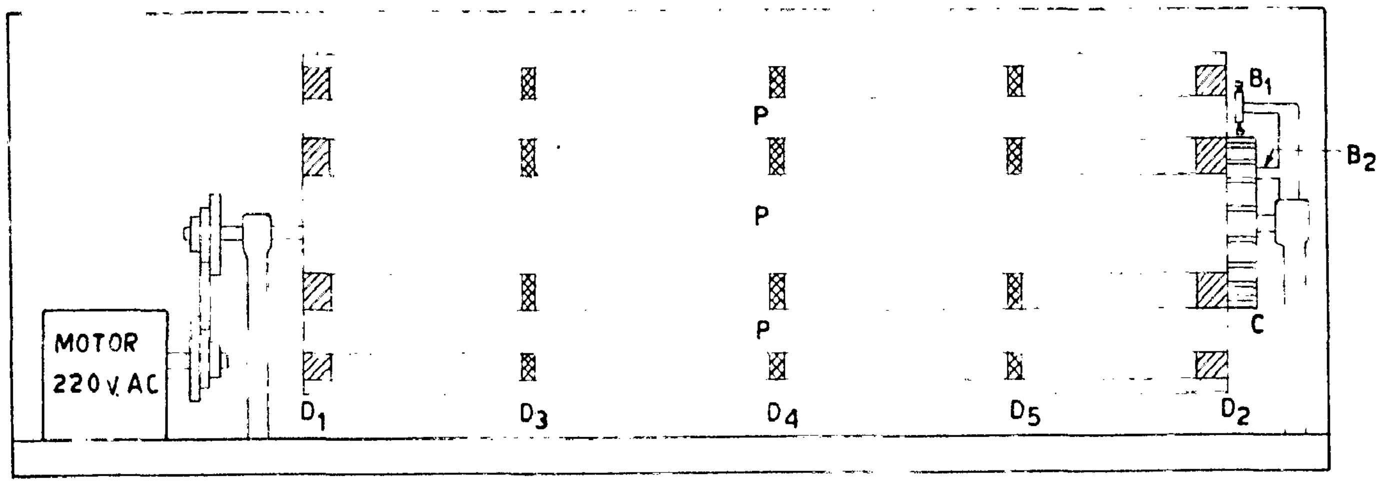

FIG 1A. AGRIMETER.

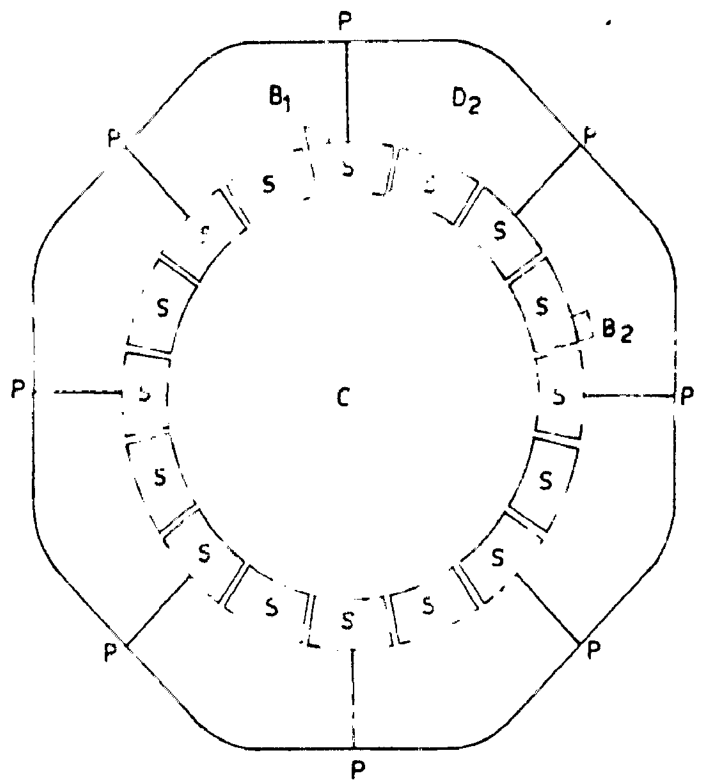

FIG.1B. AGRIMETER END ON VIEW.

8 cm. In between these two perspex discs, three thin ebonite discs D_3, D_4 and D_5 of radius 12 cm. and thickness 0.7 cm, are also introduced at equal distances and the copper plates are clamped with these also. These ebonite discs avoid the bulging of the plates in outward direction when rotated at high speed. All these five discs are fixed horizontally on an iron shaft which is supported by two ball-bearings fixed in two stout iron pillars outside the perspex discs. This shaft is rotated with a $\frac{1}{2}$ H.P. motor at 1410 rev./min. To avoid spurious effects due to vibrations, the shaft is rotated with the help of pullies and belt arrangement as shown in the figure.

Commutator C consists of sixteen equal copper sectors of breadth 2.1 cm. each fixed on the rim of a perspex disc of radius 6 cm. and breadth 2 cm. Each sector is separated from the other by a distance of 0.2 cm. and is well insulated. This commutator is fixed on the rotating shaft just outside the disc D_2 as can be seen clearly in fig.1. Each alternate sector of this is coaxially in line with one of the plates P and is connected with it with copper leads. Two spring-loaded carbon brushes B_1 and B_2 move on this commutator such that B_1, makes contact with a sector when its corresponding plate is at the top and is horizontally flat and B_2 touches that sector when the plate has moved through 60^o to the vertical. B_1 is connected to the earth and B_2 with the measuring instrument.

The whole system and the motor is mounted on a heavy iron base of length 76 cm. and breadth 39 cm. and is covered on the four sides by wooden case of height 33 cm. The upper cover of the whole assembly is of aluminium and has a slit in it, of length [illegible]9.8 cm. and breadth 6 cm, directly over the top position of plates P such that the discs D_1 and D_2 remain shielded. The whole apparatus can be grounded.

(iii) D.C. Amplifier

Amplification is necessary, if we want to use some pen-recorder for recording purpose. In the case of continuous recording, the stability of the amplifier is an important factor which must be looked into carefully. For this reason we selected differential type of d.c. amplifier for our purpose. The circuit diagram of this amplifier is shown in fig.2. The amplifier is similar to that used by Tamura[54] and uses two 3S4 valves. The power was drawn from dry batteries in order to avoid voltage-variation on the plate or the filament that may eventually cause fluctuations in the output. To avoid any leakage, the valve bottoms were cleaned with ethyl alcohol and connections were made directly with the pins of the valves, thus avoiding the use of valve basis which may be a cause of leakage. The whole circuit was enclosed in a metallic box to safeguard against any spurious effects from outside.

The output of agrimotor from carbon brush B_2 is

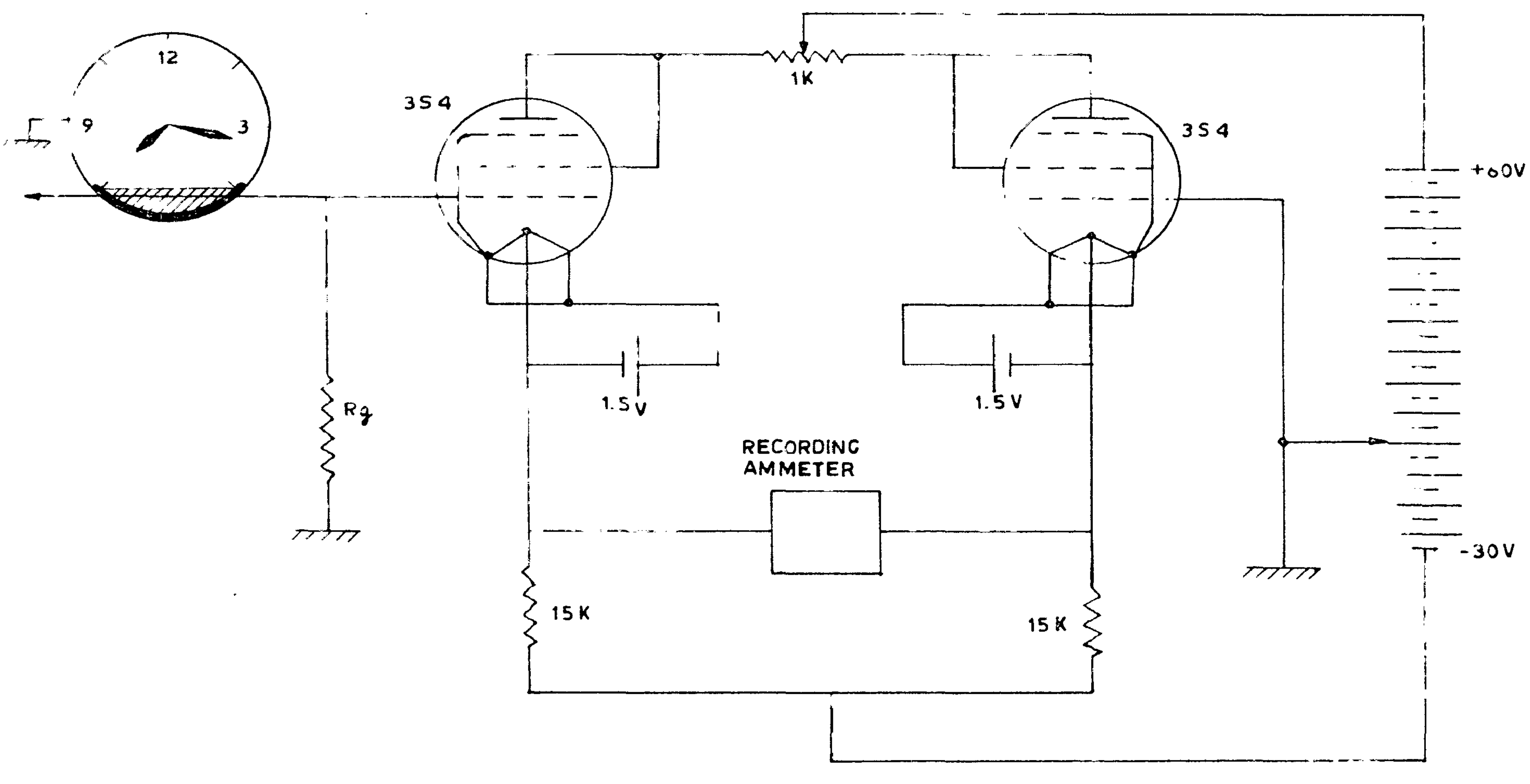

FIG. 2 - D.C. AMPLIFIER

fed, through a coaxial wire, to the amplifier. By using different values of grid-leak resistances at the input stage of the amplifier, different ranges of magnitudes of potential gradient could be made to amplify linearly. In our amplifier, we used three different grid-leak resistances with values of 3.3×10^8, 8.8×10^7 and 2.2×10^7 ohms.

Balanced-out signal from the amplifier is applied to an 'Adopt' stripchart d.c. recorder with a range of ± 5 mA on a 11 cm wide stripchart. The chart can move with three different speeds of 2, 5 and 10 cm/hr. In fair weather, usually, the chart speed has been kept at 2 cm/h while in disturbed weather conditions other two speeds have also been used.

(IV) Zero-shift

To check time and to maintain the zero of potential gradient, the input grid of the amplifier was earthed after every one hour. To do this, the following arrangement was used.

A mercury cup made of perspex was fixed at the front-bottom of a clock's dial as shown in fig.2. The signal from agrimotor was passed through a wire touching the mercury in the cup. While the whole clock body was earthed, the mercury was quite well insulated from it. Whenever, the hour-needle touched the mercury, the grid was earthed.

It was observed that even after many days of continuous operation, there was little or no shift of the zero-line. However, it was occasionally checked by placing an earthed conductor above the agrimeter and adjusted to zero, if need be.

(V) Calibration and Reduction Factor

The apparatus was calibrated by placing a metallic plate at a fixed distance over the agrimeter and applying different potentials to it, with dry batteries. The corresponding outputs from the amplifier were observed, both with open and closed agrimeter and for all the three grid-leak resistances separately.

It is not always possible to install the agrimeter at the earth's surface and some building's roof is prefered for different reasons. In such cases, the surrounding buildings and other objects affect the electric field very much and so the electric field measured by the apparatus differs from its absolute value. Therefore, knowledge of some factor, to reduce the measured values to their absolute magnitudes, is very necessary. This factor, usually known as 'reduction factor', is generally found by making simultaneous measurements at the place of actual measurement and in a ground of sufficient extension.

In our case too since the agrimeter was installed on the top third floor of the Physics Department, plane reduction of the measured potential gradients was necessary. The following method was used.

A 6 meter long wire was stretched one meter above the earth's surface, in a ground. There was no big object less than about a hundred meters from that place and the ground underneath the wire had no grass etc. and was quite plane. A radioactive collector was fixed in the centre of the wire and the potential of wire was measured by a quadrant electrometer. The electrometer was calibrated at that very place by giving known potentials to its quadrants, with dry batteries. Night-time was selected for this purpose since the potential gradients are relatively steadier in night. Observations for one hour were taken at an interval of one minute and compared with the corresponding agrimeter values. The mean value of reduction factor came out to be 0.21.

(VI) Sensitivity of the Apparatus

With open agrimeter, a field of 60 V/m gives a deflection of 1 cm on the strip-chart while with closed agrimeter the deflection of 1 cm needs a field of 330 V/m.

The sensitivity could, however, be reduced in very high fields, using other grid-leak resistances.

(VII) Performance of the Apparatus

The agrimeter has been operating continuously for the last more than a year except on a few occasions of unavoidable circumstances, such as power breakdowns, or maintenance checking and greasing etc. of the machine.

In no weather has it shown any sign of its failing to response. It has always been kept covered during periods of precipitation. Doubts may be raised that ebonite discs D_3, D_4 and D_5 might produce some trouble in rainy season by shortening the copper plates with each other. The point was kept in mind while constructing the instrument and to avoid any such trouble, a smooth layer of paraffin wax was coated on the rim portions of the ebonite discs lying in between two successive plates. This coating was also extended to those edges of the copper plates which are resting on the ebonite discs. These layers of wax do not let the falling water drops stick on the surface, while the contrifugal force cleans them off as soon as they fall. The smoothning of the wax layers after about a month has ensured that there is no leakage due to shortening of the plates. The agrimeter has responded normally in the heaviest rain and even in the falling haile.

Figs. 3(a) and 3(b) show records of potential gradient during fair weather and continuous rain respectively.

It should be mentioned here that the present instrument has come to its final shape after many trials and modifications. Previously, a 'field-mill' was constructed in which a pair of quadrant type of vanes rotated along a vertical axis. Above this pair was fixed a similar pair of vanes which was earthed. This field mill was similar to that of Tamura[34]. Due to lesser area

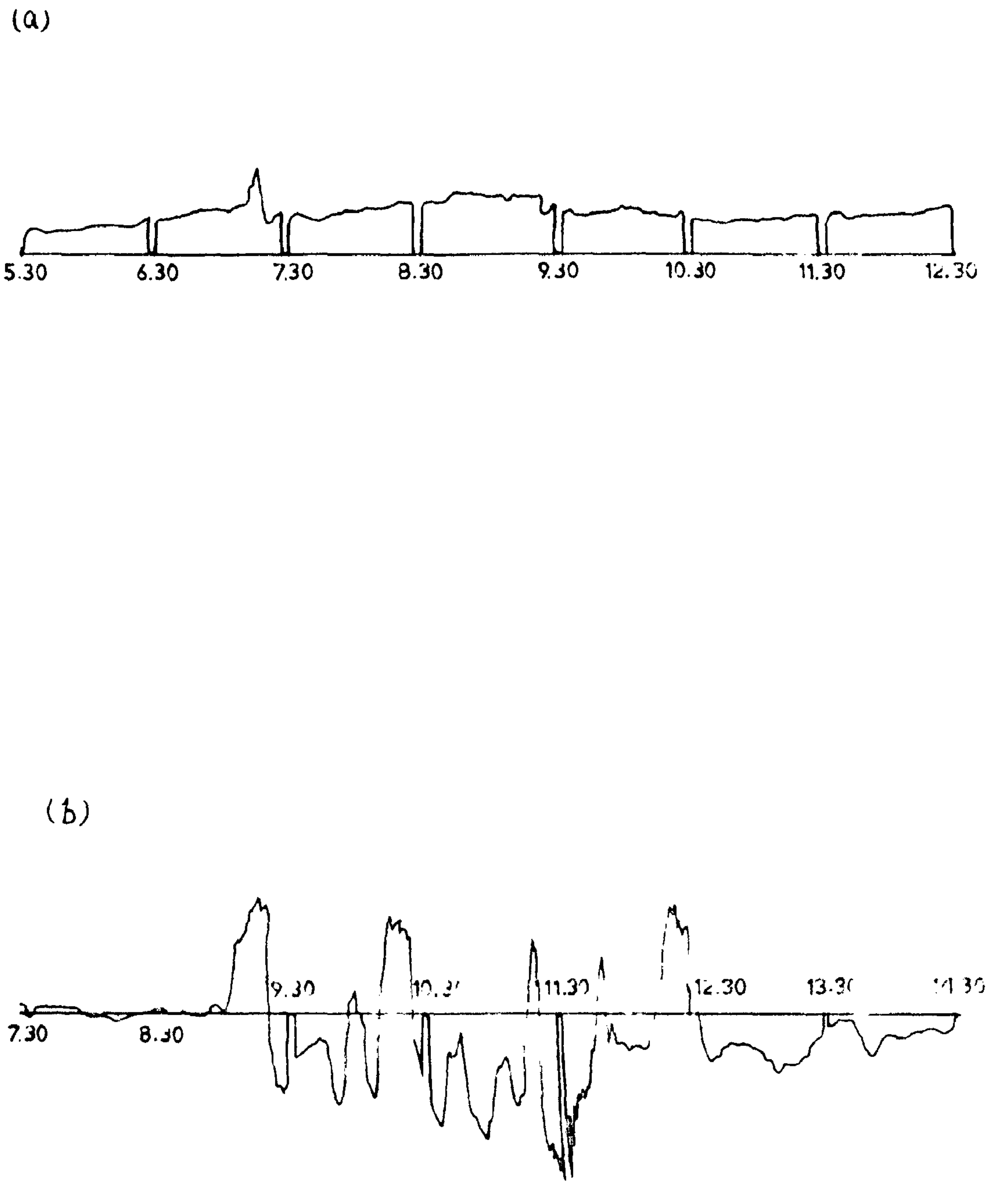

FIG.3-A FAIR WEATHER RECORD WITH OPEN AGRIMETER (a) AND A RECORD DURING CONTINUOUS RAIN WITH CLOSED AGRIMETER (b).

of vanes being exposed to the field, it was not found possible to operate the recorders with its output in low fields. The agrimeter in its final and present shape gives sufficient output to furnish necessary details with good accuracy.

1.2 INSTRUMENTS FOR POINT-DISCHARGE CURRENTS

An artificial sharp point was erected above a long pole to measure point-discharge currents through it during periods of high field. The construction of the point is shown in fig.4. A 1.8 cm long and of 0.14 cm diameter, sharpened copper point A was fixed at the end of a 36.5 cm long and of 0.36 cm diameter brass wire B. The wire B passed through an ebonite cylinder F which was encircled by a 12.5 cm long and of 4.8 cm diameter cylinder of brass. To protect this cylinder from dust and rain one more cylindrical cap E of brass (of 5.0 cm length and 4.8 cm diameter) with an ebonite overhead D was placed above it. The overhead D has an ebonite screw C to fasten the wire B. The whole assembly was fixed at the end of a 4.2 m long pole.

The signal from wire B was taken through a coaxial wire and was fed to a strip-chart pen recorder through a differential type of d.c. amplifier. The amplifier was similar to that used for the amplification of agrimeter's signal with the only difference of values of the grid leak resistances. The different ranges of

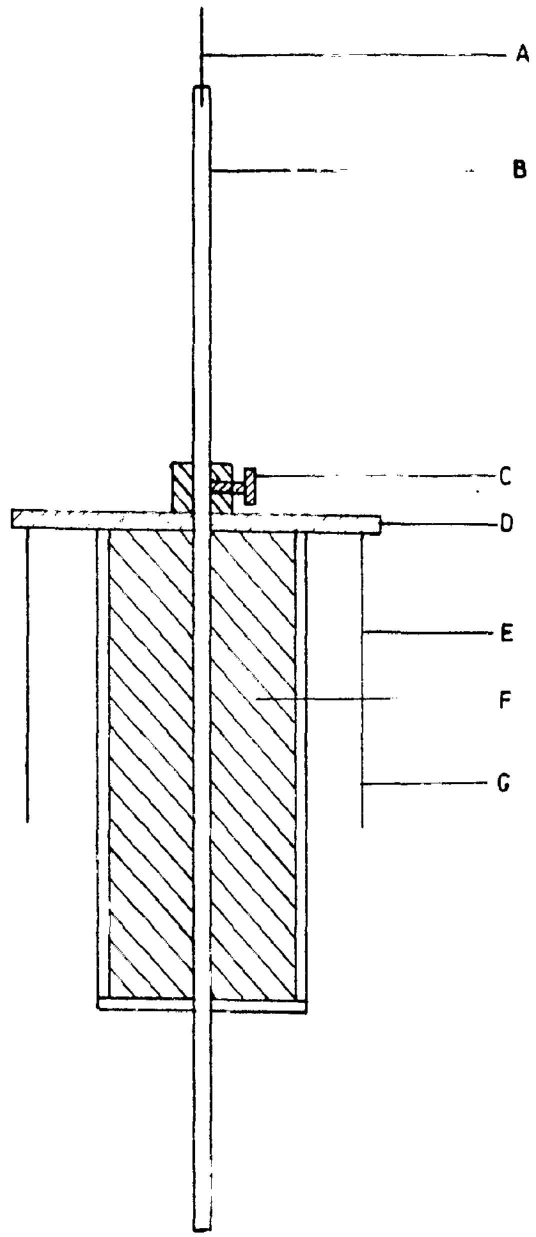

FIG. 4 - SCHEMATIC DIAGRAM OF POINT DISCHARGER.

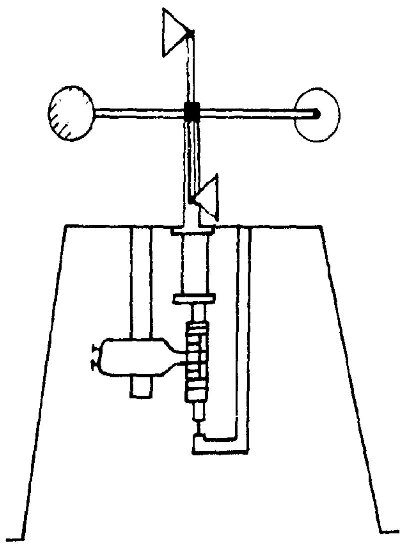

FIG. 5 _ ANEMOMETER

point-discharge current were divided on three different grid-leak resistances.

Point-discharge currents upto ± 25 μA could be measured using different sensitivities.

1.3 INSTRUMENTS FOR WIND SPEED

A four-cup anemometer was constructed to measure wind speed. The size of the cups (diameter = 20 cm) is greater than usual. A dynamo is rotated through a gear attached with the axle of the anemometer. The systematic arrangement is shown in figure 5. The dynamo is covered in an iron box.

The output from dynamo which is proportional to the wind speed, is fed through a coaxial wire to a pen-recorder and recorded.

The anemometer was calibrated with a pressure-type of anemometer situated at the top of the building of Central Building Research Institute, Roorkee. The output was found to be linear for wind speeds upto 88 km/h. Wind speeds as small as 0.5 m/s could be measured and wind speed of 9.2 m/s gave a deflection of 1 cm on the recorder.

1.4 INSTRUMENTS FOR TEMPERATURE AND RELATIVE HUMIDITY

A thermo-hygrograph has been used to record atmospheric temperature and relative humidity. Both parameters are recorded on the same chart.

1.5 INSTALLATION OF THE APPARATUS

Agrimeter, point discharger, anemometer and thermo-hygrograph were installed at the top third floor of Physics Department. Point-discharger and anemometer were nearly at the same height and were 15.8 m high from earth's surface. This was done so to have a better understanding of the correlations in potential gradient, point-discharge current and wind speed. The thermo-hygrograph was placed in an especially built ventilated wooden box.

Recording system was placed in an iron-mesh cage at the second floor of the department.

CHAPTER II

DIURNAL AND SEASONAL VARIATIONS OF ATMOSPHERIC ELECTRIC FIELD

2.1 INTRODUCTION

Considering the atmosphere as a dielectric between two plates-earth and the upper atmosphere - the whole atmosphere can be viewed as a spherical condenser. The potential gradient in the atmosphere can be regarded, for all practical purposes, as vertical and can be represented by

$$E = \frac{W}{R} V \qquad .. (2.01)$$

where W is the local specific resistance of the air, V the difference of potential between the earth and the upper atmosphere and R is columnar resistance i.e.

$$R = \int_{0}^{H} W d_h$$

where H is the height of the ionosphere from earth surface.

Eq. (2.01) is based on the assumption that all changes proceed in quasi-stationary manner i.e. so slowly that their variation may be considered as a connective series of equilibrium states. It can be calculated that changes with half-time more than half an hour can be regarded as quasi-stationary variations and thus can be studied with the help of eq. (2.01).

Potential gradient undergoes diurnal and seasonal variations. At oceans and poles where there is no pollution in the air, the potential gradient undergoes a single periodic variation with a minimum at 04.00 GMT and a maximum at 19.00 GMT. Since V and R at such stations remain constant throughout the day, the potential gradient varies parallel to the variation of V which is governed by world-wide generating effects of thunderstorm activity. So, it is natural to expect that all the variations at such places should occur simultaneously round the globe. The cruises of Carnegie and Horison have well confirmed these unitary variations.

The diurnal variation of potential gradient at land is different in behaviour to that over oceans and poles and is governed by local time and locality. It shows both-single and double periodic-variations and the times of maxima and minima are governed by local time. Generally, potential gradient undergoes a single periodic variation in winter which changes to double periodic in summer. However, some places show single periodic variation throughout the whole year and others a double periodic variation in both summer and winter.

V and R should vary at land stations under the effect of development of austausch layer. The relative variations of V and R, which depend upon the local time and local circumstances, give rise to different modes of variations of potential gradient at different places. Israël[55] has suggested the study of variation of percentage of mean values of potential gradient, instead of the variation of absolute values, to nullify the effects of variation of V.

We have studied, in this chapter, the diurnal and seasonal variations of potential gradient at Roorkee ($29^{\circ}51'$N, $77^{\circ}53'$E; 899 Ft. from M.S.L). Since the wind has been found to have very predominant effect upon the potential gradient, the days with high wind speeds have been separated from fair-weather days and the relative diurnal variations of potential gradient on fair-weather days, excluding and including days with high winds, have been examined.

3.2 METHOD OF SELECTING DATA

Hourly values of atmospheric electric field have been taken to study its diurnal variations. To do this, every one hour record has been marked at six places and thus divided into five equal parts i.e. of 12 minutes each. Average value of potential gradient's values at two places before and three places after a particular hour gives the hourly value at that hour.

All days of the year have been divided into three categories, viz. fair-weather days, fair-weather days but with high wind speeds and disturbed days. By fair weather we mean, meteorologically calm days and with wind speeds less than 4 m/sec. To these have also been added, days with some light cirrus or some fair weather small cumuli clouds at some hour of the day. Such clouds have generally been found to have no appreciable effect on potential gradient and thus can be treated as fair weather days without any error. The data of days with heavy clouds, such as cumulus, stratus strato-cumulus etc., have been analysed separately and shall not be taken in this chapter.

The number of days of the three different categories in different months of the year are given in Table I.

2.3 DIURNAL VARIATION

Fig.6 shows diurnal variation of potential gradient for fair weather days at Roorkee from May 1966 to April 1967. The following points are noteworthy:

1. Throughout the year, the potential gradient undergoes double periodic variation with first maximum between 7.00 and 9.00 and second maximum in between 20.00 and 22.00.

2. Morning maximum falls earlier in summer and occurs late by about two hours in winter.

Table I

Months 1966–67 / Category	May	June	July	August	Sept.	October	Nov.	Dec.	Jan	Feb.	March	April
Fair weather days	11	3	9	6	14	24	28	27	28	10	14	6
Fair weather days including wind-disturbed days	15	8	1	1	0	1	0	2	3	10	3	14
Disturbed days	5	19	21	24	16	6	2	2	0	8	14	10

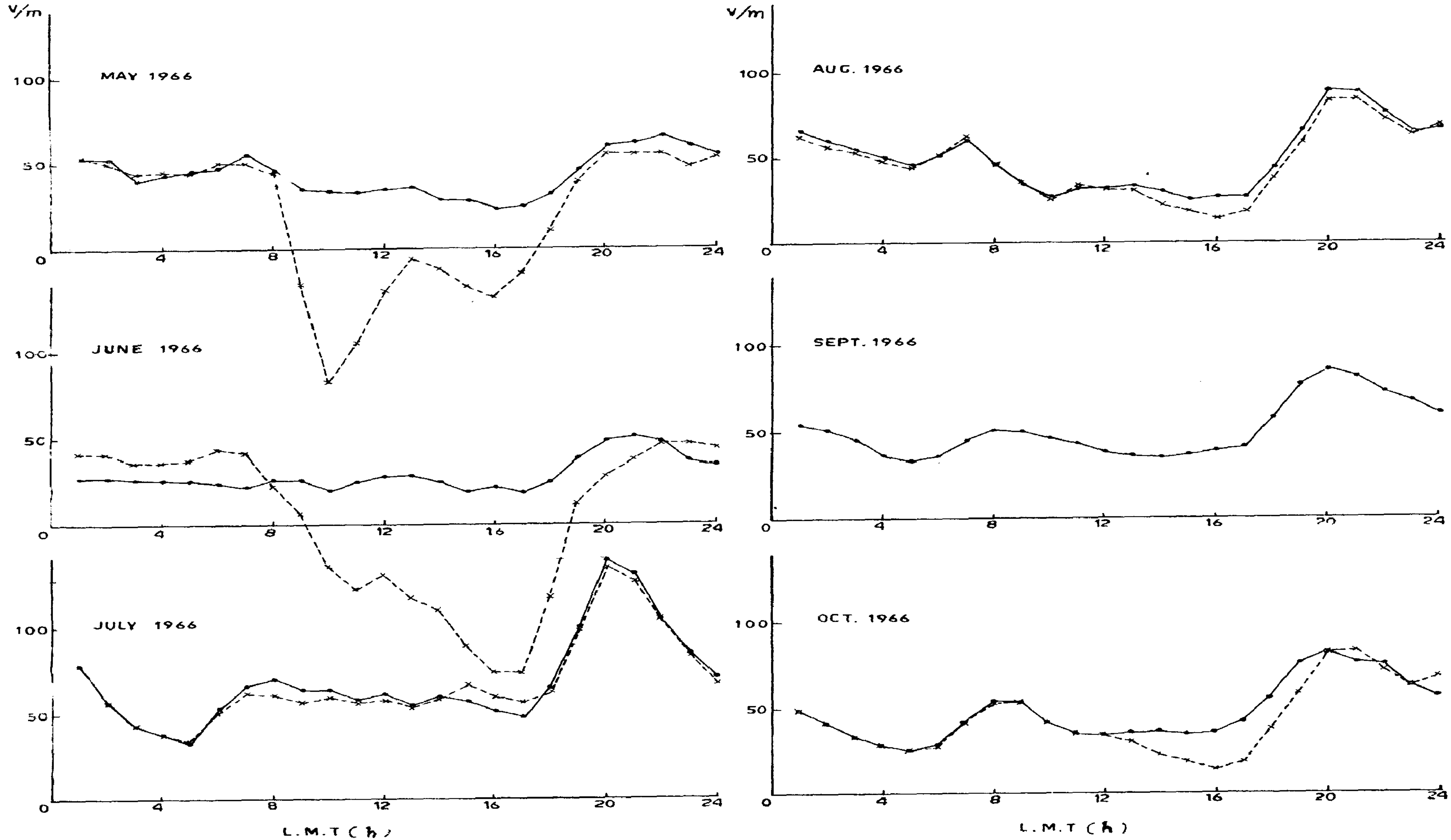

FIG. 6 - DIURNAL VARIATION OF POTENTIAL GRADIENT ON FAIR WEATHER DAYS EXCLUDING (CONTINUOUS CURVES) AND INCLUDING (DOTTED CURVES) WIND-DISTURBED DAYS (CONTINUED)

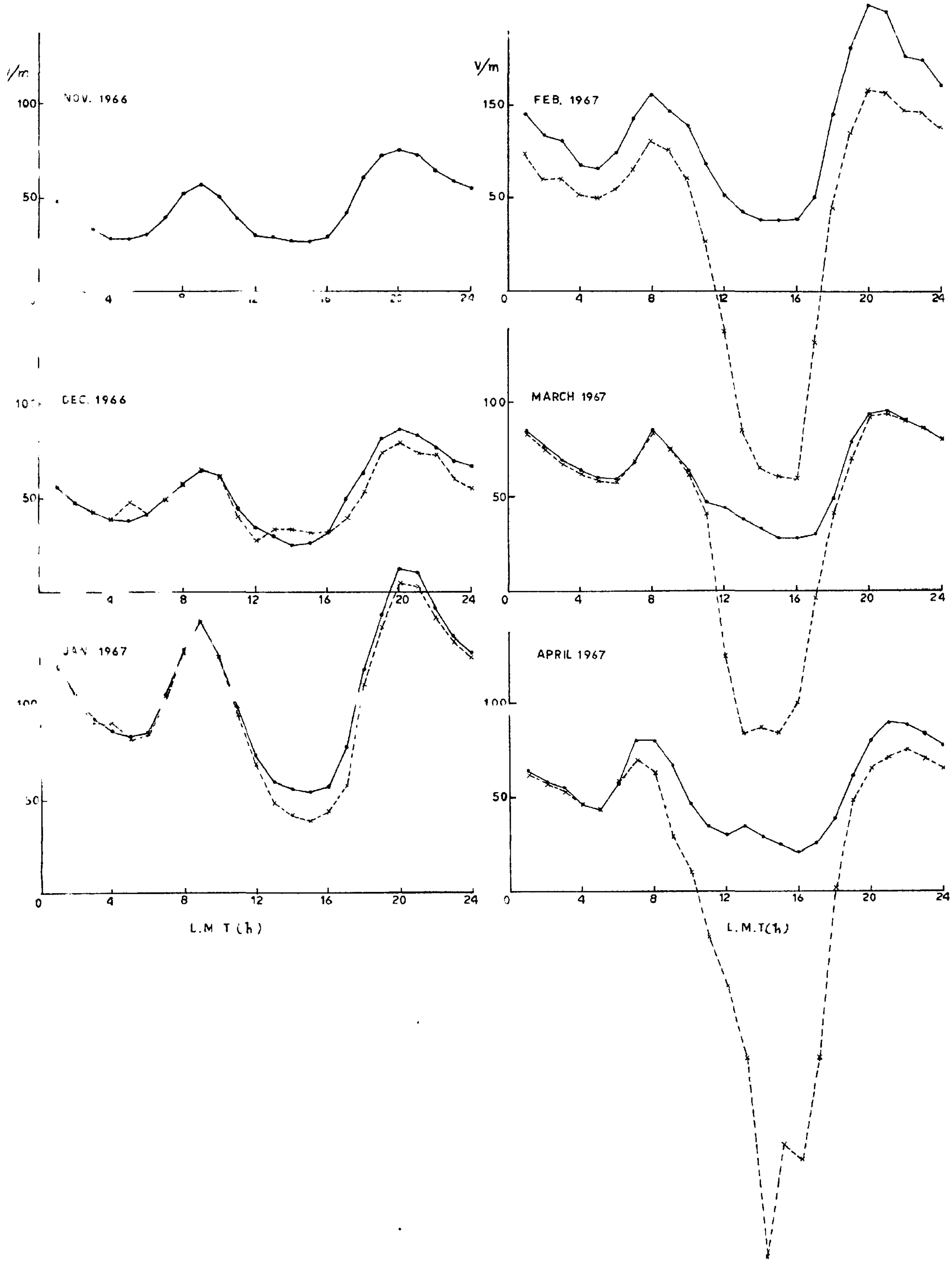

FIG.6. DIURNAL VARIATION OF POTENTIAL GRADIENT ON FAIR WEATHER DAYS EXCLUDING (CONTINUOUS CURVES) AND INCLUDING (DOTTED CURVES) WIND-DISTURBED DAYS.

3. Morning maximum is very much diffused in summer e.g. in June and July, but becomes significant and isolated in winter. The second maximum also gains amplitude from summer to winter.

4. Percentage variation about mean values is more in summer than in winter e.g. it is 77 % in January and 88 % in June.

5. It is very clear from the records that variations are more regular in winter than in summer and they tend to a more definite pattern in winter.

2.4 EFFECT OF WIND ON DIURNAL VARIATION

Dotted line in fig. 6 shows diurnal variation of potential gradient in respective months on fair weather days including days with high wind speeds. The number of such days is shown in table I. No such 'wind disturbed days', as we shall call them, were present in the months of September and November.

It is clear from the records that high wind tends to reduce the value of fair-weather potential gradient. In the night and morning the variation of potential gradient on days, with and without winds, is nearly similar and same in magnitude. But in the noon time, when high winds generally prevail, the value of potential gradient lowers down when we include wind-disturbed days. In some cases, generally in summer, the value becomes even negative and we get a depression in

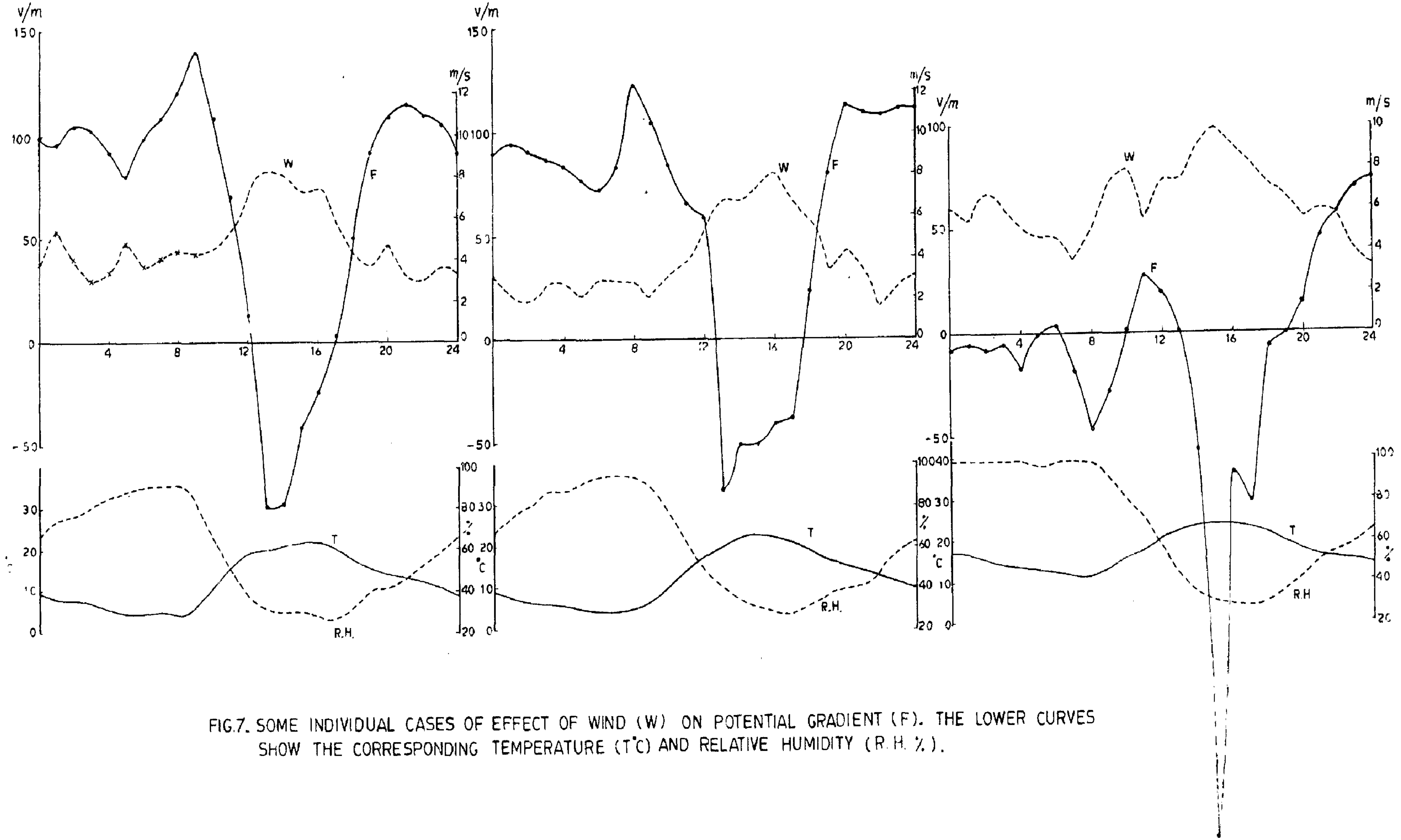

FIG.7. SOME INDIVIDUAL CASES OF EFFECT OF WIND (W) ON POTENTIAL GRADIENT (F). THE LOWER CURVES SHOW THE CORRESPONDING TEMPERATURE (T°C) AND RELATIVE HUMIDITY (R.H.%).

noon time. Such negative dips are very clearly evident from February to June in the figure. In the evening again the potential gradient attains the same value as on fair-weather days excluding wind-disturbed days.

It has been observed that wind reacts on potential gradient more predominantly at high temperatures and in dusty weather. The same wind speed which makes the potential gradient negative in noon time, does not affect to that extent at night or in the morning hours.

Some cases of individual day's recordings of potential gradient and wind speed are shown in fig.7. The lower portions show the simultaneous records of temperature and relative humidity. These days were otherwise fair except high wind speeds in different hours of the day. Whenever the wind speed exceeds about 4 m/sec, the potential gradient decreases. At high temperatures and low humidities in the noon time, the effect is very spectacular. Records of 22nd February 1967 is very much noteworthy. On this day strong winds continued throughout the day and night. Most of the time the wind speed was greater than 4 m/sec and so the potential gradient remained negative, giving negative dips for every corresponding high wind speed maximum. In the late evening at about 19.00, though wind speed was still high, due to lowering of the temperature, the potential gradient became positive. Comparison of different records shows that for potential gradient to be negative, greater wind speed is needed

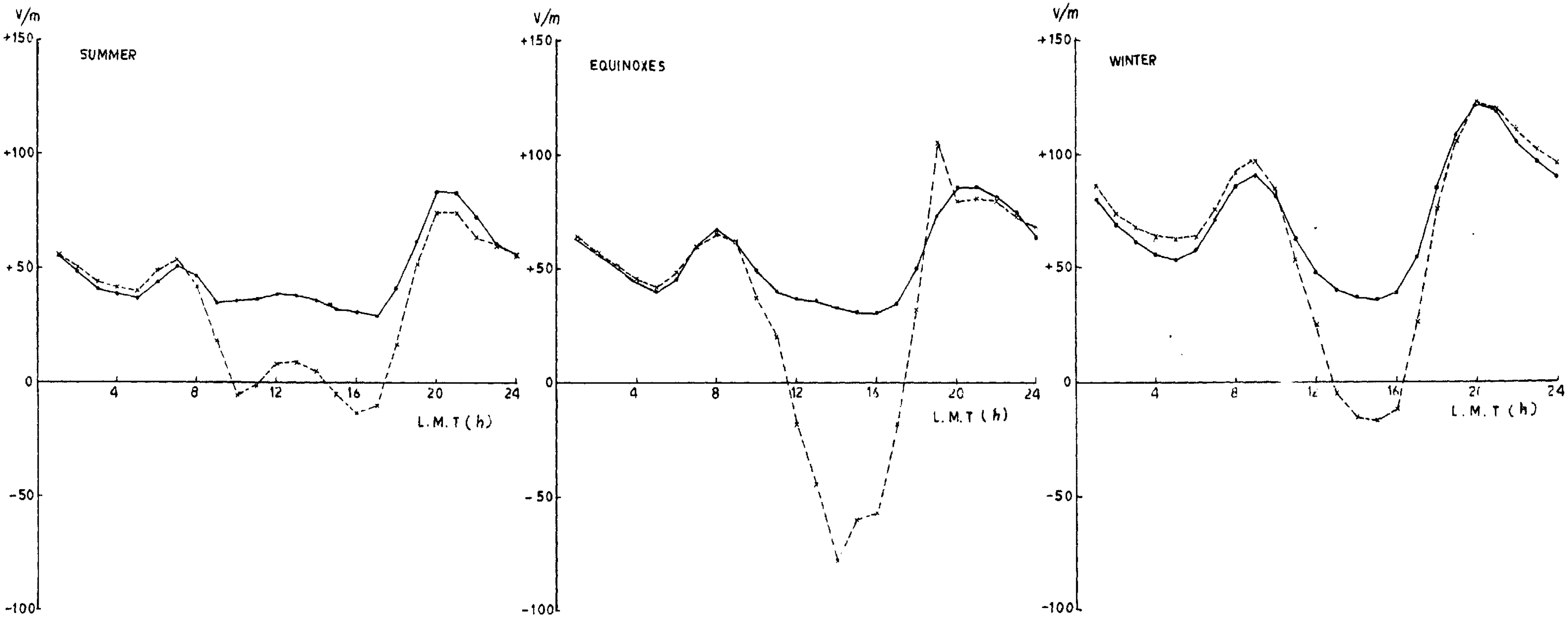

FIG.8. DIURNAL VARIATION OF POTENTIAL GRADIENT ON FAIR WEATHER DAYS EXCLUDING (CONTINUOUS CURVES) AND INCLUDING (DOTTED CURVES) WIND-DISTURBED DAYS.

during night time than during day time.

2.5 SEASONAL VARIATION

Average values of diurnal variation of potential gradient in fair weather were calculated for summer (May to August), Equinoxes (March-April and September-October) and Winter (November to February). These are shown in fig.8. Dotted lines show the corresponding variations for days including wind-disturbed ones.

The average mean value of potential gradient at Roorkee in fair weather is 48 V/m in summer which changes to 74 V/m in winter through 55 V/m in equinoxes. The total mean value is 59 V/m.

A comparison of the two curves in three different seasons gives some of the following important conclusions:

1. The variation of potential gradient in night is similar in both cases but potential gradient decreases and becomes negative in noon hours when we include wind-disturbed days.

2. The wind reacts on potential gradient earlier in summer than in winter. In summer, the value of potential gradient begins to deviate from mean fair-weather value from about 7.00 while this time shifts to 9.00 in equinoxes and to 10.00 in winter.

3. In the evening the effect of wind ends earlier

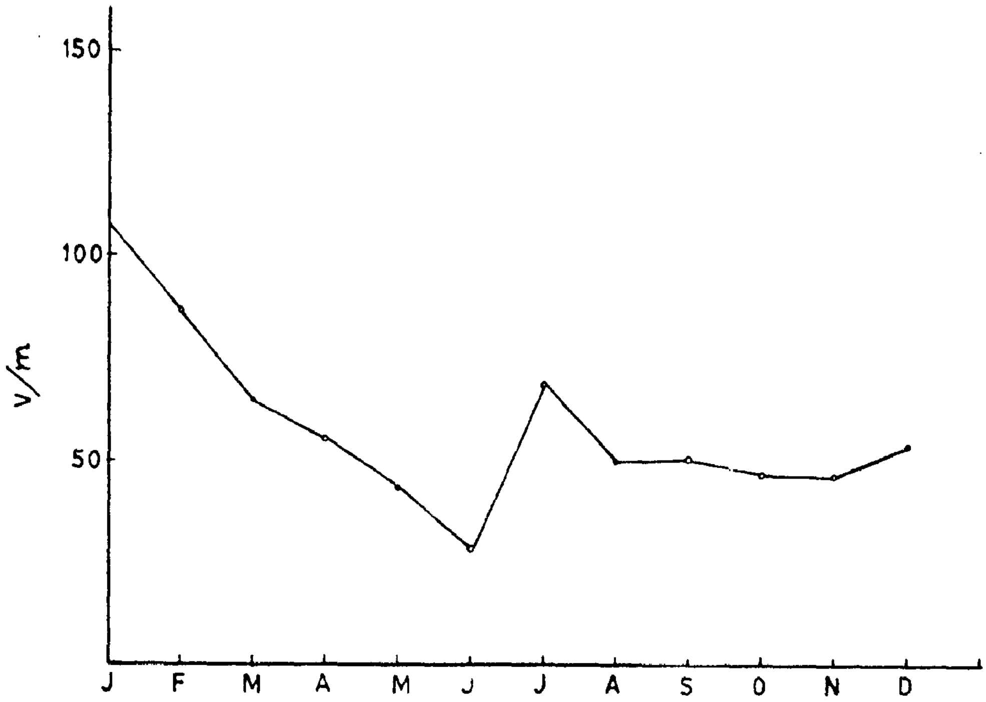

FIG. 9 - SEASONAL VARIATION OF POTENTIAL GRADIENT.

in winter than in summer. In winter the mean fair weather value is attained at about 18.00 while the effect of wind continues upto about 19.00 in summer.

So the total breadth of time in which wind reacts on potential gradient is greater in summer and less in winter.

4. Value of potential gradient at night is slightly greater for fair weather days including wind-disturbed days than those of only fair weather days. This greater value by the dotted curve is attained sooner in winter than in summer as can be seen in the figure. The nature of diurnal variation for the period of equinoxes is intermediate between the summer and winter variations and well represents the switchover from one season to other.

Annual variation of potential gradient in fair weather has been shown in fig.9. Average value for each month has been calculated. It is clear that average mean value of potential gradient in fair weather, except for the month of July, is smaller in summer and increases as we pass on towards winter. The abnormal increase of potential gradient for the month of July, however, is quite surprising.

2.6 SUNRISE EFFECT

It has been noted that conductivity of the atmosphere is maximum in the early morning and decreases soon after sunrise; correspondingly, the potential gradient increases from its early morning value and gives a maximum at about 9.00 as is clear from our observations also. Mühleisen[24] has recorded potential gradient along with other meteorological parameters at different places with varying degrees of pollution and gives 'evaporation' due to rise in temperature, as a possible cause of this morning maximum or 'sunrise effect', as it is generally known. With the help of experiments at field and in laboratory, Mühleisen has shown that the effect becomes stronger when relative humidity is changing fast and the content of condensation nuclei is high. However, his explanation of evaporation as a possible generator of negative charge is only hypothetical and cannot have a strong footing unless the exact nature and mobility of negative charge carriers is known.

Ogawa[86] gives a very interesting result about this morning maximum of potential gradient in his observations at Kyoto. He reports that the decrease in conductivity and thus increase in potential gradient starts even before sunrise. He argues that the increase in condensation nuclei due to human activity in the early morning, and not the sunrise, is the cause of this morning maximum of potential gradient Ogawa further points out that free convection by itself cannot increase the potential gradient.

We have studied the occurrence of this morning maximum of potential gradient from our records of one year.

According to our observations, the statement of Ogawa needs some flexibility. It should be emphasised here that increase of temperature and not the sunrise as an inter-terrestrial phenomenon, is the cause of free convection which may affect the conductivity or potential gradient. So, the time of increase of potential gradient should coincide with the time of increase of temperature and not with the time of sunrise. Actually, the atmospheric temperature begins to increase somewhat earlier than the sunrise and that perhaps, has been ignored by Ogawa.

We have plotted the time of beginning of morning maximum of potential gradient by points and the time of reaching its maximum value by crosses in fig.10. The time of sunrise shown by continuous line, lies in between the two and does not seem to have any effect, as pointed out by Ogawa. Fig.11 shows the times of beginning of increase of potential gradient by points and times of beginning of increase of temperature by crosses for four months only. It is clear from the figure that the two times are rather mixed with each other, so that free convection which is associated with rise in temperature, may be a possible cause of morning maximum of potential gradient.

It has been found that a continuous sheet of cloud in the morning hours, without any precipitation, suppresses the occurrence of morning maximum of potential gradient. If human activity would have been the cause of morning

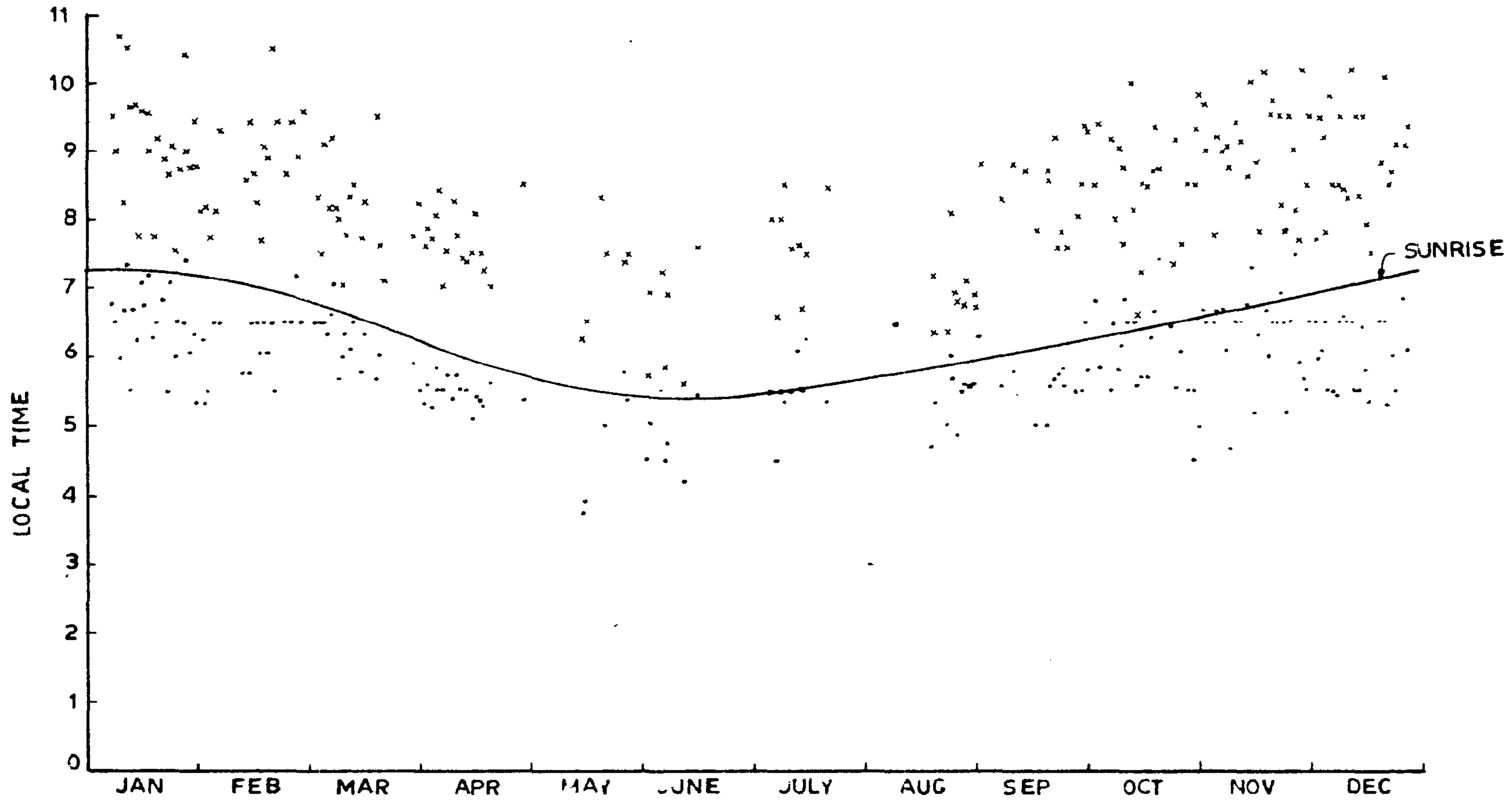

FIG.10. RELATION BETWEEN SUNRISE AND POTENTIAL GRADIENT. DOTS SHOW THE TIMES OF BEGINNING OF INCREASE OF POTENTIAL GRADIENT AND CROSSES THE TIMES OF REACHING THE MAXIMUM VALUE.

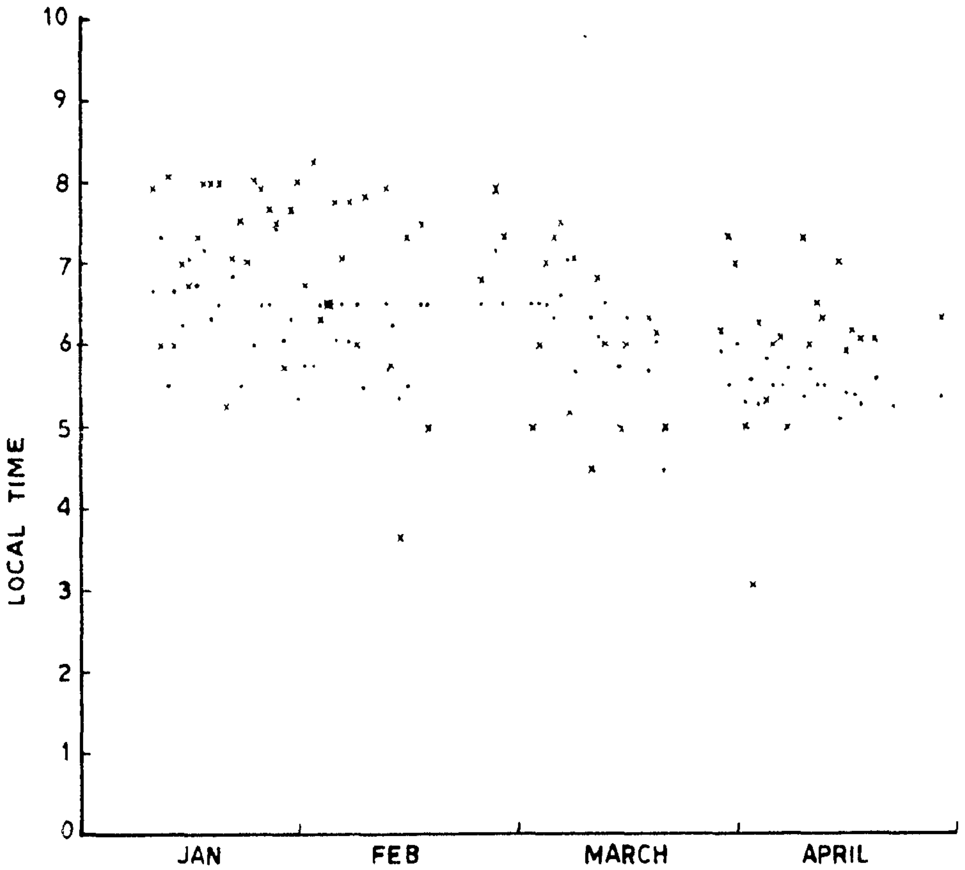

FIG.11.RELATION OF POTENTIAL GRADIENT AND INCREASE OF TEMPERATURE DOTS SHOW THE TIMES OF BEGINNING OF INCREASE OF POTENTIAL GRADIENT AND CROSSES THE TIMES OF BEGINNING OF INCREASE OF TEMPERATURE.

maximum, there should have been no such suppression due to the sheet of cloud.

Again, the occurrence of morning maximum has been found to be very sensitive to the wind speed. The maximum value reached and the rate of coming down of potential gradient depends very much on the time of start of wind and wind speed. As shown in fig.7(c) where wind continues throughout the whole day and night, the morning maximum is missing.

2.7 DISCUSSION

Potential gradient at this station undergoes a double periodic variation throughout the year, which is a characteristic of land stations. As we know, the conductivity of the atmosphere is influenced by the number of nuclei present and production of nuclei is maximum in the early morning and their dissipation is maximum in the afternoon. Brown[57,58] has tried to separate the local component of the potential gradient from its world-wide variation and attempted to explain it in terms of some local phenomena. According to him, the double periodic variation can be explained with a 24-hour wave of local effect with a maximum in the afternoon together with a superimposed 'depression' in the afternoon. The 24-hour oscillation has been attributed to the production of nuclei and the depression to the dissipation of nuclei which result due to 'austasch' effect.

Israël[58] has given a similar explanation. He attributes the 24-hour oscillation as variation of R-the columnar resistance-, and the depression to the change in local conductivity at the place of measurement. While the latter depends on the local content of nuclei, the former is independent of the distribution of the nuclei and depends upon the total number of nuclei present in a column of unit horizontal cross-section.

To understand the nature of atmospheric electricity, Mühleisen[24] argues the consideration of three generators- (i) Thunderstorm generator, which causes unitary variation, (ii) Evaporation generator, which is governed by local conditions and is the cause of local component, and (iii) Man-made space charges at urban places which are the causes of electrical unrest in potential gradient and other electrical elements. Further, Mühleisen[21] has carried out experiments at different places in industrial towns and argues that change in conductivity only cannot account for all the potential gradient variations and the presence of space charges in the atmosphere would have to be taken into consideration.

Transportation of nuclei and ions in the atmosphere should largely be influenced by wind. As we have seen, high wind speeds produce negative potential gradients and oftentimes these negative values are sufficient enough to give point-discharge currents. It will be interesting to know, what are the charge carriers and how the charge is produced in high wind speeds?

Freier[59] and Crozier[60] have noted potential gradients when a dust-devil passed near their station and both of them report a negative dip in potential gradient. This, they explained by assuming the dust-devil as an electrical dipole with negative charge upwards and positive downwards.

The occurrence of negative potential gradients during high winds, which raise dust from the earth surface, may be explained by assuming the dust particles to be negatively charged. It seems probable that when wind strips off dust particles which may be quite large in size, from earth surface, or in successive jumps from the earth surface, they carry with them a negative charge proportional to their capacity. These negatively charged dust particles go up under 'austausch' effect and superimpose a negative potential gradient over those normal fair weather positive potential gradients. The magnitude of negative potential gradient shall clearly depend upon the number of dust particles raised and thus on the aerosol condition and atmospheric temperature of that place. That may be the reason why greater wind speeds are needed in night time than in day time, to get negative potential gradients.

The building-up of negative potential gradients, however, cannot go on uncontrolled. The process seems to be self-quenched. As the negative potential gradients grow, a corresponding charge is induced on the earth surface and thereafter the dust particles carry with them positive instead of negative charge. This may be the reason, as pointed out by Crozier[60], why his and Freier's field patterns were of the shape as being originated from the passage of an electrical dipole. However, this quenching-effect may be challenged as it cannot permit negative potential gradients greater than normal positive potential gradients at that time of the day. We, in our observations, do find very large negative values, sometimes large enough to produce point discharge.

Another source of positive ions, when negative potential gradient due to high wind speeds increases very much, is the point discharge. Experience has shown that this source of positive ions may provide large concentration of ions to give electrical moment to dust storm.

We can now say that while high wind speeds produce negative potential gradients, high temperature acts as a catalysis in this wind-effect. Though no quantitative constant can be given at this stage, yet it seems from our observations that some product of wind speed and atmospheric temperature is necessary to deviate potential gradient from its fair weather value. In summer this constant is attained earlier due to high temperatures and wind speeds and is maintained longer. That is why potential gradient for wind-disturbed days deviates from fair weather value earlier and continues upto late hours in summer than in winter.

As the temperature falls in the evening, the dust begins to settle down and the negative potential gradient attains the positive fair-weather value. The time of attaining the positive fair-weather value reaches sooner in winter than in summer, since the amount of dust raised in the noon and the atmospheric temperature is relatively higher in summer than in winter. It seems that nuclei which attain very high levels and do not settle down upto late night, increase condensation and thus increase the conductivity of the atmosphere. This results in an increase of air-earth conduction current and potential gradients. So that the cause of occurrence of negative potential gradients on wind-disturbed days becomes the cause of increased potential gradients on these days in the late night. The effect can clearly be observed in fig.8 where the dotted curve, both in winter and summer, remains a bit higher than the continuous curve.

CHAPTER III

ELECTRICAL AGITATION IN ATMOSPHERIC ELECTRIC POTENTIAL GRADIENT

3.1 INTRODUCTION

We have discussed in the previous chapter some of time-variations of potential gradient whose periodicity is larger than the relaxation time of the atmosphere. Such periodic variations may be studied considering a quasi-stationary electrical state in the atmosphere and therefore we can determine the quantitative picture of mechanics of the electrical processes behind them, with the help of electrostatic laws. Hourly values of the electrical elements are used to study such 'long' time variations. This is done so as to smooth out the 'short' time changes of the electrical element. The period of these 'short' time variations is smaller than or of the order of the relaxation time and generally ranges from a few minutes to one hour. These short-time variations or electrical agitation or electrical unrest, as they are known, exhibit themselves in all the geophysical, meteorological and atmospheric electrical elements. It shall be interesting to study the nature and origin of the electrical agitation in atmospheric electric potential gradient, which forms the subject of the study of present chapter.

Similar to Israël[61] , we shall consider two magnitudes amplitude and frequency - of electrical agitation. Amplitude of electrical agitation gives the total width of variation of potential gradient in one hour and its frequency represents the number of reversal points during one hour i.e. the number of secondary maxima and minima in one hour.

3.2 PREVIOUS RESULTS

Little attention has been given in the past, to the study of electrical agitation; the greater interest being given either to the diurnal and secular variations or very rapid variations due to lightning discharges. Electrical agitation has, generally, been considered as undesirable fluctuations of the electrical element, in the study of long-time variations and thus evaluated by taking hourly means.

Israël[61] has studied electrical agitation in potential gradient and air-earth current during 'Alps project'. The potential gradient and air-earth current, along with some meteorological elements such as temperature, pressure, wind speed etc. have been measured, under this project, at three different stations and they have been found to show electrical agitation in both fair and disturbed weathers; being more in disturbed than in fair weather. The electrical agitation has been found to be more in day time than in night time and has also been found to undergo a seasonal variation. Electrical conductivity, temperature, brightness and vapour pressure have been found to exercise their effects on the electrical agitation. Moreover, the value of parameter itself also shows its influence over its electrical agitation.

Ogawa[56] has studied short-time variations in the form of 'fluctuations' i.e. the differences between the hourly values and the overlaping means of five hours period, at any time. He has shown the variation of agitation in potential gradient, air-earth current and conductivity, with the element-value but has not found any definite diurnal variation of the agitation. The results of Ogawa are, however, confined to the observations of 24 fair weather days only.

Measurements of potential gradient with two field mills at a distance apart in a line along the direction of wind, have been done by Whitlock and Chalmers[22]. The observations, which have been taken both in fair and disturbed weather, show 'cusp' like variations in fair weather and V-, and U-type of patterns in showers. Effect of brightness in fair weather and in overcast and the effect of space charges on the potential gradient have very well been studied by this method.

In order to understand the meteorological - atmospheric electrical correlations and the fundamental processes behind the origin of these short-time variations in potential gradient, we have analysed our data of one year and separated the amplitude and frequency of electrical agitation directly from records. As for the study of the diurnal variations of potential gradient, we have divided the total material in three categories i.e. (i) fair weather days, (ii) fair weather days including wind-disturbed days and, (iii) the total days excluding the periods of actual precipitation.

From now onwards, we shall represent electrical agitation amplitude and frequency by U_A and U_F respectively.

3.3 DIURNAL VARIATION OF ELECTRICAL AGITATION

Fig.12 shows the diurnal variation of agitation amplitude of potential gradient for different months. Continuous lines show the variation on fair weather days and dotted lines on fair weather days including wind-disturbed days. The values have been represented as the percentage values of the mean value of the respective months.

It is clear from the figure that, similar to potential gradient, U_A also shows double periodic diurnal variation. The positions of maxima are nearly in the same position as in that of potential gradient. The double periodic nature is somewhat diffused for the months of April and May and to some extent in the summer as a whole but in winter the variation becomes more steady and regular. Actually, U_A looks to have an increasing tendency in noon in summer, instead of giving a dip as in winter. Effect of wind on U_A can be seen from the dotted curves. One very surprising result is

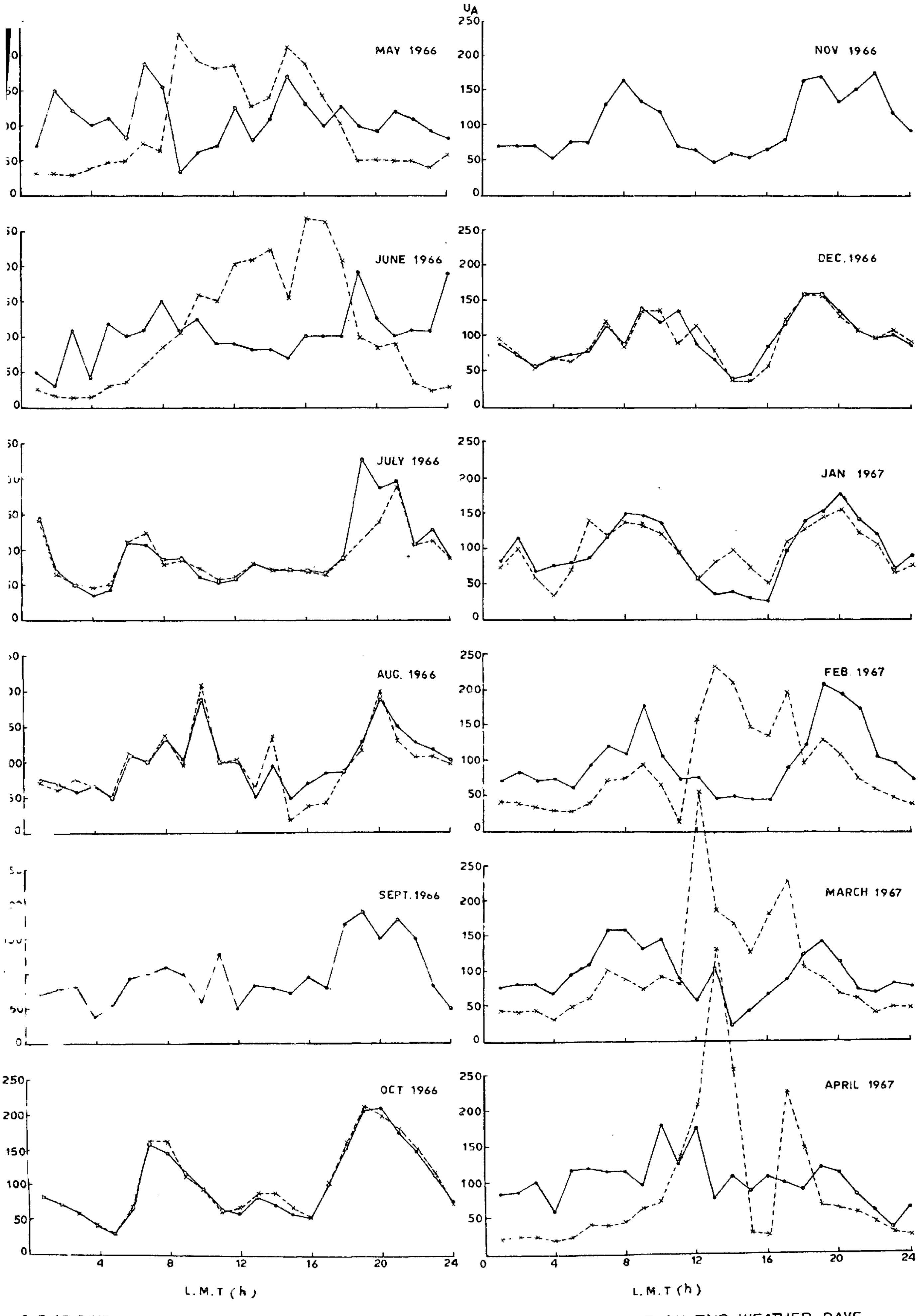

FIG. 12. DIURNAL VARIATION OF AGITATION AMPLITUDE OF POTENTIAL GRADIENT ON FAIR WEATHER DAYS EXCLUDING (CONTINUOUS CURVES) AND INCLUDING (DOTTED CURVES) WIND-DISTURBED DAYS.

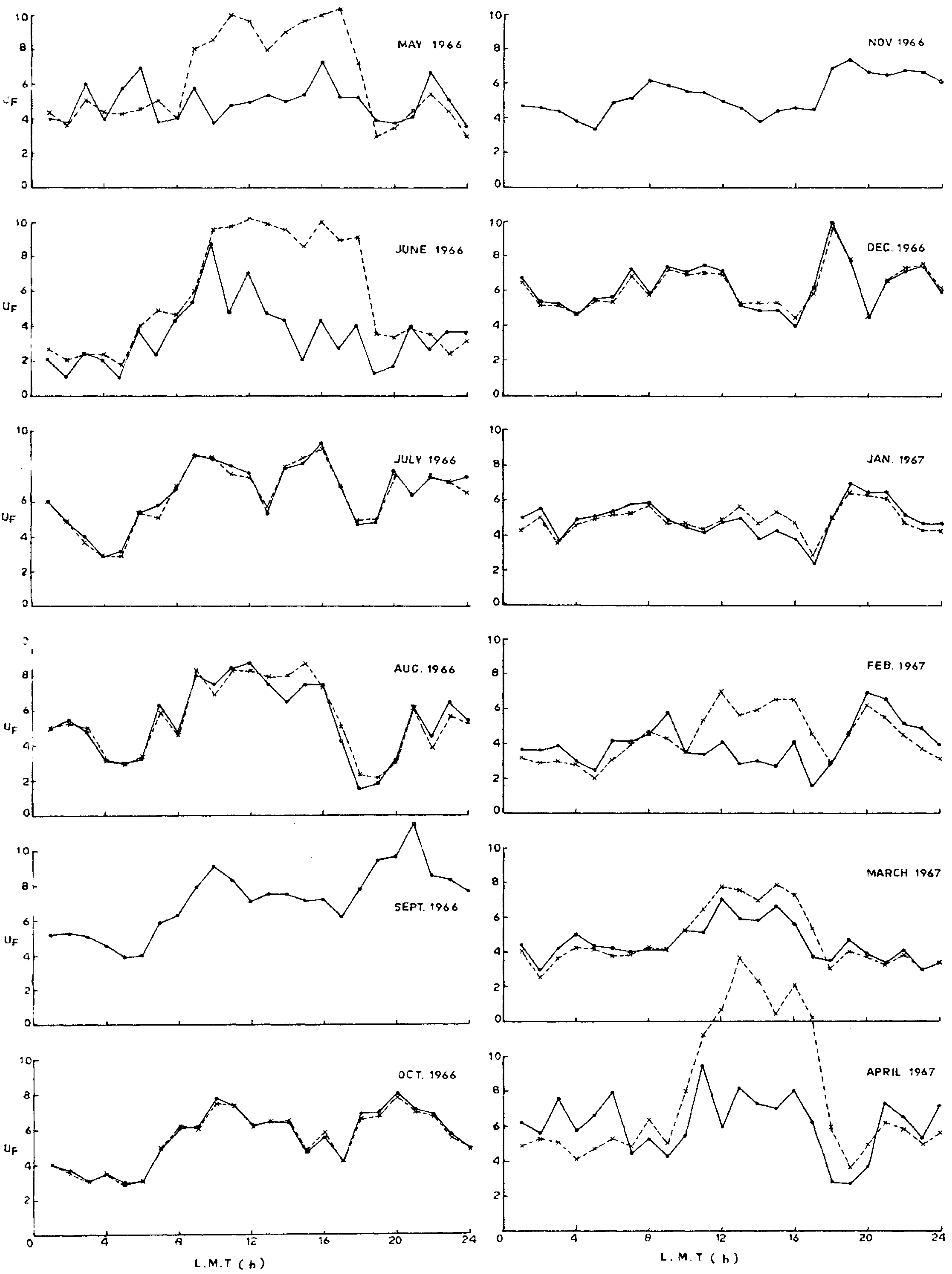

FIG.13. DIURNAL VARIATION OF AGITATION FREQUENCY OF POTENTIAL GRADIENT ON FAIR WEATHER DAYS EXCLUDING (CONTINUOUS CURVES) AND INCLUDING (DOTTED CURVES) WIND-DISTURBED DAYS.

that when we include wind-disturbed days, U_A goes on increasing in noon, from its morning maximum value, instead of decreasing in noon as on fair weather days. Moreover, the morning and afternoon maxima are suppressed. In summer, double periodic variation changes to single periodic with a single maximum in the noon when we include wind-disturbed days. In winter, however, the double periodicity of the variation is still maintained with some change in its magnitude.

Fig.13 shows the diurnal variation of agitation frequency. The continuous and dotted lines mean the same as in fig.12. The variation is not very systematic and regular as that of agitation amplitude. However, the winter pattern is more steady and regular than that of summer. A very remarkable difference in the diurnal variation of agitation frequency can be noted from that of agitation amplitude: Variation of U_P on fair weather days tends to be single periodic in summer and double periodic in winter. In summer the maximum lies in the noon and in winter maxima lie in the forenoon and afternoon. (For the sake of interest, this tendency of change of periodicity with season is the reverse to that of diurnal variation of potential gradient at some land stations). When wind-disturbed days are included, the single periodic nature of U_P in summer becomes very prominent and the absolute values of U_P also increase in day time. Thus the nature of diurnal variations of amplitude and frequency of electrical agitation react somewhat differently with the change of season. This point shall be further explained in the next article.

3.4 SEASONAL VARIATION OF ELECTRICAL AGITATION

To further establish the nature of change of diurnal variation with season, average values of diurnal variations were calculated for summer, equinoxes and winter separately for fair weather days both including and excluding wind-disturbed days. Fig.14 shows the diurnal variations of U_A and U_D in different seasons. Values are represented as the percentage values of the average mean values of the respective seasons. Some of following points are noteworthy:

1. Percentage variation from the mean value on fair weather days is more for U_A than for U_D. For U_A the percentage variation is more in winter and less in summer while for U_D reverse is the case i.e. more in summer and less in winter.

2. Agitation amplitude shows double periodic variation throughout the whole year but agitation frequency is double periodic in winter and tends to be single periodic in summer. The double periodic variations, both in amplitude and frequency, have their maxima in forenoon and afternoon while single periodic variations have their maxima in noon.

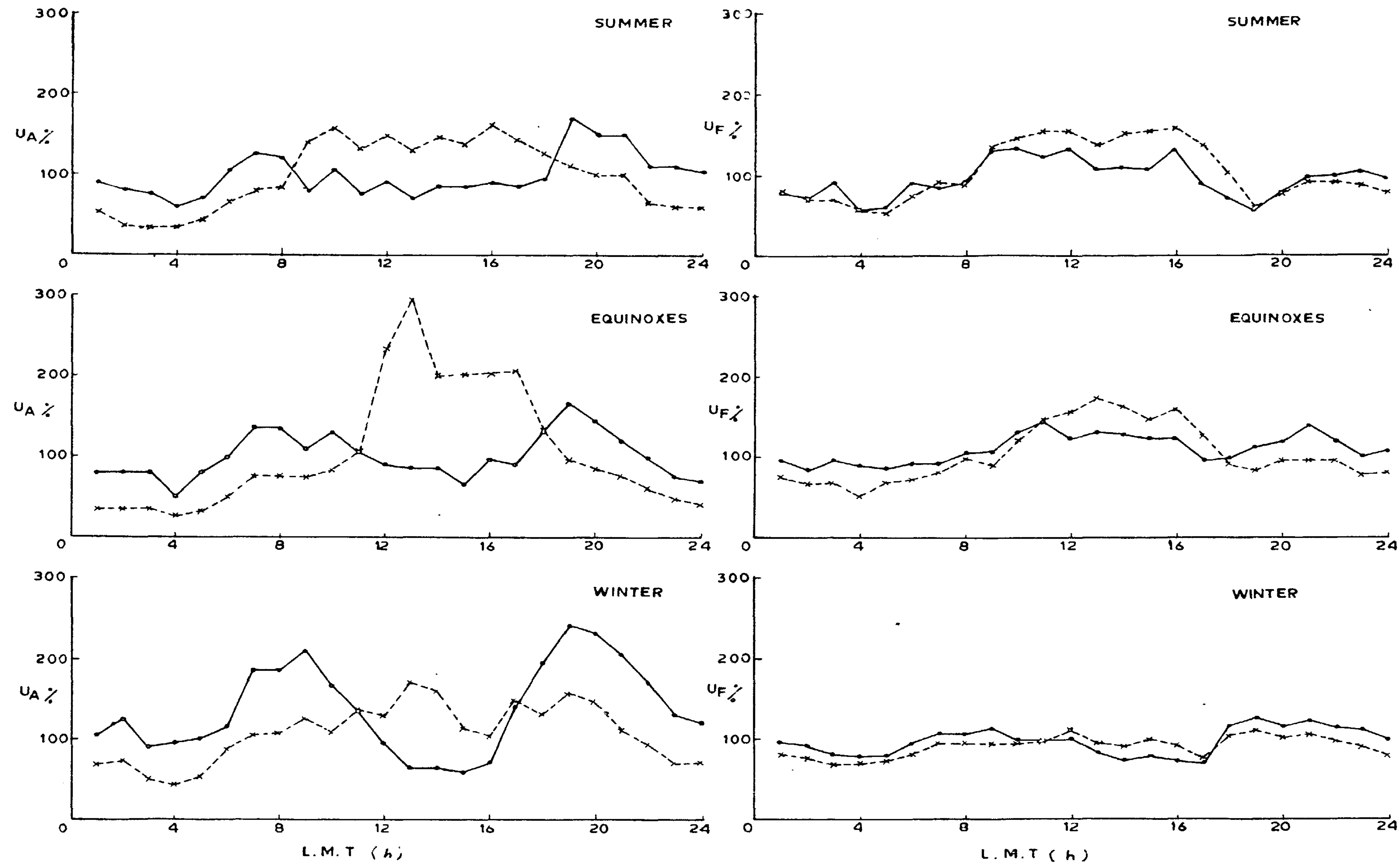

FIG. 14 - DIURNAL VARIATION OF AGITATION AMPLITUDE (U_A) AND FREQUENCY (U_F) ON FAIR WEATHER DAYS EXCLUDING (CONTINUOUS CURVES) AND INCLUDING (DOTTED CURVES) WIND-DISTURBED DAYS. THE VALUES ARE SHOWN AS PERCENTAGE VALUES OF MEAN OF SUCH TOTAL DAYS.

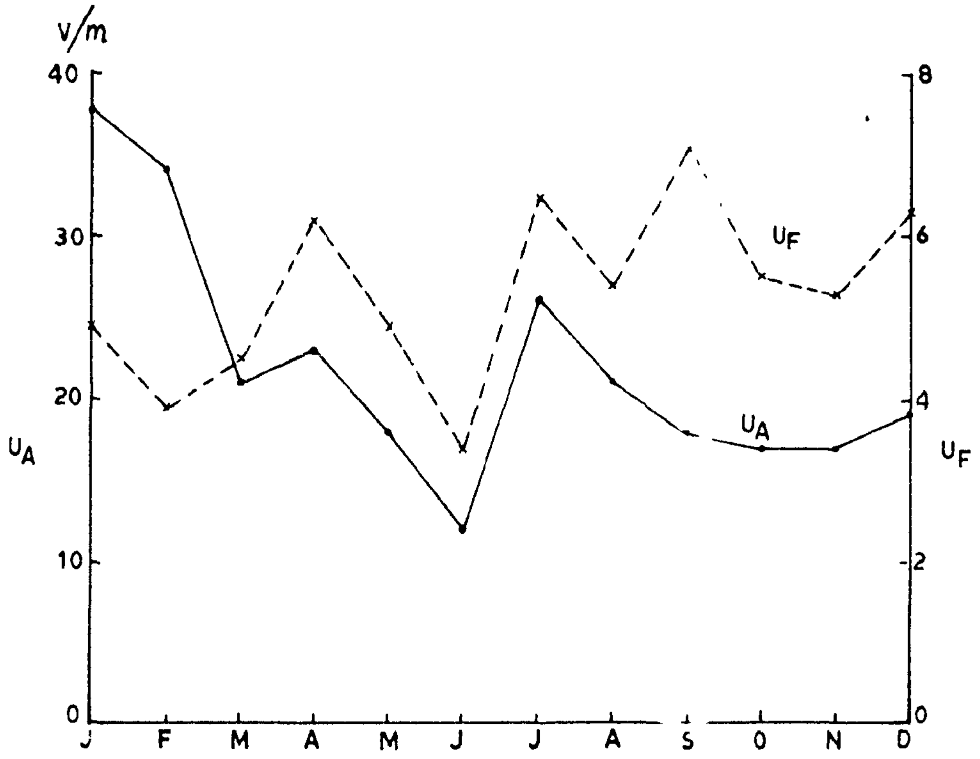

FIG.15.SEASONAL VARIATION OF ELECTRIC AGITATION OF POTENTIAL GRADIENT.

3. When wind-disturbed days are included the values of U_A and U_P are modified in such a way that they become lesser in night and more in day than those of fair weather days only. The increase in noon time is more in summer and less in winter.

4. The time, when the agitation on fair weather days including wind-disturbed days, exceeds that of fair weather days only, is earlier in the morning and late in the evening, for summer than for winter. The difference is about two hours in both sides. Thus, the total duration, during which wind-disturbed curve remains higher than fair weather curve, is more in summer than in winter.

5. The inclusion of wind-disturbed days to fair weather days causes the diurnal variation of U_A and U_P, to be single periodic in all seasons, with their maximum values in noon.

6. The inclusion of wind-disturbed days to fair weather days, affects agitation's frequency lesser than its amplitude.

7. The transition period of equinoxes shows intermediatory character for all the above characteristics.

We have calculated also the average values of U_A and U_P for different months and fig.15 shows their annual variation. The continuous line shows amplitude variation and dotted line the frequency variation. It is clear that both run nearly parallel to each other.

3.8 EFFECT OF POTENTIAL GRADIENT ON ITS ELECTRICAL AGITATION

The parallel nature of diurnal and seasonal variations of potential gradient for fair weather days and U_A, initiates one to think of some dependence of U_A on potential gradient. We have tried to see the nature and magnitude of this dependence. Unlike Israël[61] and Ogawa[86] who have taken average values of potential gradient and U_A for some individual fair weather days, we have selected our material from the hourly average values of different months, from which diurnal variation curves for fair weather have been drawn. Corresponding values of U_A for nearly equal hourly average values of potential gradients (within ± 5 V/m) have been selected and their average has been taken.

Fig.16 shows the variation of U_A with potential gradient. It is clear that U_A increases with potential gradient, first slowly and then rapidly. It is significantly different from that of Israël[61] and Ogawa[86], both of whom found the variation to be linear; the discrepancy being more at lower values of potential gradient. Moreover, our results show much less scattering than those of previous two workers.

Variation of U_B with potential gradient has also been studied in the same way as that of U_A but no definite inter-dependence has been observed.

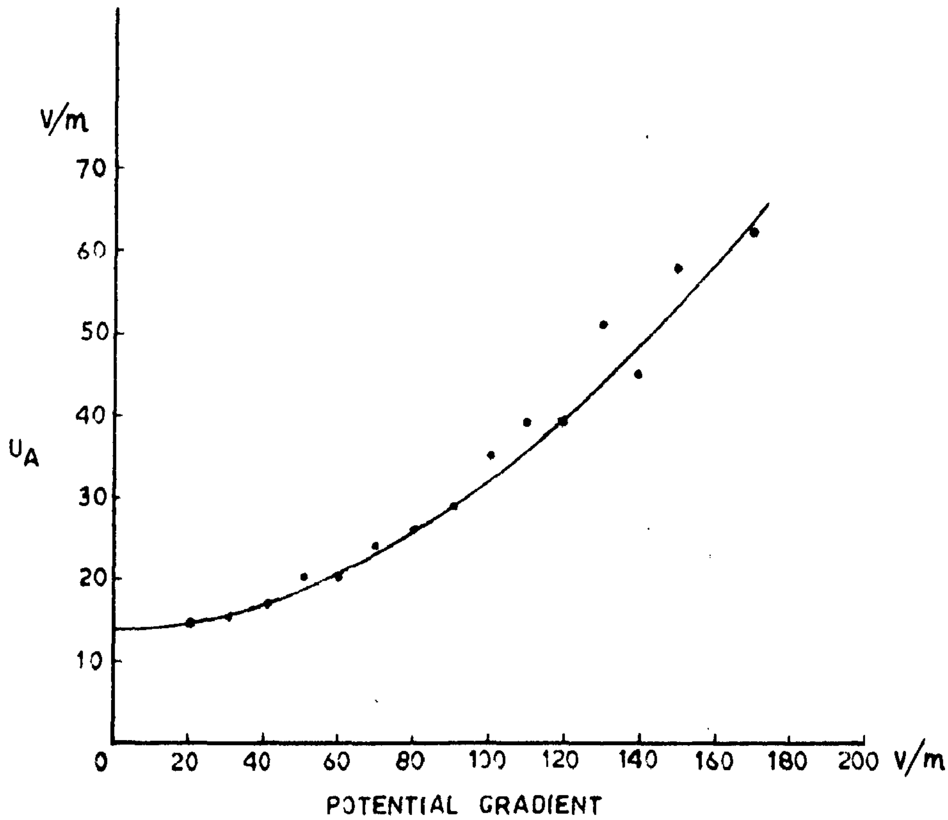

FIG.16_VARIATION OF AGITATION AMPLITUDE OF POTENTIAL GRADIENT WITH THE ELEMENT VALUE.

3.6 ELECTRICAL AGITATION IN DISTURBED WEATHER

As mentioned earlier, we have divided the total material in three different categories and calculated electrical agitation of potential gradient for each of them separately. The absolute values of amplitude and frequency of the agitation are shown in the table II.

Table II

Seasons	Fair weather days		Fair weather days including wind-disturbed days		Total material	
	U_A	U_F	U_A	U_F	U_A	U_F
Summer	19	5.1	34	6.0	41	5.8
Equinoxes	20	5.8	34	5.9	34	6.1
Winter	22	6.1	33	5.2	29	5.3
Total average	20	5.3	35	5.7	35	6.0

U_A is 34 % of the average value on fair weather days, and it increases to 73 % when we include wind-disturbed days. The values of U_A and U_F are nearly equal for total material (excluding periods of actual precipitation) and for fair weather days including wind-disturbed days. This is an important conclusion and shall be further discussed in the next article. The value of U_F in fair weather is 5.3, that means that potential gradient changes its direction in fair weather, after about

11.3 minutes. This period is , however, reduced in disturbed weather.

Another important conclusion from the table I can be drawn i.e. the value of U_A increases from summer to winter in fair weather while reverse is the case for the total material.

3.7 SOME PECULIAR SHORT-PERIOD VARIATIONS IN DISTURBED WEATHER

The existance of high electric fields in clouds of both types - warm and cold - is undoubted and the distribution of charge in them have well been confirmed as an electric dipole of positive polarity with a positive charge pocket in the bottom. This electrical dipole exercises its effect on the field patterns, measured below such clouds, proportional to its dipole moment. Whitlock and Chalmers[28] have studied some of these field patterns and have attempted to get some information as to the sizes and heights of space charge pockets, causing these variations. In our visual observations we found some patterns of interest under varying atmospheric conditions which might help in the interpretation of short-time variations of the potential gradient. We present some of them, shortly, as below:

1. Overcast Sky:

Fig.17(a) shows a record of potential gradient

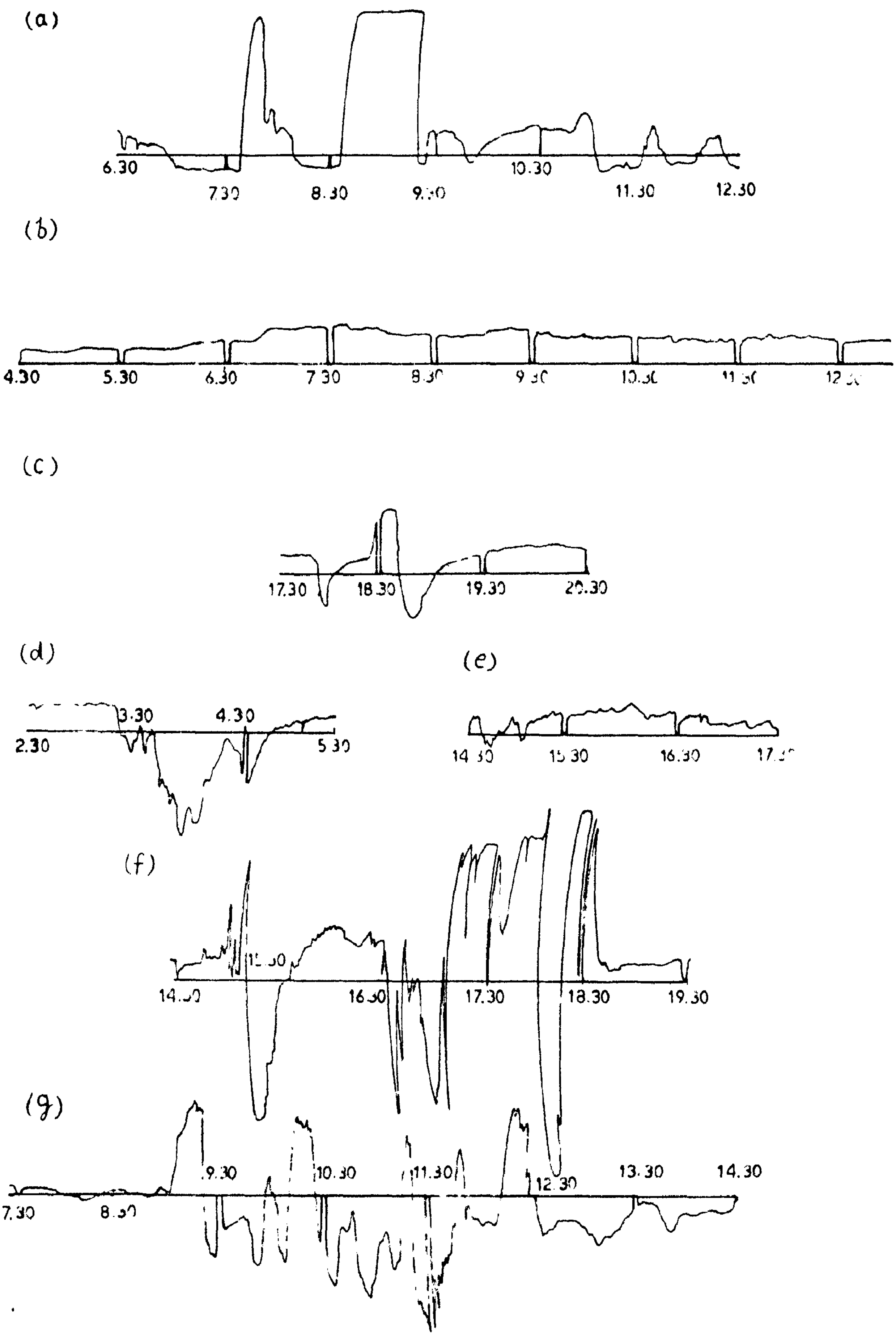

FIG.17 SOME PECULIAR FIELD PATTERNS IN DIFFERENT WEATHER CONDITIONS.

when sky was overcast by stratus and strato-cumulus. While most of the time, potential gradient remains positive , it often jumps to negative values. Visual observation on such occasions has shown that potential gradient has highest negative value when the overhead cloud is darkest i.e. thickest, and highest positive value when overhead sky is bright - a clear indication of negative charge concentration in the bottom of the clouds.

If the overcast clouds are thin uniform and less mobile, then, generally, only positive values are observed and potential gradient has been found to be steady and constant throughout the period of overcast. Such a uniform overcast has been found, in some cases, to suppress the noon depression and afternoon maximum.

2. Misty Sky

Potential gradient in misty weather has been found to be sensitive to wind. If there is no or very light wind, then the potential gradient has been found to have a very steady positive value as shown in fig.17(b). In such a case gradient and its electrical agitation is much reduced than that of fair weather. Alternatively, in the presence of wind, negative values have been observed. The reason may be looked into some insulation breakdown due to high humidity, as suggested by Chalmers[23].

3. Fair Weather Cumulii:

Passage of a fair weather cumulii gives a dip, sometimes going to negative values, in the potential gradient. One typical case is shown in fig.17(c) where two fair weather cumulii passed overhead against clear blue sky giving two V-type of shapes. If these cumulii are large in size, the agitation increases very much.

4. Non-raining Stratus:

Fig.17(d) gives a record of potential gradient while a stratus cloud passed overhead without any rain. The potential gradient gives a negative dip. The presence of lower positive charge pocket may be estimated from the reduction of potential gradient from its negative peak-value which gives a W-shape pattern to the field. The second negative peak may be caused by another small stratus cloud.

5. Thin Sheets of Clouds:

Some low altitude thin sheets of clouds has sometimes been observed to pass under relatively high altitude thick clouds. These sheets are nearer to water vapour than to clouds so far as their structure is concerned, and pass with velocities greater than the big heavy clouds. The passage of such sheets overhead has given an indication of positive charge in them. Fig.17(e) gives an example of such a record. Four positive kinks between 15.30 and 16.30 were visually observed to be associated with the passing of four thin cloud sheets directly overhead with speeds many times greater than the higher cumulus and cirrus clouds.

6. Showers:

Potential gradients during showers have been found to be largely fluctuating from positive to negative and vice-versa. The value of potential gradients is fairly higher than that under non-raining clouds. One such example is shown in fig.17(f). No definite conclusion can be drawn as to what is the sign of the charge on rain and what is the cause of its origin but the onset of actual shower did show some change in the field pattern.

7. Continuous Rain:

Fig. 17(g) gives one of many such field patterns observed during periods of continuous rain. Though potential gradient often changes sign in this case also but for most of the time, it remains negative. Moreover, the fields are not so high as during showers.

3.0 INTERPRETATION OF RESULTS

Any change in potential gradient can, normally, be considered to be caused either by change in potential of the global atmospheric condenser or by change in conductivity of the atmosphere at the place of measurement. The order of the duration of time of electrical agitation does not permit us to consider the first possibility to be behind the mechanism. The change in local conductivity can, however, be caused again by two processes i.e. change in space charge distribution or change in nuclei content of the atmosphere.

From table II we see that electrical agitation exists even in fair weather and it has equal values for the total material and for fair weather days including wind-disturbed days. So that the mechanism of origin of agitation should be such that it could operate even on fair weather days. The reverse increasing ordersof U_A with season for fair weather days and for the total material, suggest that either the cause of agitation is different in two cases or there are two controlling factors of agitation, one predominating in winter on fair weather days and the other in summer in the case of total material.

Israël[61] finds its explanation in atmospheric turbulence in which air masses having different aerosol contents cause the atmospheric conductivity to change. As he writes[63]

"The properties described above are typical for the atmospheric turbulence processes and especially those of the atmospheric mass exchange processes (Austausch). So, it can be said with certainty that the atmospheric agitation is in general a direct result of the atmospheric exchange processes. These exchange processes produce turbulence cells which, due to their different aerosol content, have different conductivities, and the various space charges thereby produced give rise to the changes in field and current at the stations over which they pass".

The suggested mechanism agrees with the observations of Israël but only partially with that of ours. Israël reports that in fair weather, electrical agitation is minimum at night and goes on increasing with time upto noon. In our observations electrical agitation runs parallel to the element-value and gives one maximum round about 9.00 and another at about 20.00 hours. If atmospheric turbulence is the only factor to control agitation, it should have one single maximum in the noon. To explain this discrepancy of diurnal variation of agitation, and other observational facts which we have described above, we suggest the following possible mechanism for the origin and variation of electrical agitation.

Positive space charge is concentrated near the earth's surface, due to electrode effect in fair weather field. This positive space charge is carried up in up-draughts due to convection currents set in the atmosphere. So that convection cells of the atmosphere give rise to positive space-charge columns rising in the atmosphere from the earth's surface. The frequency of convection cells is roughly of the order of the agitation in potential gradient. This 'basic-state' of electrical agitation is, however, modified on wind-disturbed days. High winds set turbulence in the atmosphere and raise dust particles from earth surface. This aerosol content of the atmosphere gives rise to air-masses of different conductivities by atmospheric mass exchange processes and thus further increase the electrical agitation. So that we can say that electrical agitation is due to free convection in fair weather and due to forced convection in disturbed weather. Moreover, the cause of change in conductivity is the space charge in fair weather and the aerosol content in disturbed weather.

Since the positive space charge concentration near the earth's surface due to electrode effect, should be large in high fields and vice versa, the parallel nature of U_A and potential gradient's diurnal variation can be explained in fair weather. Since in high wind speeds, the phenomenon of electrode effect is not observed, the variation of aerosol content becomes the controlling factor to change the air mass conductivities and thus electrical agitation. So, the double periodic diurnal variation of U_A on fair weather days and its change to single periodic variation on wind-disturbed days, can now be explained by considering the two mechanisms operative in the different circumstances.

Recently, Bent and Hutchinson[31] have measured space charges at three different altitudes close to the earth surface, and also measured some meteorological elements. They have observed that space charge changes simultaneous to the changes in wind speed, temperature and humidity. They observed some peaks in space charge records and explained it due to the origin of turbulence cells rising from earth surface, carrying positive charge in them due to the electrode effect. The periodicity of these peaks has been reported to be 11 min. which is in close agreement with 11.3 min. which is the average period after which potential gradient changes its direction in fair weather, as shown in table II.

Another observation to support our proposed theory of electrical agitation, is the observation of low-level ion clouds of both signs by Bracefield[28], passing overhead at altitudes as low as 10 m. The frequency of such ion clouds has been observed to be proportional to the electrical field itself.

In table II we see that U_A increases from summer to winter in fair weather, which must be so if our proposed theory is to be correct, because average value of potential gradient in fair weather increases from summer to winter. When we take the whole material, the U_A is greater in summer than in winter i.e. reverse to that of during fair weather. This is, however, probably due to the increased agitation in summer due to the presence of charges in clouds.

CHAPTER IV

THE EFFECT OF A SOLAR ECLIPSE ON ATMOSPHERIC POTENTIAL GRADIENTS

4.1 INTRODUCTION

In the preceding chapters, we have seen that solar radiation and meteorological factors have their dominant effect on the atmospheric electric elements. The relative magnitude of their effect, of course, depends on the local conditions of the place. It is mainly because of such influences that different places have their local anomalies in diurnal and other variations of atmospheric electric elements. It is, therefore, natural to expect that a solar eclipse which is nothing but an obstruction of solar radiation for a particular area of the earth's surface, should have its effect on potential gradient. Our routine recording of this parameter, do reveal an eclipse effect (Kamra and Varshneya[62]).

4.2 PREVIOUS RESULTS

Many workers have reported their results of the measurements of potential gradient during the period of eclipses, at different places and at different times but their results are so contradictory that a state of confusion prevails. With the present literature available, even it is difficult to say whether the eclipse has or has not any effect on the potential gradient.

Chauveau[63] and Preier[64] in their observations found the potential gradient to be unaffected. Jones and Giesecke[65] made measurements at Huancayo on 25th January 1944 and found the value of potential gradient during the eclipse to be less than that in normal conditions. Mühleisen[66] also found a decrease in potential gradient at and after the total eclipse of 30th June 1954. Extensive measurements have been made at the earth's surface and higher altitudes during the eclipse of 25th February 1952 in the Belgian Congo, by Koenigsfeld[10]. He reports two broad dips in potential gradient towards the beginning and end of the eclipse and a positive value at the totality of the eclipse. For measurements at higher altitudes, Koenigsfeld launched three radiosondes, one at the beginning of the eclipse, one during the eclipse and one after the eclipse. While in the first and the third flights, the potential gradient was found to be weak and steady, the second sounding gave relatively very high and very unstable values. The unsteadiness of potential gradient during the height of the eclipse gives a clear indication of disruption and rearrangement of stratification of the atmosphere.

4.3 OBSERVATIONS

Measurements were made of the potential gradient

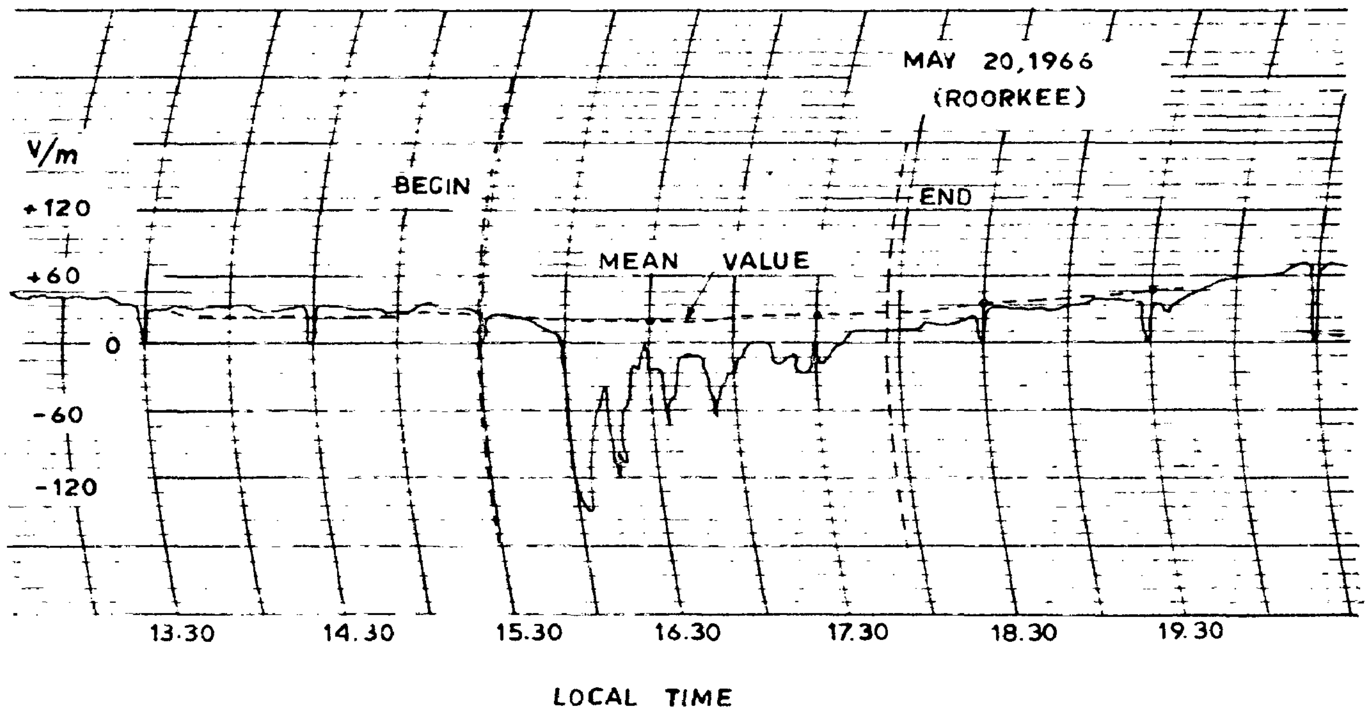

FIG.18 EFFECT OF SOLAR ECLIPSE OF 20TH. MAY, 1966 ON POTENTIAL GRADIENT.

during the solar eclipse of 20th May 1966 at this station and the record is reproduced in fig.18. The conditions during the eclipse were excellent, the sky being clear and weather calm. The continuous line shows the record on eclipse-day and the dotted line shows the mean-value of potential gradient for the month of May,1966. Only five days were included to draw the mean-value-curve. These days were clear and calm, while other days were disturbed either by clouds or by strong winds and dust-storms. The duration of eclipse ranges from 15.30 h to 17.56 h L.M.T. It was maximum (about quarter of the Sun under shadow) at about 16.45 h LMT.

In the beginning it had no effect on the potential gradient, but when the eclipse became appreciable, the potential gradient began to decrease and then became negative at 16.00 h LMT. It very soon attained a high negative value of 148 V/m which was great deviation from the otherwise fair-weather positive value of + 21 V/m at this hour of the day. This value , however, fell within about 10 minutes to -37 V/m. It again increased and decreased four times, giving rise to peaks. In all, there were five peaks with maximum at -148, -117, -7[illegible], -66 and -24 V/m occurring at 16.06, 16.18, 16.35, 16.52 and 17.26 hours LMT respectively. The last peak, however, has a secondary maximum just prior to it. At 17.40 h LMT the potential gradient again became positive and attained its normal fair-weather value.

In this record the following two points are noteworthy:

1. Potential gradient remains negative throughout the appreciable eclipse. It begins to decrease after about 15 min. of the beginning of the eclipse and again becomes positive before about 15 min. of the end of the eclipse.

2. The variation is regular. Each peak has a lower negative value than its preceding one, so also has each minimum.

4.4 DISCUSSION

In trying to search for some explanation for the effect of solar-eclipse on potential gradient, it is natural to take the change in solar radiation and its associated effects into consideration. Sieh[07] has suggested the interruption of heating of earth by the sun and the local circumstances to be the cause of the effect. Koenigsfeld[10] also explains it on the basis of change of convection currents due to change in heating of the earth's surface.

Comparing our observations with those of other workers, it will be found that in so far as the potential gradient remains negative for the most time during eclipse, our results have some resemblance with Koenigsfeld's[10]. In other details, however, there is not much resemblance. Koenigsfeld, for instance, observed a positive value at about maximum eclipse, we did not.

One possible explanation of the effect can be found from the observations of Kawano and Nakatani[66]. They found an increase in ionisation at the earth's surface, during the period of eclipse. This increase in ionisation may result in some decrease of potential gradient, but this does not give any explanation for the negative values of potential gradient. However, if negative ions out of this increased ionisation of the atmosphere be somehow carried up by convection currents (the positive ions going towards earth due to decreased eddy-diffusion), it may give rise to negative potential gradients.

The following two facts give some support to the proposed theory:

1. Disturbance in stratification of the atmosphere and its rearrangement due to the change in convection currents because of change in heating of the earth, should be maximum just after the beginning of the eclipse. By the time, equilibrium should reach. The regular decrease in the height of the peaks from beginning to end of the eclipse may find its explanation in this fact.

2. Both the increase in ionisation and the increase in potential gradients, are nearly more than double their respective mean fair-weather values.

A better confirmation of the proposed theory may be had by the measurement of space charge density of each polarity separately at different altitudes at the place of measurement during the period of eclipse.

PART - II

CHAPTER V

POINT-DISCHARGE CURRENTS FROM AN ISOLATED ARTIFICIAL SHARP POINT

5.1 INTRODUCTION

The phenomenon of point discharge occurs at sharp points, raised above the earth's surface, during high fields in disturbed weathers. The concentration of lines of force round the point gives rise to exceptionally high fields in its neighbourhood and as a result, atmospheric ions are attracted towards the point. In high fields the energy of these ions becomes so great that they produce ionisation due to collision. The ions of the sign of the potential gradient are attracted towards the point, thus giving point-discharge current of the same sign as that of potential gradient.

Due to its importance, as being a major source for transfer of charge in the atmosphere, the phenomenon of point discharge has been studied by different workers, taking different types of points or sets of points. Experiments have been made both with natural and artificial points. It is now clear that natural points such as tree, do not behave similar to that of artificial erected points.

Magnitude of point-discharge currents may depend upon the field, wind speed, shape and height of the point and perhaps on other factors also. However, if we take one particular isolated artificial point fixed at a particular height, it may be considered that field and wind speed remain the only governing factors for point-discharge current through the point. Many attempts have been made to find out an exact correlation between field, wind speed and point-discharge current but no definite conclusive result has yet been obtained. It shall, therefore, be worthwhile to study this phenomenon in order to find out the relative dependence of point-discharge current on wind speed and field.

Any attempt to study the correlation of the three parameters, with laboratory experiments, can give only superfluous results. The atmospheric conditions are widely different from those that can be produced in laboratory. Moreover, any attempt to compare the laboratory and atmospheric discharges, shall be so much an over-simplification of the problem that the results cannot be justified. The effect of space charge produced and its transfer by wind are among the main effects which cannot be considered to behave similarly in laboratory and atmosphere.

6.2 PREVIOUS RESULTS

Whipple and Scrase[8] ignoring the effect of wind on point-discharge current, found that current through a point at about the height of neighbouring trees, and the potential gradient measured at ground, can be related by the equation

$$I = a (F^2 - M^2) \qquad .. (5.01)$$

where I is the point-discharge current, F the potential gradient and a and M are constants. Chalmers[69] derived it theoretically, ignoring the effect of wind and taking the point as one of a rectangular set of points Chiplonkar[70], Yriberry[71] and Hutchinson[72] found this formula to be in agreement with their observations. Hutchinson, however, indicated a tendency of his observations towards a first-power law for high potential gradients. Kirkman and Chalmers[73] reanalysed the observations of Whipple and Scrase[0] and others and showed that a relation of the type

$$I = B (F - M)^n \qquad .. (5.02)$$

with proper values of n, can better fit with them. They found that with $n = 1.07 \pm 0.13$ for Whipple and Scrase's results and $n = 1.09 \pm 0.06$ for Hutchinson's results, the observations better fit with (5.02) rather than (5.01).

Chalmers and Mapleson[74] measured current through points attached to a captive baloon, keeping them at different heights and found that their results can be fit-in with the theoretically derived relation:

$$I = K\, V^{q-1}\, W^{3-q} \qquad .. \; (5.03)$$

where V is the potential difference between the point and its surroundings, W the wind speed and K and q the constants (q could not be determined by theory). For their observations, they took q = 2.75 and gave the relation

$$I = K(Fh)^{7/4}\, (W)^{1/4} \qquad .. \; (5.04)$$

where h is the height of the point, so that V=Fh if there is no space charge in between.

Kirkman and Chalmers[73] measured currents through a point at a high mast, measuring wind speed at about 8 m below the point, and potential gradient at ground and also 7 m below the point. They found that their observations can be represented by the relation

$$I = K\,(\,W + c\,)\,(\,F - M\,) \qquad .. \; (5.05)$$

where K and c are constants.

Chapman[75] did laboratory experiments on point-to-plane discharge and also studied discharge from points attached to aeroplane. He suggested that the correct relation should be of the type

$$I = k (V - V_o) v \qquad .. (5.06)$$

where V is the potential of the point with respect to its surroundings, V_o the minimum potential to start point discharge, k the constant and v the velocity of ions. In no wind, v is proportional to F and (5.06) becomes similar to (5.01) and in high wind, $v = W$ and (5.06) takes the form of (5.05) with $c = 0$.

Chalmers[63] has suggested that v should be taken as vector sum of W and aV, so that

$$I = C(V-V_o)(W^2+a^2 V^2)^{1/2} \qquad .. (5.07)$$

Here aV represents the ion speed in field. Large and Pierce[76] confirmed this relation by measurements of current through a point in the atmosphere, maintained at high potential.

Recently Chalmers[77] has derived a theoretical relation taking some assumptions which can be fairly justified. He shows that for high wind speeds the point discharge through an isolated point can be represented by

$$I = 2\pi C (V - V_o) W \qquad .. (5.08)$$

where ε is the permittivity of free space. This may further be extended to

$$I = 2\pi\varepsilon(V - V_0)(U^2 + \omega^2 F^2)^{1/2} \qquad .. (5.09)$$

where ω is the mobility of ions.

Therefore, we see that the exact nature of dependence of point-discharge current on field and wind speed is still not clear and needs further experimental and theoretical exploration. Here, we have measured point-discharge current from an isolated artificial sharp point along with the measurement of potential gradient and wind speed. The relative positions of point, agrimeter and anemometer have already been given in Chapter I.

5.3 OBSERVATIONS

In all, a record of about 45 hours was analysed, and many other cases were rejected because these were not suitable for analysis. In them either the variations in point-discharge current, wind speed or potential gradient were very rapid, or some of them had gone out of scale, for the sensitivity used at that time.

Cases of negative point-discharge currents were separated from those of positive point-discharge currents. They were divided into different groups of wind-speed ranges of 1 m/s width and the variation of point-discharge currents - both negative and positive- with potential gradients was studied separately for each group. The data was also divided into different groups of potential ranges of 2 KV width and the variation of point-discharge current with wind speed was studied for each group separately.

Fig.19 shows, for one particular case of W = 2.5 to 3.8 m/sec., the variation of positive and negative point-discharge currents with potential gradient which has been found to be linear. Dotted lines show the calculated values of point-discharge currents, from theoretically derived relation (5.03) of Chalmers. The agreement is fairly satisfactory for currents of both signs. Positive currents are larger than the negative currents at constant potential gradient and wind speed, a result opposite to that obtained by Milner and Chalmers[37].

Fig.20 shows, for one particular case of V = 7.00 to 9.00 KV, the variation of point-discharge currents of both signs with wind speed. Circles represent the negative current values while crosses show the positive current values. The current first increases with wind-speed but then becomes constant.

Equation (5.03) can be represented by

$$I = C (F - M) \quad .. (5.10)$$

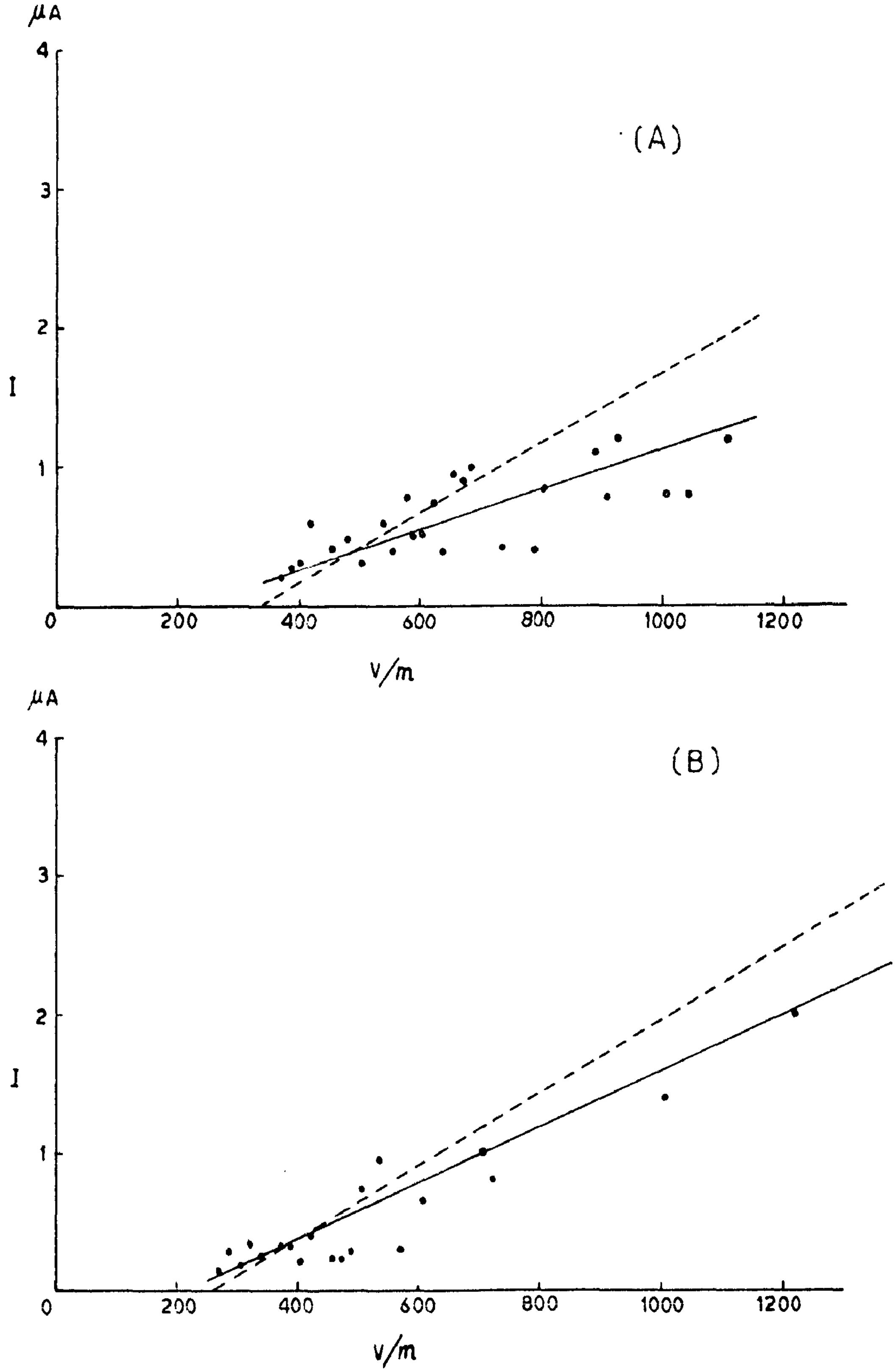

FIG. 19_VARIATION OF NEGATIVE (A) AND POSITIVE (B) POINT-DISCHARGE CURRENT WITH POTENTIAL GRADIENT AT WIND SPEED = 3 m/s.

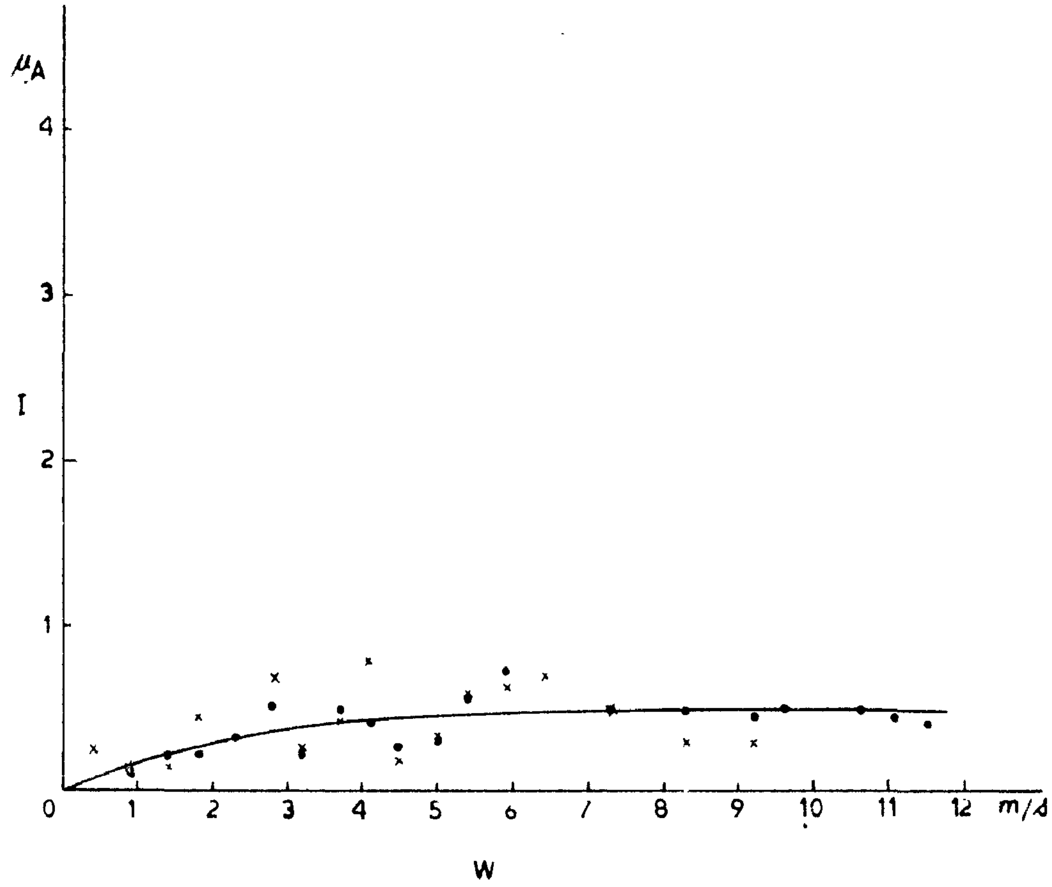

FIG 20. VARIATION OF NEGATIVE (DOTS) AND POSITIVE (CROSSES) POINT-DISCHARGE CURRENTS WITH WIND SPEED AT V =7.00 TO 9.00 KV.

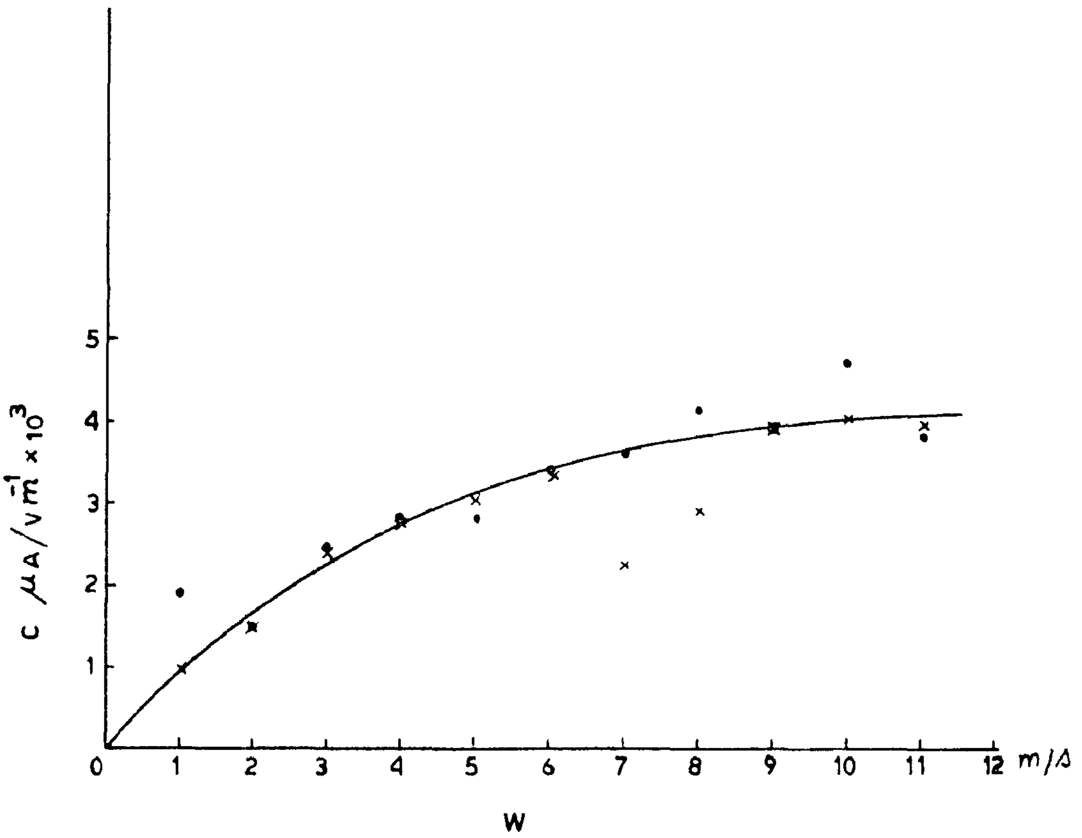

FIG.21. VARIATION OF C WITH WIND SPEED. DOTS SHOW VALUES FOR NEGATIVE CURRENTS AND CROSSES FOR POSITIVE CURRENTS.

where C is a constant. We plotted the values of C against W and the variation is shown in fig.21. It is noteworthy that while Kirkman and Chalmers[73] and Milner and Chalmers[57] have reported this variation to be linear, in our case it tends to be constant at high wind speeds. At lower wind speeds, however, the variation of C with W is nearly linear.

We determined the values of constants K and a of relation (8.08) for low wind speeds. To compare with the values of Kirkman and Chalmers, we present them below, both for negative and positive point-discharge currents

$$I_- = 8.14 \times 10^{-4} (W+2.64)(F-336) \qquad ..(8.11)$$

$$I_+ = 0.64 \times 10^{-4} (W+.64)(F-262) \qquad ..(8.12)$$

which are valid at low wind-speeds only.

8.4 DISCUSSION

The experimental results show agreement with the theoretical relation of Chalmers[77]. Also they show agreement with the relation of Kirkman and Chalmers[73], at low wind speeds. The observations that point-discharge currents first increase and then become constant at high wind speeds, has also been indicated previously by Chalmers and Mapleson[74] in their experiments with points attached to baloons, which represent a better example of an isolated point.

Value of V_0 in our observations is 5.31×10^3V for negative currents and 3.98×10^3V for positive currents. To compare with, this value was found by Kirkman and Chalmers to be 8.0×10^3V and 7.4×10^3V for 27 m and 34 m high points respectively for negative currents. Chapman found it to be $6 \pm 4 \times 10^3$V and Large and Pierce, 7×10^3V. The values are quite comparable considering the variation of V_0 with height and shape of the point.

Converting the equation (5.11) in terms of potential, the constant comes out to be 19.8×10^{-6} which is nearer to the value 14×10^{-6} of Chapman than to the values 4.3×10^{-6} and 6.3×10^{-6} of Chalmers.

CHAPTER VI

EXCESS POINT-DISCHARGE CURRENTS DURING RAPID FIELD-CHANGES

6.1 INTRODUCTION

We have studied in the previous chapter the variation of magnitude of point-discharge current with potential gradient and wind speed. In all the work so far done, it has been believed that for a given height of the point above earth, there exists a certain minimum critical potential gradient, below which no point discharge occurs. Thus, to get point-discharge current the corresponding potential gradient must be higher than the critical. In the present work, the magnitudes and directions of the point-discharge current from the isolated sharp point during periods of fast potential gradient changes have been studied (Kamra and Varshneya[78]). By fast field-changes we mean here, the changes associated with lightning discharges. During these fast changes of potential gradient, it has been observed that the point-discharge current flows even if the corresponding potential gradient is below the critical value. Another observation is that the direction of the point-discharge current at times is the opposite of the potential gradient. The observed phenomena have been given a theoretical justification-both qualitative and quantitative.

The effect of potential gradient and wind speed on this anomalous behaviour of point-discharge current, has also been found by analysing the data obtained in this laboratory.

6.2 OBSERVATIONS

Point-discharge current is, under normal circumstances, assumed to depend on at least two parameters: the potential gradient and the wind speed. The point-discharge current first appears at a critical (threshold) potential gradient, F_0 , and then for all changes of potential gradient, $F (F > F_0)$ and at constant wind speeds, the point-discharge current varies with it. Conventionally, positive potential gradients give rise to positive point-discharge currents and vice-versa. Here and in the following, for the sake of convenience, we shall consider the case of positive potential gradient, i.e. we shall take the earth to be negative. Thus, there are two critical potential gradients, $+F_0$ and $-F_0$, and the region lying between these two values ($+F_0 > F > -F_0$) is a sort of a 'dead zone' for point-discharge current.

Our observations of point-discharge current during slow changes of potential gradients are indeed in conformity with the above understanding. For fast changes of potential gradient, such as are associated with lightning discharges, the corresponding changes in point-discharge current are, however, of different nature. A record of typical observations has been reproduced in fig.22, where fast changing potential gradient, the associated point-discharge current and the wind speed for the same duration of time have been shown. The following facts come to light:

1. If the potential gradient suddenly falls from an above-critical value to one below critical, then contrary to the expectation that the associated point-discharge current ceased at the critical value, as soon as the potential gradient crosses the critical-value level there occurs a pulse of negative point-discharge current. This negative 'point-discharge pulse' occurs for every 'after-discharge' potential gradient below its positive critical value. Cases of this negative point-discharge pulse have been observed when the 'after-discharge' potential gradient is positive or negative or even if it is zero. So, the 'dead-zone' for point-discharge current which appears in slow potential gradient changes, vanishes here and, instead, we get negative point-discharge pulses.

2. If the lightning discharge reverses the positive potential gradient to such an extent that it

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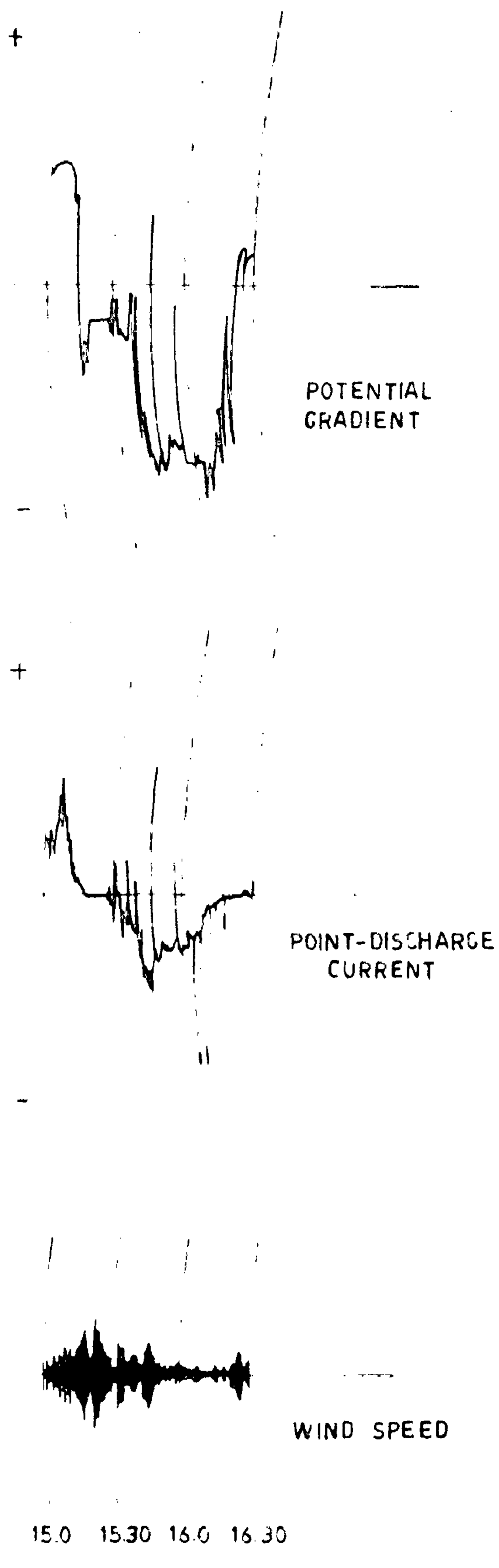
+
POTENTIAL
GRADIENT
-
+
POINT-DISCHARGE
CURRENT
-
WIND SPEED
15.0
15.30
16.0
16.30

FIG. 2 2

could by itself start the point discharge (i.e. above its negative critical value), then the corresponding point-discharge pulse has been found to be much larger than what it would have been, had the potential gradient changed its direction slowly. So, we can say that in such cases we got an 'excess point-discharge current'.

The phenomenon is true for both positive and negative field-changes. It should be mentioned here that while the potential gradient, as well known, falls exponentially from its 'after-discharge' value, the point-discharge current on the other hand becomes zero immediately after giving a pulse.

3. One more interesting feature of this phenomenon is, that if the lightning discharge, instead of decreasing the potential gradient from its above-critical value, increases it rapidly, then the corresponding point-discharge pulse is of the same magnitude as it would have been, had the potential gradient reached that after-discharge value at a slow rate. It means that the 'anomalous' behaviour of this point-discharge current is associated only with the rapid reversal of the potential gradient.

Moreover, for the excess point-discharge current to appear, it is also necessary that point discharge should already be occurring at the pre-discharge potential gradient. If there is no point-discharge at 'pre-discharge' potential gradient, then the magnitude of point-discharge current at the 'after-discharge' potential gradient (provided it is above critical value) is the same no matter whether the potential gradient increases or decreases, or it changes rapidly or slowly.

The above points will be seen illustrated in fig.22. The rapid potential gradient changes are due to lightning discharges. The potential gradients at 16.29, 16.32, 16.36, 16.39 and 16.55 hours decrease below the critical potential gradient (252 V/m) and remain negative, while the corresponding point-discharge pulses are positive. The potential gradient at 16.46 h reverses from negative to positive. The value of point discharge due to this pulse, though positive, is greater than it would have been had this positive potential gradient arrived at slowly. The rapid changes in potential gradient at 16.12, 16.14 and 16.17 hours do not give any excess point-discharge current since their direction increases the pre-discharge negative value. The two rapid changes at 16.03 and 16.08 hours should not be confused for excess point-discharge current, since the potential-gradient response at these values does not remain linear with the used sensitivity of the amplifier. One point-discharge peak at 16.08 hours could not be recorded due to some manual-arrangement in the recorder at that time.

6.3 THEORETICAL DISCUSSION

Consider the case of an earthed point in positive potential-gradient and let us study the mechanism of point discharge through it. As the field increases sufficiently high, ionisation due to collision takes place and more ions are produced round the point. These ions are influenced by electric field and wind speed. Let us follow the assumption made by Chalmers[77] viz., that the volume round the point can be divided into two regions: (1) The field-region, where field is the predominating factor to govern the motion of ions, and (2) The wind-region, where wind removes the ions. At the boundary of the two regions, the forces on the ions due to electric field and wind-speed are equal. Inside the field-region, due to the existing electric field the ions of opposite charges will separate and, therefore, the field-region will get polarised. Positive ions will accumulate near the point while negative ions near the boundary.

Let the positive potential surrounding the point be $+V$, and the critical potential to start the point discharge be V_0; $V > V_0$. As V decreases, ionisation and consequently, point-discharge current, decreases till at $V=V_0$, it becomes zero. All the ions round the point, are removed by wind. Thus, point-discharge current appears only at potentials above V_0. At lower potentials, normally speaking, there are no ions available and therefore no current. If, however, ions could somehow be made available at potentials below V_o, there could be a corresponding point-discharge current also at those potentials. This is what actually happens in the case of rapid potential gradient changes. During rapid decrease of V upto or below V_o, more of the positive ions, around the point are 'squeezed-out' of the field-region, and since now there is no more ion production, the field region is finally left with an excess of negative ions. At this stage there exists eventually a transient 'local potential gradient' which is reverse in direction to the original atmospheric potential gradient. In this case this local potential gradient will be negative. Since, normally, point discharge ceases to occur at $V=+V_o$, and in the present case we get negative point-discharge current below $+V_o$, we take the assumption that this local potential, developed around the point, is equal in magnitude (but reverse in direction) to the potential at which it starts to build i.e. $-V_o$. Since the potential gradient changes very rapidly, and the local potential gradient develops immediately, the negative ions of the field-region, do not get sufficient time to move away with the wind (as they do in slow potential gradient changes) and as a result they are attracted and absorbed by the point under the effect of local potential gradient, rather than the normal atmospheric potential gradient. This gives rise to a negative point-discharge current. As soon as the already present concentration of negative ions is absorbed or removed away with wind, point-discharge current becomes zero. That is why we get point-discharge pulses, and not continuous current.

Thus, rapid decrease of +V produces a local potential gradient which, below $V = +V_0$, makes the direction of the total potential gradient negative and gives rise to a negative point-discharge pulse. In other words, we can say that the zero-level of potential gradient with respect to the zero-level of point-discharge current, has 'shifted' by an amount V_0 in positive direction. This 'shifting of zero-level' shall be explained further in section 7.

To calculate the point-discharge current before and after a lightning discharge, consider any pre-discharge potential difference +V, between the point and the atmosphere. According to Chalmers[77], point-discharge current is given by:

$$I = -2\pi\varepsilon\,(V - V_0)\,U \qquad \text{.. (6.01)}$$

where U is the wind velocity, ε the permittivity of free-space and V_0 the minimum value of V for point discharge to occur. Now suppose V reduces to V' after discharge, such that $V' < +V_0$. The mechanism of point-discharge current, after discharge remaining the same as before the discharge, except that the potential gradient is different and reversed, we can apply eq. (6.01) in this case also and write down for point-discharge current after discharge, as:

$$I' = -2\pi\epsilon(V' - V_o)V \quad .. (6.02)$$

It should be noted here that V_o in the two equations has been introduced for two different reasons. In eq. (6.01) V_o has been put to account for the minimum value of V to start point discharge. In the after-discharge state, there is no such need. Ions are already present there and what is needed, is only a proper potential gradient to attract them. But we have just seen that a rapid change in potential causes a 'shifting of the corona-level' by V_o in positive direction. So the effective value of V' shall be $(V' - V_o)$.

From (6.01) and (6.02) we see that while $(V - V_o)$ is always positive $(V > V_o)$, $(V' - V_o)$ shall always be negative $(V' < V_o)$, so that the directions of I and I' shall always be opposite to each other.

From (6.01) and (6.02), we get:

$$I' = I\,\frac{V'-V_o}{V-V_o} \quad .. (6.03)$$

This solution gives some interesting results considering different values for V'. Taking the case of V' reducing from positive to negative direction, we get the following:

1. At $V' = +V_o$, $I_1' = 0$

2. At $V' = 0$, $I_2' = -I \frac{V_o}{V-V_o}$

3. At $V' = -V_o$, $I_3' = -2I \frac{V_o}{V-V_o}$

$= -2I_2'$

4. At $V' = -V$, $I_4' = -I \frac{V + V_o}{V - V_o}$

$= -I(1 + \frac{2V_o}{V-V_o})$

or $I_4' = -I + I_3'$.

The last case explains why we get an excess point-discharge current when V' crosses V_o in the reverse direction. It also explains why there is no excess point-discharge current when V increases instead of decreasing. The excess of current I_3' is due to the shifting of zero-level of V_1 and in the case of increasing V_0 there occurs no such shift.

On the basis of the above, ionization at the pre-discharge potential is essential to supply ions as well as to produce local potential gradient. Therefore, if the pre-discharge potential is below V_o, there shall be no excess point-discharge current at the after-discharge potential also, as indeed is in our observations.

6.4 CONDITION FOR THE PRE-DISCHARGE CURRENT AND THE AFTER-DISCHARGE CURRENT TO BE EQUAL

It will be interesting to find out such values of V and V' so that the point-discharge currents at those two potentials be equal to each other. Let for any particular value of V, the corresponding value of V' be

$$V' = K\,V_0 \qquad \text{.. (6.04)}$$

where K is a constant.

From (6.03)

$$\frac{I'}{I} = \frac{(K-1)V_0}{V - V_0} \qquad \text{.. (6.05)}$$

so if $I' = -I$,

$$V_0 - V = (K - 1)\,V_0$$

or $$V = (2 - K)\,V_0$$

$$= \left(2 - \frac{V'}{V_0}\right)V_0$$

or $$V = 2V_0 - V' \qquad \text{.. (6.06)}$$

which gives the required condition. Some of the following particular cases, will illustrate the phenomenon:

1. At $V' = V_0$, $V = V_0$

2. At $V' = 0$, $V = 2V_0$

3. At $V' = -V_0$, $V = 3V_0$

6.8 VARIATION OF EXCESS POINT-DISCHARGE CURRENT WITH POTENTIAL GRADIENT AND WIND SPEED

Records of a period of more than seven months were reviewed and more than 70 events were found in which the data could be analysed to compare the observed values with those calculated theoretically. Quite a many events were left out because of their ambiguity. There were the cases in which either the events occurred so quickly in succession that they overlapped each other or that the pre-discharge or after-discharge values went out of scale being used at the time and thus could not give definite values. The selected events were divided separately into groups of nearly equal wind-speeds and after-discharge potentials V'. For each of these groups theoretical values of after-discharge point-discharge current were calculated from (6.02).

Fig. 23 shows the variation I' with V' at constant wind speeds. It should be mentioned here that no consideration was made of positive and negative field-changes separately. The polarity of after-discharge potential V', stated in the fig., depicts only whether it has reversed

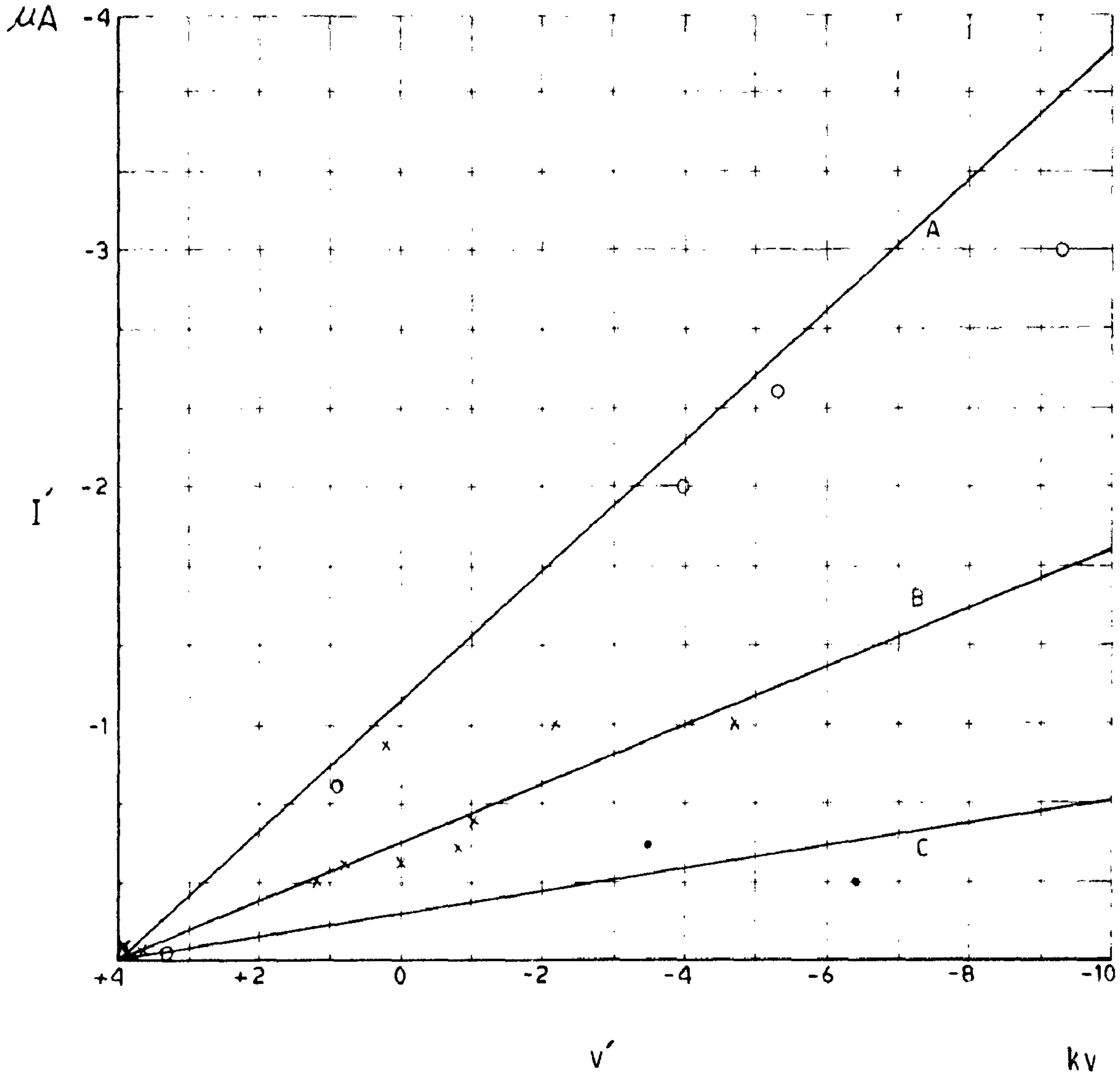

FIG.23_VARIATION OF I′ WITH V′ FOR SMALL RANGES OF W. CONTINUOUS LINES REPRESENT THEORETICAL VALUES AND DIFFERENT POINTS REPRESENT OBSERVED VALUES.

A FOR W = 5 m/s ∘ FOR W = 4.5 - 5.5 m/s

B FOR W = 2.3 m/s × FOR W = 1.8 - 2.8 m/s

C FOR W = 0.9 m/s • FOR W = 0.9 m/s

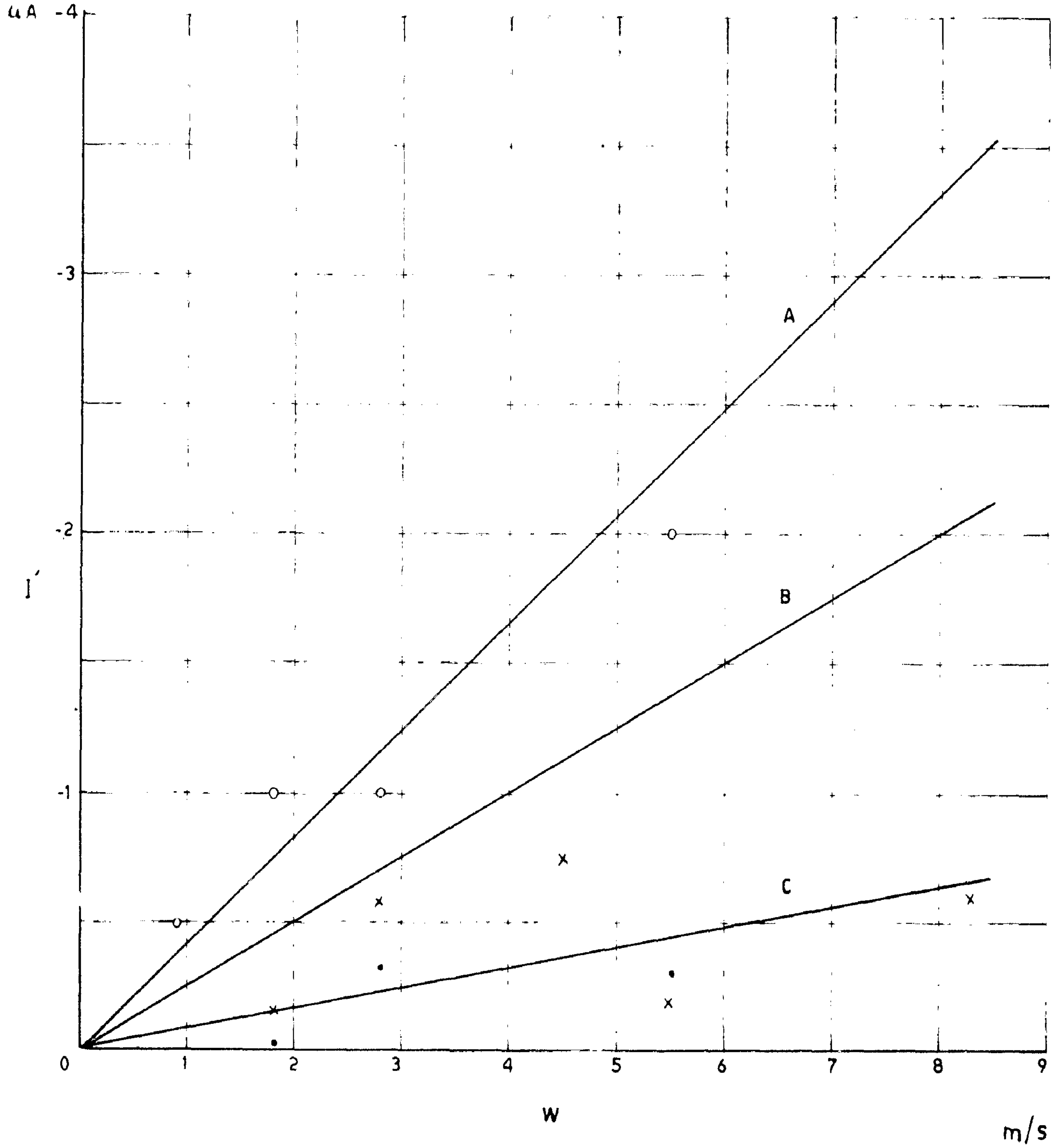

FIG 24. VARIATION OF I′ WITH W FOR SMALL RANGES OF V′. CONTINUOUS LINES REPRESENT THEORETICAL VALUES AND DIFFERENT POINTS REPRESENT OBSERVED VALUES.

A FOR V′ = + 2.5 KV
B FOR V′ = - 0.5 KV
C FOR V′ = - 3.5 KV

o FOR V′ = +4 TO +1 KV
x FOR V′ = +1 TO -2 KV
• FOR V′ = -2 TO -5 KV

its direction or not. Since I' always changes direction, it is always negative. The agreement between the observed and calculated values for the meagre statistics available, is not bad.

In fig. (23) it will be noted that, while the values of I' in slow field-changes would converge at $-V_o$, in the present case they are seen converging at $+V_o$; the point discharge occurs also in between $+V_o$ and $-V_o$. This justifies the 'shifting of the zero-level'.

Fig. (24) shows the variation of I' against W at constant V'. The agreement between the observed and the calculated values is good for higher values of V'. For lower values of V' the agreement is good only at lower wind speeds; at higher wind speeds there is increasing disagreement. This is, however, not surprising. We know that for values of V' below $- V_o$, point-discharge current is limited by the number of ions, already available there and wind-velocity itself is no ion-producing agent. So, the point-discharge current shall vary with W only upto a particular value of it. However, at higher values of V' the fresh production of ions can take place and give a linear variation of I' upto higher values of W. More precise conclusions can be drawn only after collecting more data.

6.6 CONCLUSION

From the observations, we conclude that the nature of variation of point-discharge current-both in its magnitude and direction during fast field-changes is different from that during slow field-changes. All the fast field-changes, however, do not behave differently. The experimental observations and their understanding lead us to a condition which must be satisfied by fast field-changes for the phenomenon of excess point-discharge current to be observed. In terms of potentials, this condition can be stated as:

$$V > V_0 > V'$$

irrespective of the direction of field-changes.

Some assumptions made to explain the phenomenon theoretically, seem justified by the agreement obtained, within meagre statistics, between the observed and the calculated values. A larger statistics of events, of course, will be a positive contribution to further establish the degree of coherence between the observations and theory.

R E S U M E

Atmospheric electric potential gradients, point-discharge currents from an isolated artificial sharp point and wind speed have been recorded for one full year along with the recording of atmospheric temperature and relative humidity for four months only. The results obtained, have been divided into two parts.

The first part deals with the short-, and long-time variations of potential gradient and the effect of wind on them. Diurnal-, seasonal-, and annual- variations of potential gradient and its electrical agitation have been studied. The effect of wind and temperature on such variations has been explained by arguing that dust particles carry negative charge with them when they are stripped-off from the earth's surface by wind. Moreover, the main cause of electrical agitation has been found to be free-convection in fair weather and forced-convection in disturbed weather in addition to charges in clouds. Electrical agitation has been found to vary, not linearly as reported by others[80,81], with its element-value.

An observation of the effect of a solar-eclipse on potential gradient has also been described in which negative peaks, during the period of eclipse, have been observed.

In second part of the thesis, correlations of

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R E S U M E

Atmospheric electric potential gradients, point-discharge currents from an isolated artificial sharp point and wind speed have been recorded for one full year along with the recording of atmospheric temperature and relative humidity for four months only. The results obtained, have been divided into two parts.

The first part deals with the short-, and long-time variations of potential gradient and the effect of wind on them. Diurnal-, seasonal-, and annual- variations of potential gradient and its electrical agitation have been studied. The effect of wind and temperature on such variations has been explained by arguing that dust particles carry negative charge with them when they are stripped-off from the earth's surface by wind. Moreover, the main cause of electrical agitation has been found to be free-convection in fair weather and forced-convection in disturbed weather in addition to charges in clouds. Electrical agitation has been found to vary, not linearly as reported by others[30,31], with its element-value.

An observation of the effect of a solar-eclipse on potential gradient has also been described in which negative peaks, during the period of eclipse, have been observed.

In second part of the thesis, correlations of

potential gradient, point-discharge current and wind speed during slow and rapid field-changes have been discussed. In slow changes, the results have been partially, found to be in agreement with those of Chalmers[77] and Kirkman and Chalmers[78] (at low wind speeds), for both signs of the current.

During rapid field-changes, caused by lightning discharges, however, our results differ from those of others, in that, we discovered a new phenomenon of 'excess point-discharge current' during these rapid field-changes. This has been explained on the basis of development of a 'local potential gradient' round the point. The observed and theoretically calculated values have been found to be in agreement.