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How to cite:

Raisbeck, I. A. (1963) *Measurements in atmospheric electricity in vertical plane*, Durham theses, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/10264/

MEASUREMENTS IN ATMOSPHERIC ELECTRICITY IN A VERTICAL PLANE.

By

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SUBMITTED IN CANDIDATURE FOR THE DEGREE OF
MASTER OF SCIENCE IN THE UNIVERSITY OF DURHAM.

April, 1963.

ABSTRACT

It was found by early workers in atmospheric electricity that, during conditions of steady rain, when the potential gradient at the ground was negative the potential gradient at the top of a high mast was occasionally positive. This indicated the presence of negative space charge in the layer between the two measurements.

To further investigate this effect simultaneous recordings were taken of the potential gradient and the precipitation current at the top and bottom of the mast, 21 metres high, situated in a field adjacent to Durham Observatory.

Large differences in the values of the precipitation currents at the two levels were found. Due to the concentration of the lines of force on the earthed mast, and so on the upper shielded collector, laboratory experiments were carried out to investigate the charging effects caused when drops splash in a region of high potential gradient. It was found that the differences between the currents could be accounted for by the splashing of drops on the edges of the upper collector. As there is no obvious way of correcting for this effect it would appear that the shielded rain collector of the design used in the present work is unsuitable for measuring the precipitation current in regions of high potential gradient and even in other regions the recorded currents must be considered with caution. Also drops were found to release negative charge to the air in regions of zero potential gradient.

The actual reversal of sign of potential gradient between the top and bottom of the mast was only observed for a number of very short periods, the longest being 4½ minutes, during low potential gradients. But on the majority of recordings the potential gradients did indicate the presence of an excess of negative space charge in the layer below the top of the mast, although on occasions the space charge was positive. The space charge was of the same sign, and varied in the same sense, as the potential gradient recorded at the ground. Considering these points an attempt is made to explain the reversal effect in terms of layers of space charge between the cloud and the ground. The layers being due to the charge on the rain, the charge released when drops splash, and a separation or electrode effect due to the potential gradient of the cloud.

MEASUREMENTS IN ATMOSPHERIC ELECTRICITY IN A VERTICAL PLANE

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CHAPTER 1

INTRODUCTION TO THE SUBJECT AND THE PROBLEM.

1. Introduction To Atmospheric Electricity

Interest in the phenomena now classed under the heading of Atmospheric Electricity was originally provoked by a number of early eighteenth century philosophers who compared the cracklings and luminosity produced by rubbing amber with their observations of thunder and lightning.

The fundamental fact of Atmospheric Electricity is the existence of a potential difference between a conducting region in the upper atmosphere and the earth. The conducting region is called the electrosphere and is at a height of 50-60 km above the earth. It is effectively an equalising layer in which there are horizontal electric currents joining the places above clouds where the positive charge moves upwards with those in fair weather regions where it moves downwards.

Above 60 km the air may be considered as a perfect conductor from the point of view of Atmospheric Electricity. Above this level are found the various conducting layers of great importance in radio.

The electrosphere and the earth so form a spherical condenser with the atmosphere as the dielectric, and the study of Atmospheric Electricity is confined to this region.

The potential of the electrosphere (V) is given by

$$V = \frac{FR}{r}$$

Where F is the average value of the potential gradient in the metre adjacent to the earth's surface; R is the resistance of a column of air of cross section 1 square metre from the earth to the electrosphere; and r is the resistance of the lowest metre of the column.

The potential of the electrosphere is also given by

$$V = iR$$

Where i is the air-earth conduction current which occurs as the atmosphere has a low but finite conductivity, of the order of 2×10^{-14} ohms^{-1}M^{-1}, due to the air being partly ionised by cosmic rays and radioactive matter in the earth.

At places where the potential gradient is dependent on local conditions that vary with the time of day then the values of the potential gradient cannot give any useful information abo~~ve~~ut the potential of the electrosphere.

Gish and Sherman (1936) determined R using a balloon and also measured i. They determined the potential V as 4×10^5 volts.

Gish (1951) estimated that the total current between the electrosphere and earth has a value of about 1800 amps and with a total effective resistance of 200 ohms, this gave the potential of the electrosphere as 3.6×10^5 volts.

An acceptable present day average potential of the electrosphere is $V = 2.9 \times 10^5$ volts.

This potential difference between the electrosphere and the earth is maintained even in spite of the fair weather conduction current. How this is done still remains a major problem of Atmospheric Electricity.

2. The Specific Problem

Kelvin (1860) and Chauveau (1900) made simultaneous measurements of the potential gradient at the ground and at some height above the ground. Kelvin worked at Glasgow while Chauveau made use of the Eiffel Tower. They both found that, in conditions of steady rain as are usually associated with nimbostratus clouds, the potential gradient at the ground was usually negative while at the upper level it was sometimes positive. This can only be explained if there is a negative space charge in the layer between the positions of the two measurements of potential gradient.

The work described here was undertaken in an attempt to determine the origin of this negative space,charge and if possible to relate this to the general conditions existing during periods of continuous rain.

Various suggestions as to the origin of this negative space charge have been made. Smith (1955) quoted a result by Lenard (1892) that when drops break on splashing the splashed drops become positively charged and the air negatively charged. Smith said that this occurred with the rain drops at the earths surface, and so accounted for the negative space charge.

Simpson (1915) suggested that gusty winds near the ground might cause the drops to collide and rupture, leading to a positive charge on the rain and a negative charge in the air. But this is unlikely to happen as drops of the same size as the majority of raindrops are very stable and would have to be subjected to very strong forces near the ground for any distruption to occur. This is shown by the

Fig.1

results of Best (1950) illustrated in Fig.2 which shows the terminal velocity of freely falling raindrops, and on the same diagram is plotted the strength of the sharp edged gust necessary to produce disruption of the raindrops (Browne et al 1954)

It was suggested by Adkins (1959a) that the precipitation was in the form of snow at the upper level and that it melted lower down and so gave rise to the observed effect. But this seems very unlikely for two reasons, the first being that Chauveau never mentioned it even though the effect was noted many times. Secondly it would mean that the 0°C level would have to be very close to the ground, which is not usually the case in steady rain conditions at Paris or Glasgow.

3. Proposed Method Of Investigation

It was originally intended to make use of a mast 30 metres high situated in a field adjacent to Durham Observatory and to record simultaneously the potential gradient and precipitation current at two levels, one of these levels being the ground. Also the rate of rainfall was to be recorded. A pulley system was devised that would enable the position of the upper level of measurement to be varied if required, and also to ease instrument maintenance. But unfortunately, after the pulley system had been constructed the mast was found to be unsafe and had to be pulled down. The mast is shown in Fig.1.

A new mast, also shown in Fig.1 in the form of an electricity pylon was erected. But the shape of the mast, and the small amount of time remaining, meant that no pulley system was devised for this mast,

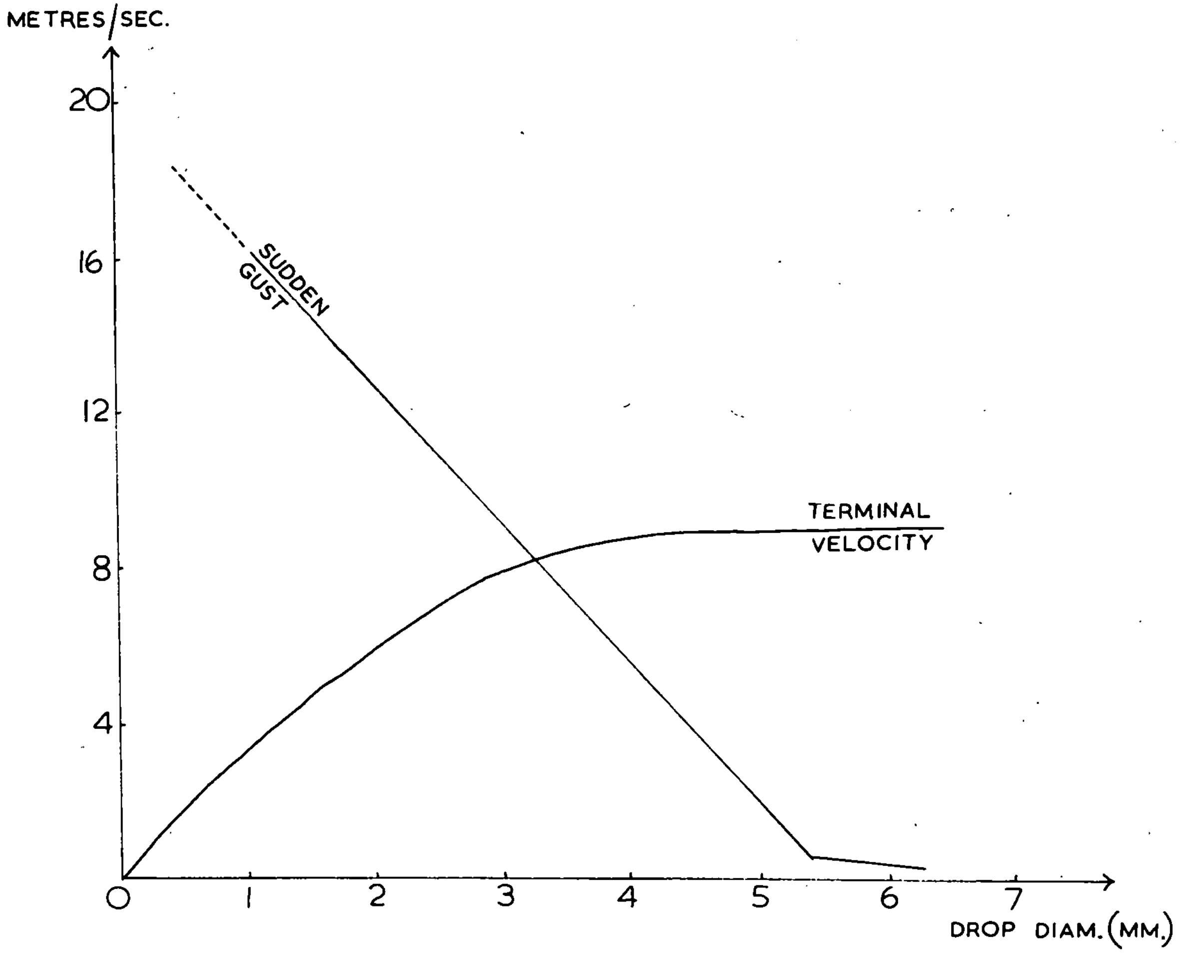

METRES/SEC.
20
16
12
8
4
0
1
2
3
4
5
6
7
DROP DIAM. (MM.)
SUDDEN GUST
TERMINAL VELOCITY

Fig.2

and the apparatus at the upper level was in a fixed position at the top of the mast.

The second mast was only available for actual use for approximately two months before it was blown down with the apparatus on it during the gales of the 24th June, 1962.

4. Previous Development Of Instruments For the Continuous Measurement Of Potential Gradient.

There are two types of mechanical instrument that measure potential gradient, one being a D.C. and the other an A.C. instrument.

In the first type an earthed conductor is exposed to the potential gradient and a charge proportional to the potential gradient is inducted on it. The connection between the conductor and earth is then broken and the conductor is moved to a screened position where it is connected to, and shares it's charge with, an electrometer. The whole process is repeated continuously and so the output from the instrument is a series of undirectional current pulses of magnitude proportional to the potential gradient.

If either the potential gradient or the exposed conductor are sufficiently large then the output can be taken directly to a galvanometer without amplification. Also the sign of the potential gradient is given directly. The main disadvantage of this type of instrument is that for use in low potential gradients the conductors have to be so large that the instrument becomes cumbersome.

This type of instrument was first developed by Russeltvedt (1926), and in more recent years by Goto (1951) and Chalmers (1953). The latter gave the name agrimeter to his particular instrument.

In the second type of instrument a fixed conductor is earthed through a high impedance and regularly exposed to, and screened from, the potential gradient. An alternating voltage proportional to the potential gradient is developed across the impedance and amplification is compartively easy. So a small collector can be used and the instrument is reasonably portable.

Th~~is~~e arrangement used by a large number of workers including Clark (1949), and Mapleson and Whitlock (1955) was one where the fixed conductor was a circle with alternate sectors removed. The rotor was similar and the waveform of the output voltage was approximately triangular. Van Atta (1936) shaped the sectors to give a sinusoidal output.

But the sign of the potential gradient still had to be determined and this was done in a number of ways among them being:- (1) Rectify the alternating signal using a commutator. (2) Use an electronic phase sensitive detector (3) By adding the output of an auxiliary synchronous generator to the output of the instrument.

This type of instrument is given the collective name of field mill.

The relative advantages of the two types of instrument were considered in connection with the present problem.

It was decided to use an agrimeter at the top of the mast as due to the concentration of the lines of force large potential gradients occured there and a small instrument would give a large enough output to be used directly with a galvanometer. This eliminated the need for amplification and sign discrimination in connection with this measurement. But at ground level the relatively low potential gradients and the possible need to be able to move the instrument easily in connection with calibration resulted in the use of an instrument of the field mill type there.

5. Previous Development of Instruments For The Continuous Measurement Of Precipitation Current.

The precipitation current is usually measured using either an open or a shielded receiver. An open receiver can be made to simulate the natural conditions at the earth's surface, but it also records conduction and displacement currents. So shielded collectors have often been used to reduce the magnitudes of these currents.

The open receiver technique was used in the form of a wire brush by Weiss (1906). It was Wilson (1916) who first suggested that the open receiver could be made to simulate the natural conditions at the ground by covering the receiver with soil and natural vegetation and surrounding it with a guard ring. A similar method was used by Adamson (1959) but he developed a method of compensation for the displacement currents.

Elster and Geitel (1888) and Simpson (1909) were among the early workers to use shielded collectors.

In this work the deflection of an electrometer was recorded or observed visually at regular intervals. The electrometer was then zeroed and a new measurement started, and so the average current over the period of measurement could be determined. But Scrase (1938) and Simpson (1949) took continuous recordings using photographic methods, and so instantaneous, as well as average, values of the current could be found. As the precipitation current appeared to depend on the rate of rainfall, the charge carried by a definite quantity of rain was sometimes recorded. This was first done by M^{c}Clelland and Nolan (1912).

In the present work it was hoped to record the rate of rainfall and the precipitation current simultaneously. The type and design of the collectors used will be discussed later.

CHAPTER 2

THE CONTINUOUS RAIN CLOUD - NIMBOSTRATUS.

1. The Meteorological Aspects

The nimbostratus cloud is a cloud of both considerable vertical height and horizontal extent. It gives rain although usually less intense than that from cumulonimbus. The nimbostratus cloud is formed when moist warm air rises over a denser mass of cold air at a warm front as shown in Fig.3. It has a smaller vertical air current and is less turbulent than the cumulonimbus cloud.

In Great Britain the rain from nimbostratus clouds has probably originated by the process suggested by Bergeron (1933) as some part of the cloud will exist above the 0°C temperature level. Hence every raindrop will have existed at some time as a snowflake.

2. Electrical Effects Associated With Nimbostratus

The Electrical effects associated with the nimbostratus cloud are often of the order of one hundred times smaller than those associated with the cumulonimbus cloud. So, even though the conditions of continuous rain are much more common than thunderstorm conditions, the total effective transfer of charge between the electrosphere and the earth by continuous rain clouds is very small compared with that by thunderclouds.

A large number of possible explanations as to the charging mechanism operating in the nimbostratus cloud have been proposed.

If it is assumed that the rain from nimbostratus

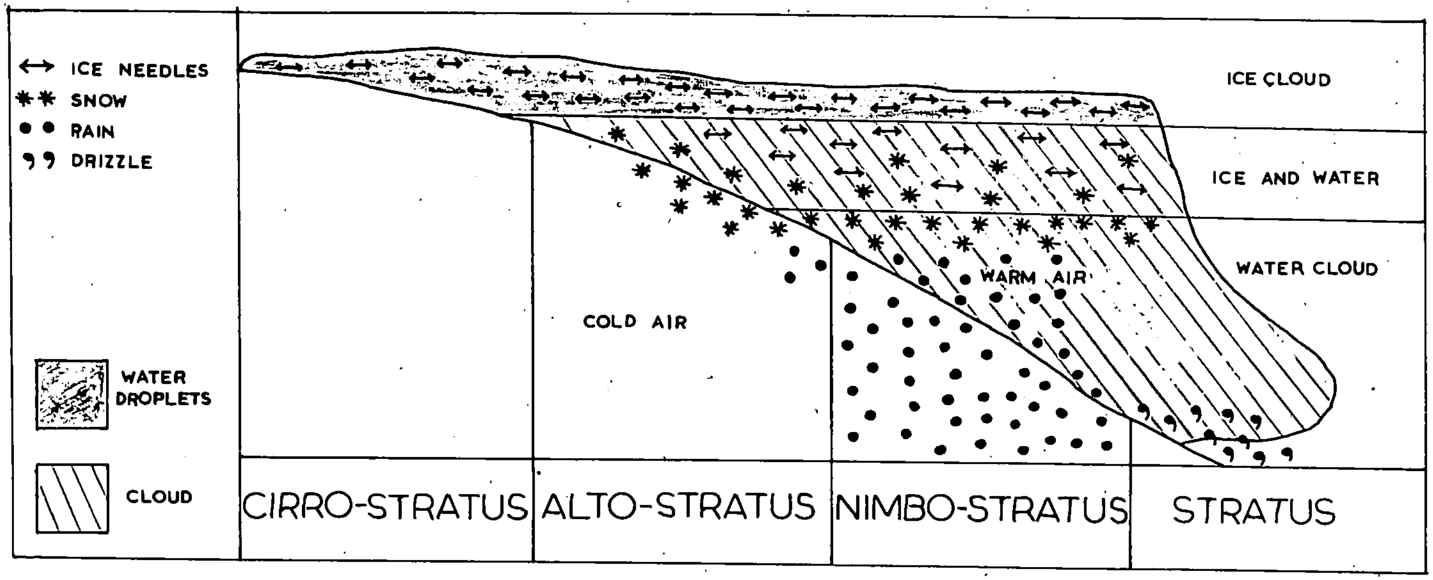

ICE NEEDLES
SNOW
RAIN
DRIZZLE
WATER DROPLETS
CLOUD
ICE CLOUD
ICE AND WATER
WATER CLOUD
WARM AIR
COLD AIR
CIRRO-STRATUS
ALTO-STRATUS
NIMBO-STRATUS
STRATUS

Fig.3

is produced by the Bergeron process, then if there is any charging process for snowflakes in the cloud, then all raindrops will have experienced this process before melting.

Snow is found to usually carry a negative charge while rain carries a positive charge. So if it is considered that all rain is some time in the form of snow thentere must be a second charge separation process operating when the precipitation is melting or in liquid form. So in the nimbostratus cloud two charge separation processes must operate. An upper one occuring at temperatures below the freezing temperature in which negative charge moves downwards, and a lower one in which positive charge moves downward. In the nimbostratus cloud the lower process must predominate.

The theory of Wilson (1929) can account for a precipitation current opposite in sign to the potential gradient. When a drop falls in an electric field it becomes polarised. If the potential gradient is negative, then the top of the drop has an induced positive charge and the bottom of the drop a negative charge. So when the drop falls through the atmosphere if it falls more rapidly than the downward motion of the negative ions it repels these ions but attracts the positive ions moving upwards. When there is an excess of ions of one sign, as occurs with point discharge, the charge acquired by the drop is greatly increased. But as the magnitude of the potential gradient associated with continuous rain is usually too low for point discharge to occur, approximately equal numbers of ions of each sign will be present. But even though the Wilson theory can account for some charging under such conditions it cannot account for the precipitation currents recorded.

Smith (1955) suggested that the precipitation left the cloud uncharged and acquired it's positive charge due to splashing at the earth's surface, the corresponding negative charge rising and producing a negative potential gradient. But Chalmers and Pasqiull (1938) measured the charge on single raindrops before they had chance to splash, and showed that they already possessed a charge.

The negative space charge in the layers close to the ground necessary to account for the Kelvin - Chauveau effect suggests that charging does occur due to fracture or impact.

The charging mechanism operating in nimbostratus conditions is still unknown, and may in fact be due to a combination of the processes mentioned or a completely different one.

3. Previous Results In Continuous Rain

Bergeron (1937) stated that rain is the precipitation of liquid water in which the drops have a diameter greater than 0.5 mm and Lenard (1904) observed that the upper stability limit for the diameter of falling drops is 5 mm.

Simpson (1949) stated three arbitrary conditions for a period of rainfall to be classed as continuous. These were that the duration of the rainfall must be at least one hour, that the rate of rainfall must be at least 1 mm/hr., and that there must not be any large variations in the rate of rainfall. He found that the rainfall tended to make the potential gradient more negative than the normal fine weather value and the potential gradient was usually in the range -300 —— - 400 v/M. He also observed that the charge per unit volume on the rain was proportional to the potential gradient and independent of the rate of rainfall. But the charge recorded by a collector is dependent on the volume of rain entering it and so on the rate of rainfall.

The earlier work of Scrase (1938) gave similar results to those of Simpson and he found that 60% of the charge carried by rain was positive, while the potential gradient was usually negative. Scrase said that the intensity of electrification of rain was possibly dependent on the rate of ascent of the associated air. So the rain produced by the ascent of air up a gradual slope, as occurs for nimbostratus, would be less intensely electrified than the rain produced by convectional ascent. Scrase said that this would explain why the rain in the summer is more highly charged as the results of Ramsay and Chalmers (1960) show.

Scrase also observed that nimbostratus clouds can exist for long periods without producing precipitation and on such occasions the potential gradient remains very close to the normal fine weather value. It was only when the cloud reached the rain stage that the potential gradient was effected, that is when charge of one sign was being removed from the cloud. So Scrase concluded that the falling of charged rain from the cloud layer is the cause rather than the effect of the disturbed potential gradient.

The results of Chalmers (1956) showed that the total current downwards is positive during continuous rain while the potential gradient is usually negative. He found that the average value of the current was $+ 3.8 \times 10^{-12}$ amps./M^2 and the average potential gradient - 176V/M.

4. The Relation Between Precipitation Current and Potential Gradient

There exists during continuous rain a general inverse relationship of positive precipitation current and negative potential gradient.

The inverse relation is not always observed, but this can possibly be explained by considering the type of collector used. If the shielding on the collector is too great it will prevent the majority of small drops, which are found to carry a charge of opposite sign to the potential gradient, entering the collector. Smith (1955) measured the charge on a large number of drops during a short time interval and found that the sum of the charges on the drops was of the same sign as the potential gradient. But he found that if he used the same apparatus as Simpson (1949) he obtained the inverse relation as obtained by Simpson. In his original experiment Smith was unable to measure the charge on small drops due to the limitations of his apparatus. This would suggest that the inverse relation is mainly due to the smallest drops.

Simpson (1949) observed that the variation of precipitation current and point discharge current with time often appear almost to be the mirror image of each other. But Sivaramakrishnan (1951) found that the change of sign of the precipitation current synchronises more closely with the change of sign of the potential gradient than with the point discharge current. It is this latter effect that will be referred to as the mirror image effect.

During periods of continuous rain the potential gradient is not usually large enough for point discharge, and Ramsay and Chalmers (1960) found that the positive maximum of the precipitation current often led or lagged behind the negative maximum of the potential gradient by a few minutes. Simpson (1949) also observed that the mirror was not the zero value of potential gradient but corresponded approximately to the normal fine weather value.

As a drop takes a few minutes to fall from the cloud to the ground the existence of the mirror image effect would suggest that the drops acquire their charge close to the ground and so that the charging of the rain is not due to the theory of Wilson (1929) as the potential gradient would be too low. But Chalmers (1957) suggested that the mirror image effect could be explained by considering the motion over the observer of clouds carrying different charges at different places rather than due to changes in the relative positions of the charges in the cloud. This would allow the mirror image effect to be observed no matter at what height the drop acquires it's charge, and so the drops could still obtain their charge according to the Wilson influence theory in the larger potential gradients at higher levels.

Magono and Orikasa (1960 and 1961) found that occasions when the mirror image effect did not hold could possibly be explained by considering the space charge due to the charge on the rain itself. They said that the mirror image effect could be explained by considering the removal from the cloud of charge of one sign and the leaving behind of charge of the opposite sign in the cloud. So any change in the rate of rainfall would result in a change of the space charge due to the drops and cause a temporary change in the potential gradient at the ground.

So the simultaneous measurement of precipitation current and potential gradient at two levels could give information about both the effects mentioned.

CHAPTER 3

THE DESIGN, CONSTRUCTION, CALIBRATION, AND OPERATION OF EQUIPMENT

1. The Rain Collectors

(a) Introduction

Two rain collectors were constructed as shown in Fig. 4 and were of similar design to those of Scrase (1938). Shielded collectors were used to reduce the displacement and conduction currents in the collector situated at the top of the mast where the concentration of the lines of force on the earthed mast pro~~cud~~duces an intense potential gradient of magnitude many times that at the ground. Also the upper edge of the outer shield of the collector was the uppermost point on the mast.

But in spite of the shielding, 98% efficient according to Scrase, it was not sufficint to prevent appreciable displacement and conduction currents being recorded by the collector at the top of the mast. So corrections for these currents had to be applied to the recorded current to obtain the precipitation current, as described in Chapter 5.

Although the concentration of lines of force was very much smaller at the collector at the ground this collector was constructed in exactly the same way so that the effective area over which rain was collected was the same for both collectors.

(b) Construction

Each collector had an outer cylindrical shield and an inner conical one. Situated below the inner shield was a cone supported on polystyrene

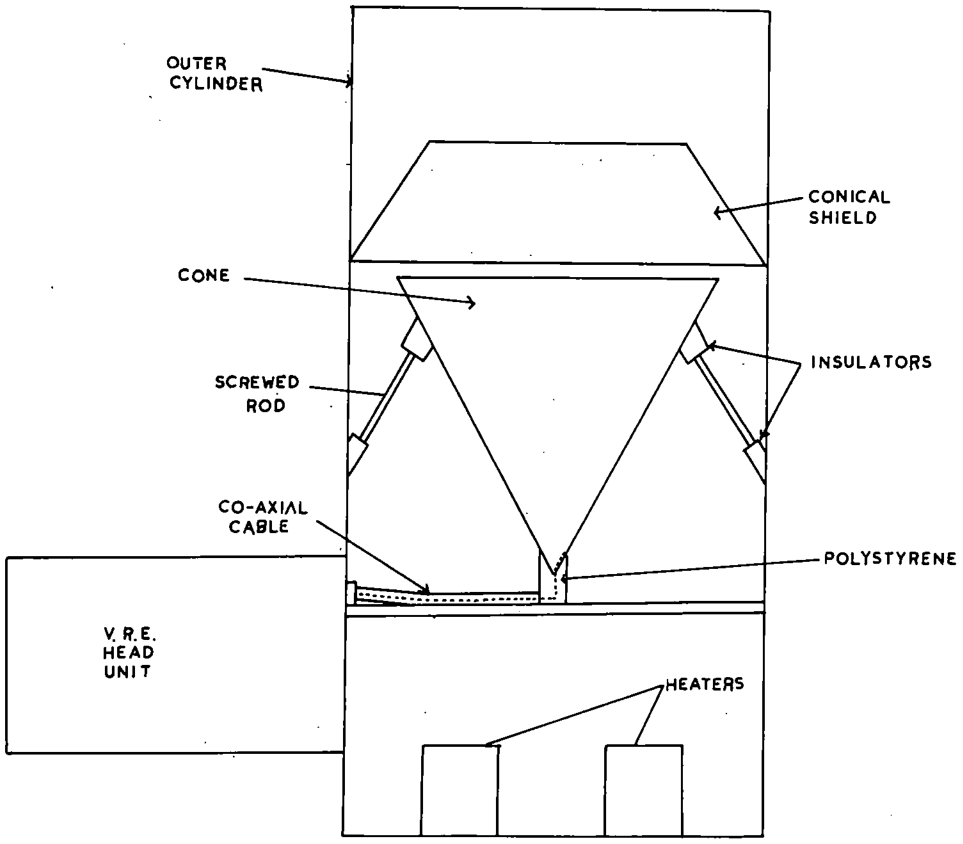


Fig.4

proof box close to the bottom of the mast and is shown in Fig.5, which shows the general view at the bottom of the mast.

The indicator unit amplified and rectified the signal from the head unit. The indicator unit

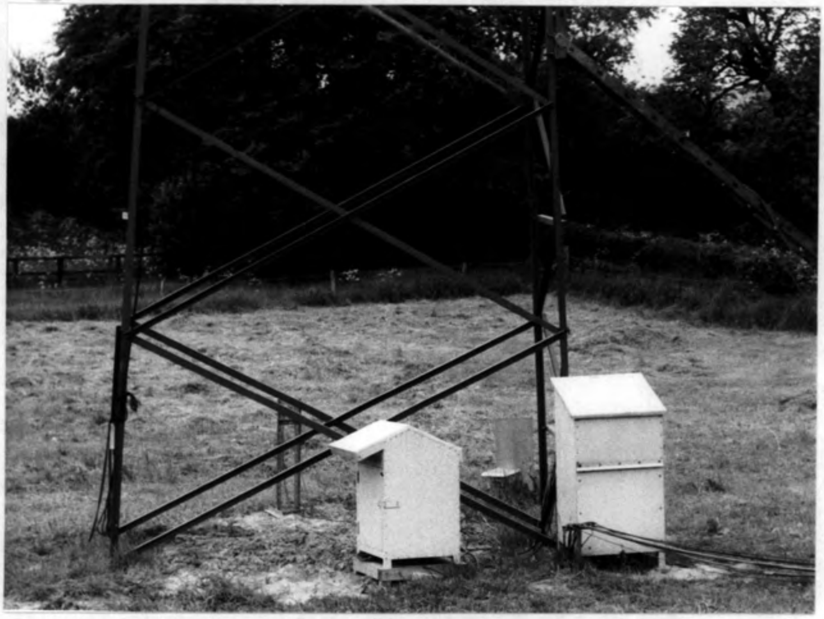


Fig.5

contained a built in sensitivity switch with the scales :- 0-30MV., 0-100MV., 0-300MV., and 0-1000MV. The output from the indicator unit was one milliamp for a full deflection on each scale.

The outputs from the indicator units were taken to another weatherproof box, again shownin Fig.5., and fed into a plugboard. From the plugboard the signal was taken directly to the observatory and after passing through the monitoring system, Fig.19, was passed directly to the galvanometer.

The indicator unit was set on the 300 MV range and the monitoring system was such that a full scale deflection was given on the monitoring meter for approximately a half full scale deflection on the indicator unit.

Five sensitivity ranges were incorporated in the monitoring system of each collector the least sensitive of which gave a full scale deflection on the photographic recording paper for the approximately half milliamp signal. The most sensitive scale was approximately thirty times more sensitive than the least sensitive.

A reversing switch was incorporated in the Observatory monitoring panel for each collector to facilitate the monitoring of the precipitation currents when they changed sign.

(d) Calibration

The calibration of the vibrating reed electrometerswas carried out by applying known D.C. voltages through the jack plug in the recording circuit of the indicator unit. To cut out any spurious effects from the collector the head unit was shorted out.

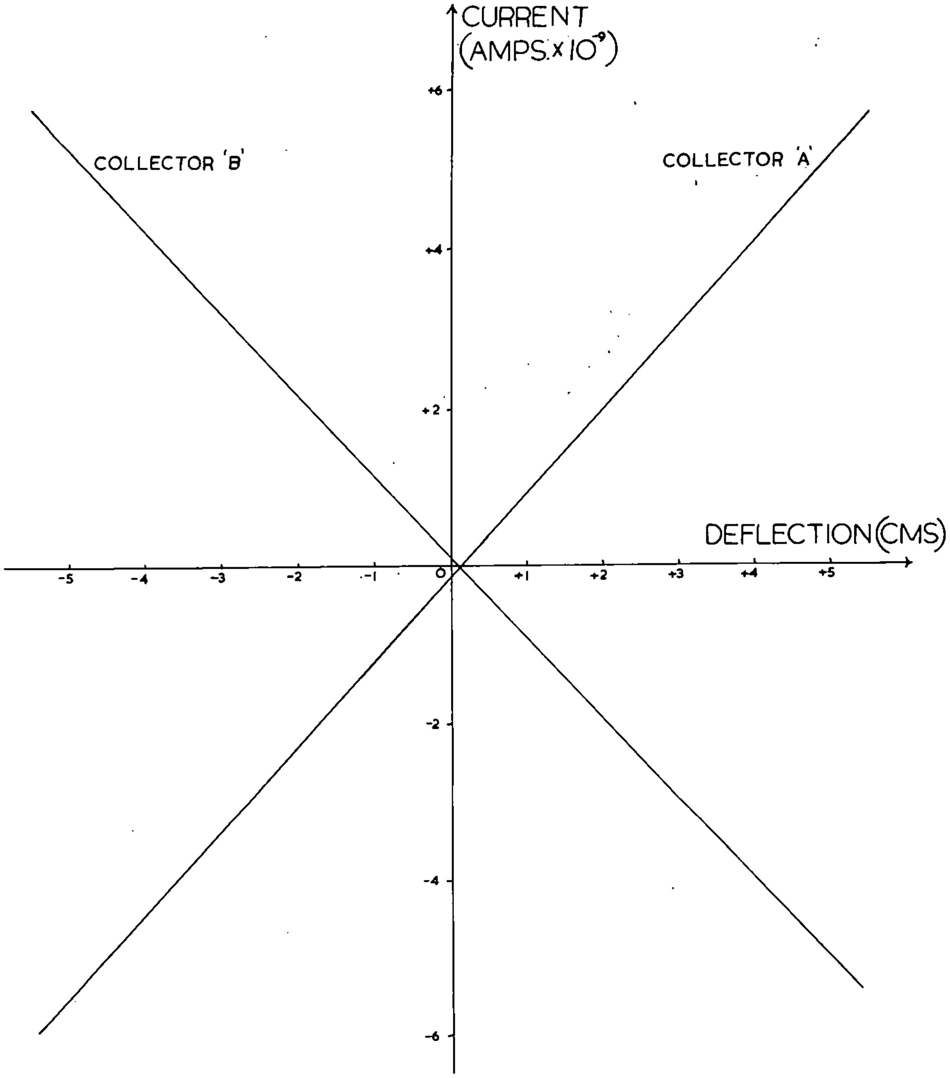

CURRENT
(AMPS.x10^{-9})
+6
+4
+2
-2
-4
-6
COLLECTOR 'B'
COLLECTOR 'A'
DEFLECTION (CMS)
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5

Fig.6

In order to calibrate the vibrating reed electrometer as a current measuring device it was necessary to know the input resistor in use as accurately as possible. According to the literature supplied with the vibrating reed electrometers the resistors were accurate to within 10%. The values of the resistors were checked by the method of leakage of a standard condenser and were found to be $(1.08 \pm .04) \times 10^{10}$ ohms for the nominal 10^{10} ohm resistors in each vibrating reed electrometer.

Using a potential divider voltages from 1 MV to 150 MV were applied. As it was intended for visual monitoring to be carried out wherever possible five sensitivity ranges were incorporated in the monitoring system. These were known as the '5', '15', '30', '80', and '160' ranges as a full scale deflection on recording paper for each range corresponded approximately to readings of 5, 15, 30, 80 and 160 MV on the indicator unit meter when set on the 300 MV range. The values registered by the monitoring microammeters when scale changes were necessary were noted, but when visual monitoring was not possible both collectors were set on the '30' range. Each range was calibrated in turn and the calibration of the '80' range for each collector is shown in Fig.6. It was arranged that when the sign of the precipitation currents from both collectors were the same their deflections on the photographic record were in opposite directions from the central zero to make for easier analysis of the records.

Full scale, 5 cms deflections on the five ranges corresponded to precipitation currents of 11, 34, 72, 171, and 345 $\mu\mu A/M^2$. As the records could be measured to an accuracy of 2 mm then the greatest sensitivity of the instrument corresponded to a current of 0.4 $\mu\mu A/M^2$. As Chalmers (1957) stated that the precipitation current during continuous rain was in the range 1-100 $\mu\mu A/M^2$ the system described should measure all the values of precipitation current encountered.

(e) Performance And Problems Encountered.

The collectors operated fairly satisfactorily over a period of 18 months during which they were outside, firstly at the Science Laboratories for testing, and then at the Observatory.

When the collectors were first outside at the Observatory they were very insensitive and did not even respond over violently to the cone being touched. This was probably due to moisture shorting out the input resistors. So the dessicators were removed and a small oven constructed to dry them. But when the dessicators were replaced the performance was even worse as possibly moisture had got into the head units. So the collectors were taken inside to dry out and spare dessicators obtained so that they could be changed every day if necessary. After this no further difficulties of insulation breakdown due to moisture were encountered even in the heaviest rainfall. Also insulation breakdown due to spiders' webs, as experienced by Merry (1960), never occurred.

When the first test records were taken the output signal from the indicator units were fed into a pen recorder. A large deflection, corresponding to an approximate 50MV deflection on the indicator unit, was observed during periods of no rain, and had a long period variation. But if the collector heaters were switched off the deflection fell to zero in about 15 minutes and returned to the original value when they were switched on again. This suggested that the cause was the evaporation of water in the cone. This was checked by emptying the cone and covering it with a zeroing plate but the deflections still occurred and varied from approximately 20 MV to over 100 MV from day to day. This showed that evaporation from the cone was not the cause, but the heaters were possibly causing evaporation of the moisture on the ground. If the evaporation caused a charge separation then part of this charge would come into contact with the cone and be recorded. This would account for the day to day changes in the magnitude of the recorded signal. So the bases of the collectors were filled in with an aluminium plate and the spurious signal was not observed again. This effect probably accounts for the large zero deflection that varied from day to day and even during recording that was reported by Merry (1960).

A large steady zero deflection was recorded by one of the collectors but this was eliminated by isolating the leads carrying the signal from the rest of the equipment at the plug board and the monitoring panel. The probable cause was contact potentials at these two earth points.

The only other difficulty encountered was when a component of one of the indicator units burnt out.

2. The Agrimeter

(a) Introduction And Theory

Due to the large potential gradients at the top of the mast it was decided to use an agrimeter of similar basic design to that of Chalmers (1953), but of much smaller dimensions, there.

The advantages of the agrimeter are that it gives the sign of the potential gradient directly and the signal from the instrument can be fed to a galvanometer without amplification.

A diagram of the agrimeter is shown in Fig.8. In the agrimeter a moving plate passes under an opening in an earthed cover. As the plate passes under the opening it is connected to earth and it's upper surface then carries a charge proportional to the number of lines of force ending on it. So the charge carried by the plate is proportional to the potential gradient. The earth connection is then broken and the plate moves on carrying it's charge with it. After passing under the cover it gives up a proportion of it's charge to a contact which acts as a 'collector'. The collector is connected to a galvanometer and if the potential gradient remains constant then each time the plate reaches the collector it carries the same quantity of charge.

So a pulsed current flows through the galvanometer and if the period of oscillation of the galvanometer is far greater than the period between successive pulses then the galvanometer shows a steady deflection for a constant potential gradient. The response of the instrument to changes in potential gradient is governed only by the response time of the galvanometer.

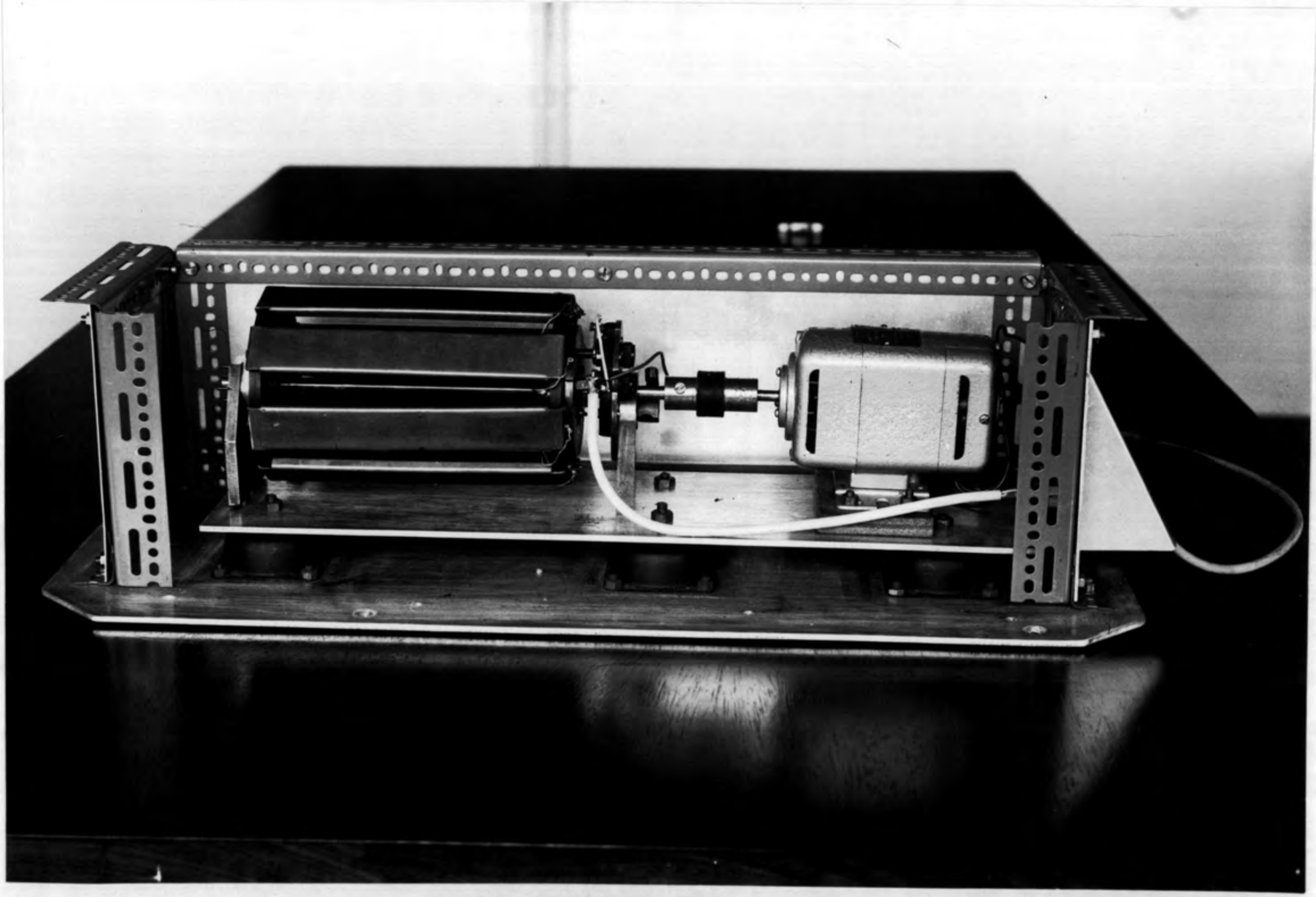


Fig.7

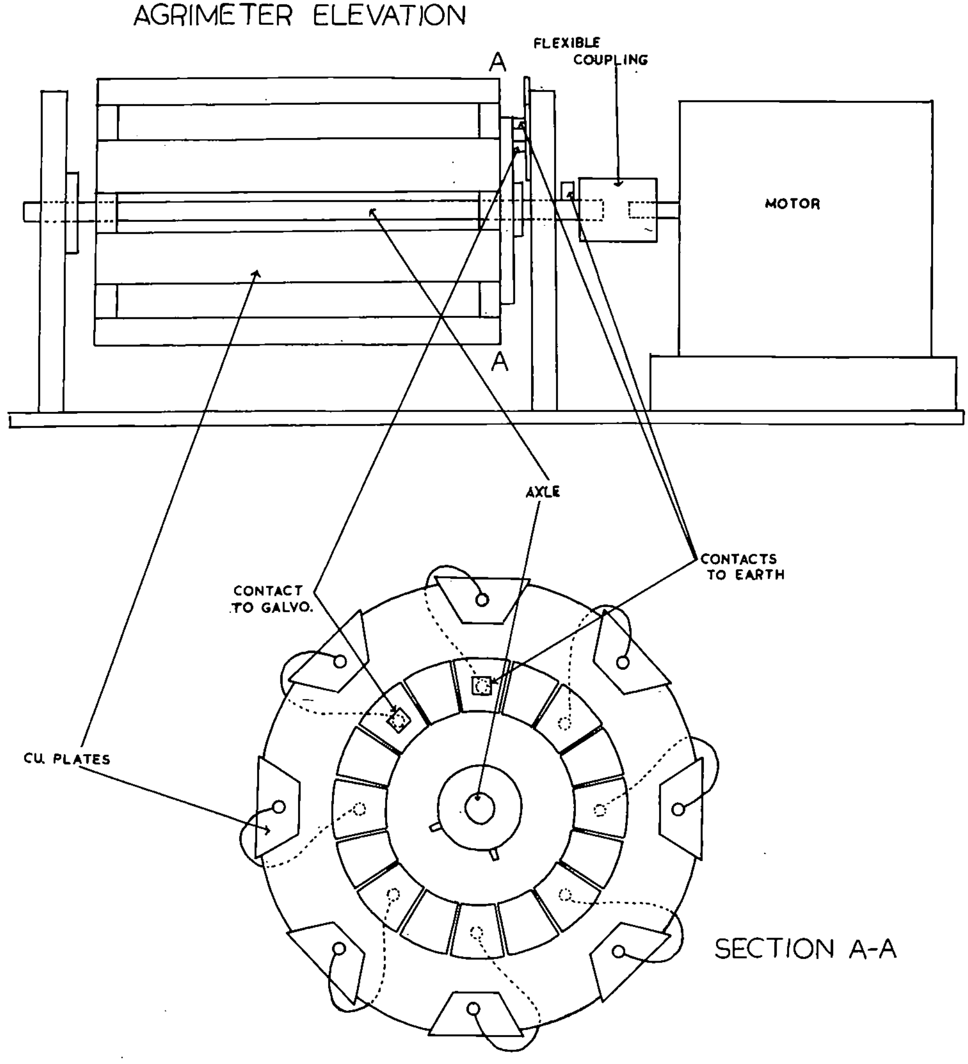

AGRIMETER ELEVATION
A
FLEXIBLE
COUPLING
MOTOR
A
AXLE
CONTACTS
TO EARTH
CONTACT
TO GALVO.
CU. PLATES
SECTION A-A

Fig.8

If the effective area of the plate exposed to a potential gradient of magnitude F volts/metre is $A\,cm^{-2}$, then the charge carried by the plate is given by,

$$Q = \frac{FA}{36\,\pi} \times 10^{-13} \qquad (1)$$

If C is the capacity of the plate when in contact with the collector; D the capacity of the collector, cable, and connected apparatus; R the resistance between the cable and earth; and T the time between successive contacts of the plates and the collector. Then if $C \ll D$ and $T/R \ll D$, the average current flowing through R is given by

$$I_r = \frac{Q}{CR + T} \qquad (2)$$

So if R is small $I_0 = \frac{Q}{T} = \frac{FA}{36\,\pi\,T} \times 10^{-13}$ amperes (3)

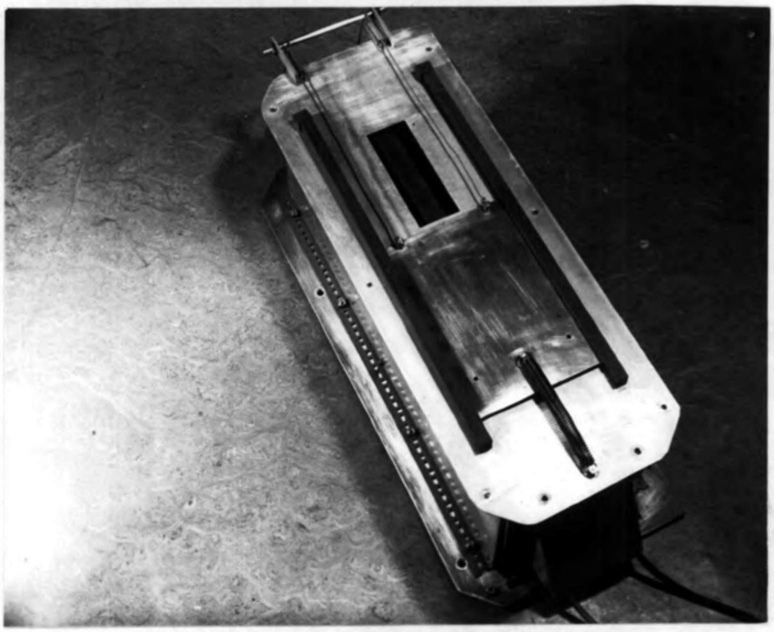
(b) Construction

A general view and two sectional diagrams of the agrimeter are shown in Figs. 7 and 8.

A 1/15 H.P. motor, giving a maximum of 4500 revs/min but which could be varied to any required rate of revolution by adjusting a series resistor, was used to drive a steel shaft through a flexible coupling. The steel shaft was supported by two tufnol bearings, mounted in steel supports, a distance of 20cms apart.

On the shaft were mounted two tufnol discs, each of 9cms diameter and 6 mm thickness, a distance of 16.5cms apart. Eight identical copper plates of area $33\,cms^{-2}$ were attached round the rims of the discs at equal intervals parallel to the shaft. The discs were fixed to the shaft and rotated with it.

On one of the discs, as shown in Section A-A



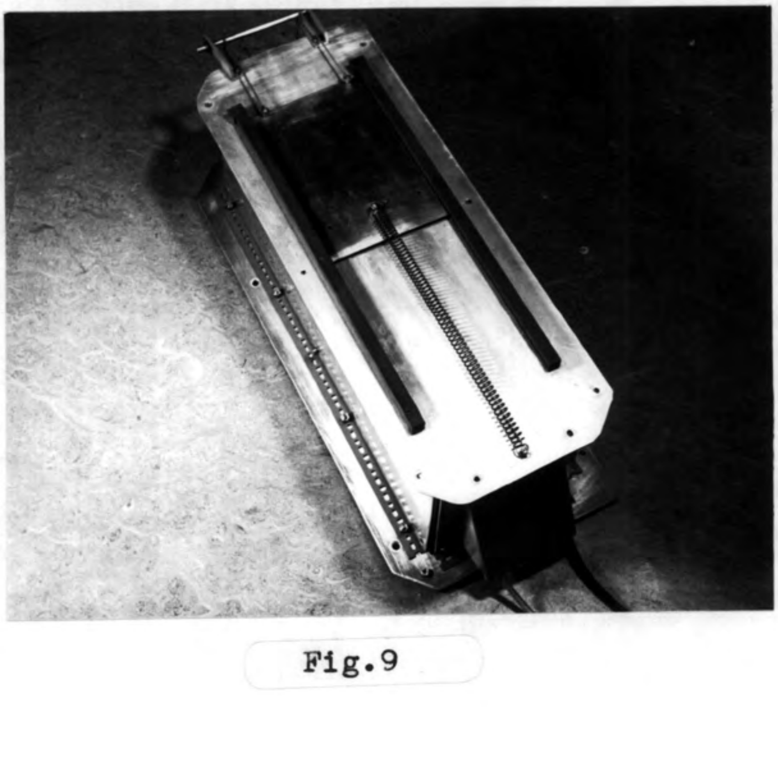


Fig.9

of Fig.8., were mounted 16 equal brass sectors insulated from each other and concentric with the shaft. Alternate sectors were connected to the corresponding copper plate nearest to the sector.

Two spring loaded carbon brushes formed the contacts to earth and to the galvanometer, the latter being termed the 'collector'. The brushes were fitted to make contact with the sectors. The contact to earth was connected to the plate when the plate was directly exposed to the electric field. This plate then came into contact with the collector after rotating through 45°. Another carbon brush connected the shaft to earth.

The instrument was mounted on a steel base which in turn was supported by antivibration mountings. The antivibration mountings were important as the instrument was bolted directly to the mast close to the rain collector and any appreciable vibration would have effected both instruments. The whole instrument was enclosed in an aluminium case.

The agrimeter was zeroed by a mechanical arrangement by which an earthed copper plate moved across the opening in the earthed cover. It was operated by a cord at the foot of the mast. The plate moved along tufnol guides and a spring attached to the plate returned it to its original position when the cord was released. Figs.9 show the agrimeter with the plate in the normal running position and in the zeroing position.

Due to the dependence of the agrimeter output on the rate of revolution of the motor a constant voltage transformer was used.

(c) Calibration

The calibration of the agrimeter was carried out using the calibration plates shown in Fig.11, and using the identical cables and associated equipment to be used during recording. The agrimeter was sunk into a pit in the ground such that the earthed cover was in the same plane as the lower calibration plate. The second calibration plate was separated from the lower one by tufnol insulators 5 cms. long and so formed a parallel plate condenser.

Five sensitivity ranges were incorporated in the monitoring system by the use of suitable shunts on the galvanometer. These were known as the '32', '100', '300','900','2700' ranges. These scale values were connected in some original calculations to the equivalent potential gradients at the ground for those recorded at the top of the mast, to give full scale deflections on the recording paper. But subsequent alterations to the instrument and errors in the estimate of the exposure factor of the mast and the effective area of the plate exposed when in the earthed position. So the scale values had no meaning except as a guide to their relative sensitivities.

Each of the scales were calibrated in turn for both negative and positive potential gradients. The calibration of the '32' range is shown in Fig.10.

In the instrument the opening in the earthed cover was such as to expose 20 cm^{-2} of the copper plate when earthed.

For a potential gradient of 5000 volts/metre and a motor speed of 2000 revs./min., T = $^{3}/800$ secs,

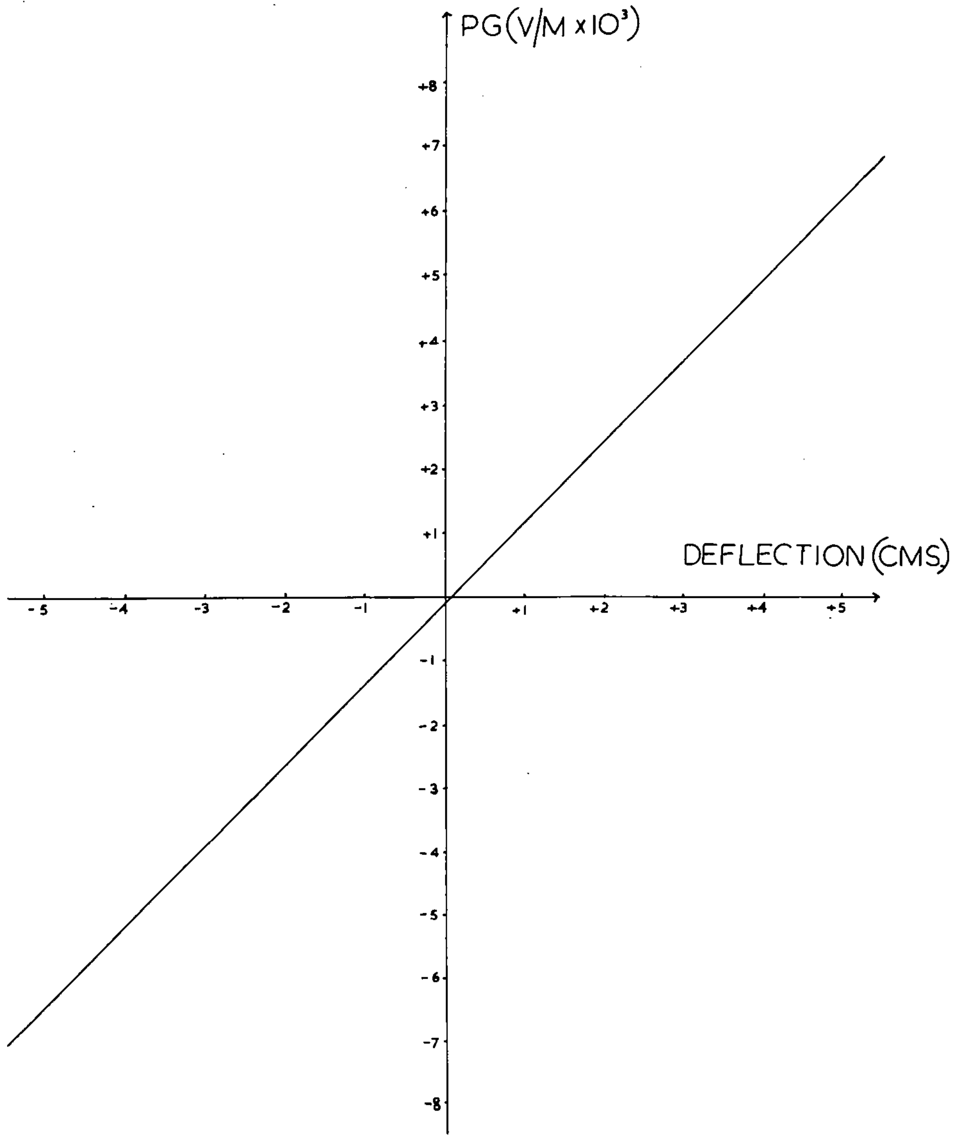


Fig.10

Fig.11

then the theoretical output of the instrument was given by III 2a(3) as

$$I_0 = 2.34 \times 10^{-8} \text{ amperes.}$$

But the current registered by the galvanometer was

$$I = 1.5 \times 10^{-8} \text{ amperes.}$$

The difference between the theoretical and practical values was because the effective area of the plate exposed was smaller than the opening in the earthed cover due to the partial shielding of the potential gradient by the earthed cover. Also, to a lesser extent, the difference was due to R, the resistance between the cable and earth, being not sufficiently small to be completely neglected.

On the most sensitive scale a deflection of 1 cm was obtained on the record for a potential gradient of 1200V/M at the top of the mast.

The instrument had a zero output equivalent to a positive potential gradient of 90 volts/metre.

The calculation of the exposure factor for the instrument will be discussed in Chapter V,2.

(e) Performance and Problems Encountered

The agrimeter was placed in position at the top of the mast just below the collector and its output signal was fed into the plugboard at the bottom of the mast before being taken to the monitoring and recording systems in the Observatory.

Initially a 130 ohm resistor was used in series with the motor to give the required rate of rotation. But it was found that the instrument took too long to accelerate to the constant rate of rotation required. So a 90 ohm resistor was placed in parallel with the 130 ohm resistor and a switch incorporated so that the 90 ohm resistor was in series with the motor for 30 secs after switching on so enabling the agrimeter to accelerate faster. The switch was then reversed to bring in the 130 ohm resistor.

With the 130 ohm resistor in series the rate of revolution was approximately 2000 revs./min., but it was found that this corresponded to a resonant vibration frequency of the instrument. The resulting vibration caused the tufnol bearings to get hot and the rate of revolution dropped by about 10% over a period of two hours. Consequently there was a 10% reduction in the output signal for a constant value of the potential gradient. But it was found that if the 90 ohm resistor was used at all times the rate of rotation increased to approximately 2350 revs/min. At this rate of rotation the vibration was practically non existent and the magnitude of the output signal showed no measurable change, for a constant potential gradient, over a period of four hours. The calibration of the agrimeter had shown that it's output signal varied in a linear way with the potential gradient and the rate of revolution. So the rate of revolution was accurately determined, ± 20%, using an oscilloscope and the calibration curves were recalculated.

When records were being taken the agrimeter was zeroed approximately every half hour for a period of 30 secs. But during the record of May 19th it was found that after about five hours of continuous rain a large zero drift occured in the agrimeter output signal. So during the remainder of this record zeroing was carried out more frequently. On investigation afterwards it was found that the

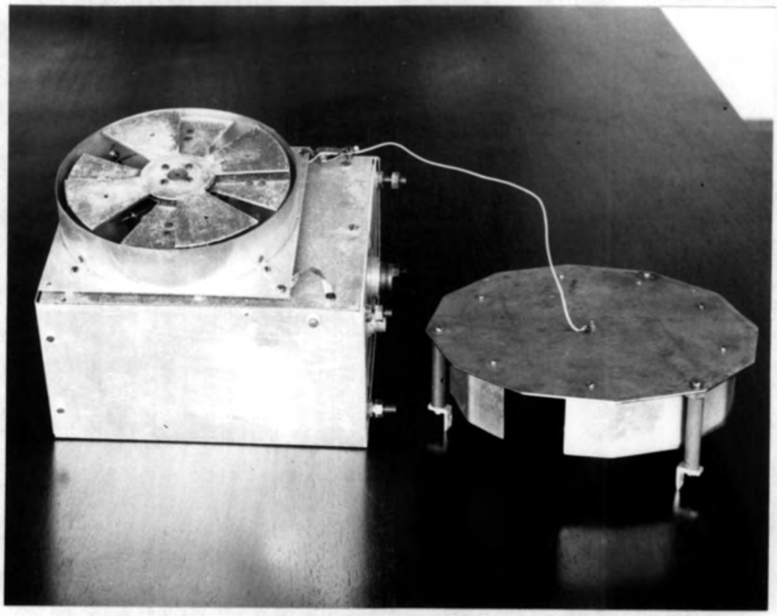


Fig.12

coaxial plug and socket where the signal cable left the agrimeter were very wet, and so the zero drift was probably due to contact potentials associated with this moisture. A shield was then built to cover the plugs and the trouble did not recur.

Apart from these faults the agrimeter worked satisfactorily during the period of record.

3. The Field Mills

(a) Introduction

Due to the lower value of the potential gradient at the bottom of the mast it was decided to use field mills, similar to those described by Mapleson and Whitlock (1955), both there and as the calibration instrument.

The majority of the work connected with the field mills was carried out by Collin, and so only a brief account will be given here and for further details the reader is referred to Collin (1962 and 1963). The main contribution of the author to this work was in the construction of a mill amplifier.

(b) Sign Discrimination

Collin (1962) devised a new method of sign discrimination. A low positive voltage was applied to the rotor for three seconds every half minute and this produced pulses on the record. The direction of the pulses gave the sign of the potential gradient. If the pulses increased the magnitude of the potential gradient the potential gradient was positive, while those that decreased the magnitude showed the potential gradient to be negative. The pulses can be seen on the records shown in Figs. 29 and 30.

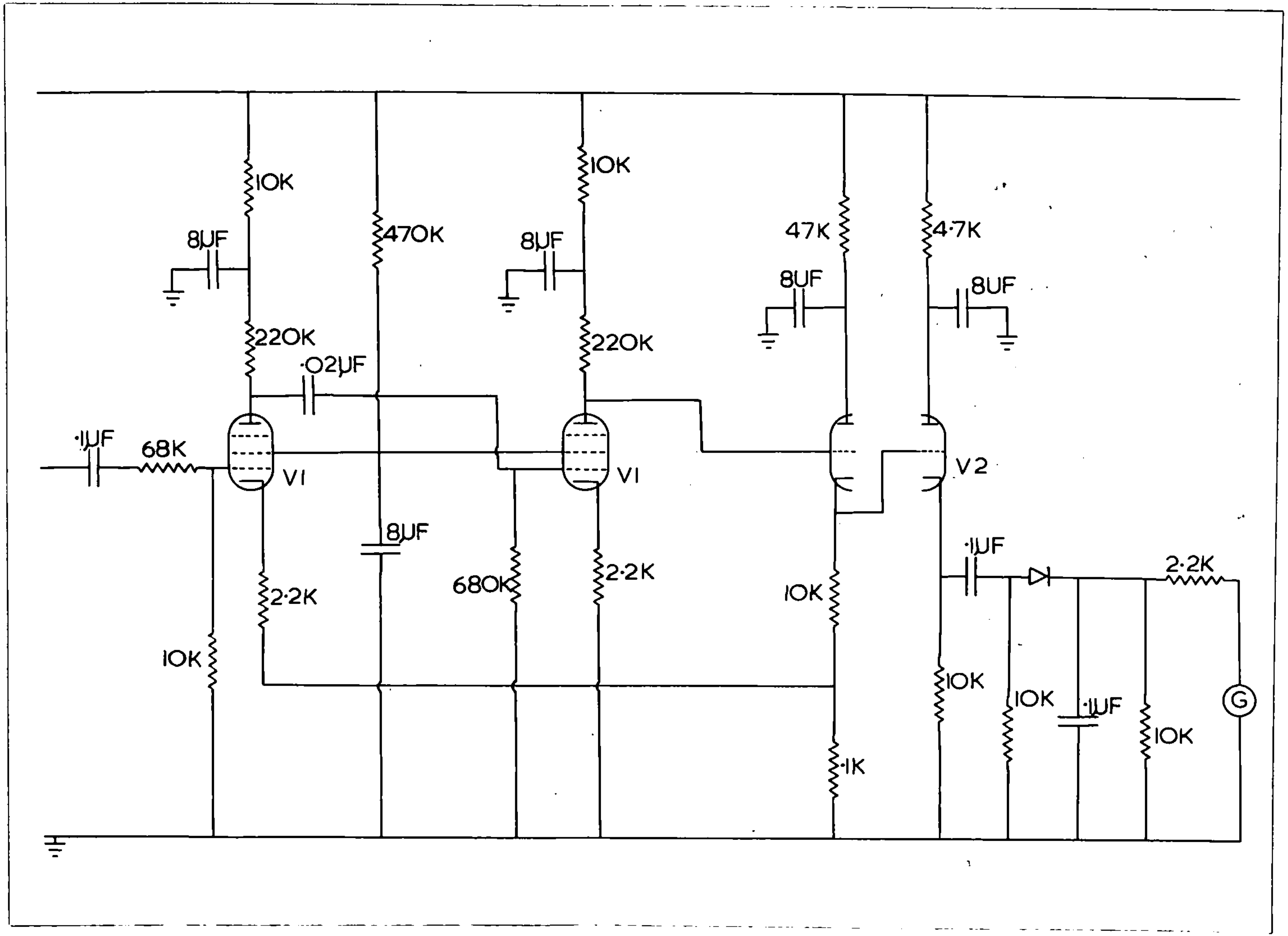

10K
8µF
220K
·02µF
·1µF
68K
V1
2·2K
10K
470K
8µF
10K
8µF
220K
680K
V1
2·2K
47K
8UF
10K
·1K
4·7K
8UF
V2
·1µF
2·2K
10K
10K
·1µF
10K
G

Fig.13

Similar amplifiers were used with each mill and were of the same basic design as those of Milner (1959). The amplifier circuit is shown in Fig.13.

(c) Calibration

The field mills were calibrated in the same way as the agrimeter. Five sensitivity ranges were incorporated in the monitoring system of each mill, namely the '50', '150', '300', '600', and '1250' ranges. Each was calibrated in turn and the calibration curves for the two mills on the '300' range are shown in Figs. 14 and 15.

Due to rectification the signal always produced deflections in the same direction and it was arranged to have the zero near to one edge of the recording paper. So the full scale deflection was approximately 10 cms instead of 5 cms as for the other instruments.

(d) Performance

It was found that after considerable rain, water tended to drip onto the rotor and caused a fluctuating output. To reduce this effect the rotor and stator were surrounded by a shield as shown in Fig.12.

The output from the mill at the bottom of the mast, mill A, was found to be reduced when the calibration mill, mill B, was operating at the same time, as the two running together effected the power supply. So when mill B was running the recorded output from mill A was multiplied by a calculated factor. Otherwise the mills, especially mill A, worked satisfactorily.

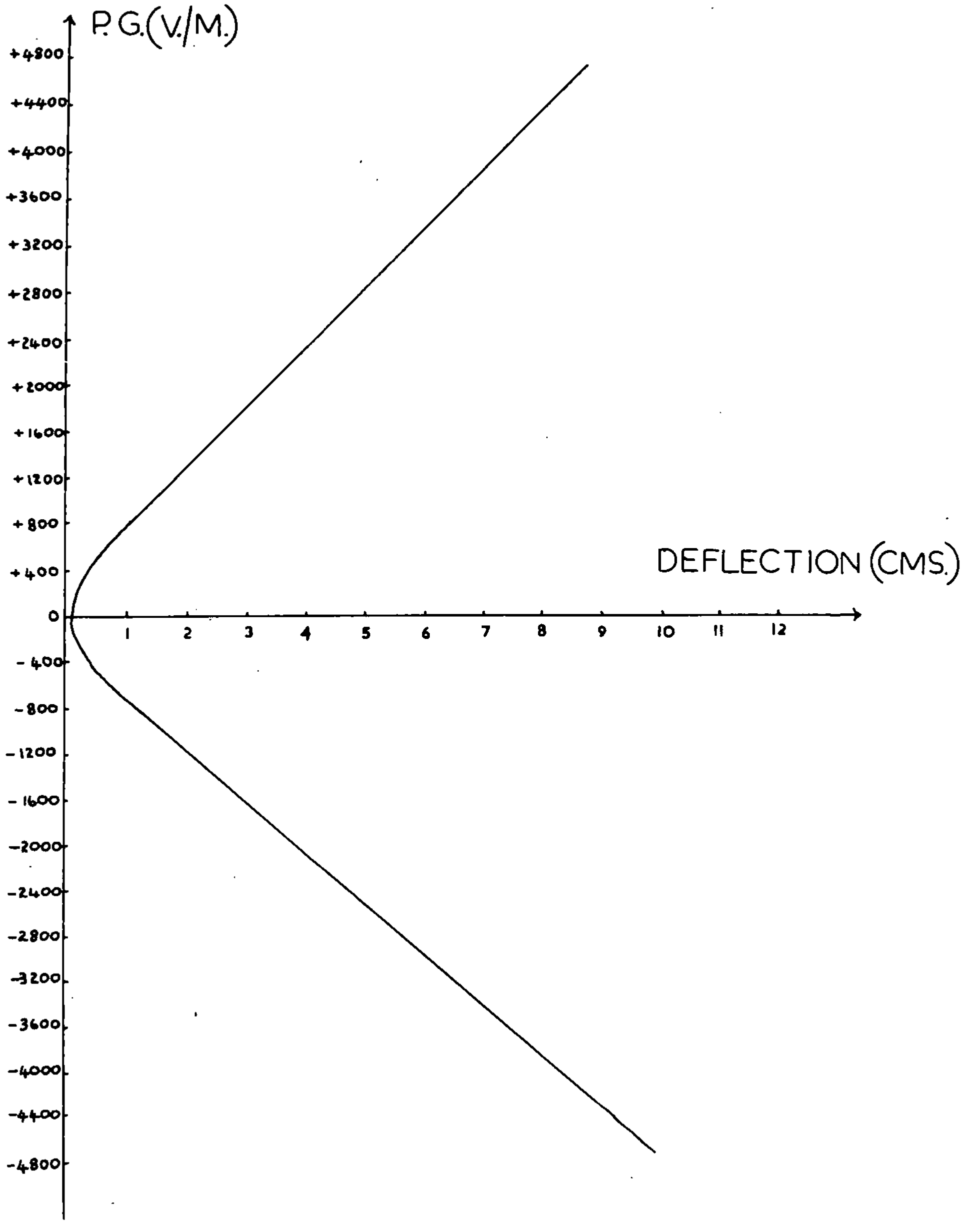

P.G.(V./M.)
+4800
+4400
+4000
+3600
+3200
+2800
+2400
+2000
+1600
+1200
+800
+400
0
-400
-800
-1200
-1600
-2000
-2400
-2800
-3200
-3600
-4000
-4400
-4800
DEFLECTION (CMS.)
1
2
3
4
5
6
7
8
9
10
11
12

Fig.14

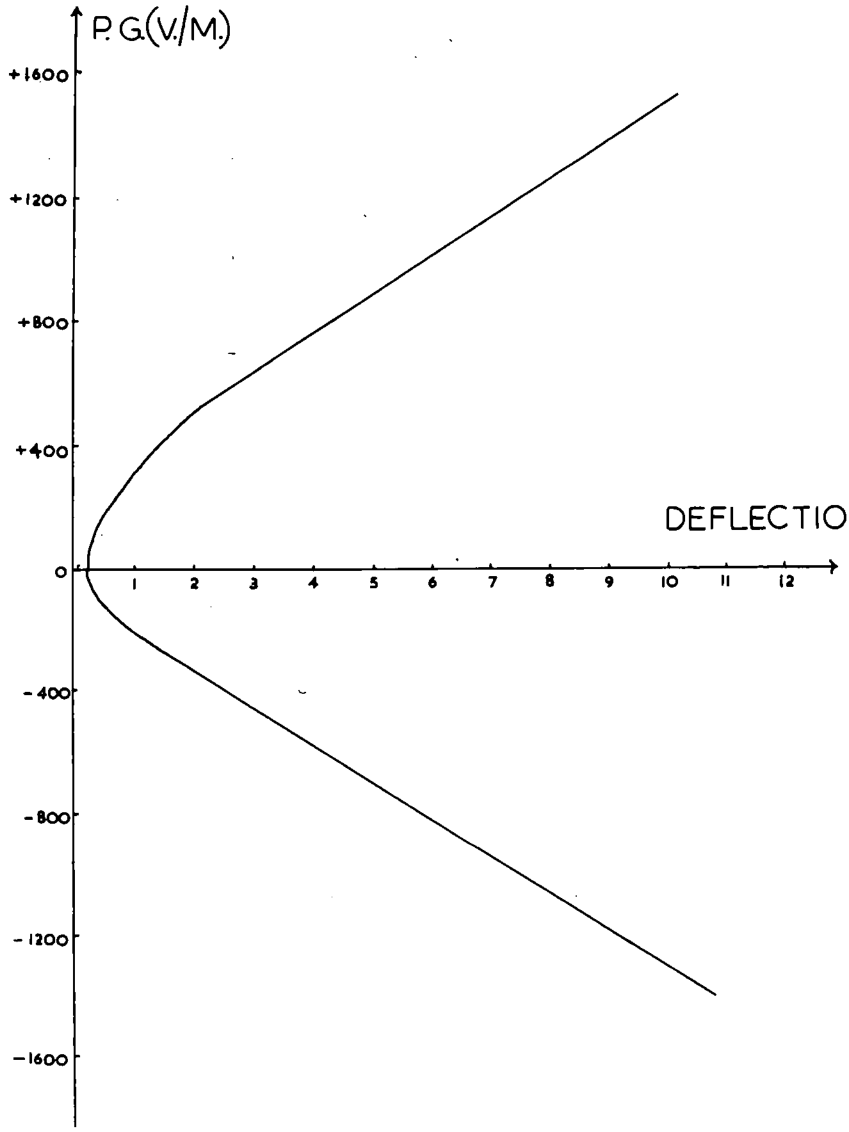

P.G.(V./M.)
+1600
+1200
+800
+400
0
-400
-800
-1200
-1600
DEFLECTION (CMS.)
1
2
3
4
5
6
7
8
9
10
11
12

Fig.15

4. The Rate Of Rainfall Recorder

(a) Introduction

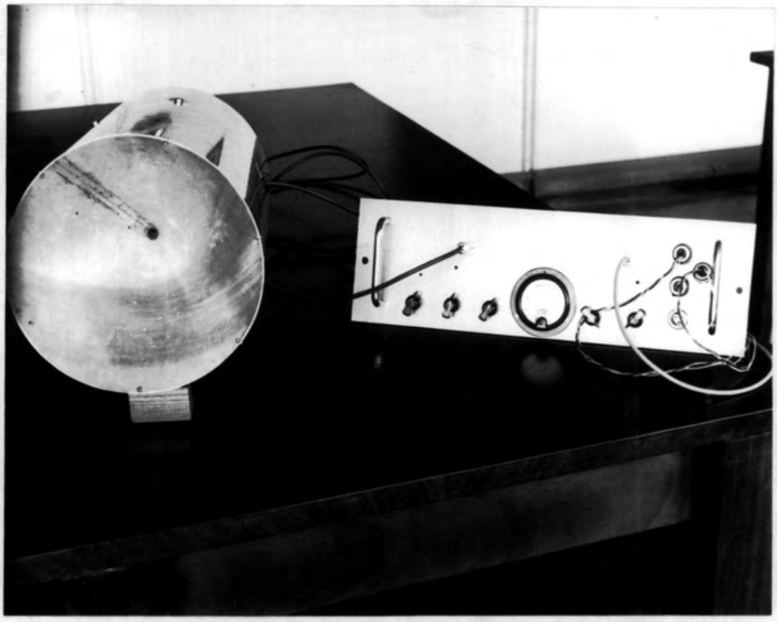
As previously mentioned the value of the precipitation current depends on the rate of rain fall. Amongst methods of measurement of the rate of rainfall has been the one of Scrase (1938) and Simpson (1949) who measured the interval between successive fillings of a vessel which tilted and emptied when full. The vessel was incorporated in the collector, but it only gave the average rate of rainfall between successive emptyings of the vessel. Ramsay and Chalmers (1960) measured the variation of the capacity of a parallel plate condenser as it filled up with water. So it was possible to determine the rate of rainfall at any instant.

The instrument constructed followed the basic design of Adkins (1959c). The rain fell into a cone at the bottom of which was a nozzle which produced drops of a constant size. They fell through a grid of parallel wires, and in so doing instantaneously completed a circuit which triggered a monostable multivibrator. The output from the multivibrator was integrated by a Miller integrator and the output was proportional to the rate of production of drops, and so to the rate of rainfall.

Due to the collapse of the mast the instrument was not used simultaneously with the other instruments, but the construction and approximate calibration were completed.

(b) Construction

The aluminium collecting cone was soldered into the top of an aluminium cylinder as shown in



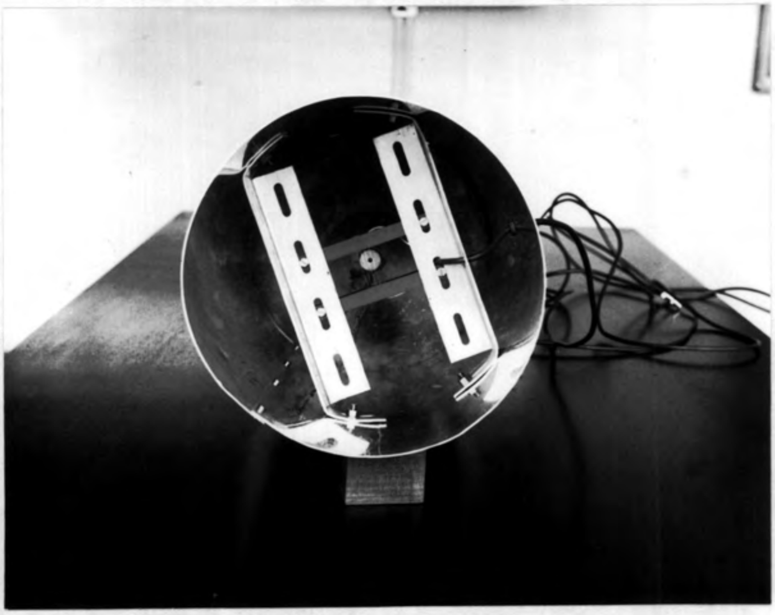


Fig.16

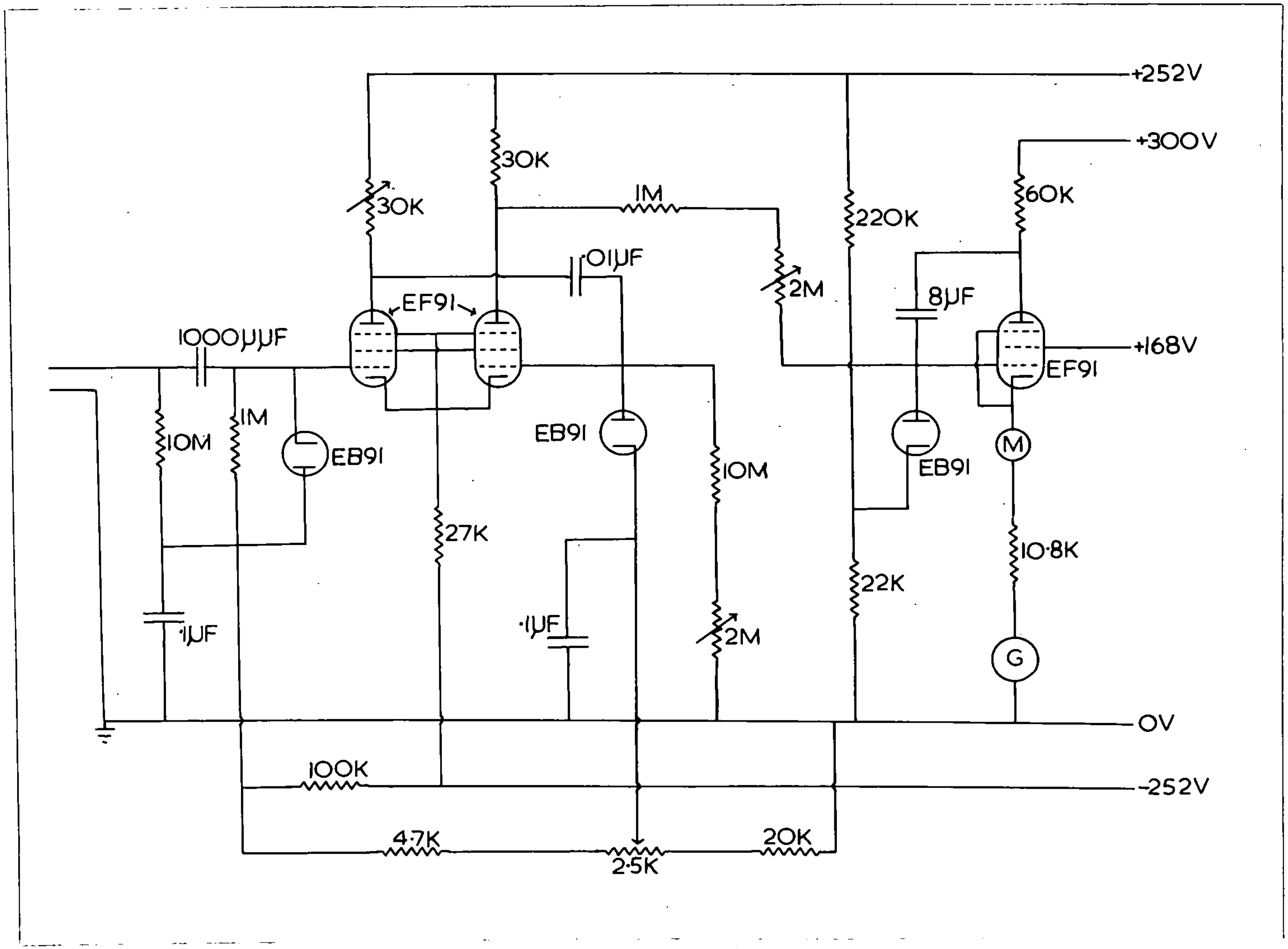

+252V
+300V
+168V
OV
-252V
30K
30K
1M
220K
60K
·01µF
2M
8µF
1000µµF
EF91
EF91
EB91
EB91
EB91
10M
1M
27K
10M
22K
M
10·8K
·1µF
·1µF
2M
G
100K
4·7K
2·5K
20K

Fig.17

Fig. 16. The nozzle was made of brass and of such dimensions that the water in the cone could always bridge the throat of the nozzle. By heating to red heat an oxide layer was formed on the nozzle which ensured that the surface wetted easily. The volume of 500 consecutive drops falling through the nozzle was determined three times and found to be constant.

The wire grid, made of platinum to avoid corrosion due to the rainwater, was adjustable to ensure the correct position of the grid below the nozzle. Alternate wires of the grid were connected to the earthed shield and the central wire of a coaxial cable. The cable led to the electronic section of the apparatus shown in Fig.17.

The 2 megohm potentiometer enabled the time constant of the instrument to be varied from 20 to 60 seconds.

(c) Calibration And Performance

Water was allowed to fall into the cone at a known rate from a pipette. The rate was varied and the deflections produced recorded photographically. The calibration was repeated and it was found that the peaks due to individual pulses could not be detected for a time constant greater than 30 secs and for a rate of rainfall greater than 1 mm/hour.

An exact calibration was not carried out but the approximate one showed that the instrument was probably suitable for the work.

5. Auxiliary Apparatus

(a) Recording System

Four Tinsley and one Pye mirror galvanometers were used of current sensitivities ranging from

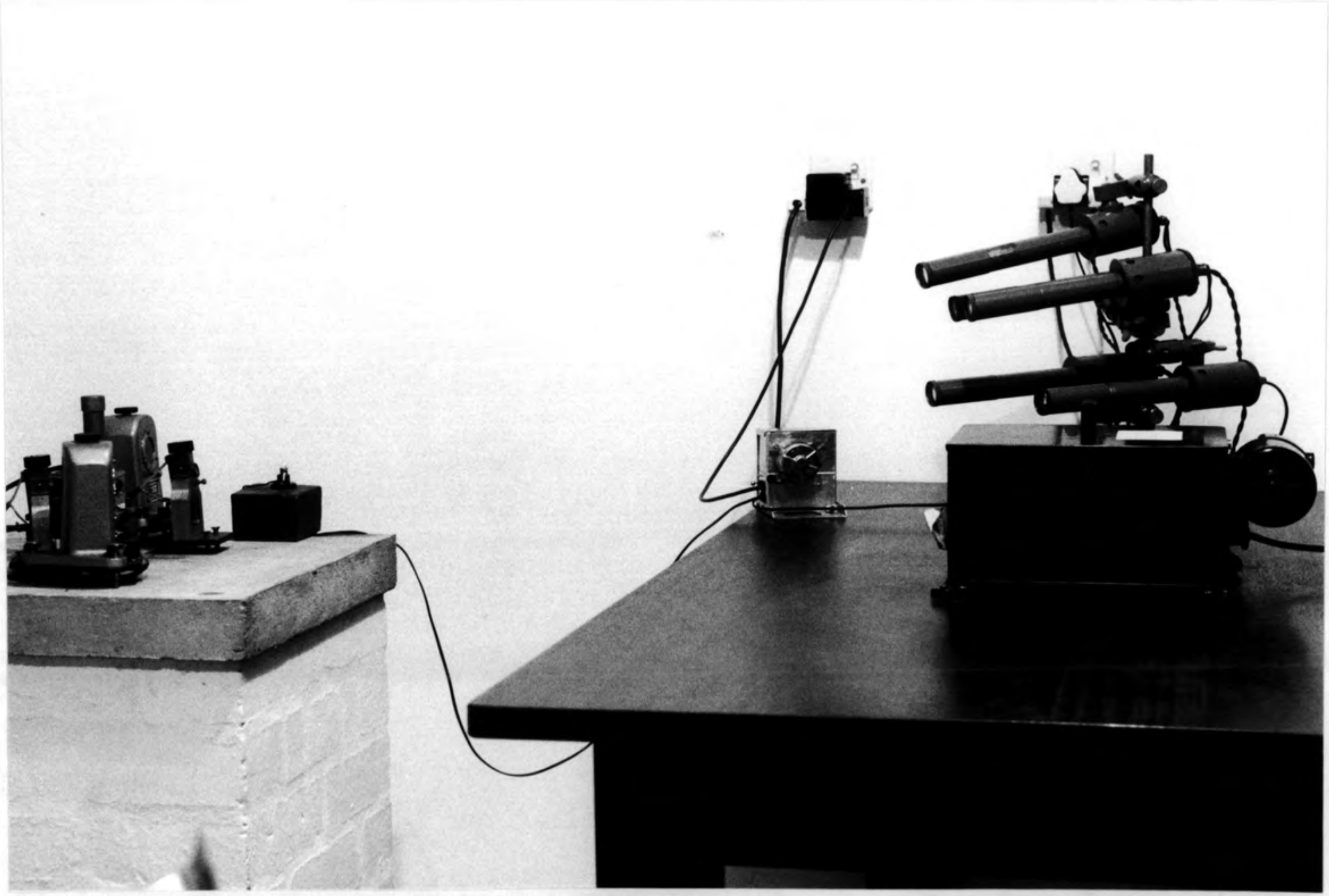


Fig.18

5.4×10^{-9} amperes/cm to 3.7×10^{-9} amperes/cm at a distance of one metre between the galvanometer and scale. The signal from the agrimeter was taken directly to the monitoring system without amplification and for low values of potential gradient the complete signal was fed directly to the most sensitive galvanometer. The recording system is shown in Fig.18.

Using standard galvanometer lamps spots of light were reflected from the galvanometer mirrors on to a slit camera carrying 120 mm sensitised paper. The camera motor was mains operated and the rate of rotation was such that 5 minutes of recording appeared on 8 cms of film. Examples of the records are shown in Figs. 29 and 30.

A synchronous motor, 1 rev./min, was used with a suitable cam to switch off the supply to the fogging lamp for 3 seconds every half minute. So white lines were produced on the film at half minute intervals and these acted as a time scale.

(b) Monitoring System

All monitoring was carried out in the Observatory and the monitoring system is shown in Fig.19. as part of the schematic diagram of the complete experimental set up. Fig.20 shows the rack mounting of the monitoring panel, amplifiers, and power supplies.

Due to the low signal a scalamp galvanometer was used to monitor the agrimeter. The precipitation current variations were observed on two suitably shunted 100 microamp. meters.

As no great differences were expected in the magnitude of the outputs from the two mills the circuit was designed so that each could be monitored in turn on ~~a~~ one 250 microamp. meter.

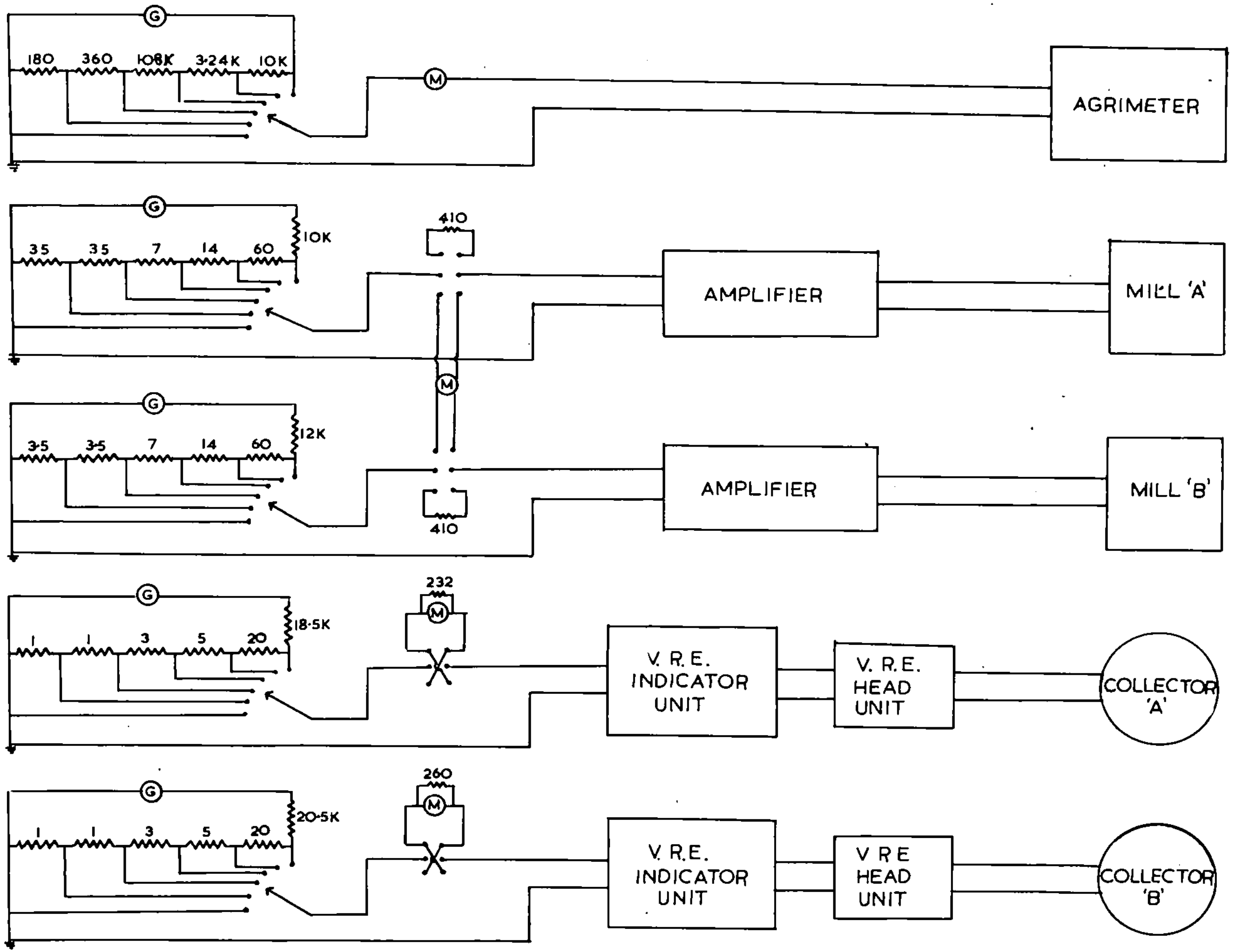

G
180
360
1·08K
3·24K
10K
M
AGRIMETER
G
35
35
7
14
60
10K
410
AMPLIFIER
MILL 'A'
M
G
3·5
3·5
7
14
60
12K
410
AMPLIFIER
MILL 'B'
G
1
1
3
5
20
18·5K
232
M
V. R.E. INDICATOR UNIT
V. R.E. HEAD UNIT
COLLECTOR 'A'
G
1
1
3
5
20
20·5K
260
M
V. R.E. INDICATOR UNIT
V R E HEAD UNIT
COLLECTOR 'B'

Fig.19

(c) Cables

At the commencement of the work all the cables in the Observatory field were pulled up as many had become overgrown. All the new mains and coaxial cables were carried between the Observatory and the mast on 'T' supports about 16 inches high.

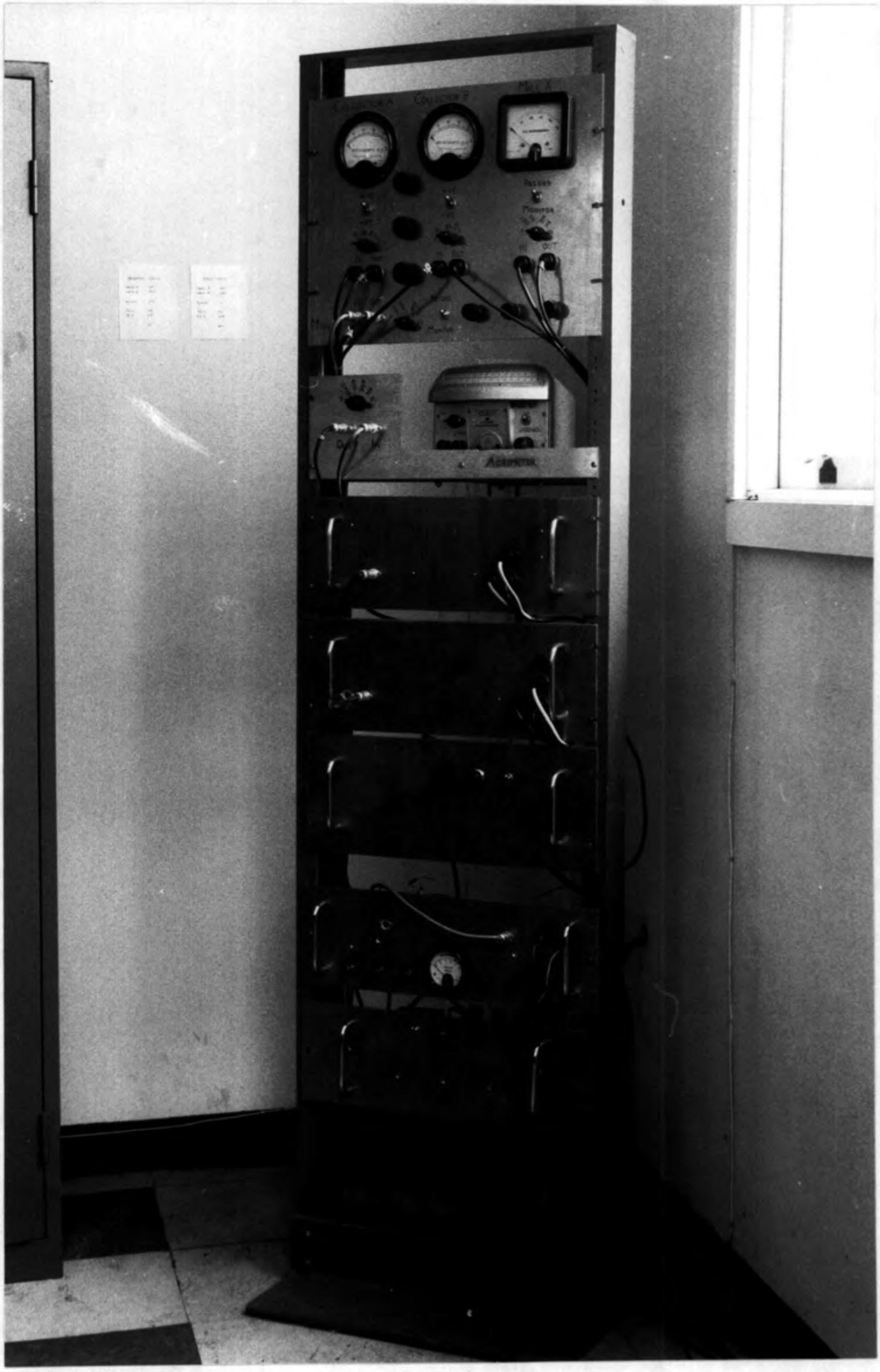


Fig.20

CHAPTER 4

EXPERIMENTS ON THE EFFECT OF SPLASHING

(1) Introduction

As previously mentioned the potential gradient at the top of the mast is extremely large. As the upper edge of the outer cylinder of the collector is the uppermost level of the mast structure then the potential gradient will tend to have its largest value at this position. Also even though the inner conical shield is itself shielded by the outer cylinder the potential gradient still has a large value close to it. So when drops are in the vicinity of the upper collector they are in a region of very high potential gradient.

Magono and Koenuma (1960) measured the charge on water droplets produced when drops were broken while under the influence of a potential gradient of 2000 volts/metre. They found experimentally, and put forward a theoretical explanation, that the charge on the droplets was due to electrostatic induction as the sign of the charge on the drops changed when the sign of the potential gradient changed.

So when the raindrops strike the outer or inner shields of the collector they are broken up into a number of droplets and this takes place in a region of high potential gradient. Some of these droplets will enter the cone and their charge will be recorded. So it would seem possible that this effect is responsible for the sudden peaks that occur in the precipitation current as recorded at the top of the mast and may make a considerable contribution to the total current recorded there.

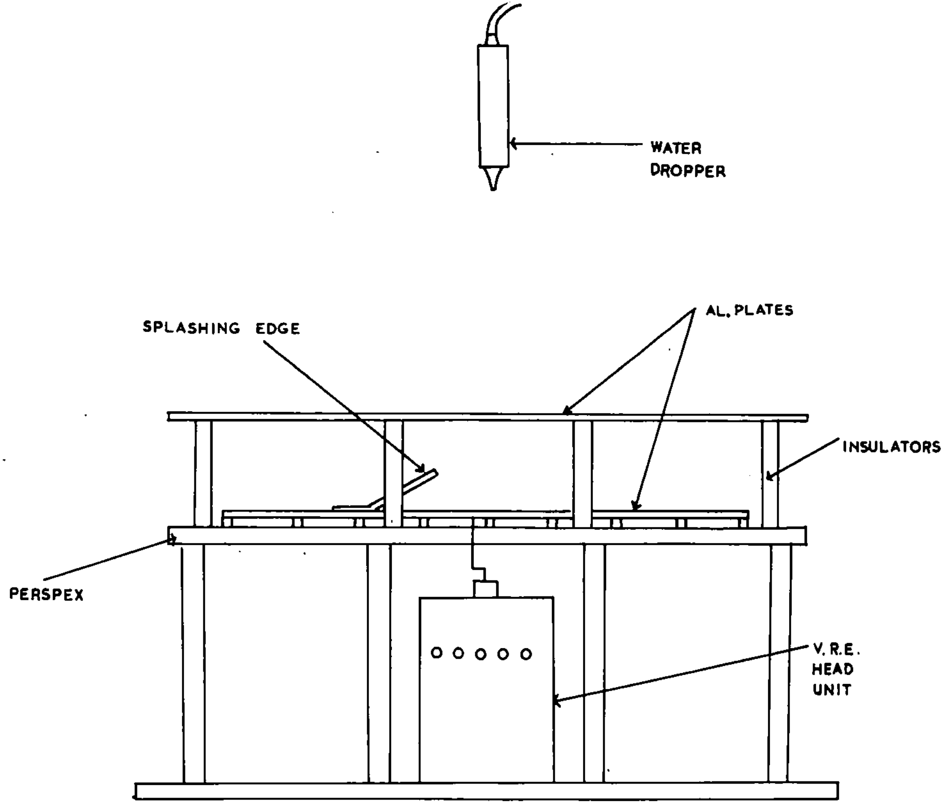
The aim of the experiments was to establish, in the laboratory, conditions similar to those at the upper collector, and to then investigate the dependence of the charging effect on the potential gradient. Also to see if the amount of splashing, and hence possibly the amount of spurious charge produced in this way, could be reduced by covering the shield edges with some form of material.

Raindrops fall at all times directly on to the surface of the collector cone and on to any water residing in the bottom of the cone. Although the potential gradient at this position would be very much lower than at the edges of the shields the charging on such impacts was also investigated. If an exposure factor of 100 is assumed for the collector and the shielding efficiency is 98% as claimed by Scrase (1938) it would still be possible to have a potential gradient of the order of 1000 volts/metre at the cone during the conditions being investigated in the present work.

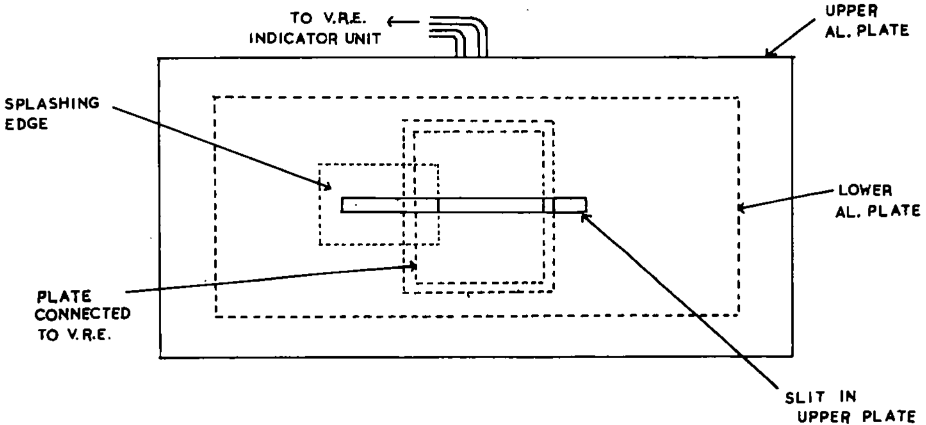
(2) Construction Of Apparatus

An elevation and plan of the apparatus is shown in Fig.21 and the complete apparatus is shown in Fig.22.

The apparatus was composed of two parallel aluminium plates separated 5 cm by insulators. A narrow slit was made in the upper plate to allow the drops to pass through. A square section was cut from the centre of the lower plate, and inside this was placed another aluminium plate in the same plane as the lower plate but isolated from it by a gap of



FRONT ELEVATION



PLAN

Fig.21

Fig.22

$\frac{1}{2}$ cm. This central plate will be referred to as the collector plate as it was the charge on the droplets falling onto this plate that was to be measured. The lower plate and the collector plate were raised from the lower perspex base so that electrical contact could not be made between them by water accumulating in the apparatus.

The splashing edge was constructed out of aluminium of the same gauge as, and inclined at a similar angle to, the inner shield of the collector so as to reproduce the conditions as accurately as possible. The splashing edge was attached at it's base to the lower plate and projected so that the edge where the splashing would occur was over the collector plate.

The splashing edge itself was only approximately 2 cms from the upper plate to which voltages were to be applied. This would cause lines of force to converge at the edge but this would be balanced to some extent as the point on the edge that the drops would strike was below the slit in the upper plate. But it would not be possible to determine the actual potential gradient at the point of impact.

The collector plate was connected through the perspex to the vibrating reed electrometer head unit.

The water dropper used was one constructed by a previous worker and a length of polystyrene tubing was attached to it to enable single drops to be released by the observer when required. The dropper was fixed 70 cms above the upper plate.

It was found that the recording apparatus was very sensitive to any movement in the laboratory and so an aluminium shield, with observation holes in it was placed between the observer and the apparatus.

3. Experimental Procedure And Results

Throughout the work two observers were required, one to release the drops and to check that they splashed off the edge, where this was required, and the other to observe the deflection registered by the meter of the vibrating reed electrometer indicator unit. The work was carried out in three parts and is discussed below as three separate experiments.

(a) Experiment 1

The charge recorded by the collector plate was observed for drops splashing on the edge with various voltages applied to the plates ranging from - 115 volts to + 115 volts. For each voltage the millivolts deflection produced for each drop was observed and the charge calculated for an average of 18 drops at each applied voltage. The average charge recorded per drop for each voltage is shown in Fig.23.

(b) Experiment 2

The experiment was repeated for a particular applied voltage, namely - 69 volts, but for different substances covering the splashing edge. This was done for four substances, namely, felt, tissue paper, foam rubber, and rubber. The charge was recorded for each drop according to the order in which the drop fell in order to determine if the charging effects associated with the surface altered as the drops continued to fall onto it. The results are shown in Fig.24 and the dotted line represents the average charge recorded for splashing directly on the aluminium edge without any covering. The charging effects produced by the aluminium edge did not alter with time.

(c) Experiment 3

The charge was observed for drops falling directly onto the aluminium collector plate, and onto water in a metal container on the collector plate, for various applied voltages. These were the conditions for the drops falling directly onto the cone and any residual water in it.

The experiment was repeated for the aluminium surface covered with blotting paper.

The results obtained are shown in Fig.25.

100 drops from the dropper were found to have a volume of 2.25 cc., and so the average drop radius was 1.75 mm.

4. Analysis of Results

(a) Experiment 1

As can be seen from Fig.23 the charge recorded by the collector plate was directly proportional to, but of opposite sign to, the applied voltage.

This can be explained in terms of the induced charge caused by the applied potential gradient. When the drop makes contact with the edge it is split into a number of fragments and for some short time these remained joined to the edge by films of water.

If we consider a negative applied voltage, as would be the most common condition in continuous rain, then the drops have been polarised, before contact with the edge, with a positive charge on the upper surface and a negative charge on the lower surface. After splashing, and while the fragments are still in contact with the edge we get further induced charges produced on the surfaces of the films. The negative charge then passes to earth through the edge and leaves a resultant positive charge on the fragments. These fragments carrying a positive charge will be in a range

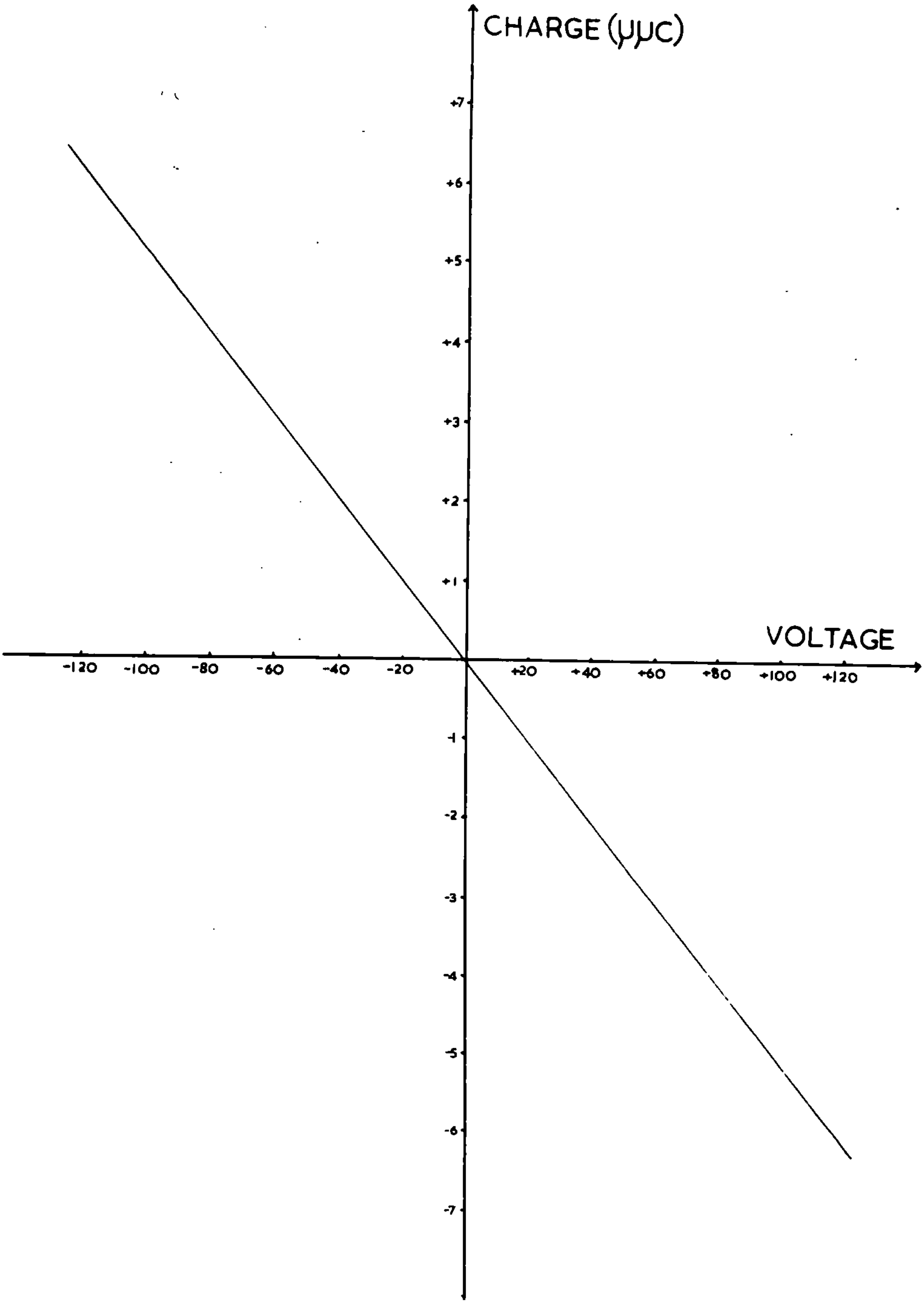

CHARGE (μμc)
+7
+6
+5
+4
+3
+2
+1
-1
-2
-3
-4
-5
-6
-7
VOLTAGE
-120
-100
-80
-60
-40
-20
+20
+40
+60
+80
+100
+120

Fig.23

of sizes varying from droplets of the same order of magnitude as the original drop to ions composed of a group of water molecules. The larger charged droplets fall to the collector plate and it is the charge on these droplets that is registered, while the smaller particles will be attracted towards the upper plate. The opposite effect would occur for a positive potential gradient.

Magono and Koenuma (1960) found that when drops were fractured in mid air by a gust from a blower after passing through a horizontal field then the surface charge present on the drops was left on the droplets. They considered a drop being split into two equal droplets such that the surface charge was exactly split, the positive charge being on one droplet and the negative on the other.

They calculated that for a drop of diameter 6.2 mm. falling in a potential gradient of 2000 volts/metre, the charge on each droplet would be 1.65μμ coulombs. In practice they found that the large drop split up into approximately 10 droplets, but that the sum of the charges measured on them of each sign was close to the theoretical value.

In the present experiment a charge of 1.65 μμ coulombs corresponded to an applied voltage of 32 volts. This corresponded to a uniform potential gradient of 640 volts/metre if only the parallel plates, 5 cms. apart, were considered. But the potential gradient at the edge would probably be larger than this. So if the difference in the radius of the drop and the different method of splashing are considered, then it is probably correct to say that the results obtained

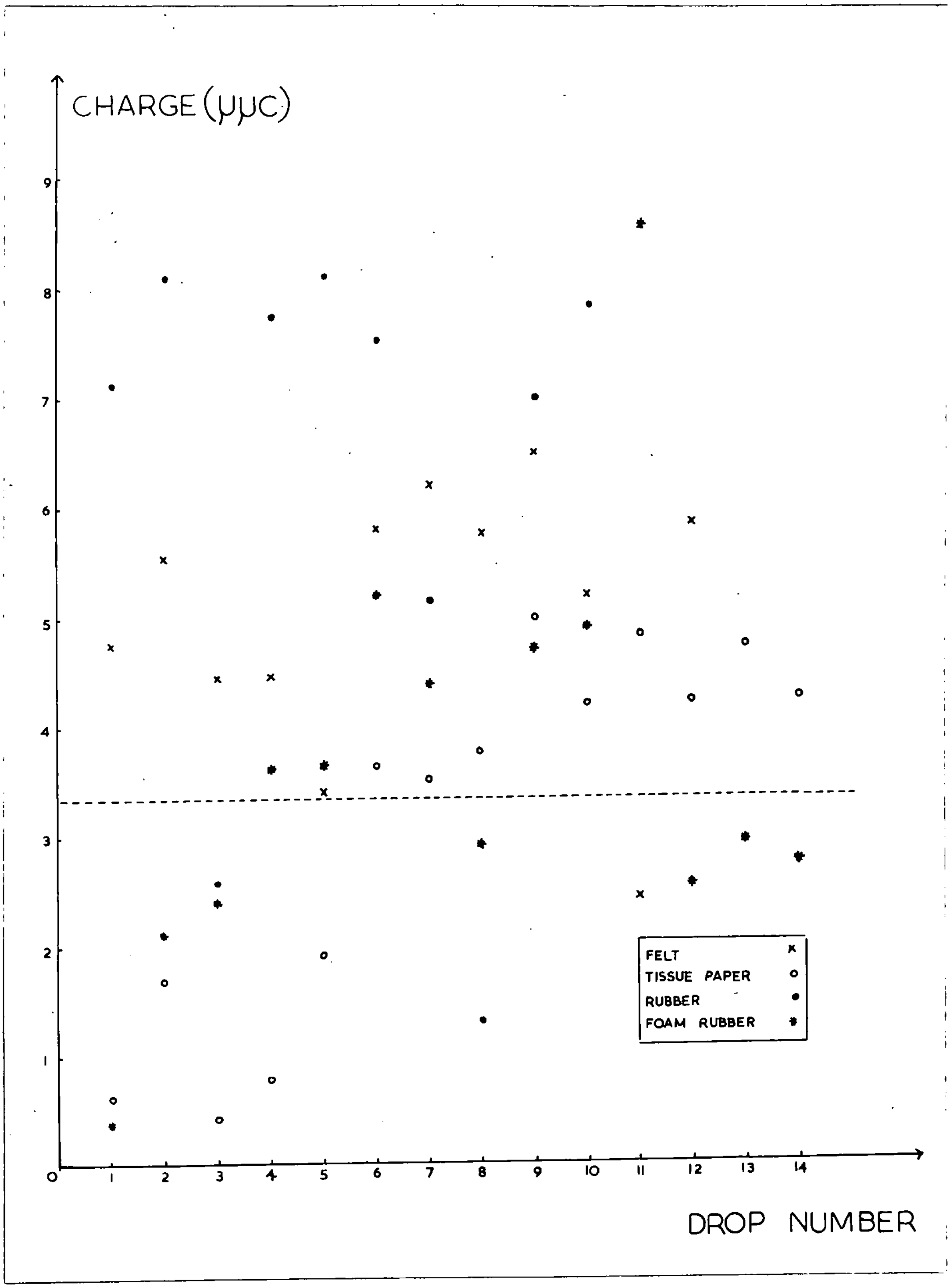

CHARGE (μμC)
0
1
2
3
4
5
6
7
8
9
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DROP NUMBER
FELT ×
TISSUE PAPER ○
RUBBER ●
FOAM RUBBER ✱

Fig.24

are of the same order of magnitude as those of Magono and Koenuma.

The results also show agreement with those of Adkins (1959a) who found that when a drop splashes at the ground it releases charge of opposite sign to the potential gradient to the air. It is part of this released charge that has been measured in this experiment.

(b) Experiment 2

Adkins (1959a) found that the amount of splashing depended upon the surface concerned and so various coverings were tried on the edge to try and reduce the splashing and so possibly the amount of charge recorded by the collector plate due to this effect.

Both the felt and the rubber coverings produced a far greater number of droplets on the collector plate than the uncovered aluminium edge. And in both cases the average charge recorded per drop was approximately double that for an aluminium edge. So it would appear that the charge is dependent on the number of droplets produced by the surface.

For the foam rubber and the tissue paper there was a reduction compared with the aluminium edge for the first few drops. This was probably due to the absorbent properties of the materials, and it was found that when the covering became wet the charging effect was slightly greater than for the aluminium.

In all cases there was greater fluctuation in the amount of charge recorded from drop to drop than for aluminium with which the charge produced was fairly constant. So none of the coverings tried showed any improvement. The experiment could possibly

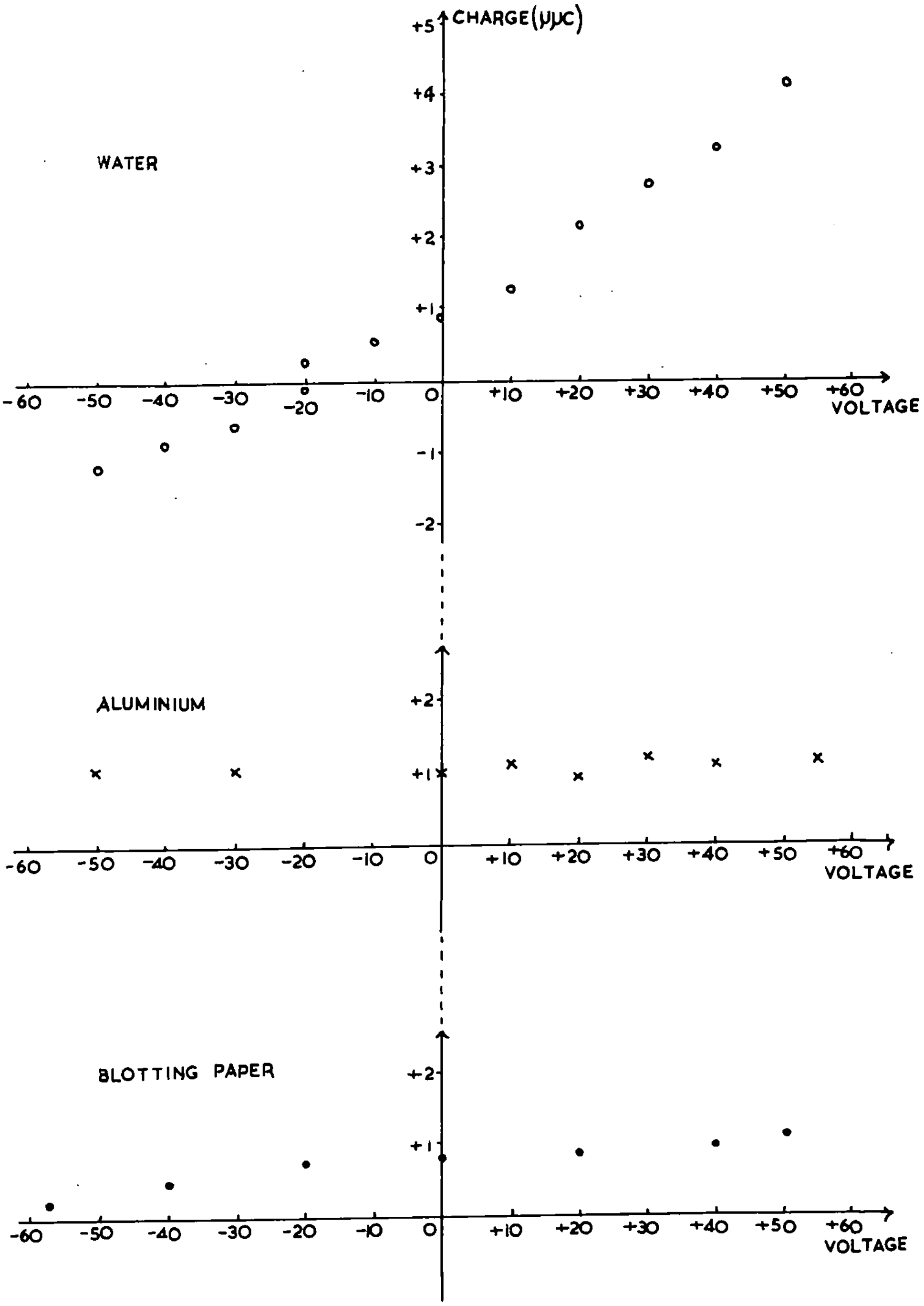

CHARGE(μμC)
+5
+4
+3
+2
+1
-1
-2
WATER
-60
-50
-40
-30
-20
-10
0
+10
+20
+30
+40
+50
+60
VOLTAGE
ALUMINIUM
+2
+1
BLOTTING PAPER
+2
+1

Fig.25

be carried out constructing the edge itself from different metals.

(c) Experiment 3

It was found that for drops falling directly onto the aluminium collector plate the charge recorded was always positive and of approximately constant magnitude for all the voltages applied to the plates. A similar effect was found when the collector plate was covered with blotting paper, except that the charge recorded showed a slight dependence on the applied voltage. So in both cases negative charge was released to the air, but the number of droplets produced and the amount of charge recorded were both considerably less than for the two previous experiments.

When the drops fell onto water a far greater amount of splashing was observed and the charge recorded was mainly of the same sign as, and proportional to, the applied voltage. So for a negative applied voltage the charge released to the air would be positive, and of similar magnitude to the charges recorded in Experiment 1.

In experiment 1 only the charge on the droplets too large to be attracted by the upper plate was recorded, while in the case of the water the recorded charge was due to the removal by the upper plate of the smaller droplets or ions which were produced on splashing and carried a charge of opposite sign to the potential gradient. The larger droplets would hardly leave the surface of the water before falling back again. This would suggest that the charge caused by induction was carried in comparable amounts by the larger droplets and the smaller droplets or ions.

In each case when zero voltage was applied approximately the same positive charge was recorded by the collector plate, and so a negative charge was released to the air. This would seem to be due to the Lenard (1892) effect. He found the results to be very sensitive to traces of impurity in the water. Lenard (1921) said that it was essential for the drop to disrupt with great violence and so was dependent on the energy of the drop. He found that a drop of 4 mm radius produced a charge of 2 $\mu\mu$ coulobes, which corresponded to about 5.4 $\mu\mu$ coulombs/c.c. Chapman (1950) found charges about 10 times greater than these. The results shown in Fig.25 are for a drop of 1.76 mm. radius and a charge of 0.9 $\mu\mu$ coulombs was recorded, corresponding to 40 $\mu\mu$ coulombs/c.c. This value is midway between those of Lenard and Chapman.

Gill and Alfrey (1952) investigated the splashing of water on various surfaces and suggested that there was no reliable evidence for the production of ions when water splashes onto a surface, and that the effect could be explained in electrostatic terms. They also claimed that the ions measured by many workers were in fact highly charged water droplets, as has in fact been considered in the present work. But it is the very existence of the charge that is of importance in the present work, and not so much its origin.

5. Splashing At The Collector

Splashing at the collector was considered from the point of how many drops would splash at the edges of the collector shields.

Dimensions of the collector:-

Diameter of outer cylindrical shield = 34 cms.
Thickness of outer shield = 0.175 cms.
Diameter of inner conical shield = 19.5 cms.
Thickness of inner shield = 0.1 cms.

For a fixed rate of rainfall, namely 2 mm/hr., and assuming that all the drops in a particular period were of the same size, then the following quantities were calculated for both the inner and the outer shields.

$$S = \frac{\text{Number of drops striking shield edge}}{\text{Number of drops entering cone directly}}$$

T = Number of drops striking the shield per sec.

The ratios were calculated for three different drop diameters ranging from 1 mm to 3.5 mm. The smaller diameter was that of the smallest drops considered to exist in continuous rainfall while the larger diameter was that of the drops used in the experiment, but these would be larger in general than those actually existing in continuous rainfall. So an intermediate diameter of 2 mm was also used.

DROP DIAMETER	INNER SHIELD		OUTER SHIELD	
	S	T	S	T
1 mm	1/16	5/3	1/10	8/3
2 mm	1/12	1/3	1/5	2/3
3.5 mm	1/7	1/11	1/4	2/11

Merry (1960), probably using drops of diameter 3.5 mm, found that for every drop splashing on the outer shield 3 observable droplets reached the cone. He used a specially treated filter paper to detect the droplets. When a drop struck the inner conical shield 79 particles reached the cone. Merry said that the drops used were large and that this would aid the splashing effect. But this would be compensated to some extent by the fact that the drops would not have reached their terminal velocity. Adkins found that the charge released, and so probably the amount of splashing, was proportional to the energy of the drop.

For the drops of 2 mm diameter one splashes off the inner shield, and 2 off the outer shield every 3 seconds. So a large number of fragments of water carrying a charge opposite in sign to the potential gradient will enter the cone, and the similarly charged smaller fragments or ions, will be released to the air.

6. Conclusions

Consider a negative potential gradient in the region of the upper collector and apply the results of the experiment. For the drops splashing off the edges of the shields all the resulting fragments will carry a positive charge. The larger fragments will fall directly into the cone while the smaller particles will rise under the influence of the potential gradient. Other drops falling towards the collector will be polarised by the potential gradient and so, according to the theory of Wilson

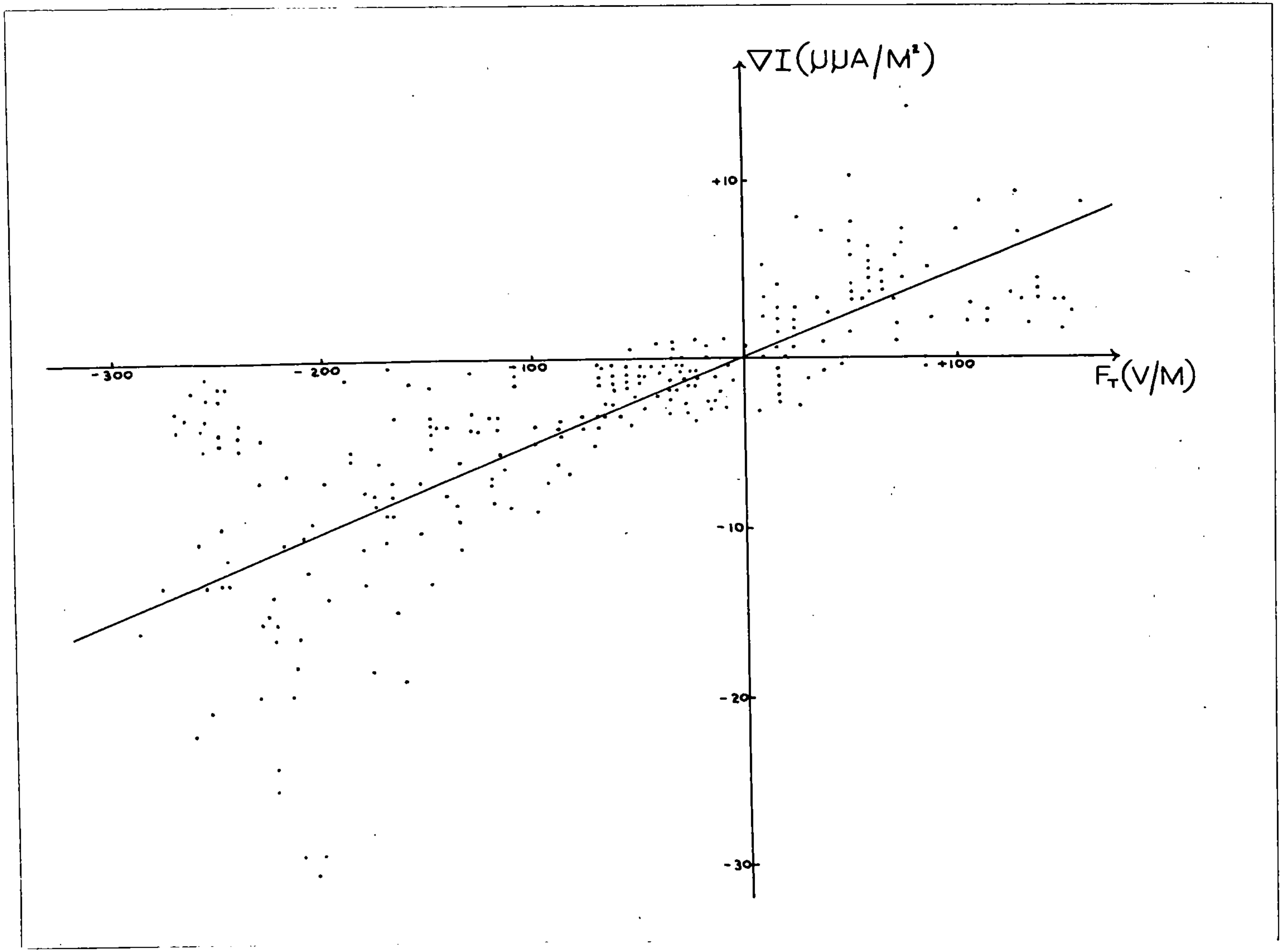


Fig.26

(1929), will collect the rising positive ions. So an increased positive charge will be carried by the drops entering the cone directly. Hence the charge recorded by the upper collector will be dependent on the potential gradient close to the collector.

Let I_B and I_T be the currents recorded by the collectors at the bottom and top of the mast, and F_T the corrected value of the potential gradient at the top of the mast. So F_T represents the value of the potential gradient that would occur at the level of the top of the mast if the mast was not present. This is discussed in more detail in Chapter 5.

$$I_B - I_T = \Delta I$$

So if the processes considered account for the difference in the currents ΔI, then ΔI should be proportional to F_T.

So two scatter diagrams of ΔI against F_T were plotted for two periods:-

(1) 9-29 a.m. - 11-35 a.m. on 19.5.62.

(2) 2-34 p.m. - 4-25 p.m. on 15.6.62.

The two periods were chosen because the average rate of rainfall for (1) was 1mm /hr., while for (2) it was 2.3 mm/hr. Also during both periods all the instruments were functioning satisfactorily. Period (2) was terminated at 4-25 p.m. as at that time the potential gradient suddenly increased above 400 volts/metre and so there was a possibility of point discharge.

Only the average rate of rainfall could be considered and not the variations during the periods. As the rate of rainfall would effect the number of drops splashing off the edges, so it would effect the current recorded. If the drops during both periods could be considered to be the same size then, ignoring any variations in the rate of rainfall, the current difference ΔI recorded by the collectors during period (2) should be of the order of two times that recorded during period (1), for any particular value of F_T. The scatter diagram for period (1) is shown in Fig.26. The regression lines calculated for the two periods were:-

(1) $\Delta I = 0.00165\ F_T + 0.00025$

(2) $\Delta I = 0.0036 F_T - 0.05$

Where dI is in $\mu\mu$amperes and F_T in volts/metre.

If we consider drops of 2 mm diameter and $F_T = 100$ volts/metre, then considering the relation for period (2)

$$\Delta I = 0.31\ \mu\mu \text{ amperes.}$$

For drops of diameter 2 mm and a rate of rainfall of 2 mm/hour one drop splashes off the inner shield, and two of the outer shield, every 3 secs. So the charged fragments of these three drops entering the cone would have to contribute a total of 0.93 $\mu\mu$ coulombs.

The exposure factor of the agrimeter was approximately eighteen, and so the exposure factor of the collector, as the upppermost point on the mast structure, would certainly be considerably larger than this. So the potential gradient close to the edge of the outer shield of the collector, for a potential gradient of 100 volts/metre at the ground, would be above 1800 volts/metre. It does not seem unreasonable to assume that the potential gradient close to the edge of the inner shield will be approximately a quarter of those at the outer edge. So the potential gradients in the region of the collector edges are of similar magnitude to those used in the laboratory experiment.

Adkins (1959a) found that the charge produced on splashing was proportional to the 4/3 power of the mass of the drop. So when this is considered with the results of the present experiments it seems very possible that the three drops could contribute a charge of the order of 0.93 $\mu\mu$coulombs, especially as the charge carried by the drops falling directly into the cone would be enhanced by the capture of charge by the Wilson process. A great many assumptions have been made but the main aim of this analysis has been to show that it is possible, and to the author's mind indeed probable that the current difference ΔI could be largely explained by the charging of droplets due to induction effects on splashing on the edges of the collector shields. So the dependence of Δ I on the charging of the rain drops while passing through the lower layers of the atmosphere may well be negligible.

An objection of Merry (1960) to the idea that a splashing effect could cause the large current that was registered by the upper collector was that he expected the charge to show as sudden peaks on the record. But in the examples considered there would be contributions due to 3 drops every 3 seconds for drops of diameter 2 mm, and for drops of 1mm.diameter

13 drops every three seconds, both for a rate of rainfall of 2 mm/hour. The charged fragments would fall at different rates into the cone according to their mass. Also, as previously mentioned, the drops falling directly into the cone would possibly contribute to the increased current. So the recorded current would not show any large fluctuations, and in fact any peaks observed are probably due to a particularly large drop splashing on the outer shield in such a way that an unusually large number of charged fragments find their way into the cone.

So it would appear that the shielded collector is an unsuitable instrument for the measurement of precipitation current at the top of an earthed mast, and until a new instrument is developed it will not be possible to determine whether the rain acquires any of its charge in the layers close to the ground.

CHAPTER 5

EXPERIMENT USING THE MAST.

1. Corrections For Displacement And Conduction Currents

As previously mentioned a shielded collector was used at the top of the mast in order to eliminate effects due to the potential gradient. But the shielding was not completely effective and so conduction and displacement currents, which during rainfall would be indistinguishable from the actual precipitation currents, were recorded by the collector.

If Ic is the conduction current, λ the local value of the conductivity, and F the potential gradient, then

$$Ic \propto \lambda F$$

If λ is constant, then $Ic \propto F$

If Id is the displacement current, then

$$Id \propto {}^{dF}/dt$$

So the total current due to the two effects is given by

$$I = AF + B\,{}^{dF}/dt$$

Where I and F are the mean values of the current and the potential gradient over a time dt, and dF is the change of potential gradient during that same time.

This current was recorded on a day when there was no precipitation but the potential gradient was varying considerably due to the clouds passing over fairly rapidly. The potential gradient was recorded by the agrimeter.

From the records obtained the mean values of the current, I, and the potential gradient, F, were determined over half minute intervals, as was the change in potential gradient dF, over the same period.

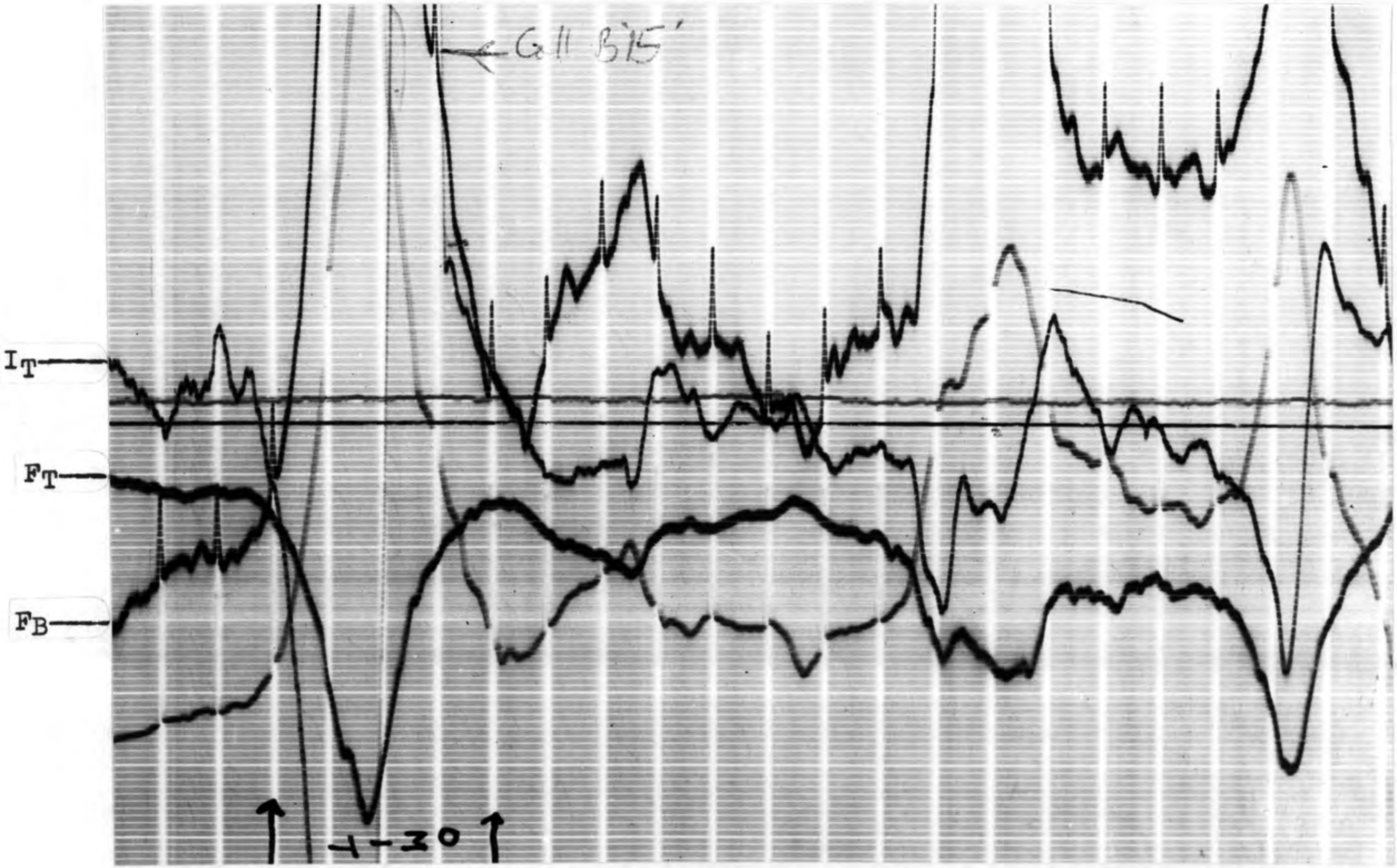


Fig.27

It was approximately true to use this value of dF in connection with the displacement current if the changes were fairly uniform over the time interval.

A total of 294 half minute intervals were considered. The potential gradient was found to vary from +15 volts/metre to + 350 volts/metre, and the value of dF from +150 volts/metre per $\frac{1}{2}$ minute to -125 volts/metre per $\frac{1}{2}$ minute.

By statistical analysis of these results the values of A and B were determined in such a form that they could be applied directly to the values of F and dF obtained from later records. Hence a correction factor, dI_T, to be applied to the recorded precipitation current recorded at the top of the mast for every half minute interval could be calculated.

If I is the current in $\mu\mu$amperes/M^2, and the values for the potential gradient, and changes in potential gradient, are the corrected values for the top of the mast in volts/metre, then the spurious current is given by

$$I = 0.015F + 0.048dF$$

where dF is considered positive when F is increasing. The effect of the displacement current is well shown in Fig.27 where sudden changes in the current at the top of the mast, I_T, coincide with sudden changes in the potential gradient.

2. Calculation Of Exposure Factors

The potential gradient was measured at the top of the mast by the agrimeter and at the bottom of the mast by a field mill on a stand. Both the mast and the stand disturbed the normal potential gradient and so it was necessary to calculate an exposure factor for both instruments relative to another instrument operating in the plane of the earth's surface some distance from the mast and so recording an undisturbed potential gradient. These factors could then be used to convert the potential gradients recorded by the instruments at the top and bottom of the mast to the corresponding value of the undisturbed potential gradient. Such values are referred to as the corrected values of potential gradient.

To carry out the calibration a day with no cloud was required so that there would be a minimum of space charge present in the layers of air between the top and bottom of the mast and the three instruments could be considered to be recording the same potential gradient. In disturbed weather space charge exists in the layers and so causes a difference in the corrected values of the potential gradient recorded at the top and bottom of the mast.

On a cloudless day the agrimeter, Ag., the field mill at the bottom of the mast, Mill A, and the calibration field mill, Mill B, were run in their respective positions for over five hours. The exposure factors, namely the ratios of the recorded potential gradients Ag/Mill B and Mill A/Mill B were calculated for consecutive half hour periods to determine if there was any variation of the exposure factor with time.

A sudden change in the values of the exposure factors was found after $2\frac{3}{4}$ hours. At this time the variation of the potential gradient became greater and also the noise level ofthe instruments increased. So the mean values of the exposure factors were calculated for the first $2\frac{3}{4}$ hours of the record.

The agrimeter exposure factor was calculated as 18 and that of Mill A as 1.53. As the output from Mill A depended on whether Mill B was running or not a different exposure factor applied to the two cases.

3. The Effect Of Space Charge On The Exposure Factor

Adkins (1959a) found that even in fine weather conditions large fluctuations occur in the value of the space charge in the lower layers of the atmosphere. He estimated a mean fine weather value of 2 $\mu\mu$coulombs /M^3. The space charge close to the ground is due to the radioactive materials in the ground and that at higher levels is due to cosmic rays. This mean value would lead to a difference of potential gradient of about 5 volts/metre between the top and bottom of the mast. But Wormell (1953) and Adkins (1959a) found that the space charge is enhanced near to human habitation due to smoke, exhaust fumes, etc. So it would appear probable that the calculated exposure factor for the instrument at the top of the mast was too low. This would be a constant error dependent on the amount of space charge present during the period of the calibration. So although any calculation of the actual amount of space charge present in the lower layers from the values of the potential gradients at the top and bottom of the mast would be subject to this error the values of these potential gradients would still reflect the variations in the space charge.

A more accurate calibration would be possible if apparatus were available to determine accurately the space charge during the period of record.

4. Analysis of Results

Cards were constructed from the calibration curves, for each scale of every instrument, such that the deflection from the zero on the record when measured with the card gave the value of the precipitation current or potential gradient directly. The values obtained were the mean values over half minute intervals.

The values were tabulated and correction factors calculated and applied where appropriate. Graphs were then plotted of the variation of the corrected values with time and scatter diagrams plotted for pairs of variables for each of the three groups of results.

The results plotted on the scatter diagrams were analysed statistically and the equations of the regression lines obtained by a method due to Morgan (1960). This method gave the straight line of best fit to observational data of two related variates when both sets of values were subject to error as in the present work. The following symbols will be used to represent the variables measured.

I_B and I_T represent the precipitation current at the bottom and top of the mast in $\mu\mu$ amperes/M^2. F_B and F_T represent the potential gradients at the bottom and top of the mast in volts/metre.

$\Delta I = I_B - I_T$ in $\mu\mu$amperes/M^2

P represents the total space charge between the top and bottom of the mast in $\mu\mu$coulombs. P_1 represents the average space charge density between the top and bottom of the mast in $\mu\mu$coulombs/M^3.

5. Results

Recordings were taken during rainfall on six days during the period 11.5.62 and 15.6.62, giving a total of approximately 20 hours records. Of these records certain periods were disregarded due to the rate of rainfall being too low, the conditions were not those of continuous rain, or because one of the instruments was not working satisfactorily.

The periods of recording used are stated below in the three groups in which they were analysed. The average rate of rainfall and the meteorological conditions were obtained from the records of Durham University Observatory.

The duration of the period of the record, D, is given in hours and minutes and the average rate of rainfall, R, is given in mm/hr.

	DATE	D	R	METEOROLOGICAL CONDITIONS
1	19.5.62.	8.40	1	DEEP LOW PRESSURE AREA MOVING ACROSS S. ENGLAND INTO THE NORTH SEA
2	15.6.62	3.42	2.3	PASSAGE OF A WARM FRONT
3	11.5.62.	0.50	1	WAKE OF STATIONERY LOW
	22.5.62.	1.50		APPROACH OF WARM FRONT
	17.5.62.	0.11		LOW PRESSURE NORTH OF SCOTLAND

The regression lines calculated for each group of results are given in Fig.28. Due to the previous work discussed in chapter IV on the precipitation current recorded at the top of the mast there will be no discussion, or attempted explanation, of any relations in which the variable I_T occurs in this experiment. Also excluded in this way are relations

19.5.62	15.6.62	MISC.
$I_B = -0{\cdot}0048(F_B - 92)$	$I_B = -0{\cdot}08(F_B - 83)$	—
FOR $F_T > 600$ V/M $I_B = -0{\cdot}01(F_B - 12)$	—	—
$I_T = -0{\cdot}046(F_T - 78)$	$I_T = -0{\cdot}32(F_T - 87)$	$I_T = -0{\cdot}05(F_T + 300)$
$F_B = 0{\cdot}39P - 10$	$F_B = 0{\cdot}26P + 60$	$F_B = 0{\cdot}45P + 107$
$I_B = -0{\cdot}017P - 2{\cdot}6$	$I_B = -0{\cdot}03P + 1{\cdot}8$	—
$I_T = -0{\cdot}02P - 3{\cdot}6$	$I_T = -0{\cdot}05P + 13$	$I_T = -0{\cdot}1P - 52$
$\nabla I = 0{\cdot}0094P - 016$	$\nabla I = 0{\cdot}022P - 7$	—
$I_B = 0{\cdot}36I_T - 1{\cdot}4$	—	—

Fig.28

involving dI, but all the calculated regression lines are included here for the sake of completeness.

The majority of the regression lines calculated in this experiment were not statistically significant, the highest correlation coefficients being obtained for the relations involving F_B and I_B. But it must be remembered here that no accurate account could be taken of the rate of rainfall.

6. Comparison With Previous Results

The only comparison with previous results will be for the I_B/F_B relationships.

Simpson (1949) found that for potential gradients in the range ± 1000 volts/metre

$$I_B = -0.0133R\,(F_B - 400)$$

where R is the rate of rainfall in mm/hr.
Chalmers (1957) obtained the following average result for all rates of rainfall

$$I_B = -0.0118\,(F_B - 150)$$

So the result of Chalmers falls between the relations obtained for groups 1 and 2 of the recordings.

The measurement of the space charge in the layers of air between the top and bottom of the mast was dependent only on the values of the potential gradient at those levels. Even if there was an error in the calculated exposure factor the values of the potential gradients would still reliably show the variations and change of sign of the space charge. The results obtained in connection with space charge are discussed in the following section.

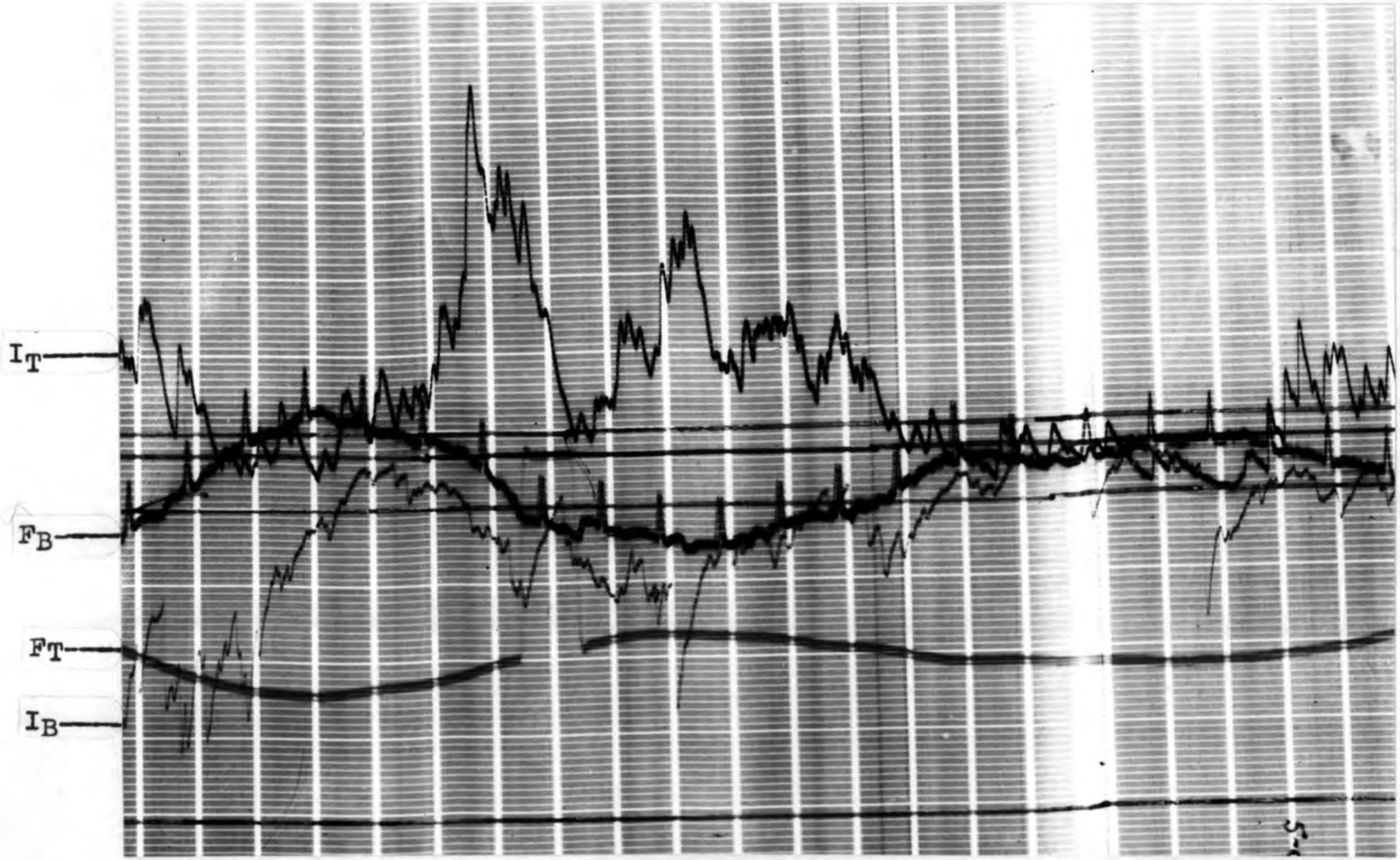


Fig.29

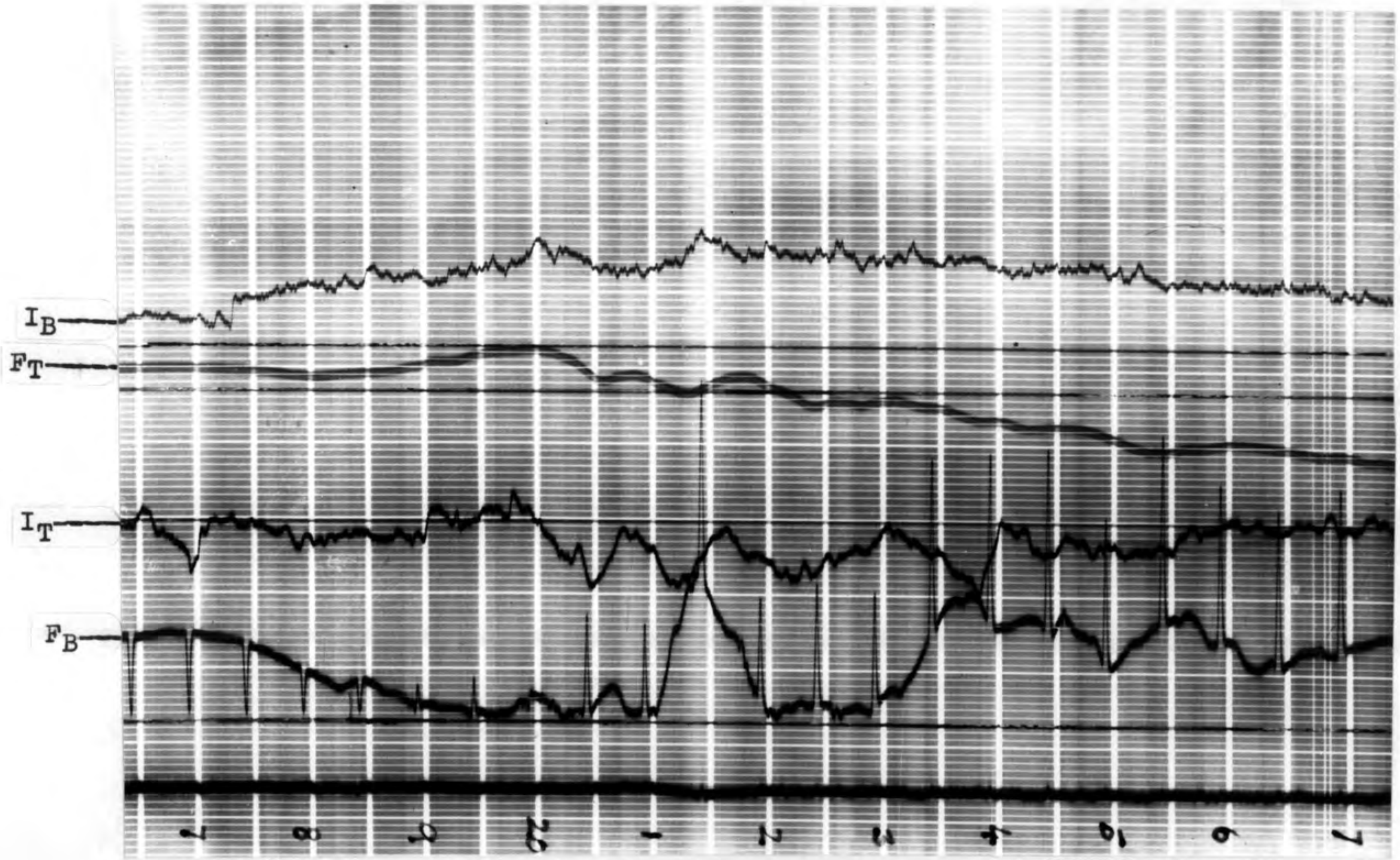


Fig.30

7. Space Charge

(a) Introduction

As the effect observed by Kelvin and Chauveau was dependent on the existence of negative space charge close to the ground it was desirable to be able to calculate it's magnitude.

Scrase (1938) used Poissons equation to obtain an expression for the average space charge per unit volume in a layer in terms of the difference between the potential gradients at the top and bottom of the layer and the thickness of the layer.

If the lower and upper levels are h_1 and h_2 respectively, measured in metres, and F_1 and F_2 the corresponding potential gradients in volts/metre, then

$$P_1 = - \frac{8.9 \, (F_1 - F_2) \mu\mu}{(h_1 - h_2)} \text{ coulombs}/M^3$$

For the mast $h_1 - h_2 = - 21$ metres, hence

$$P_1 = 0.42 \, (F_1 - F_2) \, \mu\mu \text{ coulombs}/M^3$$

In the regression lines P is the total space charge in a column of one square metre cross-section between the top and bottom of the mast.

$$P = 8.9 \, (F_1 - F_2) \, \mu\mu \text{ coulombs.}$$

(b) Previous Results

Adkins (1959a) referred to an "electrode effect" that occurred in undisturbed conditions. He found that ions of opposite sign to the potential gradient were removed from the air near to the ground for large potential gradients. So an excess of ions of the same sign as the potential gradient were left behind. During the increased ion concentration that occurs during rainfall a similar effect was found to occur for smaller potential gradients. Adkins found that during disturbed conditions four distinct processes occurred in connection with space charge. They were:-

(1) That during low potential gradients the space charge was subject to small changes in the same sense as the potential gradient.

(2) During periods of natural point discharge there was a large space charge of opposite sign to the potential gradient.

(3) In heavy rain space charge of opposite sign to the potential gradient was produced by the splashing of rain drops. The space charge in this case remained close to the ground but was only significant in heavy rain.

(4) Regions of high space charge were sometimes found in association with a column of rain due to the charge on the drops.

Magons and Orkasa (1960 and 1961) investigated the last of these effects. They found that the space charge due to the rain for a shower in which the rate of rainfall was 2 mm/hr., and the precipitation current - 160 $\mu\mu$ amps/M^2 to be 40 $\mu\mu$ coulombs/M^3.

For many years attempts have been made to estimate the charge distribution in clouds from measurements of the potential gradient at the ground. But it is clear that the surface potential gradient can be greatly modified in all conditions by the space charge. So great caution must be exercised when interpreting potential gradients.

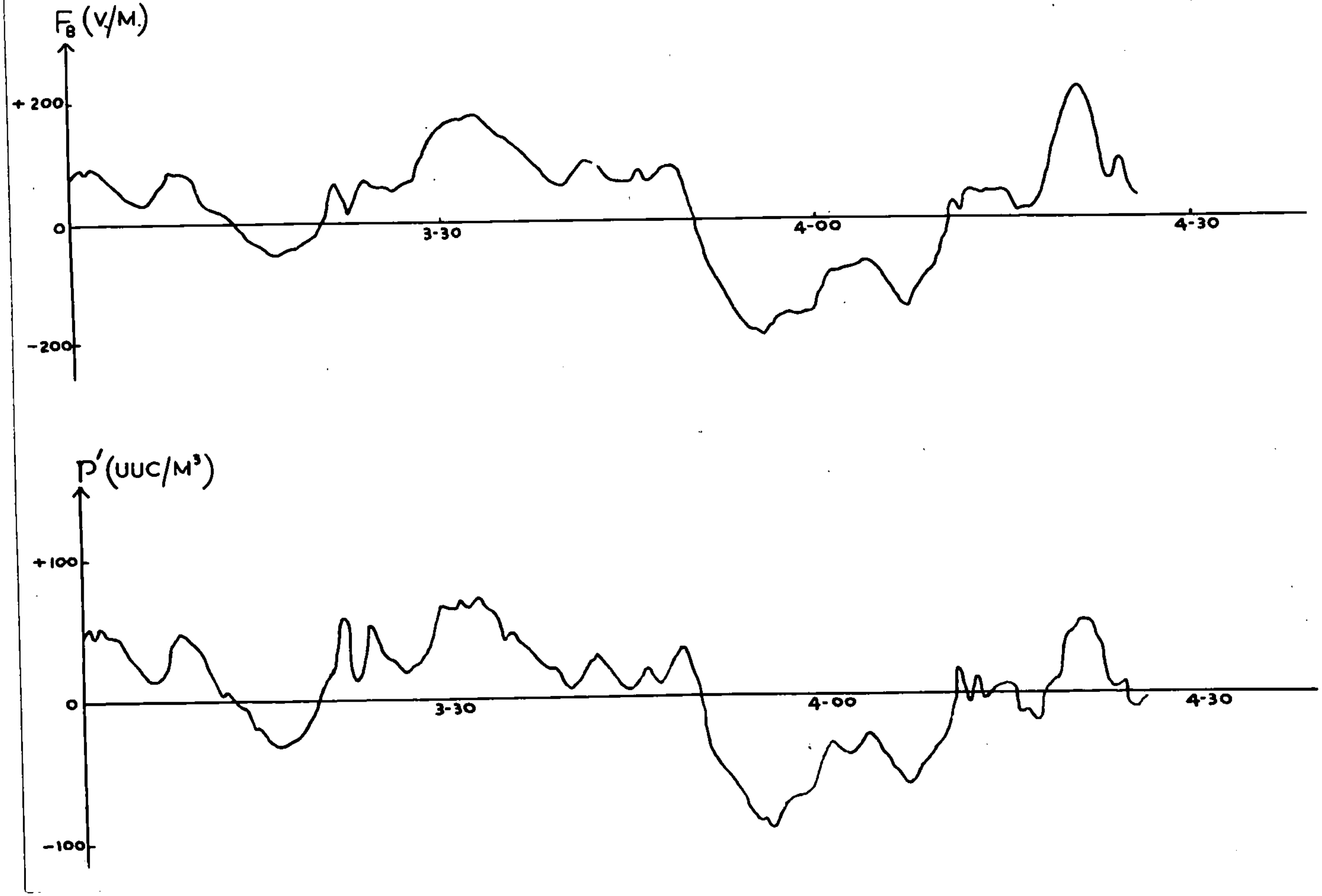


Fig. 31

(c) Results

The results obtained during continuous rain show general agreement with those of Adkins. For low surface potential gradients, less than 800 volts/metre, the space charge was nearly always of the same sign, and varied in the same sense, as the potential gradient. Such a variation of space charge with surface potential gradient is shown in Fig.31.

Fig.32 shows a period during which natural point discharge occured for potential gradients greater than 800 volts/metre and the space charge was of opposite sign to the potential gradient.

On some occasions, when the potential gradient was low, the space charge had a larger magnitude than expected. It was found that the space charge was of the same sign as the precipitation current recorded by the collector at the ground. At such times it would appear that the charged rain is the dominant space charge factor.

The production of space charge due to splashing is only important for intense rainfall and fairly large potential gradients. So as the space charge would be of the same sign as that due to point discharge it would probably be masked by the space charge due to point discharge except for very intense rainfall. As such conditions were probably not observed it is not surprising that there was no occasion on the records that obviously support the production of space charge in this manner.

The signs of the space charge over half minute intervals were grouped according to the three periods of record as previously considered. The~~re~~ results of 19.5.62. were split into two groups. (a) and (b), the

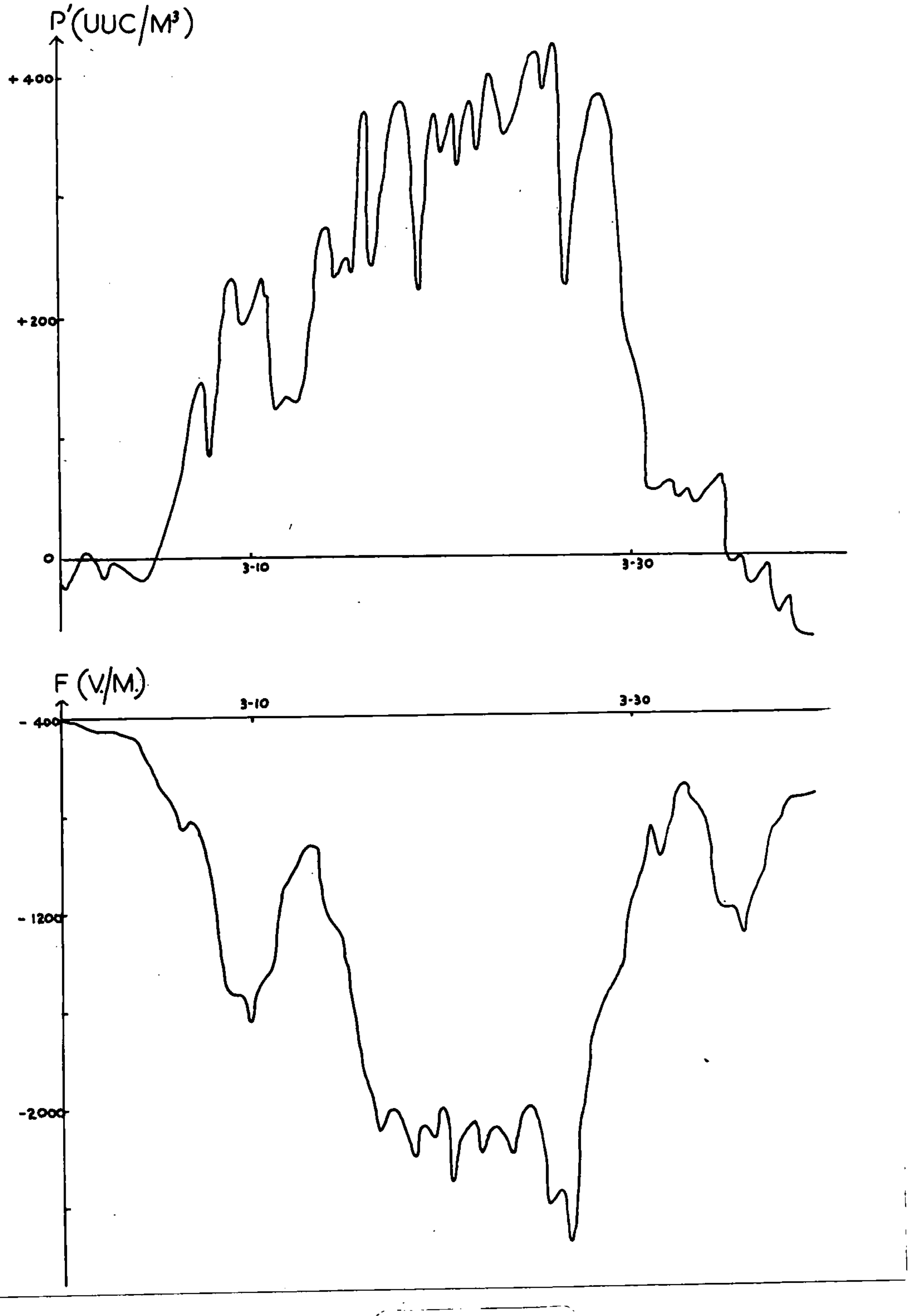


Fig.32

latter being when the potential gradient was above 800 volts/metre.

PERIOD			POSITIVE	NEGATIVE
1.	19.5.62.	(a)	197	684
		(b)	60	0
2.	15.6.62.		294	92
3.	Miscellaneous		38	192

So the space charge was predominantly negative during periods 1 and 3, but mainly positive in period 2. The latter was the period of more intense rainfall.

During periods when the space charge was of the same sign as the potential gradient then the measured potential gradient would decrease with height from the ground as far as the upper level of the space charge. The reverse would occur for space charge due to point discharge.

Except during the periods of point discharge the space charge on 19.5.62. was the same sign as the potential gradient. On this day there were long periods when the space charge remained negative which were the conditions required for observation of the Kelvin Chauveau effect. Two such periods of forty minutes were noted and one of these is shown in Fig.33. As the space charge usually increased in magnitude with increase in potential gradient the magnitude of the space charge was not usually sufficiently large to cause a difference of sign between the potential gradients at the top and bottom of the mast, except

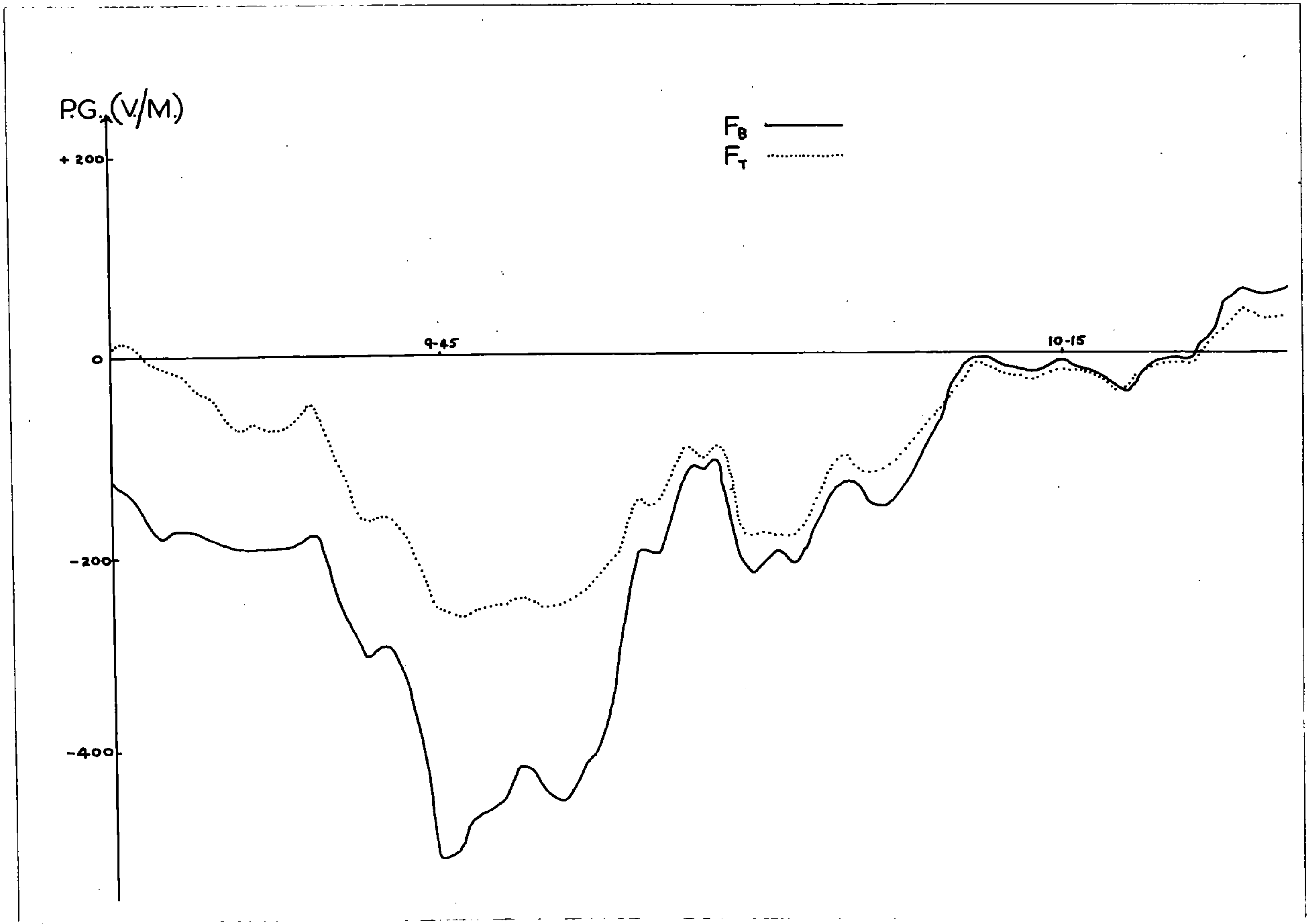


Fig. 33

for a few very short periods. But as can be seen in Fig. 33 the space charge was sufficient during certain periods to cause a difference of 250 volts/metre between the potential gradients at the two levels. This corresponded to a space charge of over 100 $\mu\mu$ coulombs/M^3. It is possible that under such conditions the reversal of sign would have been observed over a longer period if the upper level of measurement had been situated at a higher level as it was in the work of Kelvin and Chauveau. This will be discussed more fully in Chapter VI.

During periods of positive space charge on 15.6.62. associated with a positive potential gradient magnitudes of space charge greater than 250 $\mu\mu$ coulombs/M^3 were observed.

During the period of point discharge the maximum value of space charge recorded was in excess of 420 $\mu\mu$ coulombs/M^3. This caused the potential gradient at the top of the mast to be approximately 50% greater than that at the ground.

CHAPTER 6

DISCUSSION AND CONCLUSIONS

1. Kelvin And Chauveau Effect

To observe the effect the space charge in the layers of air close to the ground must be of such sign to cause the magnitude of the potential gradient to reduce with height and possibly eventually change sign. So the space charge must be of the same sign as the potential gradient at the ground. This would eliminate the possibility of the space charge being due to point discharge or to the charge released when raindrops splash under the influence of a potential gradient as both these effects would lead to a space charge of opposite sign to the potential gradient. Also the potential gradient during steady rain is usually not large enough to cause point discharge and the charge released due to splashing under the influence of such a potential gradient would be small. The charge on the rain is also usually of opposite sign to the potential gradient.

In considering the Kelvin and Chauveau effect the positive potential gradient at the top of the mast has to be accounted for, If the potential gradient due to the cloud alone is negative and there is no other space charge present between the cloud and the top of the mast then irrespective of the amount of negative space charge close to the ground the effect would not be observed. But if it is assumed that the rain carries a charge of opposite sign to the potential gradient due to the cloud then a space charge of opposite sign to the potential gradient will exist above the mast. Such an upper space charge could account for the positive potential gradient at the top of the mast under conditions to be discussed later, and the negative space charge can be explained by the release of negative charge by drops when they splash at the ground.

But sometimes a positive space charge was found near the ground when the recorded potential gradients were positive and so there was a tendency towards the effect occurring in the opposite direction. As there does not seem to be any obvious source of positive space charge close to the ground a separation or electrode effect is considered in which the potential gradient due to the cloud alone will exert a vertical upward force on ions or particles carrying a charge of opposite sign and those of suitable size will be removed from the air close to the ground. The dependence of the space charge between the top and bottom of the mast on the potential gradient, as discussed in Chapter 5, would support this idea.

The Kelvin and Chauveau effect could also be explained by considering that during continuous rain the positive fine weather potential gradient is modified by negative charges in the cloud and below. If there is insufficient negative charge in the cloud then the potential gradient at the top of the tower might be positive while the potential gradient at the ground would be modified by the negative space charge close to the ground and so be recorded as negative. But this would not account for the occasions when the space charge close to the ground is positive without either a separation effect or the existence of an unknown mechanism by which positive space charge is produced close to the ground during certain periods of continuous rain. So in the remainder of this section an attempt will be made to explain the Kelvin and Chauveau effect by considering a separation process.

So the build up of negative space charge close to the ground would appear to be due to the separation of the charge existing in the air due to an electrode effect and to the release of negative charge when drops splash violently at the ground. As can be seen in Fig.25 the amount of charge released depends to a certain extent on the nature of the surface and Lenard (1921) said that the effect depended on the violence of disruption of the drops. So it would appear possible that the production of charge in this manner would be greater for a concrete or metal surface rather than a natural vegetation surface. It is probable that there would be a large amount of the former types of surface present in the region of the experiments of Kelvin and Chauveau.

In steady rain there would appear to be three sources of space charge, namely:-

(1) The space charge present under fine weather conditions which according to Adkins (1959a) has an excess of positive space charge.

(2) The negative charge released when the drops splash at the ground.

(3) The charge on the rain which is probably of opposite sign to the potential gradient due to the cloud alone.

So if we assume a negative potential gradient due to the cloud itself then eventually there would build up a negative layer of charge close to the ground and

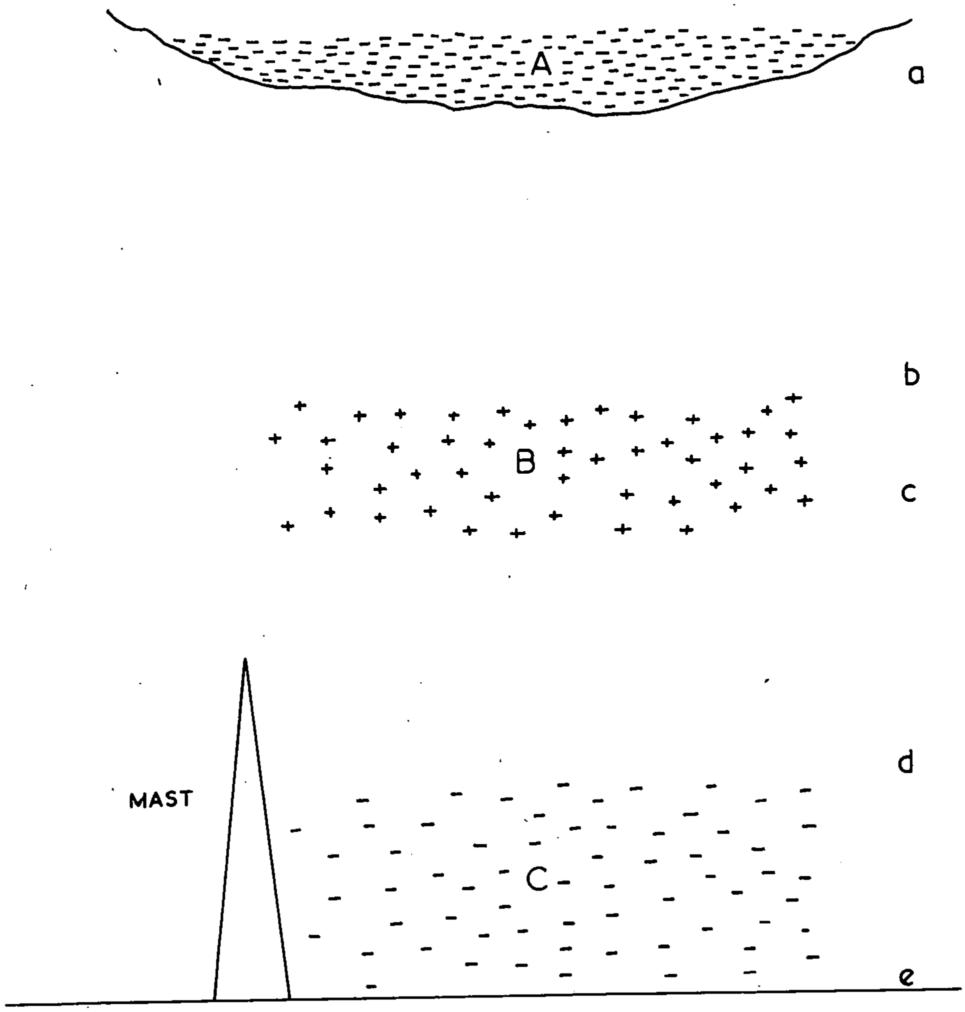


Fig.34

an upper layer of positive charge partly due to the separation of charge by an electrode effect and to the charge on the rain.

Consider Fig. 34 and let A be the negative potential gradient due to the cloud alone, B the positive potential gradient due to the positive space charge alone, and C the negative potential gradient due to the lower layer of negative space charge. Then the potential gradient at the ground will be given by B-A-C. Then if C and B remained approximately constant over a certain period then the variations in the recorded potential gradient at the ground would reflect variations in the potential gradient due to the cloud alone, but only if B=C would the recorded potential gradient be exactly that due to the cloud alone, A. But B and C are dependent on A, on the rate of rainfall, and on the charge on the rain, and so all these would have to remain constant for B and C to become approximately constant.

If $A > 2B$ then a negative potential gradient will exist at all levels. So if the space charge conditions are suitable the separation process could continue until $A = 2B$. Then the potential gradient in the region b-c would be zero. The condition $A = 2B$ could also be reached by A reducing in magnitude.

If the value of A then decreases and $A < 2B$ then a positive potential gradient will exist in the region b-c. The potential gradient due to the cloud would then not be able to maintain the same amount of charge separation and the layers of space charge B and C would start to mix. But the positive potential gradient in the region b-c would remain as long as A continued to decrease. The length of time for which the effect would continue would then depend on the rate of decrease of A and the consequent mixing of the layers of space charge.

As the value of A continued to fall the positive space charge would fall and mix with the negative space charge. So eventually the sign reversal might not be observed due to the low value of A. If this were the case then it would be expected that the negative space charge close to the ground to increase in the same sense as the potential gradient at the earth's surface. So a low value of space charge would be expected when the potential gradient at the ground was close to zero. This can be seen in Fig.33 where the difference in the potential gradients at the two levels gives a measure of the space charge.

The difference of sign of potential gradient would also cease to be observed if A were to increase to become greater than 2B.

During the present work there was evidence of negative space charge existing near to the ground during the majority of the periods of continuous rain. The upper instrument only recorded a positive potential gradient FOR A NEGATIVE POTENTIAL GRADIENT at the ground, for five short periods the longest being 4½ minutes. Those periods were normally associated with low values of potential gradient and were often followed by a change of sign of the potential gradient at the bottom of the mast. The actual reversal of sign was probably not observed more often due to the upper instrument not being either above or sufficiently near the top of the layer of negative space charge. It is of interest to note here that Kelvin's work was carried out with the upper instrument at a height of 30 metres and Chauveau used the stage at the top of the first section of the Eiffel Tower.

But a momentary reversal might be observed for a larger potential gradient at the ground during a period of rapid decrease of A. During such a period 2B would be considerably greater than A until the mixing of the layers occurs and the unusually strong positive potential gradient in the region b-c might outweigh the negative space charge above the upper instrument.. But such rapid changes in A are probably not common under steady rain conditions.

It was found that after the surface potential gradient had become zero and then changed to positive the space charge in the lower layers was also found to be positive. This positive space charge also increased in magnitude as the potential gradients recorded by both instruments increased. Under the conditions the only process by which an accumulation of positive charge would be found close to the ground would seem to be by an electrode effect with its consequent charge separation. This would support the idea of two layers of space charge of opposite sign and the one close to the ground being of the same sign usually as the potential gradient due to the cloud alone.

A reversal of sign in this direction, with a positive potential gradient at the ground and a negative potential gradient at the upper level, was not reported by Kelvin and Chauveau. But strong tendencies towards this effect were observed on a number of occasions in the present work, and in this case the signs of the space charge layers would be opposite to those shown in Fig.34, and A would be positive due to an excess of positive charge in the upper part of the cloud. The reason for it not being observed is possibly that the negative charge is associated more than the positive charge with the larger ions and water droplets and so the separation due to the electrode effect would not be as effective as for the positive charge. Also observation of the effect is more dependent on the magnitude of B rather than C as it only occurs for $2B > A$. It also depends on the relative positions of the two charge layers and the upper instrument.

The reversal of sign would possibly be observable in shower and thunder conditions if there were few ions produced close to the ground of opposite sign to the potential gradient by point discharge or the inductive charging on the splashing of drops, and then if $A < 2B$. But it seems unlikely, on considering previous results and the turbulent conditions that exist, which would lead to the mixing of the layers, that the effect would be observed.

In the atmosphere there would not exist the idealised situation of Fig.34 as in both layers, especially the lower one, ions of both signs would exist. Only the sign of the excess space charge has been considered.

If we consider A to be constant then in steady continuous rain we would reach a steady state eventually and there would be no measured variations of the potential gradient at the ground. So it would seem unlikely that the variations of potential gradient at the ground are completely dominated by changes in the space charge. But if in steady rain we reach a steady state in ion production and density, then the potential gradient at the ground will reflect variations in A as these would cause variations in the space charge separation. The main effect of the space charge will be to alter the magnitude of the potential gradient at the ground, but variations in this potential gradient will reflect very approximately variations of the potential gradient due to the cloud alone, although there will be a slight time lag as the time taken for the separation or remixing to take place must be considered.

But before any further conclusions can be made about the charge in the cloud, and its variation, the relative values of B and C must be further investigated. So measurements will be required of the rate of rainfall, precipitation current, and the height of the cloud base to determine the contribution of the charge on the rain to B. Also measurements of the space charge per unit volume at various levels and of the rate of movement of charge in a vertical plane under the influence of a potential gradient would be of value.

2. Space Charge Due To The Charge On Rain

To estimate the contribution to the upper space charge layer B by the charge on the rain consider the results of 19.5.62. Assume that the charge on the rain remains constant during it's fall from the base of the cloud to the ground.

For a rate of rainfall of 1 mm/hr. the number of drops per cubic metre, n, is 150 according to Magono and Orikasa (1961). The average value of the precipitation current during long periods was + $3\mu\mu$amperes/M^2. So if the terminal velocity of the drops is 4 metres/sec. Then the average charge per drop = $0.005\mu\mu$ coulombs = Q.

$$\therefore \text{Space charge density} = nq = 150 \times 0.005$$
$$= 0.75\,\mu\mu\text{coulombs/M}^3$$

The average height of the cloud base of nimbostratus is in the range 500 - 1000 metres. This would correspond to a positive space charge between the cloud and the earth in a column of one square metre cross-section of 300 - 750$\mu\mu$coulombs.

The comparable measured values of negative space in a similar column between the two measuring instruments had an average value of 1200$\mu\mu$coulombs and reached values of over 2000$\mu\mu$coulombs. This does not include the layer close to the ground as the lower instrument was situated approximately 1 metre from the ground. There is also the possibility that the negative layer extends above the upper instrument. So, in this case, for the two space charge layers to have effects of equal magnitude an electrode effect would appear to be necessary. But the charge on the rain does make an appreciable contribution to the upper space charge layer.

3. Other Conclusions And Suggestions For Further Work

It would appear that the shielded collector is a completely unsuitable instrument for the measurement of precipitation current in regions of high potential gradient due to the charge produced when drops splash on the collector shielding. It was also found that when uncharged drops splashed directly onto an aluminium surface, such as the collector cone, under zero potential gradient then a positive charge was recorded. The charge depended, according to Lenard (1921), upon the violence of the impact and so may be somewhat reduced due to the sloping sides of the cone. The potential gradient would tend to concentrate at the upper edge of the collector on the ground and so would have an exposure factor greater than one. So even for the values of the potential gradient recorded at the ground it would seem possible that the charging by induction on splashing by drops on the edge will make a contribution to the recorded current. This contribution to the precipitation current would reinforce the mirror image effect. So caution must be exercised even in interpreting the results from the collectors in low potential gradients, especially for low values of the precipitation current.

It would seem impossible to correct for the splashing effect so a new type of instrument is required for the measurement of precipitation currents especially in regions of high potential gradient. It might be possible to adapt the induction ring method of measuring the charge on single drops.

If this were to be done then value can come from the continuation of the present work. At the same time it would be important to measure simultaneously the rate of rainfall, and if possible incorporate direct measurement of space charge at various heights o~~f~~n the mast.

Further investigation of the release of charge due to splashing should be made, considering splashing onto natural vegetation surfaces.

Further conclusions might have resulted from the present work if a greater period of recording had been possible as the teething troubles were only just being overcome when recording had to stop due to the collapse of the mast.

ACKNOWLEDGEMENTS

The author wishes to express his thanks to his co-worker, Mr. H.L. Collin, and to his superviser, Dr. J.A. Chalmers, without whose aid and advice the work would never have been completed. He is also indebted to Professor GD. Rochester for the provision of research facilities and to D.S.I.R. for a maintenance grant during the period 1960-1962.

Thanks are also due to the author's wife and to Mr. A.J. Mace for the photographing of diagrams. Finally the author would like to express his appreciation for all their help to his fellow research students and to the technical staff of the Physics Department.

REFERENCES

Adamson J.	1958	Durham Ph.D. Thesis
Adkins C.J.	1959a	Quart J.R. Met.Soc. 85 PP 237-252
Adkins C.J.	1959b	Quart J.R. Met.Soc. 85 P.363
Adkins C.J.	1959c	Quart J.R. Met.Soc. 85 P.419
Bergeron T.	1933	Proc. 5th Assembly U.G.G.I. p.156
Best A.C.	1950	Quart J.R. Met.Soc. 76 PP 16-36
Browne I.C., Palmer H.P. Wormell T.W.	1954	Quart J.R.Met.Soc. 80 PP.291-327
Chalmers, J.A.	1953	J. Atmosph Terr.Phys. 10 PP 124-12
Chalmers J.A.	1956	J. Atmosph.Terr.Phys. 9 PP311-321
Chalmers J.A.	1957	"Atmospheric Electricity' Pergammon Press.
Chalmers J.A. & Pasquill F	1938	Proc. Phys.Soc. Lond.50 PP 1-16
Chauveau B.	1900	Annales Du Bev.Mét. Fr. 5 P.1
Clark J.F.	1949	Instruments 22. P.1007
Collin H.L.	1962	J.Atmos. & Terr.Phys. 24 PP743-745
Collin H.L.	1963	Surham M.Sc. Thesis
Elster J. & Geitel H.	1888	Met.Z. 5 PP 45-100
Gill E.W.B. & Alfrey G.F.	1952	Proc. Phys. Soc. B 65 P.473
Gish O.H.	1951	Compendium of Meteorology PP 101-119.
Gish O.H. & Sherman K.L.	1936	Nat.Geog.Soc.Strato.Ser. 2 PP 94-116.
Goto	1951	J. Geomagn.Geolect.Kyoto, 3 PP 22-23
Kelvin, Lord	1860	Phil.Mag. & B.A. Papers on Electrostatic & Magnetism PP 316-320.

Lenard P. 1892 Ann.Phys.Lpz. 46PP584-636

Lenard P. 1904 Met. Z. Meterol. Vol. 21

Lenard P. 1921 Ibid, 65 P.269

Macky W.A. 1937 Terr.Magn.Atmos.Elect. 42 PP. 77-86

Magono C & Orikasa K. 1960 J.Met.Soc.Japan II Vol.38 No.4.

Magono C & Orkiasa K. 1961 J. Met.Soc.Japan II Vol. 39 No.1.

Magono C., Orkasa K., & Okabe H. 1957 J. Faculty Science Hokkaidio V. Japan 1

MA

Magono C & Koenuina S. 1960 J. Met.Soc. Japan II Vol.36 No.3.

Mapleson W.W. & Whitlock W.S. 1955 J. Atmosph.Terr.Phys. 7 PP 61-72.

Mclelland J.A. & Nolan J.J. 1912 Proc.R.Irish Acad.A. 29 PP 81-91

Merry G. 1960 Durham M.Sc. Thesis

Milner J. 1959 Durham Ph.D. Thesis

Morgan W.A. 1960 Quart. J.R. Met. Soc. 86 P.107

Ramsay M. & Chalmers J.A. 1960 Quart J.R.Met.Soc. PP.530-539

Russeltvedt N. 1926 Beiheft Zurjb. Norweg.Met. Inst. PP.11-15

Scrase F.J. 1938 Geophys Mem., Lond. 75 PP.1-51

Simpson G.C. 1909 Phil. Trans. A. 209 PP. 379-413

Simpson G.C. 1915 Phil.Mag. 30 PP.1-12.

P

Simpson G.C. 1949 Geoghys.Mem.Lond 84 PP.1-51

Smith L.G. 1955 Quart. J.R. Met. Soc. 81 P.23.

Weiss E. 1906 Akad.Wiss.,Wein B. 104 PP 1937-1434.

Wilson C.T.R. 1916 Proc.Roy.Soc.A. 92 PP.555-574

Wilson C.T.R. 1929 J.Franklin Inst. 209 PP.1-12