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Point discharge current, the earth's electrical field and rain charges during disturbed weather at Poona

M. V. SIVARAMAKRISHNAN

Meteorological Office, Poona

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ABSTRACT. An analysis of measurements of the current flowing to earth through an insulated point set up at the Meteorological Office, Poona, at a height of 17·8 metres together with simultaneous measurements of potential gradient by a quick-run photographic electrograph during fourteen thunderstorms in 1955 show that point discharge currents of either sign can be represented as increasing with the square of the field as found by Whipple and Scrase for Kew, Hutchinson for Durham, Chiplonkar for Colaba (Bombay). An advancement of the field change ahead of the corresponding point discharge current is shown during a few thunderstorms at Poona like the one noticed by Hutchinson for Durham. A comparison of point discharge current measurements with field strength at Poona (taken typical of tropical region) and Kew (taken typical of temperate region) show that there is no major difference in the electrical conditions in the tropical and temperate regions. Simpson's 'mirror image' effect is also shown by Poona records but the synchronisation of the change in the sign of the rain current is more with the field change rather than with the point discharge current which lags behind the field change. Preliminary results with four-point discharger show that the total current is more than the current from a similar single point for the same field.

1. Introduction

The study of atmospheric electricity during disturbed weather has assumed some importance in recent years due to its intimate connection with the physics of rain clouds and the electric charge brought down by rain drops. The practice in most observatories is generally to adjust the self-recording instruments to register only the fine weather field (potential gradient) so that records during disturbed weather periods are 'off the trace' and are lost. A closer study of the simultaneous values of rain electricity, the potential gradient, the rate of rainfall, point discharge current and other factors at shorter intervals, a minute at the most, is required for the proper understanding of the electrification of clouds. The object of this study is, therefore, to investigate the relationships between the above factors from the continuous records taken at the Instruments Section of the Meteorological Office, Poona, during the years 1954 to 1956. In this paper an analysis of the continuous records of the point discharge currents and earth's electrical field has been made as the process of point discharge plays the most important part in the transfer of negative charge to the earth during storms to balance the arrival of positive charge during fine weather.

Measurements of the discharge from a single insulated point exposed to the high earth's field have been made by a number of workers like Wormell for Cambridge (1927, 1930), Whipple and Scrase for Kew (1936), Schonland for South Africa (1928), Hutchinson for Durham (1951) using different methods. In India, Chiplonkar (1940) working at Colaba Observatory, Bombay, had measured the current through a point 8·3 metres high and recorded the field simultaneously using a radio-active collector during the monsoon season of 1938. In this paper the measurements of the discharge current through an insulated raised point and the simultaneous values of potential gradient and rainfall electricity at Poona during 1955 are discussed.

2. Experiments and results

The point discharger used in this investigation is shown in Fig. 1. The point consists of a fine platinum wire 0·5 mm in diameter and about 2 cm long soldered to a tapered brass rod, 3 mm in diameter and about 20 cm long. The connection to the galvanometer is made with coaxial cable, one end of which is soldered to the brass rod. The brass rod is insulated by fixing the same through an amber rod fixed inside a brass tube 1·5 cm in diameter. In order to protect the exposed amber rod from rain and dirt, it is covered by a brass tube 4 cm in diameter, one end of which is fixed to an amber washer as shown in Fig. 1. The height of the brass rod carrying the platinum wire can be adjusted by means of a set screw fixed to a Tufnol Bush. The whole system is clamped to the top of a wooden mast. The height of the point above the ground is 17·8 metres. The point discharge currents is registered with a Moll Galvanometer, the sensitiveness of which can be adjusted by suitable shunts. For the present investigation, a shunt of 10 ohms is used which gives a sensitivity of 1 micro-ampere for 22·5 mm deflection, the scale being kept at a distance of 1 metre from the mirror of the galvanometer. Movements of the galvanometer are recorded photographically on a drum which rotates once every hour and traverses about 8 mm every revolution. The minute marks are provided in the photographic paper by cutting off the light from a small lamp by a suitable relay in the circuit of a time marking eclipse clock. The time scale of the record is about 8 mm per minute. The discharging point was observed daily and straightened whenever necessary.

Records of the potential gradient are obtained with a photographic electrograph manufactured by Cambridge Instrument Company. The electrograph consists of a Dolezalek Electrometer and Radium Spiral Collector. The radium collector is exposed through a hole in the wall of the recording room (Fig. 2 D) and the distance of the collector is adjusted during times of high potential gradient so that the sensitiveness is reduced in definite ratios. The usual run of the paper is only 1·5 cm per hour, but occasionally during thunderstorms, it is made to run more rapidly giving a run of 6 cm per hour by suitable gears in order to get the value of the field with greater accuracy at short intervals of time.

The exposure of the collector at the present site though not ideal, had to be chosen because the electrograph was located in a dark room in the fourth floor of the observatory building. Comparison of potential gradient over level ground was made using Simpson and Wright's (1911) method periodically in the nearby open ground and the reduction factor obtained in fine weather was found to vary from 3 to 3·5. In this investigation a reduction factor of 3·5 is used for reducing the values obtained from the photographic record to that of level ground.

For measuring the electrical charge carried by rain, another sensitive Dolezalek Electrometer is used. The electrometer deflections are recorded photographically on another drum, identical to the one used for recording point discharge current in the same recording hut, so that the two records can be compared at minute intervals. The amount of rain caught by an insulated funnel is measured by a tilting bucket raingauge. The gauge carries a mercury switch which at each tilt of the bucket turns on a light source to the photographic paper, thereby giving a vertical line on the record for every cent of rain collected by the apparatus amounting to 8 cc. The time interval between tilts of the bucket can be measured accurately and the rate of rainfall determined. Fig. 3 gives a portion of the rain electrograph record taken during a thunderstorm on 27-28 September 1955 with this arrangement.

(*a*) *Relation between point discharge current and field strength at Poona during thunderstorms*—A few typical records obtained during point discharge are given in Figs. 4, 5 and 6. An upward deviation from the straight line indicates a downward current, *i.e.*, a flow of positive electricity into the point and therefore a positive potential gradient. The records obtained during 14 thunderstorms during 1955 are analysed (Table 1) and the mean values of the point discharge current and the potential gradient during each minute are tabulated. The results are summarised in Fig. 7. The potential gradient has been reduced to the value over level ground. There is considerable scatter in the points, the rate of increase of the current with increasing potential gradient tending to become more rapid as the gradient increases. The curves drawn through the points are similar to those obtained for Kew by Whipple and Scrase (1936) and represent the empirical relation

$$i = a\,(F^2 - M^2)$$

where i is the downward current in micro-amps, F the downward directed field in volts/cm, M the minimum field for the onset of point discharge and a a constant depending on the sign of the current. Table 2 gives the relation between point discharge current and field strength for various values.

In the relation $i = a\,(F^2 - M^2)$, Whipple and Scrase have found the values $M=7 \cdot 8$ v/cm for positive currents and $M=8 \cdot 6$ v/cm for negative currents and $a=0 \cdot 0008$. The curves of Fig. 7 for Poona yield $M=5$ v/cm for positive currents and $M=6$ v/cm for negative currents.

(*b*) *Comparison of point discharge current measurements with field strength at Poona with measurements at other places*—A comparison of point discharge measurement taken at Poona (taken typical of tropical region) and Kew (taken typical of temperate region) has been made with a view to find out whether there is any genuine difference in the electrical conditions during storm in the tropics and temperate regions. Tables 3 and 4 give the results of the comparison of measurements taken at Poona (Table 2) and Kew (data taken from *Geophys. Mem.*, 84, Table 3, p. 26—Simpson 1949). It is seen that for the same field at both places the point discharge current is more or less same indicating perhaps no major difference in the electrical conditions in the tropical and temperate regions. But the maximum current observed at Poona is only of the order of one micro-ampere during 1955 (Fig. 8). Generally the point discharge currents observed at Poona are less than 0·4 micro-ampere agreeing with the observations by Chiplonkar (1940) at Colaba but very much lower than that observed at Kew or Durham (Fig. 9). At Kew, currents of the order of 15 micro-amperes have been observed sometimes during storms. Also the fields at the ground at Poona during thunderstorms are found to be of the order of 30–40 v/cm whereas at Kew, fields of the order of 100–150 v/cm are observed. This difference between the tropical and temperate storms probably arises due to the difference in meteorological conditions. Gunn (1935) has explained this difference due to the level of condensation in the tropics occurring at greater heights than in temperate latitudes. It is also known that in the tropics the water vapour content of the atmosphere is greater than elsewhere and since the amount of water vapour determines the degree of instability and the velocity of rising air currents, these air currents extend to greater heights. Thus in the tropics during thunderstorms the rain formation levels are at greater heights and so the actively charged region is relatively far away from the earth's surface. Thus the active and induced charges on the earth are well separated. It is perhaps these factors which make lightning discharges to earth relatively infrequent in tropical storms. On the other hand in the temperate regions discharges to the ground are usual rather than exceptional.

(*c*) *Relation between point discharge currents from multiple points and a single point*—Chiplonkar (1940) used in his experiments four similar discharging points in a square and found less total current than a single point. Chalmers and Mapleson (1955) in measurements of point current from a captive

TABLE 1

Measurements of point discharge currents from a few thunderstorm records at Poona during 1955

S. No.	Date	Duration (min)	Discharge in millicoulombs — Inflow	Outflow	Net outflow
1	3 May	39	..	·693	0·693
2	5 May	200	·656	·290	—0·366
3	6 May	87	·533	·407	—0·126
4	17 Sep	121	·565	·575	0·010
5	18 Sep	40	·119	·634	0·515
6	25 Sep	107	·676	·235	—0·441
7	26 Sep	80	·145	·721	0·576
8	27-28 Sep	193	·835	1·339	0·504
9	29 Sep	75	..	1·209	1·209
10	30 Sep	50	..	·422	0·422
11	19 Oct	52	..	·619	0·619
12	20 Oct	47	·032	·396	0·364
13	24 Oct	61	·311	·217	—0·094
14	2 Nov	20	·037	·251	0·214
	Total	1172	3·909	8·008	4·099

TABLE 2

Connection between point discharge current and field strength

Current (micro-amps)	Deflection on record (*D*) (mm)	i* (e.s.u./sec)	Field strength (v/cm) — Positive	Negative
0	0	—	5	6
·05	1·1	·147	9·0	9·0
·1	2·3	·306	10·5	11·5
·2	4·5	·598	14·0	15·5
·3	6·7	·891	17·0	19·0
·4	9·0	1·200	20·0	23·0
·5	11·3	1·500	24·0	26·0
·6	13·5	1·800	27·0	29·0
·7	15·7	2·090	31·0	32·0
·8	18·0	2·390	34·5	35·0

$*i = \cdot 133 \times 10^3 D$

TABLE 3

Comparison of point discharge current and field strength between Poona and Kew

Place	Point discharge current i (e.s.u./sec) $\times 10^3$	Field strength (v/cm) — Positive	Negative
Poona*	1·5	24·0	26·0
Kew 6-7-1943, 3-4-1944	1·4	..	23·0
Poona*	1·2	20·0	23·0
Kew (19-10-1943)	1·2	..	20·0
Poona*	1·8	27·0	29·0
Kew (6-7-1943)	1·9	26·0	..
Poona*	2·1	31·0	32·0
Kew 20-10-1942, 25-10-1942	2·2	..	29·0
Poona*	2·4	34·5	35·0
Kew 9-8-1945	2·3	..	30·0
Kew 2-9-1944	2·6	32·0	32·0
20-10-1942, 25-10-1942	2·4	..	32·0

*From Table 2 and Fig. 7

TABLE 4

Comparison of point discharge measurement at Poona with other places

Place	Height of point discharger (metres)	Year	Outflow / Inflow
Cambridge (Wormell)	12·3	1927, 1928	2·0
Kew (Scrase)	8·4	1933, 1934	1·7
Colaba (Chiplonkar)	8·3	1940	2·9
Durham (Hutchinson)	12·0	1951	..
Poona (Sivaramakrishnan)	17·8	1955	2.0

balloon found that eight points gave *together half the current* from a single point under similar conditions. On the other hand Belin (1948) in laboratory experiments used seven and thirteen points and found the *same amount of current per point* in the same field. In view of these conflicting results an attempt was made at Poona to measure the point discharge current using four similar points (Fig. 2) and records were obtained during a few thunderstorms. It appears from the preliminary results that the total current from the four points is more than that from a single point for the same field (Fig. 10). This result is different from that obtained by Chiplonkar at Bombay.

(*d*) *Relation between the field and the sign of point discharge current*—Generally the sign of the point discharge current is the same as the sign of the field. However, it has been observed on many occasions that the changes in the sign of the field and that of the point discharge current are not synchronous. Often a change in the sign of the field is observed near the ground ahead of the change in the point discharge current. This has also been observed by Hutchinson (1951) at Durham. Table 5 (Figs. 3 and 8) gives the details of an observation at Poona during thunderstorms on 27–28 September 1955 and 18 September 1955.

TABLE 5

Change in the field at the ground (F) ahead of the corresponding change in point discharge current (i)

Time (IST)	Field change	i at $F=0$ μ (*ma*)	Approx. interval $F=0$ to $i=0$ (sec)	F, at $i=0$ (v/cm)	F, when i begins with changed sign (v/cm)
		28 September 1955			
0025	— to +	— ·176	300	+ 3·9	+ 7·9
0105	+ to —	+ ·088	300	— 5·6	—11·2
0123	— to +	— ·176	540	+ 5·1	+ 9·0
		18 September 1955			
2247	— to +	— ·880	420	+11·5	+12·3

3. Mirror image effect

While discussing the electric charge carried by precipitation at Kew, Simpson (1949) observed that the sign of the charge on rain drops was generally opposite to that of the field particularly when the field strength was high enough to cause point discharge currents. This he called as the 'mirror image' effect. He had found no similar relationship between the potential gradient and rain electricity in his observations at Simla (India). Gerdien, Kähler and Schindelhauer had observed many cases of changes in the sign of the rain electricity accompanying changes of the opposite sign in the potential gradient, but they had also found many cases in which no such relationship was present. Hutchinson and Chalmers (1951) have observed that the signs of the rain drop charge and field are opposite. Gunn and Devin (1953) have *not* observed any systematic dependence of the sign of rain drop charge with the sign of electric field, both being measured at the surface. Thus many of the data regarding the 'mirror image' effect are contradictory.

In the observations made at Poona, there have been a number of occasions in which the 'mirror image' effect has been observed but the change in the sign of the rain charge does not synchronise always with the point discharge current. The synchronisation is more with the field near the ground. Fig. 3 shows portions of electrograph record, point discharge current, and the rain electrograph record respectively during the thunderstorm on 27-28 September 1955. It will be observed from this diagram that the changes in the sign of the rain charge synchronise more with the changes in the field at 0105 and 0123 IST on 28 September 1955 than with the changes in the sign of the point discharge current which lags behind the changes in the field at these times. While discussing the origin of electric charges in rain drops, during periods when point discharge occurs, Chalmers (1951) has shown that ion capture at a considerable height above 800 metres from the ground is important for explaining the origin of rain charges. But the sign of the electricity carried by precipitation changing simultaneously with the sign of the field measured *at the ground* and not simultaneously with the point discharge current indicates that the sign of rain charge depends upon the electric field through which the drop is falling.

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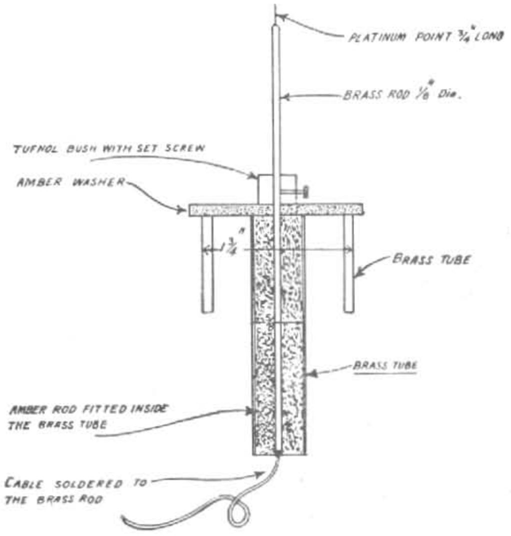


Fig. 1. Diagram showing construction of discharging system

Fig. 2. Diagram showing exposure of (A) 4-point discharger and single point discharger, (B) Natural syphon raingauge, (C) Raingauge receiver and tilting bucket and (D) Collector projecting from the recording hut

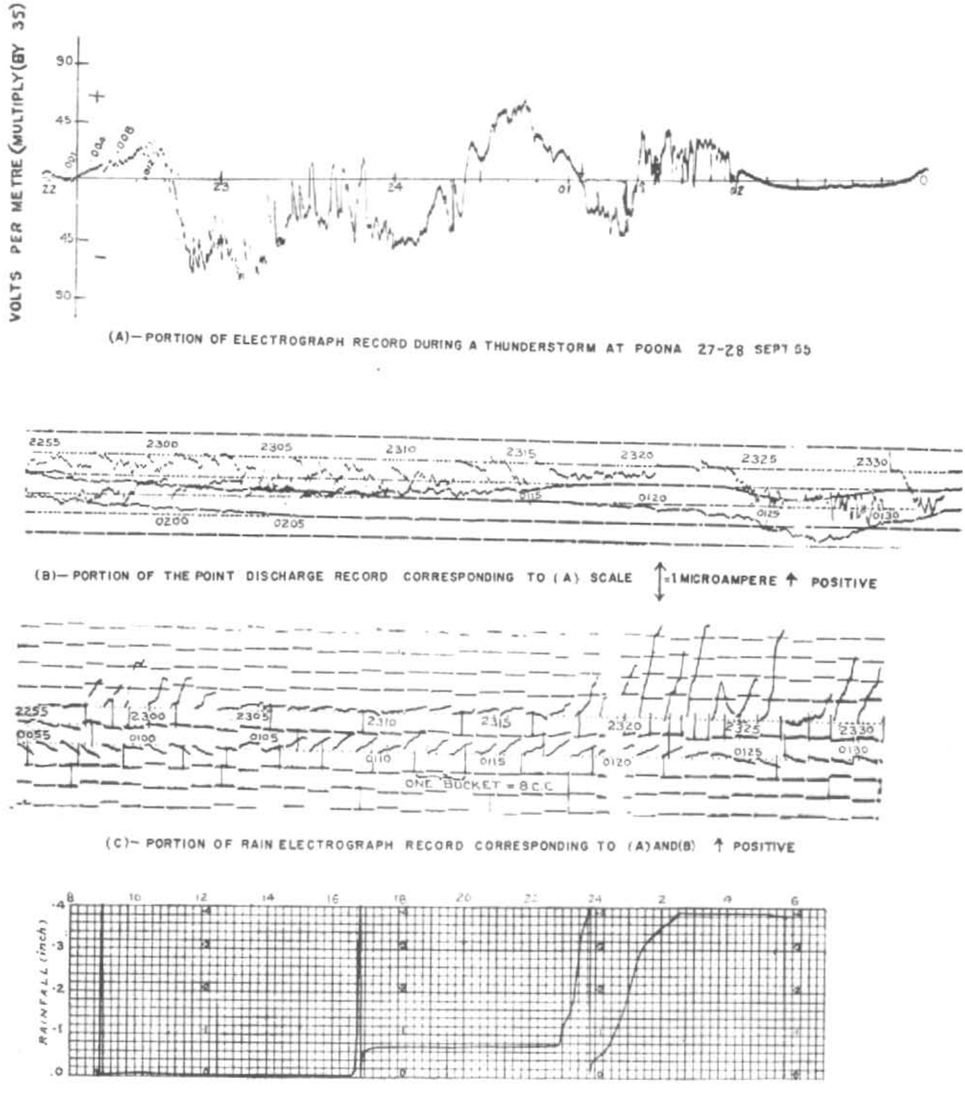
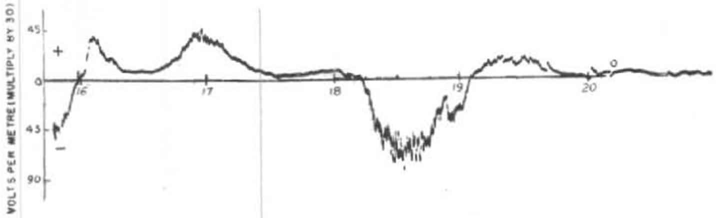
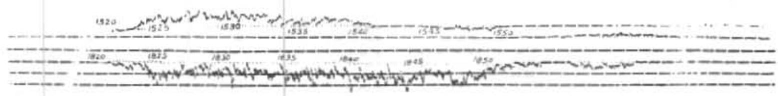


Fig. 3. Portions of potential gradient, point discharge current, rain electrograph and natural syphon raingauge records during a thunderstorm on 27-28 September 1955 showing simultaneous change in the sign of rain charge and field (mirror image effect) at 0105 and 0123 IST and not with the point discharge current at those times

Fig. 4

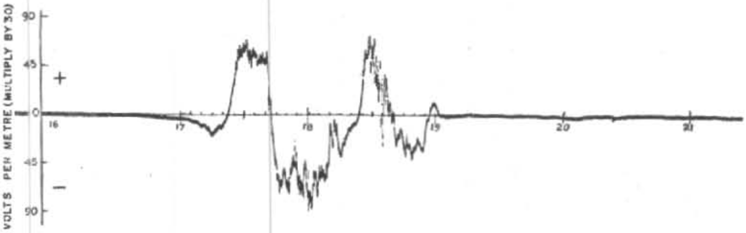


(A)–PORTION OF ELECTROGRAPH RECORD DURING A THUNDERSTORM (WITHOUT RAIN) AT POONA 3-5-55

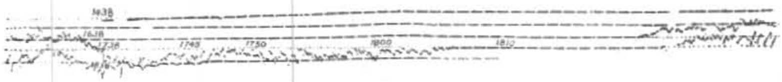


(B)– PORTION OF THE POINT DISCHARGE RECORD CORRESPONDING TO FIG (A) SCALE ↕ = I MICROAMPERE

Fig. 5

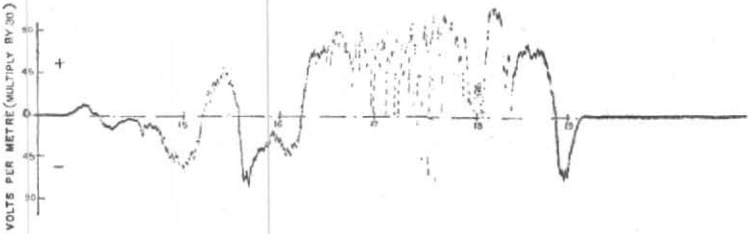


(A)– PORTION OF ELECTROGRAPH RECORD DURING A THUNDERSTORM (WITH RAIN) AT POONA MAY 6 1955



(B)– PORTION OF POINT DISCHARGE RECORD CORRESPONDING TO FIG. (A). SCALE ↕ = I MICROAMPERE

Fig. 6



(A)– PORTION OF ELECTROGRAPH RECORD DURING SEVERE LIGHTNING FLASHES MAY 5 1955

(B)– TYPICAL RECORD OF VARIATIONS IN POINT DISCHARGE CURRENT CORRESPONDING TO FIG(A)
SCALE ↕ = I MICROAMPERE

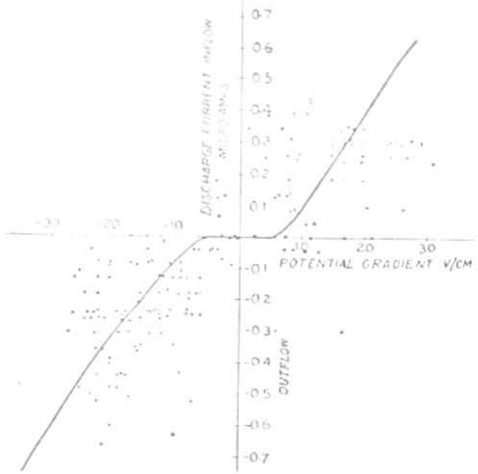


Fig. 7. Comparison of point discharge current and potential gradient

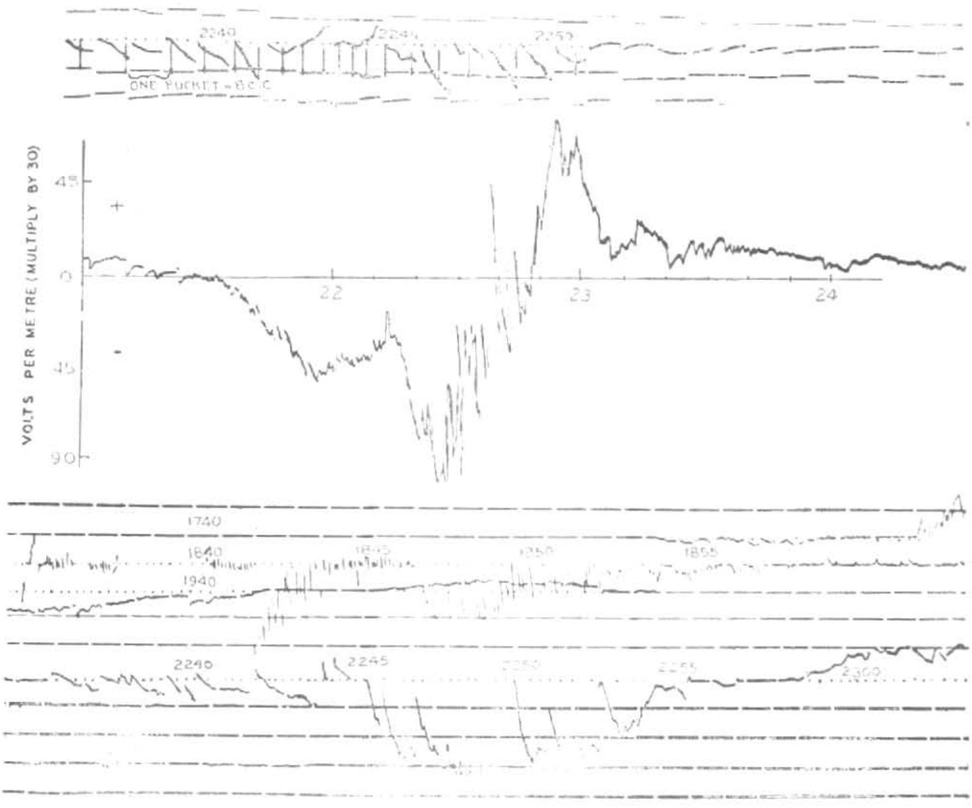
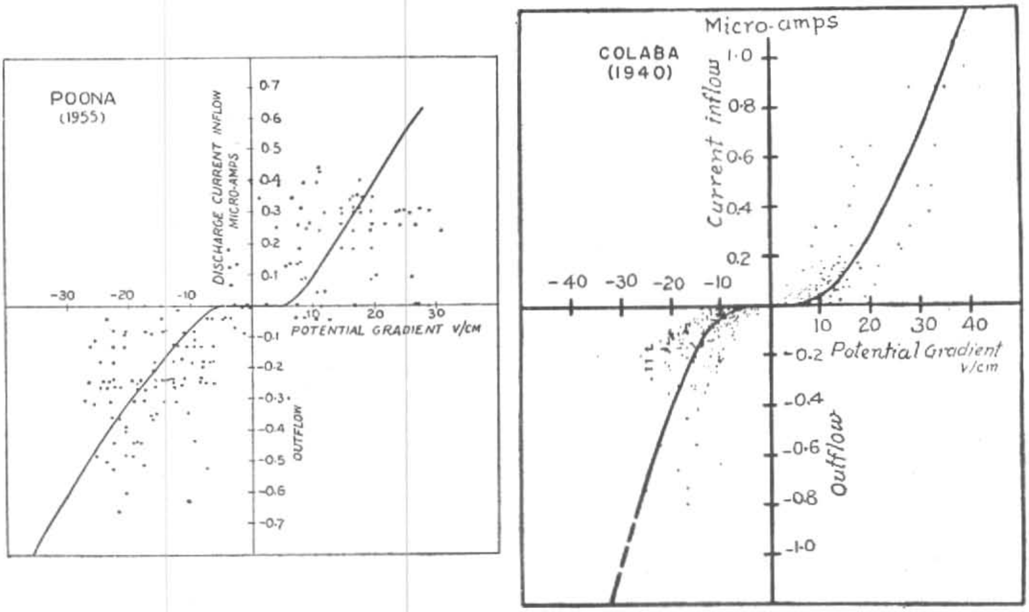


Fig. 8. Portions of rain electrograph, potential gradient and point discharge current records during a thunderstorm on 18 September 1955 showing simultaneous change in the sign of rain charge with the field at 2247 IST (mirror image effect) and not with the point discharge current



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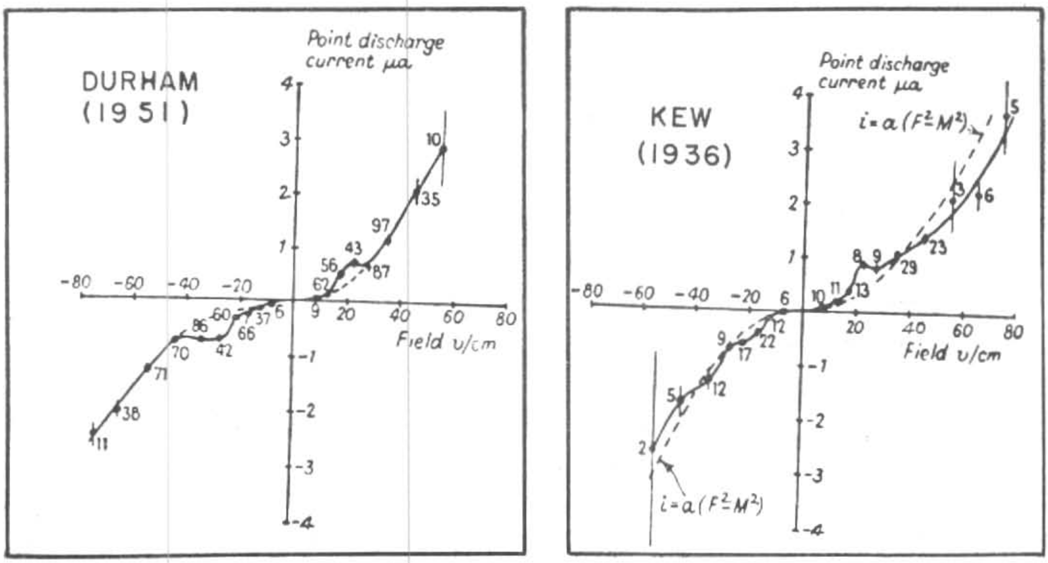

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Fig. 9. Comparison of point discharge current and potential gradient (Poona, Colaba, Durham and Kew)

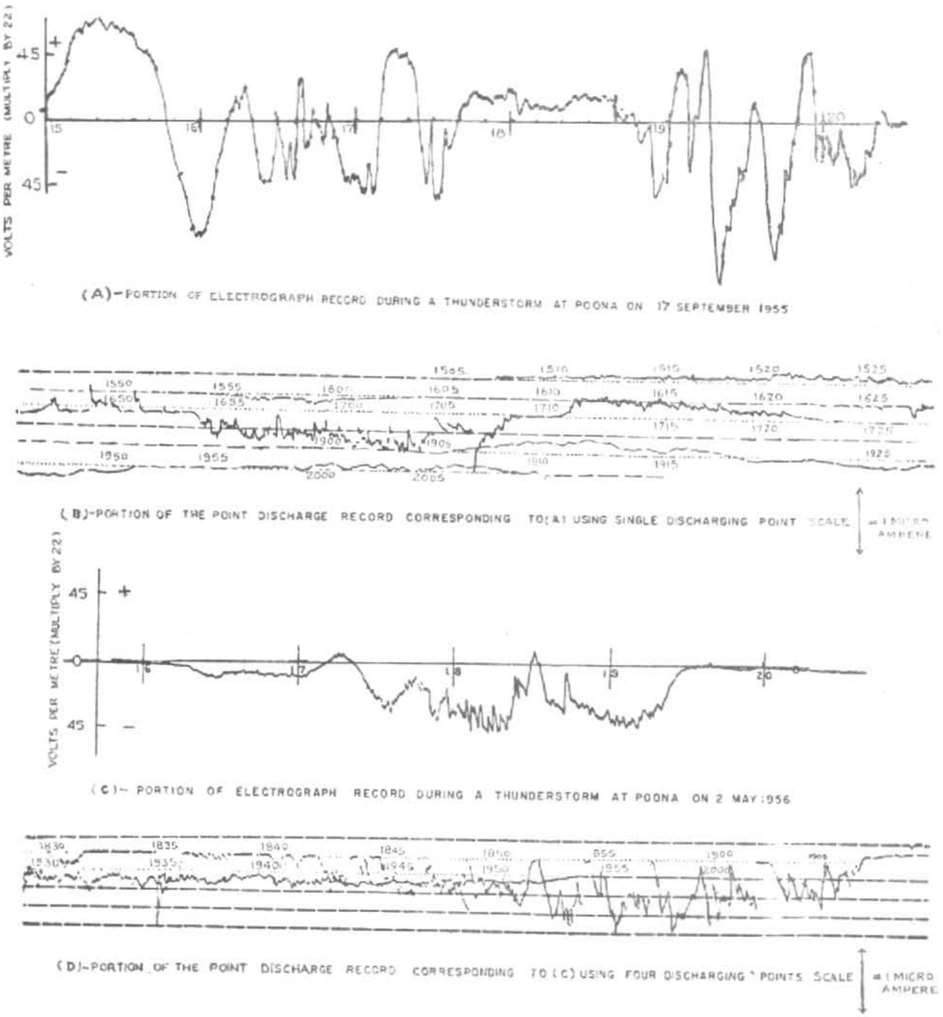

Fig. 10. Diagram showing point discharge current from 'multiple' points more than from a single similar point for the same field