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# Measurement of the two components of air earth conduction current in the tropics

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ABSTRACT. An attempt has been made for the first time at Poona (India) to measure both components of air earth current corresponding to the positive and negative ionic conductivities. To avoid electrode effect, at a distance of about 15 m above the ground, two duraluminium test plates (1 m square approximately) are being used one above the other separated by 20 cm. To measure the two components of air earth current, the top and bottom plates are connected to the two pairs of quadrants respectively of a quadrant electrometer and the needle is connected to a steady battery of 22·5 volts. To avoid displacement currents due to potential gradient changes two radioactive collectors are used one for each plate so that the correction due to the displacement current is rectified at the plates themselves. Full details of measurement of the two components of air earth current using the above apparatus are given and their importance in the study of the various problems in atmospheric electricity has also been indicated.

Measurements at Poona during the years 1967, 1968 of the potential gradient and conduction current during widespread fog, mist showed considerable increase in potential gradient and decrease in conduction current often changing from positive to negative values. Thus, the atmospheric electrical elements undergoing specific variations about 1 to 2 hours before the onset of fog and about ½ to 1½ hours before dissipation will be of special importance for meteorological forecasters, in agreement with the results of Dolezalek, Israel and Kasemir.

## 1. Introduction

The origin of air earth current and the factor which control its variation constitute one of the most important problems of atmospheric electricity. Continuous direct measurements of the air earth current are meagre especially from the tropics. The most successful continuous direct records of the air earth current were that of Simpson (1910) at Simla. The disadvantage of Simpson's method was that the record gave the charge brought down by the air earth current *plus* any induced charge produced by changes in the earth's field, which may have occurred during the period of measurement. It was necessary therefore to allow for field changes by applying corrections obtained from a simultaneous potential gradient record. An improvement of Simpson's method was made by Scrase(1933) using a compensating condenser which would automatically compensate the field changes. In practice it is found difficult to compensate the field changes using Scrase's method as the slightest variation in the adjustment of the condenser alters the compensation for field changes. It can perhaps be argued as Chalmers (1957) had expressed that Scrase's method is not truly a direct measurement of air earth current but only apparently so, and that what is really measured is the unipolar conductivity of the air between the wire net and the plate, by measuring the current for a given applied potential gradient to the region. The effect of connecting the wire net to the collector, rather than of having it at some other potential, is to make the conditions between the net and plate as close as possible to the natural conditions in the atmosphere. The current measured is not quite the natural current to an area of the earth,

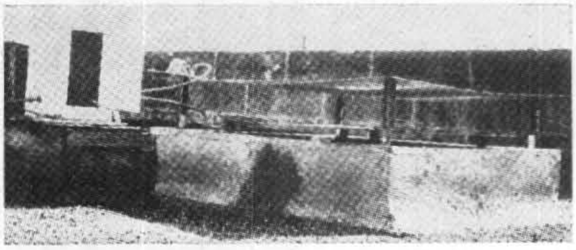


**Fig. 1**

Position of two duraluminium plates about a metre square one above the other supported by plexiglass insulators for measurement of the two components of air earth conduction current. The top plate receives positive ions coming from above and bottom plate receives negative ions coming from below (earth)

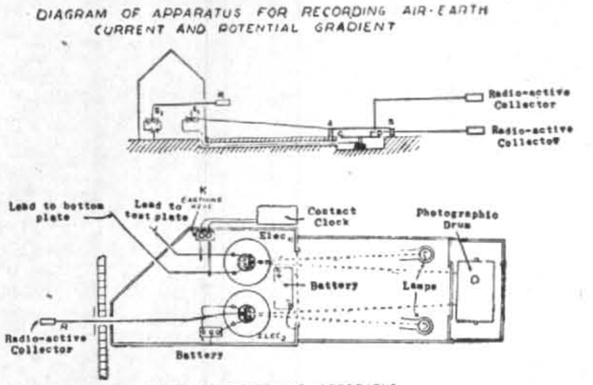



**Fig. 2**

Scrase's apparatus (1933) with modification for the measurement of two components of air earth current by using two duraluminium plates (AB, CD, one metre square) one above the other using plexiglass insulators. Compensation for the displacement current due to field changes has been arranged by fixing two radio-active collectors one for each plate

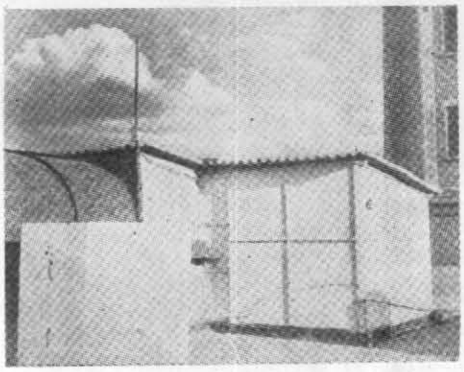


**Fig. 3**

A view of newly constructed Faraday Cage Hut wherein sensitive electrometers, sensitive galvanometers, photographic recorders for recording potential gradient, air earth current, rain charge, point discharge current from an artificial metal point, point discharge current from tree are housed

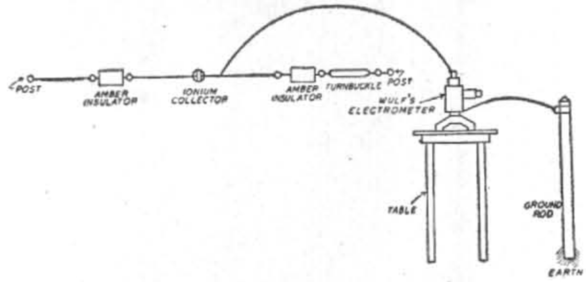



**Fig. 4. Diagram showing arrangement for absolute potential gradient measurement**

when the net is not at the exact potential of the air in its neighbourhood. The improvement made in the present study for the continuous measurement of air earth current is by using two duraluminium plates (Fig. 1), about a metre square, one above the other, separated by a very small distance of 20 cm, using plexiglass insulators. The whole apparatus is at the potential of this level. The exact details of the apparatus and the method of calculation of air earth current are given below.

## 2. Description of the apparatus

Fig. 2 shows the plan of the recording apparatus for recording air earth current and potential gradient. AB, CD are two duraluminium **plates** about a metre square and 0·2 cm thick supported by plexiglass insulators in a shallow concrete pit. The bottom plate is arranged to be above the ground level. The air gap between the plate and ground is about 3 cm across while the depth of the pit is 15 cm. The bottom plate CD is connected by coaxial cable to one pair of quadrants of Dolezalek electrometer $E_1$. The top plate AB is connected by coaxial cable to the second pair of quadrants of this electrometer $E_1$. The needle of another quadrant electrometer $E_2$ is connected to a radioactive collector R fixed to an insulated rod projecting through a hole in the recording hut, a Faraday cage (Fig. 3), and the needle of the first quadrant electrometer $E_1$ is connected to a steady battery of 22·5 volts.

By means of electromagnetic keys K worked by a contact clock both pairs of quadrants of the electrometer $E_1$ are earthed for one minute at regular intervals of ten minutes. To avoid displacement currents due to potential gradient changes, two radioactive collectors are used one for each plate so that the correction due to the displacement current is rectified at the plates themselves. The whole set up has been fixed on the third terrace of the observatory building (Fig. 2) and as such the measurements of air earth current and potential gradient are made far away from the earth's surface as suggested by Israel (1963).

As shown in the plan of recording apparatus, two lamps are used, one for the measurement of potential gradient and another for the measurement of air earth current. The spots of light coming from the two lamps are reflected by the mirrors of the two electrometers $E_1$ and $E_2$ and allowed to fall on the same photographic paper so that we get the continuous record of potential gradient and air earth current on the same photographic paper. Fig. 4 shows the arrangement for absolute potential gradient measurement.

### 3. Calibration and reduction of records

*Air earth current*

The magnitude of the air earth current is obtained by the formula—

$$i = \frac{C.V}{A\,t}$$

where, $i$ is the current per unit area, $C$ is the capacity of the test plate system, $A$ is the area of the plate and $V$ is the change of potential recorded in $t$ seconds.

If $k$ is the scale value of the electrometer in volts per division and $d$ is the deflection in cm recorded in $t$ seconds, the calculation of air earth current in practical units is given by —

$$i = \frac{C\,k}{A\,t}\;\frac{d}{9\times10^{11}}\ \text{(amp per sq.cm)} \qquad (1)$$

The capacity between the two plates is measured accurately by means of a standard bridge. The value of $C$ obtained is 544 cm. The scale value of the electrometer $E_1$ is determined by applying a known voltage (1·45 volts) after both pairs of quadrants have been earthed momentarily and then insulated. The sensitivity is such that one cm in the record (at 100 cm from the electrometer) is equivalent to 1·45 volts on the test plate. The area $A$ of the plates being 11881 cm$^2$ and the time interval $t$ between successive earth marks being 9 min (540 sec), the calibration factor given by formula (1) is obtained as follow—

$$i = \frac{544 \times 1{\cdot}45 \times d}{109 \times 100 \times 450 \times 9 \times 10^{11}}$$

$$= 136{\cdot}5 \times 10^{-18}\ \text{amp/sq cm}$$

where, $d$ is the deflection in cm reached in 540 sec.

The scale value $k$ is measured once a month and the factor is altered if necessary by applying proper voltage to the needle of the electrometer $E_1$; generally 22·5 volts is applied to the needle of the electrometer $E_1$.

*Analysis of records*

In consequence of the vertical electric field and of the conductivity of the air, an electric current flows downward in fine weather through the lower atmosphere into the earth, the positive and negative ions, moving downwards and upwards respectively. The magnitude of the conduction current in the free air is given by—

$$i = F\,(\lambda_+ + \lambda_-)$$

where, $i$ = conduction current intensity,
$F$ = intensity of electric field
$\lambda_+$ = positive conductivity,
$\lambda_-$ = negative conductivity.

If there is a vertical gradient of space charge density, turbulent transfer will cause a vertical convection current and indeed careful consideration is necessary in attempting to derive total vertical current into the ground from measurements of the field and the polar conductivity of the air. By the method described already it is possible, however, to measure the current directly.

The conductivity of the air increases fairly rapidly with increasing height above the ground, for two reasons; ionic mobility is greater at lower air densities and the number of ions present is also greater owing to the enhanced effect of the downcoming cosmic radiation. A vertical current independent of height, is thus maintained through a considerable vertical thickness despite the decrease in the vertical field at higher levels.

The circulation of electricity in the atmosphere above any place may be expressed by the simple equation,

$$i = \frac{V}{R}$$

where, $i$ is the air earth current, $V$ is the potential difference between the ionosphere and the ground, $R$ is the total effective resistance of the air column above the place. The potential gradient $F$ at the surface is the product of the current and the specific resistance of the air $r$ (*i.e.*, the reciprocal of the positive conductivity at the surface). Thus we may write —

$$F = ir = V\,(r/R)$$

Whipple (1932) has shown how the current flowing from the air into the earth is better represented by the product of the potential gradient and the positive conductivity.

During the Third International Conference on Atmospheric and Space Electricity held at Montreal in 1963, Prof. H. Israel had emphasized the importance of measuring simultaneously the atmospheric electric parameters, *viz.*, potential

TABLE 1

Hourly means of potential gradient (volts/m) at Poona during Nov 1965-Dec 1966

| Time (IST) | 1965 Nov | 1965 Dec | 1966 Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-1 | 182 | 212 | 152 | 134 | 112 | 84 | 51 | 36 | 31 | 33 | 74 | 108 | 146 | 169 |
| 1-2 | 160 | 190 | 135 | 105 | 104 | 75 | 48 | 35 | 32 | 36 | 74 | 103 | 123 | 136 |
| 2-3 | 128 | 152 | 144 | 96 | 104 | 75 | 43 | 26 | 29 | 36 | 67 | 98 | 107 | 115 |
| 3-4 | 94 | 146 | 97 | 82 | 96 | 69 | 44 | 29 | 23 | 31 | 67 | 90 | 92 | 107 |
| 4-5 | 104 | 139 | 98 | 82 | 93 | 79 | 43 | 35 | 26 | 30 | 61 | 89 | 100 | 100 |
| 5-6 | 119 | 143 | 108 | 93 | 101 | 98 | 51 | 40 | 30 | 45 | 67 | 101 | 123 | 123 |
| 6-7 | 154 | 209 | 143 | 134 | 138 | 127 | 63 | 37 | 41 | 38 | 96 | 128 | 161 | 176 |
| 7-8 | 221 | 225 | 175 | 209 | 196 | 175 | 75 | 38 | 40 | 45 | 120 | 180 | 230 | 222 |
| 8-9 | 274 | 291 | 283 | 272 | 217 | 188 | 70 | 50 | 45 | 44 | 138 | 231 | 238 | 308 |
| 9-10 | 333 | 400 | 303 | 270 | 212 | 146 | 61 | 46 | 35 | 40 | 116 | 221 | 222 | 314 |
| 10-11 | 265 | 337 | 251 | 236 | 155 | 135 | 51 | 44 | 37 | 38 | 115 | 188 | 184 | 262 |
| 11-12 | 188 | 238 | 191 | 174 | 121 | 97 | 36 | 36 | 31 | 36 | 109 | 147 | 176 | 192 |
| 12-13 | 147 | 209 | 153 | 120 | 96 | 83 | 31 | 32 | 37 | 32 | 89 | 116 | 146 | 138 |
| 13-14 | 121 | 198 | 104 | 89 | 71 | 70 | 31 | 29 | 37 | 37 | 70 | 109 | 138 | 107 |
| 14-15 | 127 | 172 | 92 | 69 | 65 | 48 | 30 | 32 | 30 | 33 | 88 | 100 | 138 | 123 |
| 15-16 | 134 | 172 | 81 | 68 | 61 | 22 | 26 | 31 | 25 | 28 | 77 | 101 | 130 | 115 |
| 16-17 | 122 | 182 | 75 | 71 | 55 | 31 | 36 | 33 | 24 | 21 | 76 | 104 | 146 | 123 |
| 17-18 | 181 | 241 | 112 | 96 | 46 | 60 | 47 | 20 | 28 | 15 | 68 | 111 | 199 | 184 |
| 18-19 | 226 | 275 | 151 | 143 | 67 | 99 | 67 | 29 | 32 | 23 | 83 | 123 | 215 | 260 |
| 19-20 | 249 | 304 | 185 | 159 | 107 | 117 | 76 | 22 | 35 | 26 | 82 | 137 | 207 | 285 |
| 20-21 | 242 | 267 | 195 | 179 | 93 | 111 | 73 | 44 | 31 | 29 | 76 | 150 | 184 | 253 |
| 21-22 | 227 | 289 | 190 | 166 | 93 | 96 | 68 | 45 | 33 | 37 | 83 | 176 | 176 | 238 |
| 22-23 | 206 | 314 | 182 | 157 | 104 | 77 | 60 | 35 | 30 | 32 | 77 | 152 | 146 | 207 |
| 23-24 | 169 | 285 | 179 | 138 | 108 | 90 | 51 | 36 | 28 | 32 | 77 | 131 | 146 | 199 |

TABLE 2

Seasonal and annual means of potential gradient ($F$), conductivity ($\lambda$) and air earth current ($i$) during January to December 1966

| Time | Potential gradient (volts/m) | | | | Conductivity ($\lambda$) ($10^{-14}\ \Omega^{-1}\mathrm{m}^{-1}$) | | | | Air earth current ($i$) ($\times 10^{-12}$ amp/m²/sec) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (GMT) | Summer | Equinox | Winter | Year | Summer | Equinox | Winter | Year | Summer | Equinox | Winter | Year |
| 0030 | 41 | 92 | 112 | 82 | — | 1·04 | 1·89 | 1·73 | — | 0·956 | 2·116 | 1·420 |
| 0130 | 45 | 122 | 153 | 107 | — | 0·78 | 1·20 | 1·23 | — | 0·956 | 1·843 | 1·311 |
| 0230 | 49 | 168 | 209 | 142 | 1·81 | 0·62 | 0·88 | 0·87 | 0·887 | 1·047 | 1·843 | 1·230 |
| 0330 | 52 | 193 | 275 | 174 | 2·10 | 0·83 | 0·89 | 0·97 | 1·092 | 1·604 | 2·457 | 1·689 |
| 0430 | 45 | 174 | 277 | 165 | 2·58 | 0·84 | 1·01 | 1·04 | 1·160 | 1·467 | 2·799 | 1·723 |
| 0530 | 43 | 148 | 233 | 141 | 2·54 | 1·08 | 1·23 | 1·27 | 1·092 | 1·604 | 2·867 | 1·792 |
| 0630 | 35 | 120 | 183 | 113 | 2·75 | 1·51 | 1·49 | 1·62 | 0·955 | 1·809 | 2·730 | 1·826 |
| 0730 | 33 | 96 | 139 | 89 | 2·48 | 1·71 | 2·16 | 1·99 | 0·82 | 1·64 | 3·00 | 1·77 |
| 0830 | 33 | 80 | 109 | 74 | 2·48 | 2·01 | 2·75 | 2·37 | 0·82 | 1·60 | 3·00 | 1·76 |
| 0930 | 31 | 75 | 105 | 71 | 2·22 | 2·37 | 2·53 | 2·43 | 0·69 | 1·77 | 2·66 | 1·72 |
| 1030 | 27 | 65 | 99 | 64 | 2·78 | 1·94 | 1·90 | 2·40 | 0·75 | 1·26 | 2·87 | 1·54 |
| 1130 | 29 | 66 | 104 | 66 | 2·82 | 1·86 | 2·49 | 2·22 | 0·82 | 1·23 | 2·59 | 1·47 |
| 1230 | 27 | 71 | 148 | 82 | 2·27 | 1·78 | 1·66 | 1·70 | 0·61 | 1·26 | 2·46 | 1·40 |
| 1330 | 38 | 93 | 192 | 108 | 1·98 | 1·25 | 1·32 | 1·29 | 0·75 | 1·16 | 2·53 | 1·40 |
| 1430 | 40 | 111 | 209 | 120 | 1·88 | 1·05 | 1·17 | 1·15 | 0·75 | 1·16 | 2·46 | 1·38 |
| 1530 | 44 | 107 | 203 | 118 | 1·40 | 1·05 | 1·11 | 1·08 | 0·61 | 1·13 | 2·25 | 1·28 |
| 1630 | 46 | 112 | 193 | 117 | 1·48 | 1·01 | 1·17 | 1·11 | 0·68 | 1·13 | 2·25 | 1·30 |
| 1730 | 39 | 103 | 173 | 105 | 1·40 | 1·13 | 1·26 | 1·20 | 0·55 | 1·16 | 2·18 | 1·26 |
| 1830 | 37 | 101 | 165 | 101 | 2·77 | 1·35 | 1·65 | 1·60 | 1·02 | 1·37 | 2·73 | 1·62 |
| 1930 | 38 | 95 | 150 | 90 | 2·15 | 1·40 | 1·87 | 1·74 | 0·82 | 1·33 | 2·80 | 1·57 |
| 2030 | 38 | 89 | 125 | 84 | 1·79 | 1·46 | 2·24 | 1·81 | 0·68 | 1·30 | 2·80 | 1·52 |
| 2130 | 33 | 86 | 115 | 78 | 1·24 | 1·48 | 2·14 | 1·75 | 0·41 | 1·27 | 2·46 | 1·37 |
| 2230 | 32 | 81 | 95 | 69 | 3·41 | 1·40 | 2·59 | 1·95 | 1·09 | 1·14 | 2·46 | 1·35 |
| 2330 | 33 | 81 | 95 | 70 | 4·14 | 1·35 | 2·59 | 2·27 | 1·37 | 1·09 | 2·46 | 1·59 |

**TABLE 3**

**Maximum and minimum times of atmospheric parameters ($F$, $\lambda$, $i$) for the various seasons**

| | Max time (GMT) | | | | | | Min Time (GMT) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Potential gradient | | Conductivity | | Air earth current | | Potential gradient | | Conductivity | | Air earth current | |
| Summer | 0330 | 1630 | 1130 | 2330 | 0430 | 1830 | 1030 | 2230 | 0230 | 1530 | 0930 | 2130 |
| Equinox | 0330 | 1630 | 0930 | 2130 | 0630 | 1830 | 1030 | 2330 | 0230 | 1630 | 0030 | 1530 |
| Winter | 0430 | 1430 | 1030 | 2230 | 0730 | 2030 | 1030 | 2230 | 0230 | 1530 | 0230 | 1530 |
| Year | 0330 | 1430 | 0930 | 2330 | 0630 | 1830 | 1030 | 2230 | 0230 | 1530 | 0230 | 1530 |

gradient, conductivity of air and the air earth current, not at the ground but at an altitude of at least two metres to avoid the electrode effect. During the discussion between Prof. Israel, Dr. Chalmers and Dr. Kasemir, on the measurement of air earth current, Dr. Kasemir said that the air earth current at a height above the earth can be measured by using two plates one above the other separated by a very small distance. The two output signals can be fed into a balance amplifier, the output of which yields the current. Dr. Kasemir had mentioned that the technical problem concerning the measurement of air earth current are quite large, but theoretically it should be possible to solve them.

A considerable number of simultaneous records of potential gradient and air earth current were obtained during 1966 and 1967. During 1966, records of air earth current and potential gradient for undisturbed conditions, hourly means centering at the exact hours were obtained. Mean values of the conductivity are obtained by dividing the monthly means of the hourly values of the current by the corresponding means of the potential gradient. Table 1 gives the mean monthly hourly values of potential gradient of 1966. Table 2 (a, b and c) gives the mean hourly values of potential gradient, conductivity and air earth current for the various seasons and year as a whole. Table 3 gives the times of maximum and minimum values of potential gradient, conductivity and air earth current. Maximum values are given in the first three columns and minimum values in the next three columns. The seasons are each composed of four months, *viz.*, *winter* including November to February, *equinox* including March, April, September and October and *summer* including May to August. Curves showing the seasonal and annual variations of the three elements are given in Fig. 6.

**4. Comparison of the seasonal and annual variations of potential gradient, conductivity and air earth current of 1966**

The potential gradient and air earth current curves follow the usual form with a maximum about mid-winter and minimum about mid-summer. The maximum of conductivity occurs in summer, at about 2330 GMT. The variation of conductivity is extremely large. It is seen that the daily variation of conductivity is very closely related to that of the potential gradient but the changes are in the opposite direction. The conductivity curves are infact almost exact mirror images of the potential gradient curves. The characteristic changes of these two elements are closely associated with atmospheric pollution showing a double oscillation. The connection between pollution and potential gradient has been studied by Chree and Watson (1924) and by Whipple (1929) who attributes to Simpson an explanation of the double oscillation of pollution as resulting from a combination of two effects — the variation in the rate of production of pollution and the variation in the stability of the atmosphere. In the winter, the air earth current more or less follows the potential gradient variation, closely, there being a very prominent maximum in air earth current at about 0730 GMT, while the potential gradient maximum is at about 0430 GMT and fairly strong minimum at 0230 GMT for air earth current at 2230 GMT for potential gradient. In summer the maximum occurs in the air earth current at 0430 GMT and minimum at 2130 GMT, while the maximum for potential gradient occurs at 0330 GMT and minimum occurs at 1030 GMT. In the equinoctial and annual curves of the air earth current, the changes are small and somewhat irregular. This is presumably because the opposing effects of summer and winter almost equal to each other. Typical fair weather records of air earth current and potential gradient for the

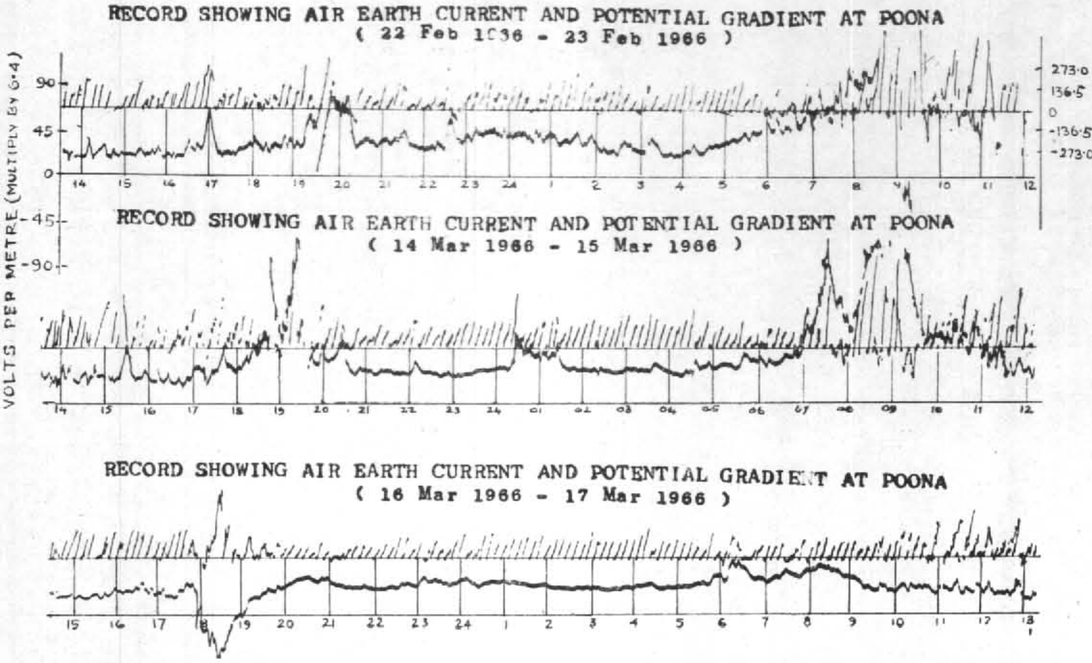



Fig. 5

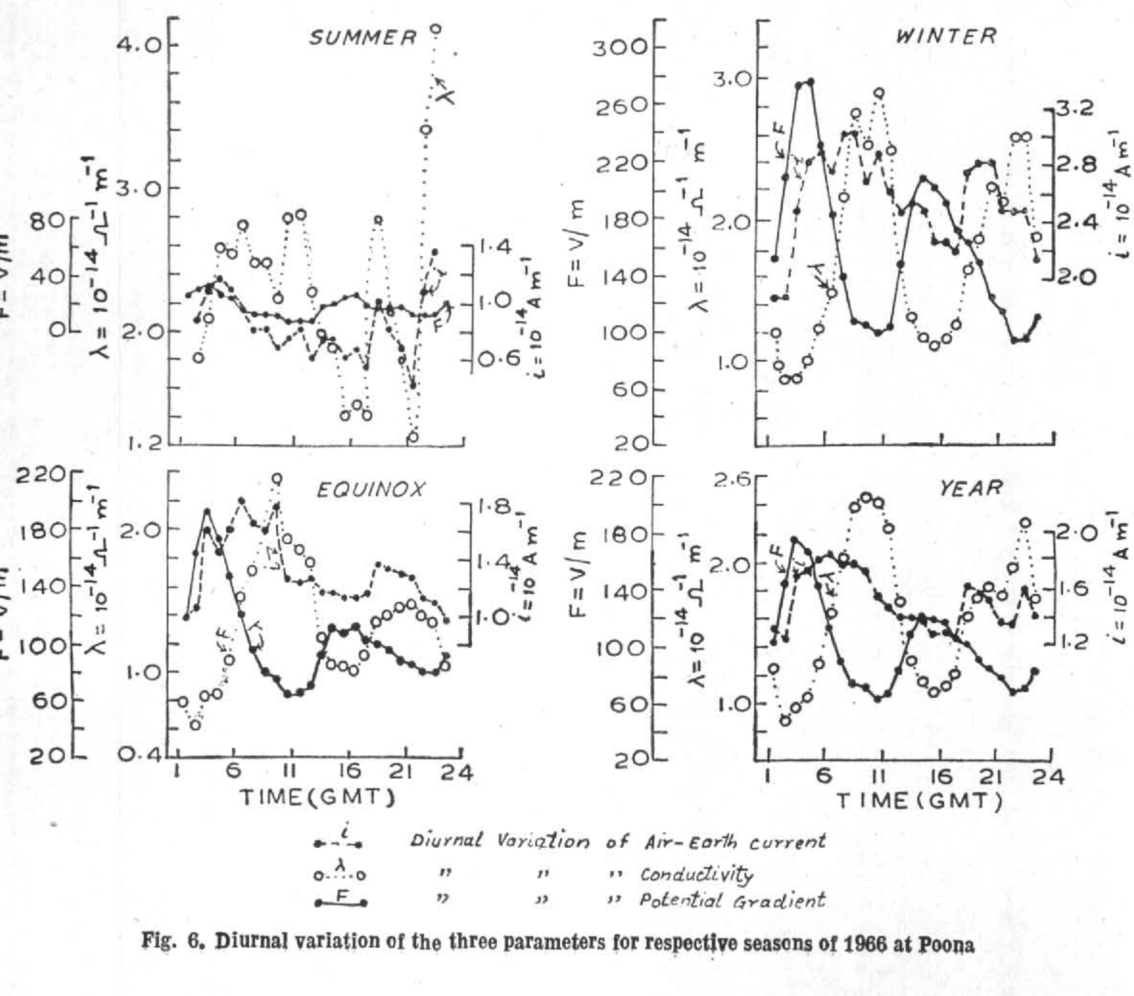



Fig. 6. Diurnal variation of the three parameters for respective seasons of 1966 at Poona

**TABLE 4**

**Seasonal and annual means of potential gradient ($F$), conductivity ($\lambda$) and air earth current ($i$) at Poona during January to December 1967**

| Time (GMT) | Potential gradient ($F$) (volts/m) | | | | Conductivity ($\lambda$) ($10^{-14}\Omega^{-1}$ m$^{-1}$) | | | | Air earth current ($i$) ($\times 10^{-12}$ amp/m$^2$/sec) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Summer | Equinox | Winter | Year | Summer | Equinox | Winter | Year | Summer | Equinox | Winter | Year |
| 0030 | 55 | 83 | 112 | 82 | —0·5 | 0·5 | —4·0 | —1·0 | —0·3 | 0·4 | —4·5 | —0·8 |
| 0130 | 63 | 132 | 171 | 119 | —0·8 | 0·2 | —4·0 | —1·3 | —0·5 | 0·3 | —6·8 | —1·5 |
| 0230 | 75 | 150 | 222 | 143 | —1·3 | 0·2 | —3·9 | —1·4 | —1·0 | 0·3 | —8·6 | —2·0 |
| 0330 | 75 | 176 | 325 | 180 | —0·4 | 0·2 | —2·5 | —0·8 | —0·3 | 0·4 | —8·1 | —1·5 |
| 0430 | 68 | 176 | 323 | 176 | 0·1 | 0·6 | —0·5 | 0·3 | 0·1 | 1·1 | —0·7 | 0·4 |
| 0530 | 56 | 142 | 285 | 150 | —0·5 | 1·3 | —1·7 | 0·1 | —0·3 | 1·9 | —4·8 | 0·1 |
| 0630 | 58 | 128 | 188 | 119 | 0·9 | 1·6 | —3·6 | —0·3 | 0·5 | 2·0 | —6·8 | —0·3 |
| 0730 | 55 | 98 | 131 | 91 | 2·0 | 1·5 | —4·7 | —0·4 | 1·1 | 1·5 | —6·1 | —0·4 |
| 0830 | 45 | 76 | 98 | 70 | 1·8 | 3·4 | —3·6 | 1·0 | 0·8 | 2·6 | —3·5 | 0·7 |
| 0930 | 52 | 67 | 97 | 70 | 0·6 | 3·7 | —1·5 | 1·1 | 0·3 | 2·5 | —1·5 | 0·8 |
| 1030 | 43 | 66 | 88 | 65 | 0 | 3·0 | —1·7 | 0·8 | 0 | 2·0 | —1·5 | 0·5 |
| 1130 | 38 | 69 | 98 | 65 | —1·3 | 3·3 | —2·0 | 0·5 | —0·5 | 2·3 | —2·0 | 0·3 |
| 1230 | 45 | 82 | 146 | 85 | —2·2 | 1·8 | —1·8 | —0·4 | —1·0 | 1·5 | —2·6 | —0·3 |
| 1330 | 54 | 100 | 175 | 104 | —4·6 | 0·8 | —2·3 | —1·4 | —2·5 | 0·8 | —4·0 | —1·4 |
| 1430 | 54 | 105 | 221 | 118 | —6·1 | 0·1 | —2·3 | —1·9 | —3·3 | 0·1 | —5·1 | —2·3 |
| 1530 | 56 | 92 | 191 | 106 | —3·6 | 0·4 | —2·4 | —1·4 | —2·0 | 0·4 | —4·5 | —1·5 |
| 1630 | 55 | 92 | 174 | 101 | —2·9 | 0·3 | —3·1 | —1·6 | —1·6 | 0·3 | —5·5 | —1·6 |
| 1730 | 52 | 83 | 169 | 96 | —2·7 | 0·5 | —2·9 | —1·2 | —1·4 | 0·4 | —4·9 | —1·5 |
| 1830 | 47 | 85 | 167 | 94 | —2·1 | 0·6 | —4·2 | —1·6 | —1·0 | 0·5 | —7·0 | —1·5 |
| 1930 | 50 | 81 | 152 | 89 | —0·8 | 1·4 | —4·0 | —1·2 | —0·4 | 1·1 | —6·1 | —1·1 |
| 2030 | 47 | 76 | 125 | 79 | 0·9 | 1·3 | —4·2 | —0·6 | 0·4 | 1·0 | —5·3 | —0·5 |
| 2130 | 43 | 73 | 94 | 68 | 1·6 | 1·4 | —4·0 | —0·1 | 0·7 | 1·0 | —3·8 | —0·1 |
| 2230 | 43 | 67 | 81 | 73 | 1·2 | 1·8 | —3·6 | 0·1 | 0·5 | 1·2 | —2·9 | 0·1 |
| 2330 | 50 | 70 | 84 | 66 | 1·0 | 1·4 | —3·9 | 0 | 0·5 | 1·0 | —3·3 | 0 |

months March and February 1966 are reproduced in Fig. 5.

**5. Measurement of the two components of air earth current during 1967**

During the measurement of air earth current in 1966, the two test plates are brought to earth potential every nine minutes. This means that each plate will receive positive charge when the potential gradient is positive. But, according to Chalmers (private communication) the plate should be brought to the potential of their surroundings each time the record is to start. As the radioactive collector is in the same equipotential as the plate, two radioactive collectors, one for each plate, were used in 1967. With these two collectors, the apparatus is corrected for displacement current, *i.e.*, change of potential gradient.

Chalmers (1957) has mentioned that one of the main problems in atmospheric electricity to be solved is the measurement of the two components of air earth current corresponding to the positive and negative conductivities. So the equation connecting the two components of air earth current, potential gradient and conductivity can be written as—

$$i_+ + i_- = F\,(\lambda_+ + \lambda_-)$$

$$\lambda_+ = n_+ \,.e.\, k_+$$

$$\lambda_- = n_- \,.e.\, k_-$$

where, $n_+$ = No. of positive ions

$n_-$ = No. of negative ions

$e$ = Charge of ion

$k_+$ = Mobility of positive ions

$k_-$ = Mobility of negative ions

**TABLE 5**

**Hourly values recorded at Poona, of potential gradient ($F$), two components of air earth current ($i_+, i_-$), two components of conductivity ($\lambda_+, \lambda_-$) and number of positive and negative ions expressed as ($n_+, n_-$)**
$F$ in V/m, ($i_+, i_-$) in $10^{-12}$ Am$^{-2}$, in $10^{-14}\Omega^{-1}$m$^{-1}$=($\lambda_+, \lambda_-$)

| Time (IST) | Quantity | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $F$ | $i_+, i_-$ | $\lambda_+, \lambda_-$ | $n_+, n_-$ | $F$ | $i_+, i_-$ | $\lambda_+, \lambda_-$ | $n_+, n_-$ | $F$ | $i_+, i_-$ | $\lambda_+, \lambda_-$ | $n_+, n_-$ |
| | 2 to 3 Jan 1967 | | | | 3 to 4 Jan 1967 | | | | 21 to 22 Jan 1967 | | | |
| 14–15 | 61 | 3·00 | 4·92 | 2050 | — | — | — | — | 61 | 2·05 | 3·36 | 1400 |
| 15–16 | 69 | 1·90 | 2·76 | 1150 | 84 | 2·74 | 3·26 | 1358 | 38 | 1·64 | 4·32 | 1800 |
| 16–17 | 69 | — | — | — | 77 | 2·74 | 3·56 | 1484 | 46 | 1·50 | 3·26 | 1358 |
| 17–18 | 84 | 3·00 | 3·58 | 1491 | 69 | 2·74 | 3·98 | 1659 | 0 | 1·37 | — | — |
| 18–19 | 123 | 3·82 | 3·10 | 1292 | 69 | 3·54 | 5·14 | 2142 | 69 | 1·64 | 2·38 | 992 |
| 19–20 | 115 | 3·82 | 3·32 | 1383 | 100 | 3·54 | 3·54 | 2142 | 61 | 1·77 | 2·90 | 1299 |
| 20–21 | 107 | 3·00 | 2·80 | 1167 | 169 | 5·18 | 3·06 | 1275 | 46 | 1·77 | 3·85 | 1604 |
| 21–22 | 115 | 3·54 | 3·08 | 1283 | 184 | 3·28 | 1·78 | 742 | 0 | −0·41 | — | — |
| 22–23 | 146 | 3·54 | 2·42 | 1008 | 169 | 7·38 | 4·36 | 1817 | −38 | −3·00 | 7·89 | −3288 |
| 23–24 | 13 | 3·54 | 2·72 | 1133 | 115 | 1·36 | 1·18 | 492 | −8 | −0·82 | −10·25 | −4271 |
| 24– 1 | 84 | 1·94 | 2·26 | 942 | 115 | 2·46 | 2·14 | 892 | −8 | 0·14 | 1·75 | 729 |
| 1–2 | 84 | 2·18 | 2·60 | 1083 | 130 | 2·46 | 1·90 | 792 | −8 | −0·27 | −3·37 | −1404 |
| 2–3 | 84 | −2·46 | −2·92 | −1217 | 92 | 1·36 | 1·48 | 617 | 0 | −0·27 | — | — |
| 3–4 | 84 | −11·74 | −13·98 | −5822 | 77 | 0·82 | 1·06 | 442 | 15 | −0·14 | 0·64 | −267 |
| 4–5 | 77 | −21·02 | −27·30 | −11380 | 69 | −1·10 | −1·60 | −667 | 23 | −1·23 | −5·35 | −2229 |
| 5–6 | 84 | −26·48 | −31·52 | −13130 | 84 | −2·18 | −2·60 | −1083 | 23 | −2·59 | −11·26 | −4691 |
| 6–7 | 115 | −28·66 | −24·92 | −10390 | 115 | −2·18 | −1·90 | −792 | 69 | −7·92 | −11·48 | −4784 |
| 7–8 | 153 | −29·76 | −19·46 | −8108 | 138 | 3·28 | 2·38 | 992 | 23 | −0·82 | −3·57 | −1488 |
| 8–9 | 146 | −14·46 | −9·90 | −4125 | 199 | 9·56 | 4·20 | 2000 | 107 | 0·82 | 0·77 | 321 |
| 9–10 | 123 | 4·64 | 3·78 | 1575 | 238 | 4·10 | 1·72 | 717 | 161 | 1·37 | 0·85 | 354 |
| 10–11 | 161 | 2·46 | 1·42 | 592 | 192 | 1·36 | 0·70 | 292 | 169 | 0·27 | 0·16 | 667 |
| 11–12 | 130 | 3·00 | 2·30 | 958 | 207 | — | — | — | 169 | −1·09 | −0·64 | −267 |
| 12–13 | 123 | 2·18 | 1·78 | 742 | 146 | 2·18 | 1·50 | 625 | 130 | 1·09 | 0·84 | 350 |
| 13–14 | 100 | 1·64 | 1·64 | 683 | — | — | — | — | 84 | 1·64 | 1·95 | 812 |
| | 31 Mar to 1 Apr 1967 | | | | 3 May to 4 May 1967 | | | | 21 May to 22 May 1967 | | | |
| 14–15 | 69 | 3·00 | 4·35 | 1812 | 23 | 3·82 | 16·61 | 6921 | 46 | 2·59 | 5·63 | 2346 |
| 15–16 | 54 | 3·14 | 5·81 | 2421 | 38 | 3·69 | 9·71 | 4046 | — | 2·59 | 5·63 | 2346 |
| 16–17 | 100 | 3·14 | 3·14 | 1307 | 46 | 4·37 | 9·50 | 3959 | 54 | 2·46 | 4·55 | 1895 |
| 17–18 | 100 | 3·55 | 3·55 | 1477 | 84 | −3·69 | −4·40 | −1833 | 38 | 2·46 | 6·47 | 2696 |
| 18–19 | 92 | 3·69 | 4·01 | 1670 | 100 | −7·92 | −7·92 | −3300 | 46 | 2·32 | 5·00 | 2084 |
| 19–20 | 107 | 3·28 | 3·07 | 1279 | 115 | −8·74 | −7·60 | −3168 | 38 | 2·18 | 5·74 | 2392 |
| 20–21 | 107 | 3·82 | 3·57 | 1488 | 115 | −10·92 | −9·50 | −3959 | 23 | 2·18 | 9·48 | 3950 |
| 21–22 | 130 | 3·41 | 3·62 | 1091 | 138 | −13·24 | −9·60 | −4000 | 15 | 1·77 | 11·80 | 4917 |
| 23–24 | 84 | 3·14 | 3·74 | 1559 | 115 | −9·55 | −8·30 | −3458 | 23 | 1·77 | 7·7 | 3206 |
| 23–24 | 100 | 2·87 | 2·87 | 1196 | 107 | −7·51 | −7·02 | −2925 | 15 | 1·37 | 9·13 | 3805 |
| 24– 1 | 69 | 3·00 | 4·35 | 1812 | 107 | −9·28 | −8·67 | −3613 | 31 | 1·91 | 6·16 | 2566 |
| 1–2 | 54 | 2·73 | 5·06 | 2109 | 84 | −3·28 | −3·90 | −1625 | 38 | 2·05 | 5·40 | 2250 |
| 2–3 | 61 | 3·10 | 4·92 | 2050 | 69 | 3·14 | 4·55 | 1895 | 31 | 1·91 | 6·16 | 2566 |
| 3–4 | 69 | 2·87 | 4·16 | 1734 | 54 | 3·69 | 6·83 | 2845 | 38 | 1·77 | 4·66 | 1942 |
| 4–5 | 54 | 2·87 | 5·31 | 2213 | 54 | 2·87 | 5·31 | 2213 | 38 | 1·77 | 4·66 | 1942 |
| 5–6 | 77 | 3·00 | 3·90 | 1625 | 61 | 3·14 | 5·15 | 2146 | 54 | 1·50 | 2·78 | 1159 |
| 6–7 | 100 | 3·28 | 3·28 | 1367 | 54 | 3·14 | 5·81 | 2421 | 38 | 2·05 | 5·04 | 2250 |
| 7–8 | 115 | 3·00 | 2·61 | 1087 | 92 | −3·90 | −3·26 | −1358 | 61 | 2·32 | 3·8 | 1583 |
| 8–9 | 77 | 3·28 | 4·26 | 1775 | 92 | −3·14 | −3·41 | −1419 | 54 | 2·46 | 4·55 | 1895 |
| 9–10 | 84 | 3·14 | 3·74 | 1559 | 69 | −0·14 | −0·59 | −246 | 54 | 2·32 | 4·30 | 1792 |
| 10–11 | 115 | 3·14 | 2·73 | 1138 | 38 | 2·46 | 6·47 | 2696 | 46 | 2·32 | 5·00 | 2084 |
| 11–12 | 77 | 3·28 | 4·26 | 1775 | 31 | 3·28 | 10·60 | 4417 | 46 | 2·59 | 5·63 | 2346 |
| 12–13 | 69 | 3·14 | 4·55 | 1895 | 23 | 3·55 | 15·43 | 6430 | 46 | 2·46 | 5·35 | 2229 |
| 13–14 | 69 | 3·10 | 4·35 | 1812 | 0 | 3·55 | — | — | 46 | 2·46 | 5·35 | 2229 |

**TABLE 6**

| Time (IST) | Quantity | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $F$ | $i_+, i_-$ | $\lambda_+, \lambda_-$ | $n_+, n_-$ | $F$ | $i_+, i_-$ | $\lambda_+, \lambda_-$ | $n_+, n_-$ | $F$ | $i_+, i_-$ | $\lambda_+, \lambda_-$ | $n_+, n_-$ |
| | 5 to 6 April 1967 | | | | 1 to 2 April 1967 | | | | 27 to 28 June 1967 | | | |
| 14–15 | — | — | — | — | 61 | 3·28 | 5·38 | 2242 | — | — | — | — |
| 15–16 | 54 | 2·73 | 5·06 | 2109 | 54 | 3·55 | 6·57 | 2738 | — | — | — | — |
| 16–17 | 46 | 2·87 | 6·24 | 2600 | 15 | 1·09 | 7·27 | 3029 | — | — | — | — |
| 17–18 | 115 | 4·09 | 3·56 | 1484 | 100 | 3·55 | 3·55 | 1479 | 32 | 0·68 | 2·13 | 889 |
| 18–19 | 161 | 3·41 | 2·12 | 883 | 138 | 0·82 | 0·59 | 246 | 45 | —2·32 | —5·16 | —2150 |
| 19–20 | 238 | —1·23 | —3·04 | —1267 | 161 | —2·05 | —1·27 | —529 | 38 | —3·14 | —8·28 | —3449 |
| 20–21 | 153 | 2·87 | 1·88 | 783 | 146 | 3·69 | 2·53 | 1055 | —7 | —0·27 | —3·86 | —1608 |
| 21–22 | 146 | 4·09 | 2·80 | 1167 | 153 | 2·87 | 1·87 | 779 | 25 | —1·37 | —5·48 | —2283 |
| 22–23 | 130 | 4·09 | 3·15 | 1312 | 100 | 3·14 | 3·15 | 1307 | 45 | —4·09 | —9·11 | —3796 |
| 23–24 | 146 | 2·96 | 2·71 | 1129 | 100 | 3·41 | 3·41 | 1419 | 32 | —2·87 | —9·00 | —3750 |
| 0–1 | 130 | 3·28 | 2·52 | 1050 | 92 | 3·55 | 3·86 | 1608 | 45 | —2·59 | 5·76 | —2400 |
| 1–2 | 123 | 4·09 | 2·33 | 1388 | 77 | 4·23 | 5·49 | 2288 | 45 | —2·32 | —5·16 | —2150 |
| 2–3 | 100 | 3·69 | 3·65 | 1538 | 84 | 3·69 | 4·39 | 1829 | 32 | —1·91 | —5·94 | —2475 |
| 3–4 | 115 | 4·23 | 3·68 | 1533 | 92 | 3·69 | 4·01 | 1670 | 20 | —0·27 | —1·35 | —562 |
| 4–5 | 107 | 3·96 | 3·70 | 1542 | 84 | 2·87 | 3·42 | 1425 | 32 | —0·17 | —0·53 | —221 |
| 5–6 | 199 | 3·69 | 1·85 | 771 | 107 | 3·41 | 3·19 | 1329 | 77 | —0·27 | —0·35 | —146 |
| 6–7 | 245 | —9·55 | —3·90 | —1625 | 138 | 2·87 | 2·08 | 867 | 70 | —0·27 | —0·39 | —163 |
| 7–8 | 346 | —13·24 | —3·83 | —1596 | 176 | —1·77 | —1·08 | —417 | 103 | 0·55 | 0·53 | 221 |
| 8–9 | 384 | —13·24 | —3·44 | —1433 | 199 | —3·82 | —1·92 | —800 | 96 | — | — | — |
| 9–10 | 222 | —13·24 | —5·96 | —2483 | 245 | —1·91 | —0·78 | —325 | 77 | 0·55 | 0·71 | 296 |
| 10–11 | 184 | —9·01 | —5·46 | —2275 | 291 | —13·24 | —4·55 | —1895 | 33 | — | — | — |
| 11–12 | 146 | —11·06 | —7·58 | —3159 | 153 | 1·09 | 0·71 | 296 | —33 | 0·68 | 2·06 | 858 |
| 12–13 | 84 | —1·09 | —1·30 | —542 | 84 | 3·82 | 4·55 | 1895 | 58 | 0·27 | 0·47 | 196 |
| 13–14 | — | — | — | — | 77 | 3·69 | 4·79 | 1995 | — | — | — | — |
| | 3 to 4 June 1967 | | | | 1 to 2 July 1967 | | | | 2 to 3 July 1967 | | | |
| 14–15 | 15 | 2·59 | 17·27 | 7201 | 32 | 4·5 | 14·06 | 5859 | — | — | — | — |
| 15–16 | 15 | 1·23 | 8·20 | 3417 | 32 | 3·69 | 11·53 | 4804 | — | — | — | — |
| 16–17 | 15 | 2·46 | 16·40 | 6832 | 25 | 2·87 | 11·48 | 4784 | — | — | — | — |
| 17–18 | 15 | 3·41 | 22·73 | 9471 | 38 | 1·64 | 4·32 | 1800 | 70 | 1·91 | 2·73 | 1138 |
| 18–19 | 38 | 4·23 | 11·13 | 4637 | 45 | 1·09 | 2·42 | 1008 | 45 | 0·68 | 1·51 | 629 |
| 19–20 | 54 | 4·37 | 8·09 | 3370 | 38 | —3·96 | —10·42 | —4342 | 38 | —0·55 | —1·45 | —604 |
| 20–21 | 54 | 4·37 | 8·09 | 3370 | 13 | —0·55 | —4·23 | —1762 | 58 | 0 | 0 | 0 |
| 21–22 | 54 | 4·37 | 8·09 | 3370 | 45 | —2·18 | —4·84 | —2017 | 58 | —0·41 | —0·71 | —296 |
| 22–23 | 46 | 4·37 | 9·50 | 3959 | 25 | —1·91 | —7·64 | —3184 | 51 | 0·27 | 0·53 | 221 |
| 23–24 | 38 | 4·37 | 11·50 | 4792 | 20 | —3·69 | —18·45 | —7688 | 38 | 0·14 | 0·37 | 154 |
| 0–1 | 31 | 3·96 | 12·77 | 5321 | 38 | —1·09 | —2·87 | —1196 | 58 | 1·37 | 2·36 | 983 |
| 1–2 | 38 | 3·96 | 10·42 | 4342 | 45 | 0·68 | 1·51 | 629 | 64 | 2·05 | 3·20 | 1333 |
| 2–3 | 31 | 3·55 | 11·45 | 4772 | 7 | 0·55 | 7·86 | 3275 | 64 | 2·40 | 3·75 | 1563 |
| 3–4 | 31 | 3·55 | 11·45 | 4772 | —218 | 2·32 | 1·06 | 4417 | 58 | 1·77 | 3·05 | 1271 |
| 4–5 | 31 | 3·69 | 11·90 | 4958 | — | — | — | — | 58 | —0·14 | —0·24 | —100 |
| 5–6 | 38 | 4·09 | 10·76 | 4483 | —223 | 0·68 | 0·30 | 126 | 64 | 2·59 | 4·05 | 1688 |
| 6–7 | 46 | 4·23 | 9·20 | 3833 | —13 | 0 | 0 | 0 | 77 | 3·00 | 3·89 | 1621 |
| 7–8 | 46 | 4·23 | 9·20 | 3833 | 20 | 0·41 | —2·05 | —854 | 77 | 3·41 | 4·43 | 1846 |
| 8–9 | 38 | 4·09 | 10·76 | 4483 | 25 | —0·14 | —0·56 | —233 | 58 | 3·41 | 5·88 | 2450 |
| 9–10 | 31 | 4·09 | 13·19 | 5495 | 13 | 0·14 | 1·08 | 450 | 64 | 1·77 | 2·77 | 1154 |
| 10–11 | 31 | 4·09 | 13·19 | 5495 | 45 | —1·91 | —4·24 | —1762 | 58 | — | — | — |
| 11–12 | 23 | 4·23 | 18·39 | 7663 | 25 | —0·95 | —3·80 | —1767 | 77 | — | — | — |
| 12–13 | 23 | 1·91 | 8·30 | 3459 | 32 | —2·18 | —6·81 | —2837 | — | — | — | — |
| 13–14 | 23 | 0·41 | 1·78 | 742 | 13 | 1·09 | 8·38 | 3491 | — | — | — | — |

TABLE 7

**Hourly values recorded at Poona, of potential gradient ($F$), two components of air earth current ($i_+, i_-$), two components of conductivity ($\lambda_+, \lambda_-$) and number of positive and negative ions expressed as ($n_+, n_-$)**
$F$ in V/m, ($i_+, i_-$) in $10^{-12}$Am$^{-2}$, in $10^{-14}$ $\Omega^{-1}$m$^{-1}$=($\lambda_+,\lambda_-$)

| Time (IST) | Quantity | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $F$ | $i_+, i_-$ | $\lambda_+, \lambda_-$ | $n_+, n_-$ | $F$ | $i_+, i_-$ | $\lambda_+, \lambda_-$ | $n_+, n_-$ | $F$ | $i_+, i_-$ | $\lambda_+, \lambda_-$ | $n_+, n_-$ |
| | 28 to 29 June 1967 | | | | 30 June to 1 July 1967 | | | | 2 to 3 July 1967 | | | |
| 14-15 | — | — | — | — | 32 | 2·05 | 6·41 | 2671 | — | — | — | — |
| 15-16 | 32 | —2·46 | —7·69 | —3204 | 64 | 4·09 | 6·39 | 2663 | — | — | — | — |
| 16-17 | 58 | —4·64 | —8·00 | —3334 | 51 | 3·00 | 5·88 | 2450 | — | — | — | — |
| 17-18 | 70 | —3·55 | —5·07 | —2113 | 45 | 0·14 | 0·31 | 129 | 70 | 1·91 | 2·73 | 1138 |
| 18-19 | 32 | —3·55 | —11·09 | —4620 | 51 | —1·50 | —2·94 | —1225 | 45 | —0·68 | 1·51 | 629 |
| 19-20 | 45 | —0·96 | —2·13 | —888 | 19 | —2·32 | —12·21 | —5088 | 38 | —0·55 | —1·45 | —604 |
| 20-21 | 58 | —0·41 | —0·71 | —296 | 83 | —3·69 | —4·45 | —1855 | 58 | 0 | 0 | 0 |
| 21-22 | 63 | — | — | — | 19 | —0·27 | —1·42 | —592 | 58 | —0·41 | —0·71 | —296 |
| 22-23 | 77 | —1·37 | —1·78 | —742 | 45 | —0·14 | —0·31 | —127 | 51 | 0·27 | 0·53 | 221 |
| 23-24 | 58 | —0·82 | —1·41 | —588 | 58 | —0·68 | —1·17 | —487 | 38 | 0·14 | 0·37 | 154 |
| 24- 1 | 58 | —0·41 | —0·71 | —296 | 64 | —1·37 | —2·14 | —892 | 58 | 1·37 | 2·36 | 983 |
| 1- 2 | 51 | —1·23 | —2·41 | —1004 | 45 | —2·05 | —4·56 | —1900 | 64 | 2·05 | 3·20 | 1333 |
| 2-3 | 45 | —1·23 | —2·73 | —1138 | 45 | —3·55 | —7·89 | —3288 | 64 | 2·40 | 3·75 | 1563 |
| 3-4 | 63 | —0·55 | —0·87 | —362 | 38 | —0·41 | —1·08 | —450 | 58 | 1·77 | 3·05 | 1271 |
| 4-5 | 83 | —0·55 | —0·66 | —274 | 70 | —2·18 | —3·11 | —1296 | 58 | —0·14 | —0·24 | —100 |
| 5-6 | 135 | —0·55 | —0·41 | —171 | 83 | —4·09 | —4·93 | —2054 | 64 | 2·59 | 4·05 | 1688 |
| 6-7 | 96 | —0·27 | —0·38 | —117 | 103 | —3·27 | —3·17 | —1321 | 77 | 3·00 | 3·89 | 1621 |
| 7-8 | 115 | —1·23 | —1·07 | —445 | 70 | —5·62 | —8·03 | —3346 | 77 | 3·41 | 4·43 | 1846 |
| 8-9 | 90 | —1·64 | —1·82 | —757 | 90 | —8·33 | —9·26 | —3859 | 58 | 3·41 | 5·88 | 2450 |
| 9-10 | 58 | —0·27 | —0·47 | —196 | 77 | —7·51 | —9·75 | —4062 | 64 | 1·77 | 2·77 | 1154 |
| 10-11 | 63 | —1·50 | —2·38 | —992 | 77 | 1·77 | 2·30 | 958 | 58 | — | — | — |
| 11-12 | 70 | — | — | — | 38 | 2·41 | —8·97 | —3738 | 77 | — | — | — |
| 12-13 | — | — | — | — | — | — | — | — | — | — | — | — |
| 13-14 | — | — | — | — | — | — | — | — | — | — | — | — |
| | 4 to 5 Sep 1967 | | | | 9 to 10 Sep 1967 | | | | 19 to 20 Sep 1967 | | | |
| 14-15 | 70·4 | 4·4 | 6·2 | 2583 | 19·2 | 2·18 | 11·38 | 4741 | 51·2 | 8·46 | 16·53 | 6889 |
| 15-16 | 70·4 | 4·1 | 5·8 | 2416 | 44·8 | 2·46 | 5·48 | 2283 | 44·8 | 8·46 | 18·89 | 7872 |
| 16-17 | 64·0 | 4·1 | 6·4 | 2667 | 44·8 | 2·46 | 5·48 | 2283 | 51·2 | 7·92 | 15·46 | 6442 |
| 17-18 | 70·4 | 3·55 | 5·04 | 2100 | 44·8 | 1·91 | 4·27 | 1779 | 57·6 | 4·37 | 7·58 | 3159 |
| 18-19 | 44·8 | 0·55 | 1·22 | 508 | 44·8 | —2·18 | —4·87 | —2029 | 70·4 | —7·37 | —10·47 | —4363 |
| 19-20 | 48·4 | —2·73 | —7·11 | —2963 | 44·8 | —3·28 | —7·31 | —3046 | 57·6 | —6·28 | —10·9 | —4541 |
| 20-21 | 51·2 | —3·0 | —5·86 | —2442 | 32·0 | —2·46 | —7·68 | —3200 | 96·0 | —7·6 | —7·96 | —3316 |
| 21-22 | 32·0 | —2·73 | —8·5 | —3542 | 32·0 | —1·91 | —5·97 | —2483 | 70·2 | —6·95 | —9·90 | —3276 |
| 22-23 | 19·2 | —1·64 | —8·5 | —3542 | 44·8 | —1·64 | —3·68 | —1533 | 70·4 | —5·46 | —7·76 | —3232 |
| 23-24 | 25·6 | —1·91 | —7·46 | —3109 | 32·0 | —1·09 | —3·41 | —1421 | 64·0 | —4·6 | —7·25 | —3021 |
| 24-1 | 25·6 | —1·91 | —7·464 | —3110 | 38·4 | —1·09 | —2·84 | —1183 | 38·4 | —2·46 | —6·40 | —2667 |
| 1-2 | 25·6 | —4·6 | —9·60 | —4000 | 32·0 | —0·82 | —2·56 | —1067 | 38·4 | —2·73 | —7·11 | —2963 |
| 2-3 | 19·2 | —4·6 | —12·79 | 5330 | 32·0 | —0·82 | —2·56 | —1067 | 44·8 | —3·0 | —6·7 | —2792 |
| 3-4 | 19·2 | —1·91 | —9·95 | —4146 | 32·0 | —0·55 | 1·71 | —713 | 32·0 | —1·64 | —5·12 | —2133 |
| 4-5 | 12·8 | —1·37 | —10·66 | —4441 | 25·6 | —0·55 | —2·13 | —888 | 44·8 | —2·73 | —6·09 | —2537 |
| 5-6 | 12·8 | —1·37 | —10·66 | —4441 | 44·8 | —0·82 | —1·83 | —763 | 57·6 | —3·00 | —5·21 | —2171 |
| 6-7 | 25·6 | —1·64 | —6·40 | —2667 | 38·4 | —0·55 | —1·42 | —592 | 44·8 | —2·46 | —5·48 | —2283 |
| 7-8 | 64·0 | —1·91 | —2·99 | —1246 | 57·6 | —1·37 | —2·37 | —987 | 57·6 | —1·37 | —2·37 | —987 |
| 8-9 | 64·0 | —1·09 | —1·71 | —713 | 51·2 | —3·00 | —5·86 | —2442 | 96·0 | 5·46 | 5·69 | 2371 |
| 9-10 | 44·8 | 1·91 | 4·37 | 1773 | 57·6 | 0·55 | 0·95 | 396 | 89·6 | 6,95 | 7·76 | 3233 |
| 10-11 | 57·6 | 2·82 | 6·64 | 2767 | 32·0 | 1·64 | 5·12 | 2133 | 89·6 | 7·62 | 8·53 | 3554 |
| 11-12 | 44·8 | 4·09 | 9·14 | 3808 | 44·8 | 2·18 | 4·87 | 2029 | 70·2 | 9·01 | 12·83 | 5346 |
| 12-13 | 38·3 | 4·09 | 10·68 | 4441 | 44·8 | 2·46 | 5·48 | 2283 | 70·2 | 7·92 | 11·28 | 4700 |
| 13-14 | — | — | — | — | 38·4 | 2·18 | 5·69 | 2371 | — | — | — | — |

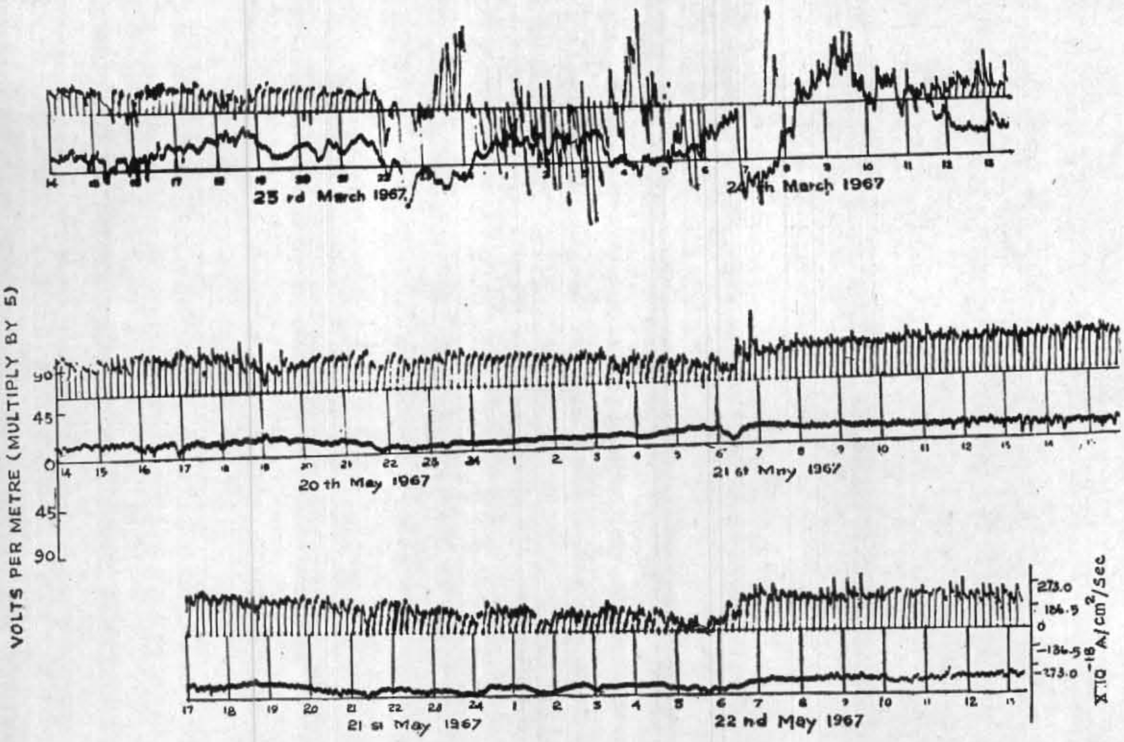



Fig. 7

Record showing air earth current and positive potential gradient at Poona on 23 March (Equinox Time) 20 May, 21 May 1967 (Summer Time). The positive and negative components of air earth current are clearly seen on 23 March 1967

Assuming the values of $e$, $k_{+}$, $k_{-}$ and from the measurement of $i_{+}$, $i_{-}$ and $F$, it is possible to calculate the number of positive ions and negative ions, which are predominant. Table 4 gives the mean hourly values of potential gradient, conductivity and the air earth current for the various seasons and year as a whole for the year 1967.

Tables 5 to 7 give the values of the two components of air earth current, potential gradient, positive conductivity and negative conductivity, positive and negative number of ions for selected days in winter, equinox and summer (Figs. 8 to 11) show the records of the two components of air earth current and potential gradient. It is interesting to see from Fig. 11 (4-5 September 1967, 9-10 September 1967 and 19-20 September 1967) that the positive air earth current becomes negative between 1800-1900 hrs and again becomes positive between 0800-0900 hrs. This means that after sunset, during night, negative ions predominate for these days. Tables 5 to 7 give the values of positive ions and negative ions also for each hour for the various dates.

It may be mentioned, however, that on some fine weather days we get only positive air earth currents throughout the day (quiet days) and on some disturbed days due to fog, mist, haze, we get only negative currents throughout the day. Fig. 7 (20 to 21 May 1967, 21 to 22 May 1967) shows only positive currents. Figs. 8 to 11 show both positive and negative currents.

## 6. Discussion

### 1. *Significance of the air earth current*

The general constancy of the air earth current with height above the ground and in different parts of the world, suggests that at any rate to a first approximation, it has its origin in a constant potential difference between the conducting layers of the upper atmosphere and the earth and that its actual value depends upon the resistance of the air between the two regions. It has been found from simultaneous determination of potential gradient and atmospheric conductivity during balloon ascents (Wigand 1925) that the rapid decrease in $F$ with height above the ground is accompanied by an increase in $\lambda$ of such magnitude as to keep the conduction currents approximately constant. Table 8 shows the results approximately constant. Table 8 shows the results of an ascent by Wigand (1925) from which it will be seen that when the field had fallen to 1/15th of its value at the gound, the conductivity had risen elevenfold.

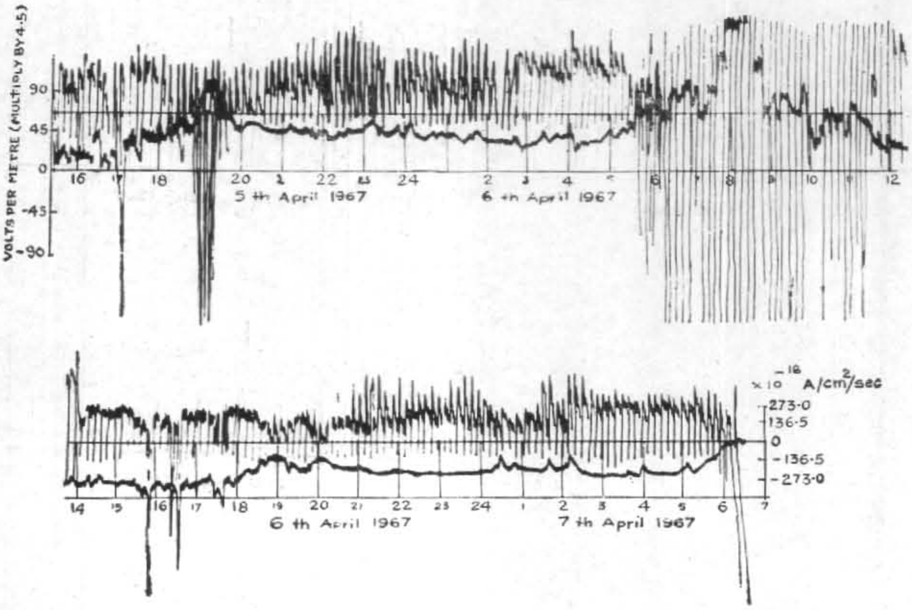



**Fig. 8**

Records of the positive and negative components of air earth current and positive potential gradient on 5–6 and 6–7 April 1967

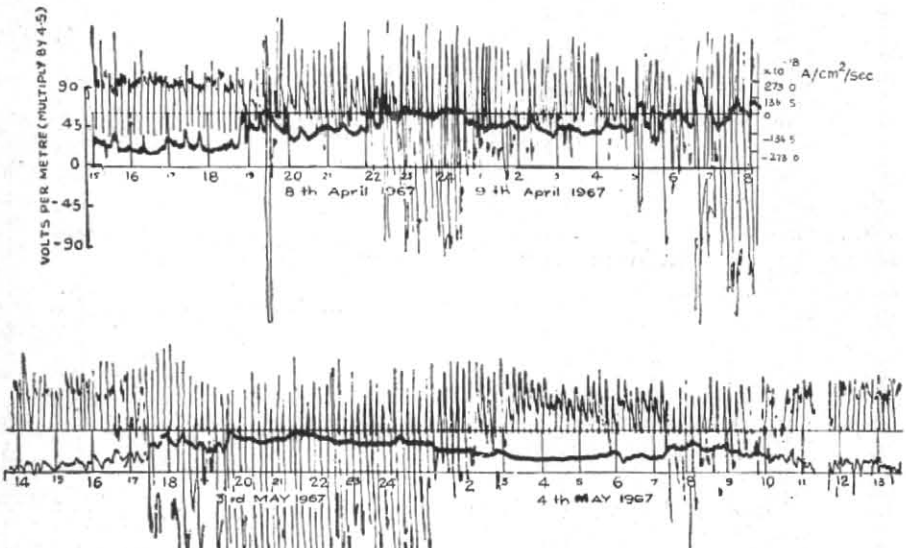



**Fig. 9**

Records of positive and negative components of air earth current and positive potential gradient on 8–9 April and 3–4 May 1967

These results have been confirmed and extended by conductivity measurements during the flight of Explorer II in 1935. They showed that the conductivity at 18 km was about 100 times the usual value at the ground.

The conductivity of the upper portion of the air path is entirely due to cosmic radiation and is unlikely to alter appreciably with time of locality or season. But below a height of about 2 km over land areas, an additional ionising influence is

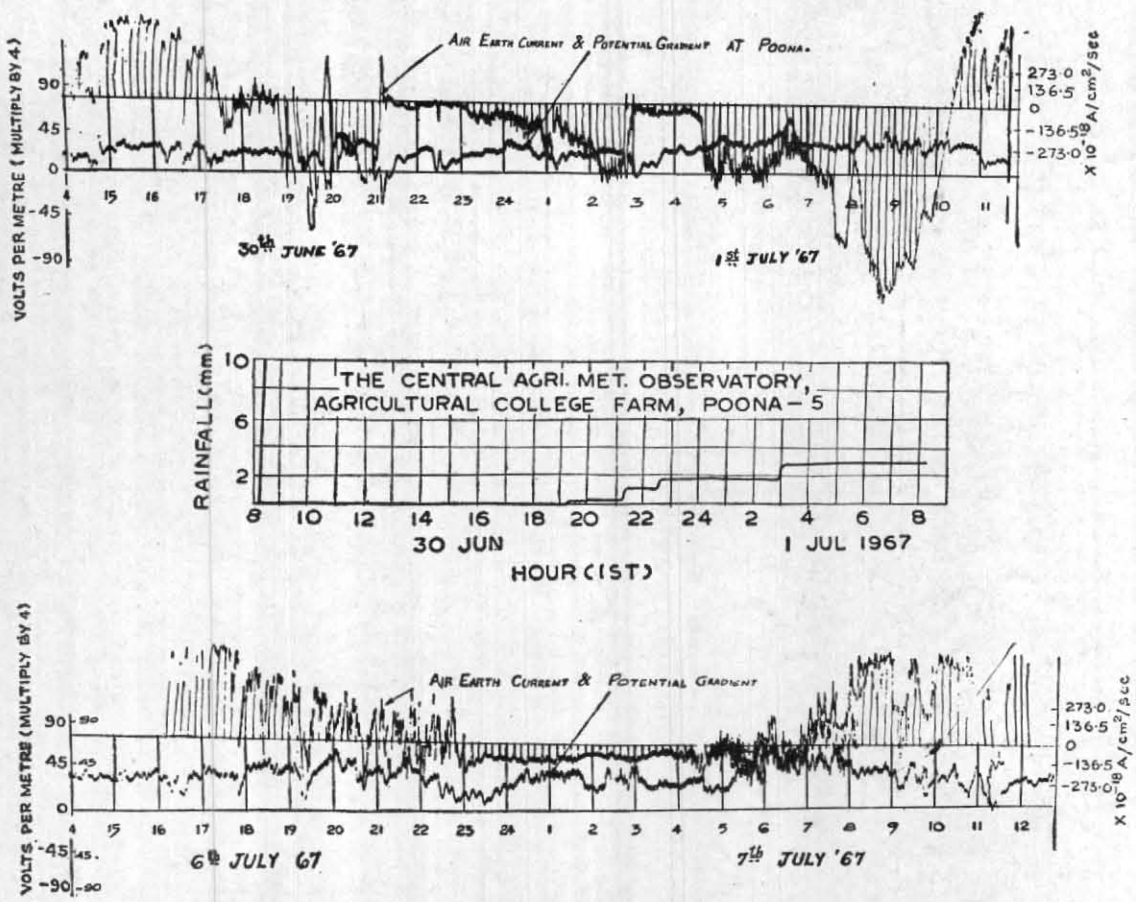



Fig. 10. Records of +ve and —ve components of air earth current and positive potential gradient

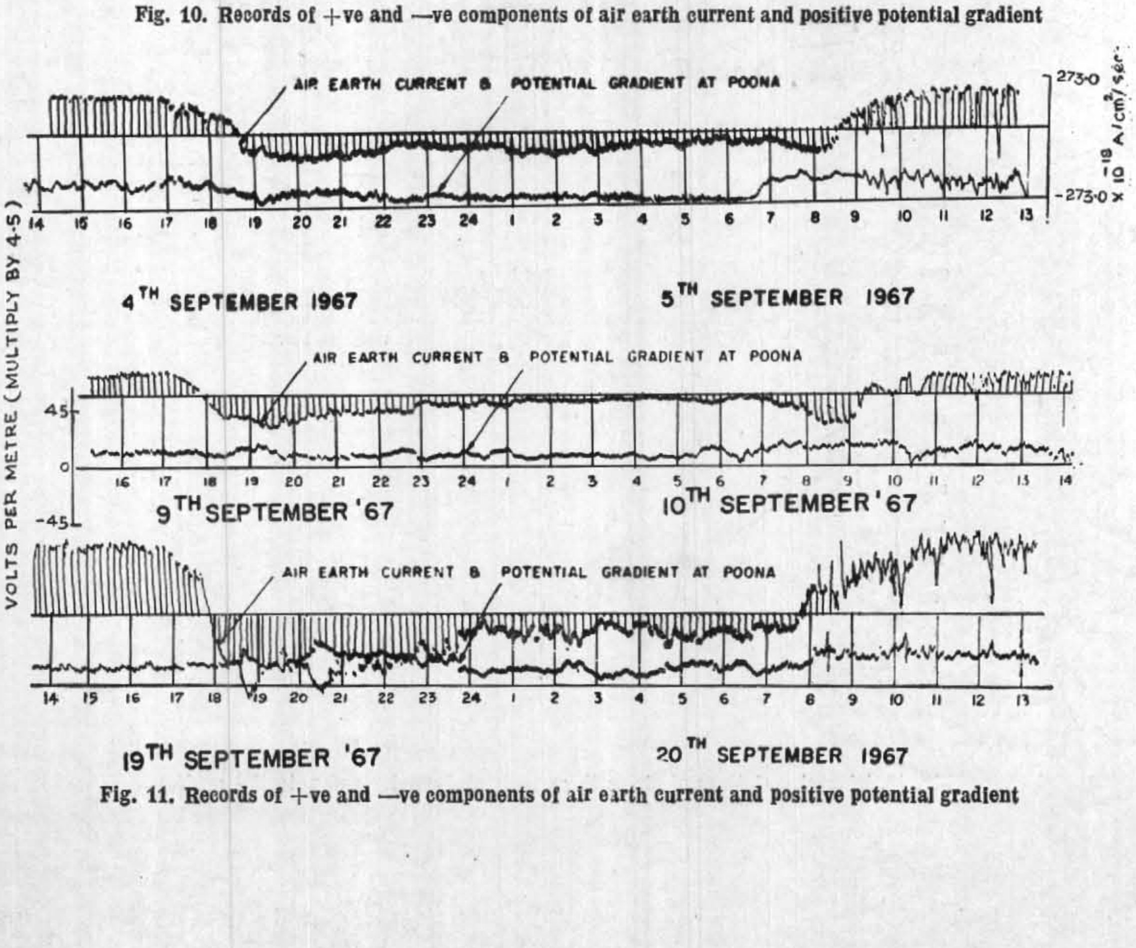



Fig. 11. Records of +ve and —ve components of air earth current and positive potential gradient

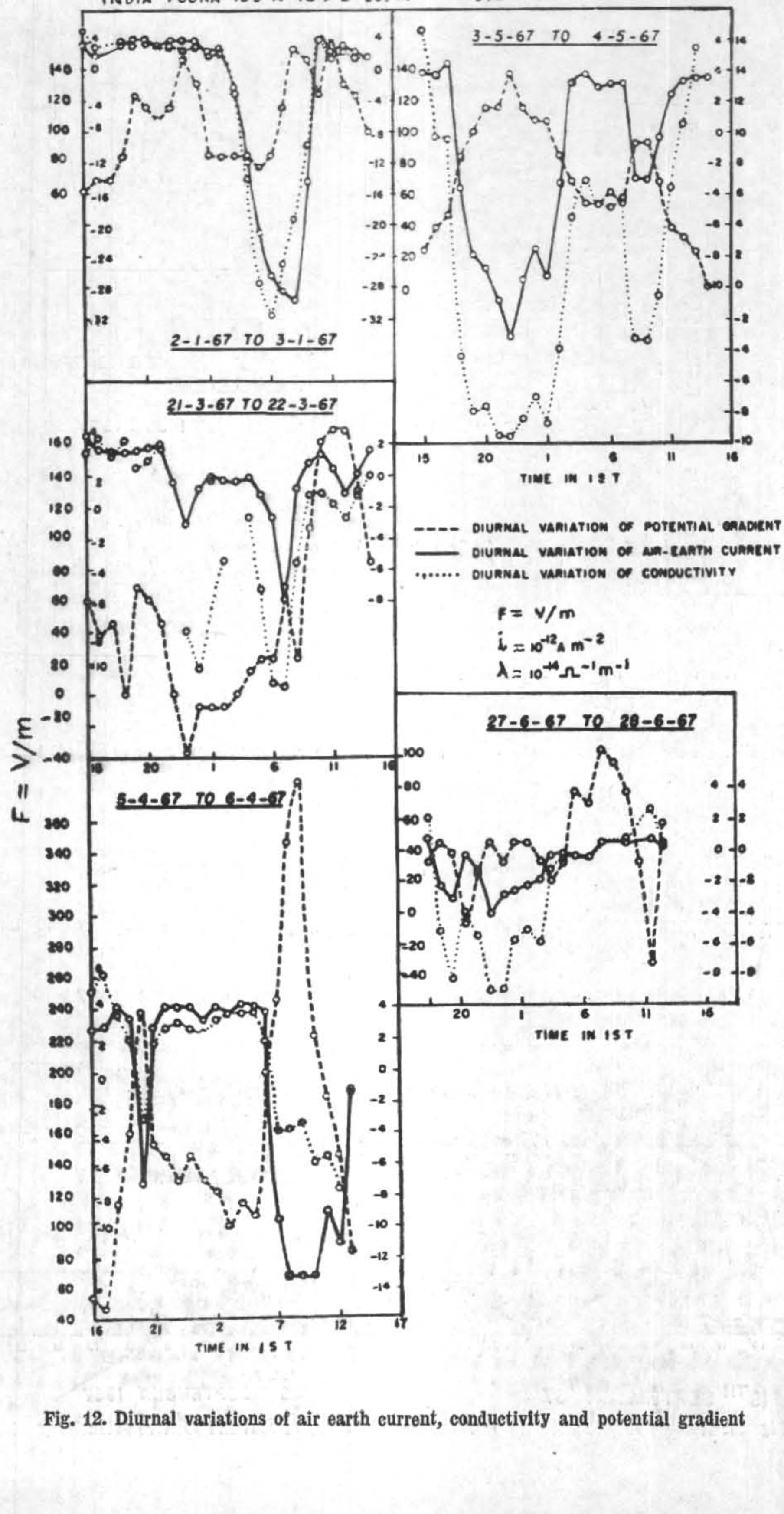



Fig. 12. Diurnal variations of air earth current, conductivity and potential gradient

exercised dy radioactive matter in the air and earth and this varies very much. The current bearing column of air above the point of observation thus consists of an upper constant resistance and a lower variable one in series with each other. The extent to which the current carried by the air column alters with local conditions will depend on the ratio which the lower variable resistance bears to the total resistance.

Law (1963) made measurements at Cambridge on ion densities and of space charge and came to the conclusion that the conductivity varies with the height so that the air earth conduction current cannot be the same at all levels thus necessitating a convection current also varying with height. The results of Higazi and Chalmers (1966) lead to the same conclusion.

Dolezalek (1960) discussed a number of measurements of potential gradient, air earth current and conductivity. With Ohms' Law it is assumed that there is no convection current; then deviations from Ohm's Law would appear if a convection current actually exists ; Dolezalek discussed the various other factors that would give apparent deviations from Ohm's Law and came to the conclusion that a comparison of results by the two methods (direct and indirect) of determining the air earth current is not simply sufficient to give the convection current, if any. It appears probably that the extent to which the convection current is important may vary from one place to another.

## 2. *The universal diurnal variations in potential gradient and air earth current*

The original Wilson hypothesis that thunderstorms and shower clouds act as the generators that maintain the fair weather aspects of atmospheric electricity is now almost universally accepted. A feature claimed to support the hypothesis is that the diurnal variations, related to U.T. (G.M.T.) of world thunderstorms activity and of the fair weather elements of atmospheric electricity at oceanic stations are in phase and of similar amplitude. In Fig. 14 the world-wide variations of thunder area is plotted from the data of Whipple and Scrase (1936). In deriving the curve for the whole world, an estimate for oceanic thunderstorms is also included. This has been omitted by several authors who have considered variations over land areas alone and thereby obtained curves whose amplitude about the mean is rather greater than it should be. Fig. 15 shows the diurnal variation with respect to U.T. of potential gradient and air earth current for observations at sea. The curves in Fig. 15 (b) are a mean derived from the results (1955) of several oceanic cruises (Carneigie, Horizon, etc). It is seen that the two world curves of Figs. 15 (a) and (b) are broadly parallel. Fig. 16 shows the annual diurnal variation of thunderstorm for various stations in India (Tropics), indicating that the maximum frequency of thunderstorms take place at about 12 GMT. The major thunderstorm activity occurs in tropical regions where the storms are mainly of the convectional type and reach their maximum activity from about mid-day to the late afternoon hours. This is the reason why the maximum of the curves for Asia, Africa and America follow in sequence at 0800, 1400 and 2000 GMT. When simultaneous measurements are made of any two of three quantities $F$, $i$ and $\lambda$, it is possible to make useful comparison of the results at different places and to distinguish local and worldwide effects.

## 3. *Electrical balance sheet*

If the negative charge on the earth is to be maintained there must be for the earth as a whole a balance between different processes bringing charge to the earth. Wormell (1930) first discussed the possibility of working out such a balance in a small area of the earth and used available data to give results for Cambridge. Since then, more accurate data have become available for some more places, but so far no attempt has been made to calculate the electrical balance sheet for the tropics. Now it has been found from the air earth current observations at Poona that there are two components of air earth current corresponding to the positive and negative conductivities. These have to be taken into account in estimating the annual loss and gain of charge by the earth. Full details of the values by the different processes (conduction currents, point discharge current, precipitation current and lightning discharges) for Poona are being discussed in another paper.

## 4. *Calculation of the number of positive and negative ions from the continuous records of air earth current and potential gradient*

The specific conductivity $\lambda_+$ of air for positive ions is given by $\lambda_+ = i_+/F$ where, $i_+$ is current density of positive ions and $F$ is the potential gradient. Similarly for specific conductivity $\lambda_-$ for negative ions is given by $\lambda_- = i_-/F$. If $n_+$ and $n_-$ are the number of positive and negative ions per c.c. with mobilities $k_+$ and $k_-$ and charge $\pm e$,

$$\lambda_+ = n_+ \cdot e \cdot k_+ = i_+/F$$
$$\lambda_- = n_- \cdot e \cdot k_- = i_-/F$$

Assuming the values of ionic charge $e$ and mobility of ion as 1·5 cm in a field of 1 volt/cm, the values of $n_+$, $n_-$ are calculated from the known values of $i_+$, $i_-$ and $F$. It is seen from Tables 5-7 that the values of $n_+$ and $n_-$ range from 100 to 13,000.

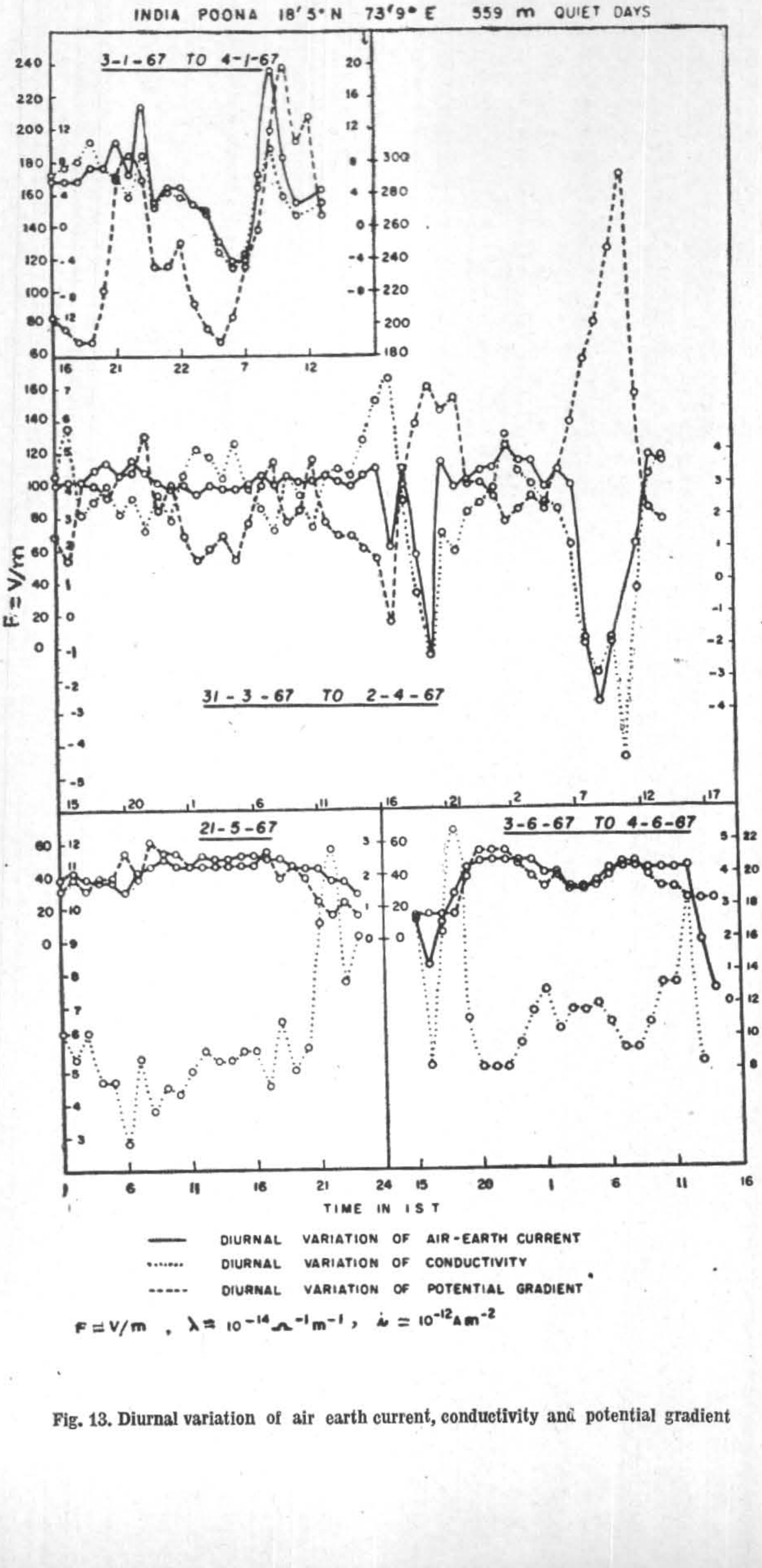



Fig. 13. Diurnal variation of air earth current, conductivity and potential gradient

Days are classified in Tables 5-7 as quiet days and disturbed days. Quiet days are days during which the air earth current throughout the day is +ve. Disturbed days are days during which the air earth current is showing both +ve and —ve currents. Generally the number of small ions per c.c. in oceanic air is 700, in country air is 600 and in city air is 100. The number of positive and negative ions are not very different but there is necessarily a small excess of positive ions to make up the positive space charge of the lower atmosphere. Measurements of the number of small ions (positive and negative) using Ebert's ion counter at Poona are given in Table 9. From this, we see that the number of positive and negative ions range from 900 to 6000. But the measurements of the number of positive and negative ions from the continuous records of air earth current and potential gradient generally range from 100 to 13,000. It is difficult to understand how the average values of small ions, positive and negative or the various hours range from a low value to a very high value, some times.

At first sight, it might appear that an ion carrying an electric charge and situated in an electric field, would experience a definite force and would therefore be accelerated acquiring a velocity which would not be constant but which would continuously increase. However, this neglects the fact that the ion experiences incessant impacts with the molecules of the air and so loses at each impact some or all of the momentum it has acquired since the previous impact. There will thus be an average velocity of travel of the ion in the direction of the potential gradient and proportional to the potential gradient ; clearly the longer the mean free path of the ion, the greater is the mobility.

Actually the existence of two main types of ion (large and small), leads to the flow of four different ion streams, two up and two down if the field is vertical, in each of which the velocity is different, being given by $F \times k$, where, $k$ is the corresponding mobility. The total current is thus —

$$i_+ + i_- = F\, e\,(n_+ k_+ + n_- k_- + N_+ K_+ + N_- K_-)$$

where, $k_+$, $k_-$, $K_+$, $K_-$ are the mobilities of the positive and the negative ions, small and large respectively, and $e$ is the elementary charge. In clear country air over land $n_+$ and $n_-$ number about 600 per c.c. while $N_+$ and $N_-$ are about 2000 per c.c., $k_+$ and $k_-$ are 1·5 approximately and $K_+$ and $K_-$ are 0·0004. Here, therefore, the ratio of the first to the second term in the bracket given above is 1100 : 1 and therefore most of the conductivity of the air is due to small ions. Thus

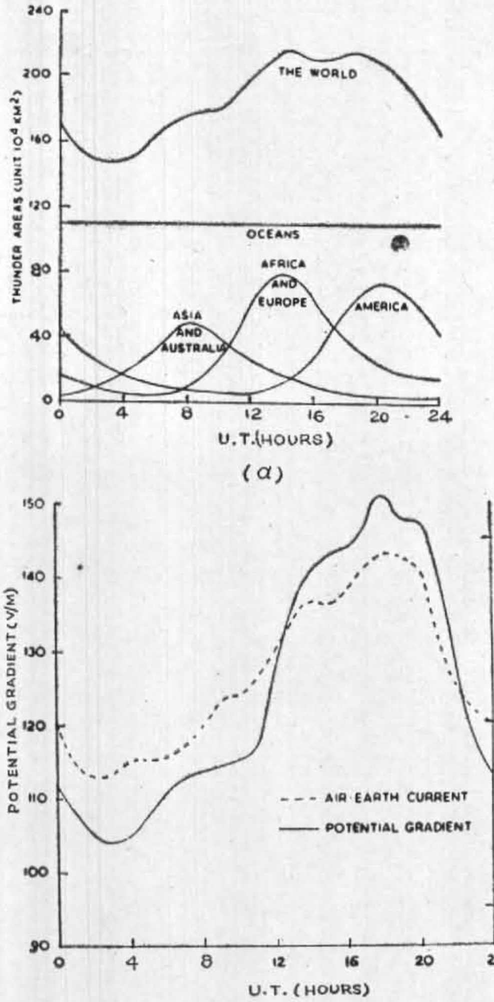



**Fig. 14**

Diurnal variation with respect to U.T. of (a) global thunder areas (*After* Ruthenberg, S. and Holzer, R.E. 1955) and (b) of air earth current and potential gradient at sea (*After* Pierce, E.T. 1958)

**TABLE 8**

**Conduction current during balloon ascent (Wigand)**

| Height (m) | F (V/m) | λ (e.s.u.) | 1 amp per sq. cm |
|---|---|---|---|
| 0 | 136 | $1{\cdot}1 \times 10^{-4}$ | $1{\cdot}7 \times 10^{-16}$ |
| 2500 | 27 | $4{\cdot}8 \times 10^{-4}$ | $1{\cdot}4 \times 10^{-16}$ |
| 4400 | 18 | $8{\cdot}2 \times 10^{-4}$ | $1{\cdot}6 \times 10^{-16}$ |
| 6500 | 8 | $12{\cdot}6 \times 10^{-4}$ | $1{\cdot}2 \times 10^{-16}$ |

**TABLE 9**

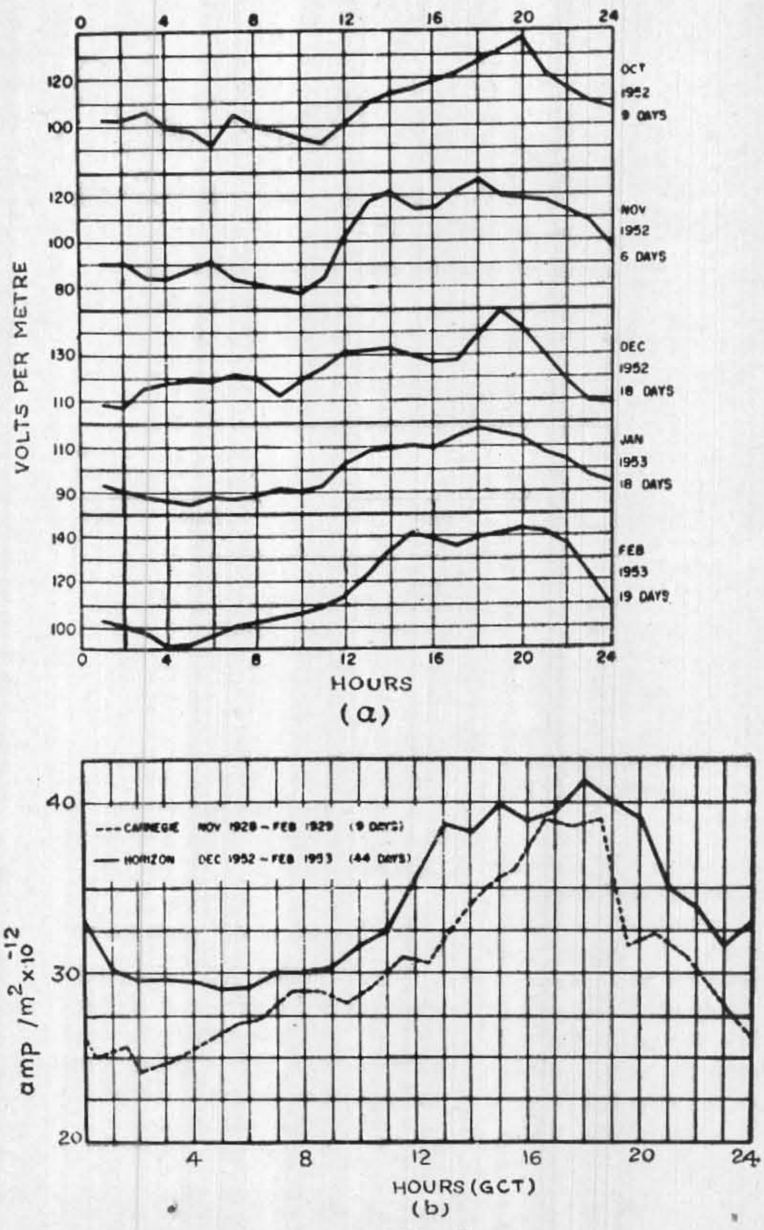
**Measurement of +ve and —ve ions using Ebert's Ion Counter**

| Date 1967 | Time (IST) | Ions | | Date 1967 | Time (IST) | Ions | | Date 1967 | Time (IST) | Ions | | Date 1967 | Time (IST) | Ions | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | +ve | —ve | | | +ve | —ve | | | +ve | —ve | | | +ve | —ve |
| 12 Jun | 1740 | 2855 | 3295 | 24 Jun | 0930 | 2915 | 3375 | 5 Jul | 0900 | 2621 | 2139 | 13 Sep | 0800 | 1443 | 1489 |
| 13 ,, | 0800 | 2648 | 2994 | | 1200 | 2276 | 2169 | | 1204 | 2429 | 2594 | | 1200 | 1627 | 1781 |
| | 1200 | 2585 | 2277 | | 1608 | 2955 | 2957 | | 1600 | — | — | | 1600 | 1992 | 1878 |
| | 2000 | 2096 | 2011 | | 1905 | 1529 | 1585 | | 2000 | — | — | 14 ,, | 0800 | 1569 | 1408 |
| 14 ,, | 0805 | 4392 | 4387 | 25 ,, | 0900 | 1765 | 1956 | 6 ,, | 0800 | — | — | | 1200 | 2164 | 1607 |
| | 1205 | 4875 | 3960 | | 1215 | 2648 | 2345 | | 1200 | 3115 | 2990 | | 1600 | 1599 | 1379 |
| | 1605 | 4463 | 4192 | | 1610 | 2404 | 2075 | | 1600 | — | — | 15 ,, | 0800 | 1383 | 1134 |
| | 1955 | 4566 | 4804 | | 2030 | 1817 | 1711 | | 2000 | — | — | | 1200 | 1865 | 1159 |
| 15 ,, | 0800 | 5774 | 6486 | 26 ,, | 0900 | 1765 | 1956 | 7 ,, | 0800 | 2055 | 1714 | | 1600 | 1785 | 1242 |
| | 1200 | 5839 | 5436 | | 1215 | 2648 | 2345 | | 1200 | — | — | | 2000 | 1214 | 486 |
| | 1600 | 3880 | 3959 | | 1610 | 2404 | 2075 | | 1600 | 2082 | 2171 | 16 ,, | 0800 | 788 | 1059 |
| | 2000 | 2845 | 2698 | | 2042 | 1427 | 1419 | | 2000 | — | — | | 1200 | 1449 | 1147 |
| 16 ,, | 0800 | — | — | 27 ,, | 0820 | 2559 | 2256 | 1 Sep | 0800 | 1920 | 1686 | | 1600 | 1335 | 1261 |
| | 1206 | 2401 | 3116 | | 1210 | 2788 | 2872 | | 1200 | 2250 | 1776 | | 2000 | 1254 | 1241 |
| | 1605 | 3781 | 2413 | | 1600 | 1855 | 1609 | | 1600 | 1319 | 1314 | 17 ,, | 0800 | 1340 | 836 |
| | 2010 | 2620 | 2422 | | 2015 | 1500 | 1092 | | 2000 | 1069 | 743 | | | | |
| 17 ,, | 0810 | 3437 | 4260 | 28 ,, | 0845 | 1226 | 1425 | 2 ,, | 0800 | 1209 | 1306 | 18 ,, | 0800 | 1447 | 1246 |
| | 1205 | 3051 | 4349 | | 1206 | 2970 | 2781 | | 1200 | 1608 | 1468 | | 1200 | 1886 | 1832 |
| | 1605 | 2026 | 1728 | | 1605 | 2680 | 2524 | | 1600 | 1293 | 1271 | | 1600 | 1443 | 1275 |
| | 2010 | 2464 | 2207 | | 2005 | — | 1866 | 3 ,, | 1200 | 1540 | 1525 | | 2000 | 1175 | 1533 |
| 18 ,, | 0825 | 2401 | 2226 | 29 ,, | 0905 | 2433 | 2374 | | 1600 | 1434 | 1369 | 19 ,, | 0800 | 1165 | 929 |
| | 1220 | 4275 | 2792 | | 1200 | 3738 | 3362 | | 2000 | 1160 | 877 | | 1200 | 1421 | 1392 |
| | 1540 | 3531 | 3033 | | 1610 | 2803 | 2867 | 4 ,, | 0800 | 1271 | 1361 | | 1600 | 1269 | 1250 |
| | 2000 | — | — | | 2100 | 3111 | 1191 | | 1200 | 1912 | 1596 | | 2000 | 865 | 628 |
| 19 ,, | 0830 | 3000 | 3291 | 30 ,, | 0900 | 1406 | 3036 | | 1600 | 1308 | 1375 | 20 ,, | 0800 | 1218 | 978 |
| | 1210 | 4669 | 4215 | | 1200 | 2853 | 2985 | | 2000 | 890 | 1615 | | 1200 | 2255 | 2232 |
| | 1605 | 4894 | 3604 | | 1605 | 3208 | 2729 | 5 ,, | 0800 | 1065 | 1064 | | 1600 | 1480 | 1490 |
| | 2000 | 4894 | 3604 | | 2030 | 1372 | 1874 | | 1200 | 1386 | 1481 | | 2000 | 1520 | 1275 |
| 20 ,, | 0850 | 2207 | 1484 | 1 Jul | 0845 | 1125 | 2217 | | 1600 | 1389 | 1353 | 21 ,, | 1200 | 2252 | 1747 |
| | 1200 | 2915 | 2649 | | 1210 | 2375 | 2041 | | 2000 | 1216 | 1379 | | 1600 | 1480 | 1007 |
| | 1600 | 5061 | 1047 | | 1625 | 2584 | 2391 | 6 ,, | 0800 | 1366 | 1356 | 22 ,, | 1600 | 1349 | 1231 |
| | 2000 | — | — | | 2050 | 1888 | 2685 | | 1200 | 1499 | 1922 | | | | |
| 21 ,, | 0900 | 1577 | 1147 | 2 ,, | 0800 | — | — | | 1600 | — | 1070 | 23 ,, | 1200 | 1994 | 2009 |
| | 1200 | 2713 | 2038 | | 1200 | — | — | 7 ,, | 0800 | 1195 | 1235 | 25 ,, | 1200 | 1782 | 1540 |
| | 1600 | 2013 | 2140 | | 1500 | 2685 | 2186 | | 1200 | 1336 | 1335 | | 1600 | 1913 | 1578 |
| | 2000 | 1429 | 1115 | | 2000 | — | — | | 1600 | 936 | 973 | | | | |
| 22 ,, | 0800 | 2199 | 2707 | 3 ,, | 0800 | — | — | | 2000 | 1070 | 1202 | 26 ,, | 1200 | 1994 | 1421 |
| | 1200 | 2783 | 2993 | | 1205 | 2985 | 3163 | 8 ,, | 0810 | 1471 | 1399 | 27 ,, | 1200 | 1662 | 1711 |
| | 1600 | 1864 | 1958 | | 1600 | 2472 | 2013 | | 1200 | 1833 | 1695 | | | | |
| | 2000 | 2159 | 1533 | | 2015 | 1674 | 1726 | | 1600 | 1244 | 1427 | 28 ,, | 1200 | 1970 | 1583 |
| 23 ,, | 0810 | 2373 | 1663 | 4 ,, | 0930 | — | — | 9 ,, | 0800 | 1417 | 1070 | 29 ,, | 1200 | 12339 | 1488 |
| | 1225 | 3192 | 3244 | | 1215 | 2082 | 2540 | | 1200 | 1391 | 850 | | 1600 | 2040 | 1177 |
| | 1605 | 2898 | 2969 | | 1605 | 2374 | 1792 | 12 ,, | 1200 | 1929 | 1734 | 30 ,, | 1200 | 2579 | 1782 |
| | 2000 | — | — | | 2005 | 1867 | 1864 | | 1600 | 1372 | 1698 | | 1600 | 1258 | 1114 |

**Monthly mean values of positive conductivity, potential gradient and air earth current density**

| Date | Positive conductivity $(\text{ohm}^{-1}\text{m}^{-1}) \times 10^{-14}$ | Potential gradient (Volts/m) | Air earth current density $(\text{amp/m}^2) \times 10^{-12}$ |
|---|---|---|---|
| 7 Oct 1952 | 1·58 | 108·4 | 2·95 |
| 3–7 Nov 1952 | 2·08 | 100·4 | 4·18 |
| 22 Dec 1952 | 1·68 | 123·1 | 4·18 |
| 18 Jan 1953 | 1·45 | 98·9 | 2·95 |
| 19 Feb 1953 | 1·19 | 107·8 | 2·55 |

The monthly means of the diurnal variation of the potential gradient are shown as a function of Greenwich Civil Time in figure below. All of the monthly curves exhibit a single daily oscillation




(a) Reduced values of the potential gradient in volts/metre taken aboard the R/V *Horizon* in the Central Pacific Ocean during Oct 1952 to Feb 1953

(b) Computed values of air earth current density in the Pacific Ocean (*Carnegie* 1928-29 and *Horizon* 1952-53)

Fig. 15

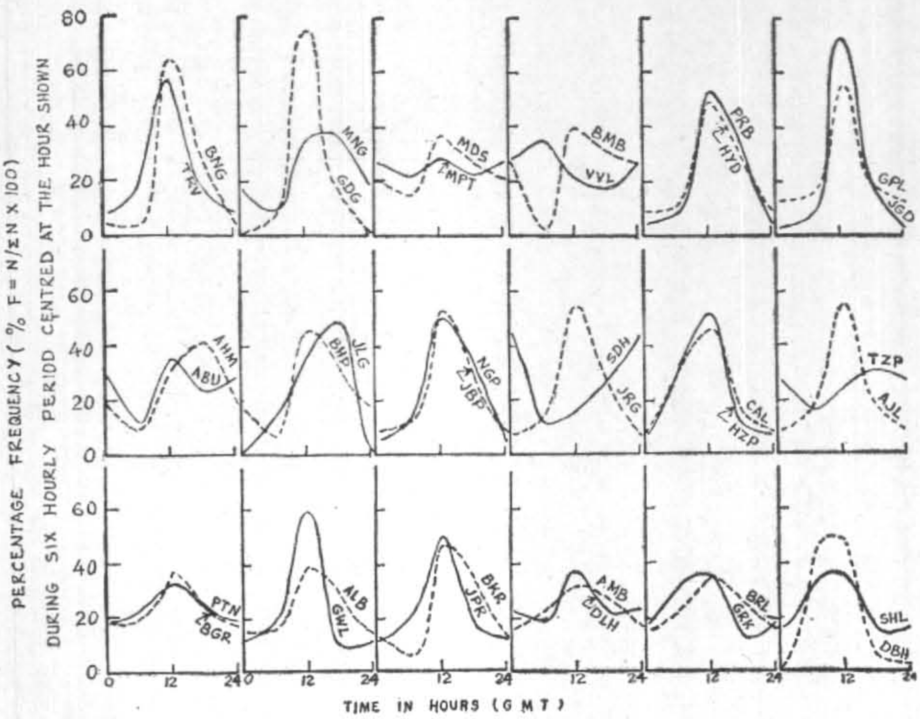



**Fig. 16. Diurnal variation of thunderstorms (1941-45) annual total**

$N$ = No of occurrences for each six hourly period of a season

$\Sigma N$ = Total No. of occurrences during all the diurnal periods

**TABLE 10**

| Quantity | Units | Poona | | Other stations (as reported by Chalmers 1967) | | |
|---|---|---|---|---|---|---|
| | | 1966 | 1967 | Kew | Average land station | Ocean |
| Potential gradient | V/m | 101 | 100 | 365 | 130 | 126 |
| Air earth current | A/m² | $1\cdot51\times10^{-12}$ | $1\cdot50\times10^{-12}$ | $1\cdot12\times10^{-12}$ | $214\times10^{-12}$ | $3\cdot7\times10^{-12}$ |
| Conductivity | $\Omega^{-1}m^{-1}$ | $1\cdot61\times10^{-14}$ | $1\cdot53\times10^{-14}$ | $3\cdot0\times10^{-15}$ | $1\cdot8\times10^{-14}$ | $2\cdot8\times10^{-14}$ |

the part played by large ions is usually negligible, as far as ionic current is concerned although they play an important part in the question of the number of small ions present.

The above factors have to be taken into account in calculating the number of positive and negative ions from the continuous records of air earth current and potential gradient. In the normal use of a quadrant electrometer for the measurement of currents one pair of quadrants is connected to the current collector while the other pair is earthed. In the present method, the second pair is not earthed. The second pair is connected to the bottom plate. The top plate is connected to the other pair. If now both pairs of quadrants are first earthed and released, the top plate would receive one component of the current (+ve) and the bottom would receive the (—ve) component of the current. As compensation for displacement currents due to field changes has been arranged, the predominant current (+ve or —ve) will be shown by the deflections of the quadrant electrometer.

5. *Changes of air earth current during fog, mist*

Scrase (1933) has observed increase of field strength and decrease of air earth current density in fog. He has also noted that during fog convection, with high relative humidity, very often the measured air earth current seems to be negative while the field is positive. Measurements by Israel and Kasemir (1952) of the potential gradient and conduction current during widespread fog showed a considerable increase in potential

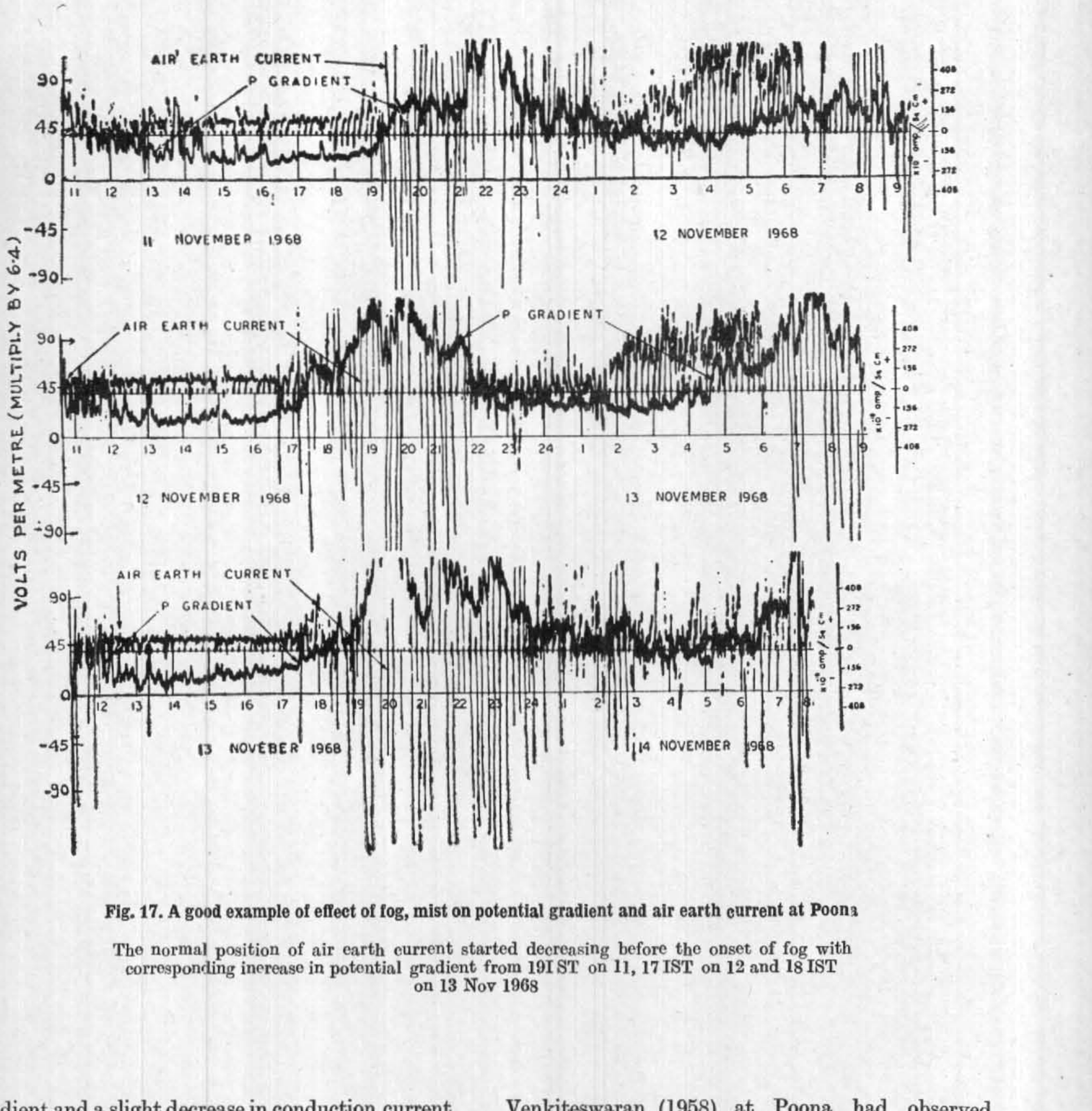



**Fig. 17. A good example of effect of fog, mist on potential gradient and air earth current at Poona**

The normal position of air earth current started decreasing before the onset of fog with corresponding increase in potential gradient from 19IST on 11, 17 IST on 12 and 18 IST on 13 Nov 1968

gradient and a slight decrease in conduction current as compared with clear air, giving on the average, a conductivity about one-third of its value in fine weather. The same facts have been observed by a number of other workers in various places and a very thorough discussion has been given by Dolezalek (1962). Serbu and Trent (1958) at Argentina in New Foundland found that the decrease in conductivity and consequent increase in potential gradient became evident 1 to 2 hours before the onset of fog and the reverse changes appeared ½ to 1½ hours before the dissipation of the fog. Dolezalek (1962) had stated that the above results, while not 100 per cent reliable for forecasting gave around 80 per cent reliability. Venkiteswaran (1958) at Poona had observed a strong increase of the electric field about 10 hr before the occurrence of fog as measured by a potential gradient radiosonde in October 1953. This increase of potential gradient had occurred in altitudes between 900 and 680 mb.

For the first time at Poona, surface observations of air earth current and potential gradient during 1966, 1967 and 1968 have shown increase of potential gradient and decrease of air earth current densitiy during fog and mist in agreement with the results of Scrase (1953) and Israel and Kasemir (1952).

**TABLE 11**

**Hourly values recorded at Poona of potential gradient ($F$), two components of air earth current ($i_+$, $i_-$), two components of conductivity ($\lambda_+$, $\lambda_-$) and number of positive and negative ions per c.c. ($n_+$, $n_-$) during fog, mist day in the year 1968**

| Time (IST) | Quantity | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $F$ | $i_+, i_-$ | $\lambda_+, \lambda_-$ | $n_+, n_-$ | $F$ | $i_+, i_-$ | $\lambda_+, \lambda_-$ | $n_+, n_-$ | $F$ | $i_+, i_-$ | $\lambda_+, \lambda_-$ | $n_+, n_-$ |
| | 11 to 12 Nov 1968 | | | | 12 to 13 Nov 1968 | | | | 13 to 14 Nov 1968 | | | |
| 16-17 | 121 | 1·1 | 0·9 | 375 | 173 | — | — | — | 138 | 1·0 | 0·7 | 292 |
| 17-18 | 150 | 1·2 | 0·8 | 333 | 357 | 2·0 | 0·6 | 250 | 184 | 1·8 | 1·0 | 417 |
| 18-19 | 150 | 1·6 | 1·1 | 131 | 576 | —7·2 | —1·3 | —541 | 311 | 0·5 | 0·2 | 83 |
| 19-20 | 277 | —2.6 | —0·9 | —375 | 680 | —15·0 | —2·2 | —917 | 588 | —10·9 | —1·9 | —791 |
| 20-21 | 461 | —12·7 | —2·8 | —1167 | 621 | —13·7 | —2·2 | —917 | 621 | —10·9 | —1·8 | 750 |
| 21-22 | — | — | — | — | 518 | —10·1 | —1·9 | —791 | 657 | —12·2 | —1·9 | —791 |
| 22-23 | — | — | — | — | 242 | 1·4 | 0·6 | 250 | 621 | —12·2 | —2·1 | —875 |
| 23-24 | — | — | — | — | 219 | —2·3 | —1·1 | —458 | 610 | —10·9 | —1·8 | —750 |
| 0-1 | 369 | 5·4 | 1·5 | 624 | 196 | 2·6 | 1·3 | 541 | 403 | 3·3 | 0·8 | 333 |
| 1-2 | 265 | 3·0 | 1·1 | 458 | 207 | —0·1 | 0 | 0 | 311 | 2·3 | 0·7 | 292 |
| 2-3 | 253 | 2·9 | 1·1 | 458 | 161 | 2·2 | 1·4 | 583 | 357 | —2·6 | —0·7 | —292 |
| 3-4 | 253 | 4·4 | 1·7 | 708 | 219 | 5·0 | 2·3 | 958 | 265 | 1·0 | 0·4 | 167 |
| 4-5 | — | — | — | — | 334 | 5·2 | 1·6 | 668 | 230 | 1·4 | 0·7 | 292 |
| 6-5 | — | — | — | — | 415 | 6·1 | 1·5 | 624 | 277 | 1·9 | 0·7 | 292 |
| 6-7 | — | — | — | — | 565 | 1·0 | 0·2 | 83 | 392 | —0·7 | —0·2 | —83 |
| 7-8 | — | — | — | — | 726 | —10·9 | —1·5 | —624 | 610 | 6·1 | 1·0 | 417 |
| 8-9 | | | | | 578 | —10·7 | —2·1 | —875 | | | | |
| | 9 to 10 Dec 1968 | | | | 18 to 19 Dec 1968 | | | | 19 to 20 Dec 1968 | | | |
| 15-16 | | | | | 230 | 2·9 | 1·3 | 541 | 196 | 3·8 | 1·9 | 791 |
| 16-17 | 150 | 2·6 | 1·7 | 708 | 253 | 4·1 | 1·6 | 668 | 357 | 3·8 | 1·1 | 458 |
| 17-18 | 150 | 2·4 | 1·6 | 668 | 438 | —1·5 | —0·3 | —125 | 300 | 1·0 | 0·3 | 125 |
| 18-19 | 323 | —0·8 | —0·2 | —83 | 668 | 4·4 | 0·7 | 292 | 403 | —2·9 | —0·7 | —292 |
| 19-20 | 703 | 5·7 | 0·8 | 333 | 657 | —1·6 | —0·2 | —83 | 323 | 3·3 | 1·0 | 417 |
| 20-21 | 541 | —0·5 | —0·1 | —42 | 691 | —13·3 | —1·9 | —791 | 357 | —9·5 | —2·7 | +1126 |
| 21-22 | 334 | 4·6 | 1·4 | 583 | 530 | —2·7 | —0·5 | —208 | 346 | 2·0 | 0·6 | 250 |
| 22-23 | 311 | 4·7 | 1·5 | 624 | 369 | 0·3 | 0·1 | 42 | 219 | 2·3 | 1·1 | 458 |
| 23-24 | 230 | 2·9 | 1·3 | 541 | 392 | —1·9 | —0·5 | —208 | 357 | 4·1 | 1·1 | 458 |
| 0-1 | 161 | 4·8 | 1·1 | 458 | 369 | —1·4 | —0·4 | —167 | 161 | 2·0 | 0·8 | 333 |
| 1-2 | 161 | 1·5 | 0·9 | 375 | 438 | —5·3 | —1·2 | —500 | 392 | 3·8 | 1·0 | 417 |
| 2-3 | 115 | 1·6 | 1·4 | 583 | 565 | 1·8 | 0·5 | 292 | 323 | —2·7 | —0·8 | —333 |
| 3-4 | 150 | 2·6 | 1·7 | 708 | 472 | 6·1 | 1·3 | 541 | 150 | —1·0 | —0·7 | —292 |
| 4-5 | 104 | 1·5 | 1·4 | 583 | 311 | 1·0 | 0·3 | 125 | 196 | 1·5 | 0·7 | 292 |
| 5-6 | 92 | 1·0 | 1·1 | 458 | 461 | —9·5 | —2·1 | —875 | 461 | —2 6 | —0·6 | —250 |
| 6-7 | 127 | 0·7 | 0·6 | 250 | 496 | 4·5 | 0·9 | 375 | 621 | —2·2 | —2·0 | —833 |
| 7-8 | 138 | 1·4 | 1·0 | 417 | 703 | —13·7 | —1·9 | —791 | 588 | —2·2 | —2·1 | —875 |
| 8-9 | | | | | | | | | 392 | 5·7 | 1·5 | 624 |
| 9-10 | | | | | | | | | 472 | 5·7 | 1·2 | 500 |

$F$ is expressed in V/m

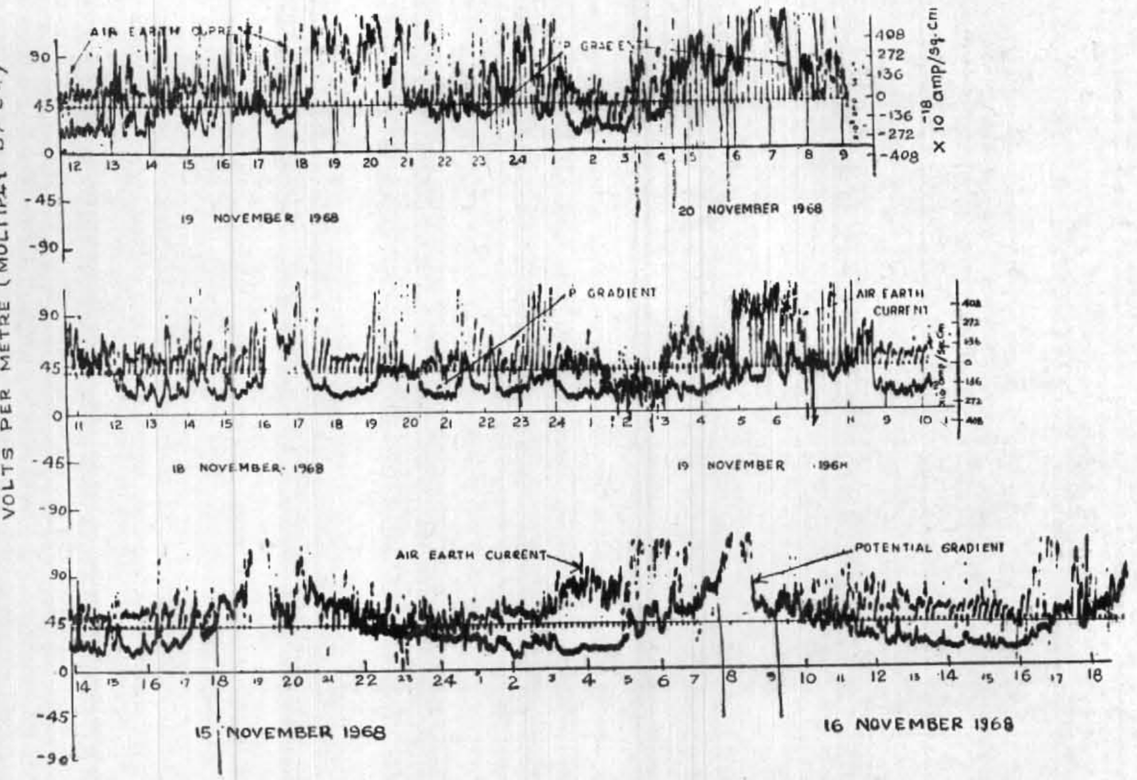



**Fig. 18. Records of mainly positive air earth current and positive potential gradient**

A few records showing the increase of potential gradient and decrease of air earth current during fog, mist at Poona are reproduced in Figs. 17,18, 19, 20 and Table 11. Scrase (1933) has explained the general effect of fog on electrical conditions as follows —

> The resistance of the air is increased owing to the diminution in the number of small ions. This diminution is brought about by the absorption of the small ions by the nuclei of condensation, the numbers of which are increased in fog. The increased resistance causes the potential gradient to assume high positive values as a rule, whilst the air earth current is zero and becomes negative. The surprising fact is that there is a reversal in the sign of the charge, entering the ground, and the reversal persists for several hours. But this is not accompanied by a corresponding change in the sign of the potential gradient. The occurrence of opposite signs for field and current is explained by Chalmers and Little (1941) by Maxwellian displacement currents generated by field changes. Basically during fog, the conductivity is decreased to about one-third. The decrease in conductivity may be reflected by a decreased air earth current density or by an increased field strength or by both. In addition, the ratio of negative to positive polar conductivities may undergo some variations in connection with fog.

### 7. Summary and conclusions

(*i*) During 1966, in undisturbed conditions, the annual mean of the air earth current at Poona is $151\cdot1\times10^{-18}$ amp per sq. cm per sec. The charge due to above conduction current reaching 1 km$^2$ of earth in a year at Poona is 48 Coulombs as compared with 35·3 Coulombs per km$^2$ at Kew (Scrase).

(*ii*) The annual variation of the air earth current is the same as that of the potential gradient, there being a maximum in winter and minimum in summer.

(*iii*) In winter the daily fluctuations of current and conductivity are very much alike. In summer on the other hand, there is more resemblance between the diurnal variation of the air earth current and that of potential gradient.

(*iv*) During 1967, with the introduction of two radioactive collectors, one for each test plate, both the components of air earth current corresponding to the positive and negative conductivities are being recorded in the air earth current records.

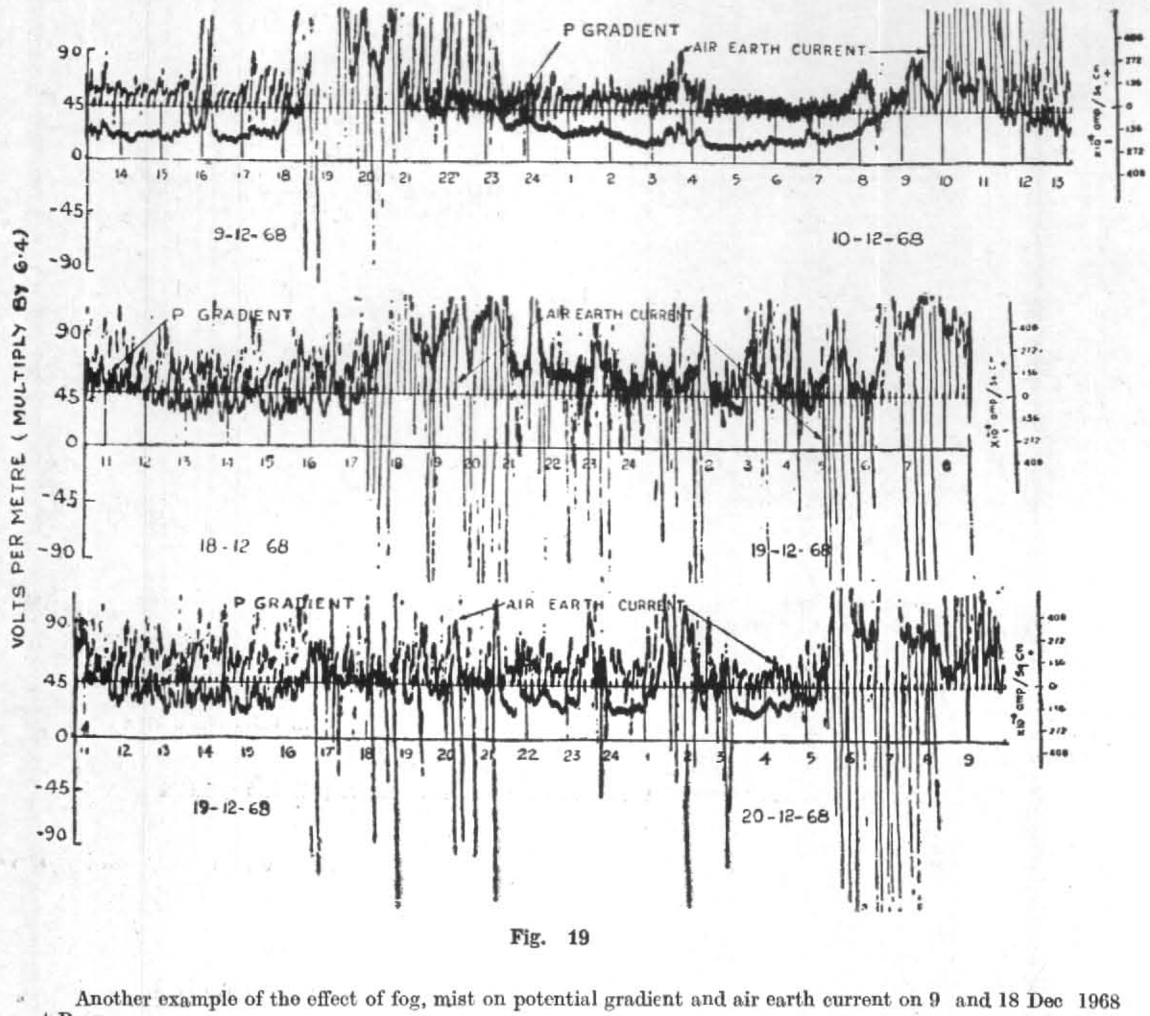



**Fig. 19**

Another example of the effect of fog, mist on potential gradient and air earth current on 9 and 18 Dec 1968 at Poona.

There was widespread fog commencing from 19 IST on 18 Dec 68 to 08 IST on 19 Dec 68. On 19 Dec 68 there was fog again commencing from 1700 IST on 19 Dec 68. On 9 Dec 68 the potential gradient started increasing from 18 IST with corresponding decreasing in air earth current changing the direction from positive to negative. On 18 Dec 68, at 1700 IST the potential gradient started increasing with corresponding decrease in air earth current and changing the direction from positive to negative at 1730 IST. On 19 Dec 68, at 1630 IST the potential gradient started increasing with corresponding decrease in air earth current and changing direction from positive to negative at 1630 IST.

(*v*) The annual total mean value of positive air earth current and negative air earth current for the year 1967 is $158 \cdot 1 \times 10^{-18}$ amp/sq. cm/sec. The charge due to above conduction current reaching 1 km$^2$ of earth in a year at Poona is $+$ 50 Coulombs as compared with $+60$ Coulombs at Cambridge (Wormell 1953) and $+60$ Coulombs at Durham (Chalmers and Little 1947) and $+90$ Coulombs over the whole world (Israel 1953).

(*vi*) Table 10 gives a comparison of average values of atmospheric electric parameters at Poona (1966-67) and other stations.

(*vii*) During fog, mist at Poona, the potential gradient increases, but the air earth current decreases and becomes negative in sign. The potential gradient increases about 1 to 2 hours before the onset of fog with corresponding decrease in air earth current. The reverse changes in both potential gradient and air earth current appear $\frac{1}{2}$ to $1\frac{1}{2}$ hours before the dissipation of fog. This fact is useful for forecasting of fog formation and dissipation.

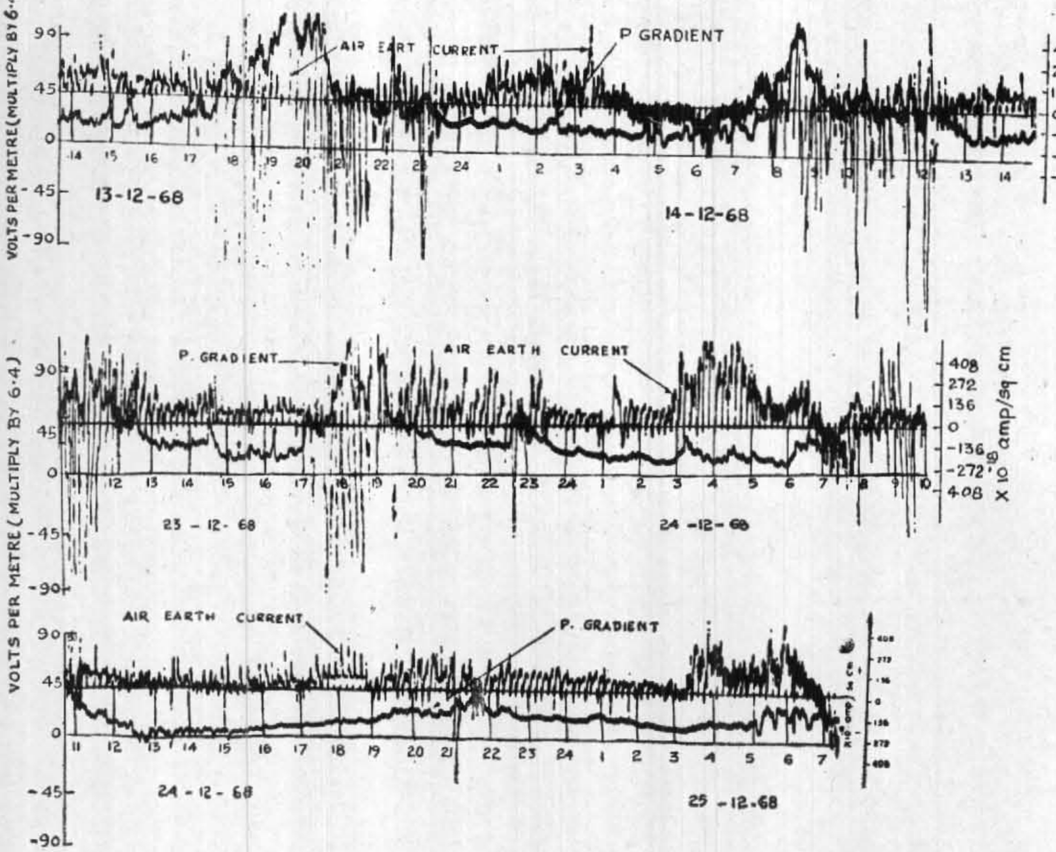



Fig. 20

The figure shows another example of fog, mist effect on potential gradient and air earth current on 13 Dec 68 with increase in potential gradient from 1700 IST and corresponding decrease in air earth current changing the direction from positive to negative at 1730 IST on 13 Dec 68. On 23 Dec 1968 the potential gradient started increasing at 17 IST with corresponding decrease in air earth current at 1715 IST. On 24-25 Dec 1968, the whole day, the air earth current and potential gradient are both positive in direction without the effect of any fog, mist.

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*REFERENCES*

| | | |
|---|---|---|
| Chalmers, J. A. | 1957 | *Atmospheric Electricity* (First Ed.), pp. 146, 281. |
| | 1967 | *Ibid.*, (Second Ed.), p. 228. |
| Chalmers, J. A. and Little, E. W. R. | 1947 | *Terr. Mag. Atmos. Elect.*, **52**, 239-60. |
| Chree, C. and Watson, E. E. | 1924 | *Proc. R. Soc. A.*, London, **105**, p. 311. |
| Dolezalek, H. | 1960 | *Geofis. Pur. Apl.*, **46**, 125-144. |

*REFERENCES (contd)*


| | | |
|---|---|---|
| Gish, O. H. | 1949 | *Terr. Mag. Atmos. Elect.* (Ed. J.A. Fleming). Chap. IV. |
| Higazi and Chalmers | 1966 | *J. Atmos. Terr. Phys.*, **28**, 327-30. |
| Israel, H. | 1963 | Proc. of the Third International Conf. on Atmos. Electricity & Space Electricity, pp. 152-53. |
| Law, J. | 1963 | *Quart. J. R. Met. Soc.*, **89**, 107-21. |
| Pierce, E. T. | 1958 | *Recent Advances in Atmospheric Electricity*, pp. 5-16. |
| Rutton Berg, S. and Holzer, R. E. | 1955 | Proc. of the Conference on Atmos. Electricity, pp. 101-108. |
| Scrase, F. J. | 1933 | *Geophys. Mem. London*, **58**, pp. 1-22. |
| Serbu and Trent | 1958 | *Trans. Amer. Geophys. Un.*, **39**, 1034. |
| Simpson, G. C. | 1910 | *Phil. Mag.*, London, 19, 715. |
| Venkiteswaran, S. P. | 1958 | *Recent Advances in Atmospheric Electricity*, pp. 89-100. |
| Wigand, A. | 1925 | *Phys. Zeit.*, **26**, p. 81. |
| Whipple, F. J. | 1932 | *Terr. Mag.*, **37**, p. 355. |
| Whipple, F. J. and Scrase, F. J. | 1936 | *Geophys. Mem. London*, **68**, p. 19. |
| Wormell, T. W. | 1930 | *Proc. Royal Soc.*, A. 127, pp. 567-590. |
| | 1953 | *Quart. J. R. met. Soc.*, **79**, 3-50. |