MEASUREMENT OF THE ELECTRICAL CONDUCTIVITY IN THE UPPER AIR BY RADIOSONDE

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THE concepts of atmospheric electric phenomena have undergone many changes recently, and as a result there is a trend now to correlate electric to meteorological processes. Measurements have to be made of all the fundamental electric elements, *viz.*, the potential gradient E, the conductivity λ and the vertical air-earth current density i, which are interrelated by Ohm's law, $E\lambda = i$. Investigations of the processes taking place in the atmospheric electric circuit under equilibrium conditions require information about any two of these fundamental quantities, while in other processes all the three quantities must be measured. So far, observations of the potential gradient and conductivity have generally been confined to near the ground, and it has not been possible to extend these observations to the upper air due to the want of a simple technique. There were a few attempts to measure the potential gradient in the atmosphere by radiosonde by Idrac,[1] Ross Gunn[2] and Belin[3] but they did not prove quite satisfactory for general use due to various reasons. But recently Koenigsfeld and Piraux[4] have shown how the simple triode valve HL 23 can be used as an electrometer; they have also shown how this valve electrometer with polonium collectors at a known distance can be coupled to the radiosonde developed in Belgium to measure the electrical potential gradient in the upper air. Venkiteshwaran, Dhar and Huddar[5] have adopted this valve electrometer for use with the audio-frequency modulated American type radiosonde to measure the potential gradient in the atmosphere. This technique has been further simplified by Venkiteshwaran, Gupta and Huddar.[6]

Thus it can be now said that a simple technique for the measurement of the potential gradient in the atmosphere by radiosonde is available due to the valve electrometer of Koenigsfeld and Piraux.

In this paper the attempts made to determine the conductivity of the air at various levels with the valve electrometer are described. Conductivity of the air at various levels have so far been made only with manned balloons by Wigand,[7] Gish and Sherman[8] during the stratosphere flight of the Explorer II, and more recently by Gish and Wait[9] from aeroplanes. In all these measurements, the Gerdien Condenser[10] has been used.

The Gerdien condenser consists of a central metal cylinder 24 cm. long and 1·4 cm. diameter mounted within a larger cylinder 56 cm. long and 16 cm. in diameter. The inner cylinder is connected to an electroscope and is insulated from the outer. A current of air is drawn through the apparatus by a fan after charging the central cylinder to a known voltage, the outer cylinder being earthed. From the rate of loss of the charge on the central cylinder, the conductivity of the air is calculated. Gerdien deduced the following formula for his apparatus:

$$\frac{C_1}{T} \log_e \frac{V_1}{V_2} = 4\pi \, nev \left\{ \frac{l}{2 \log_e \frac{ra}{ri}} \right\}$$

where C_1 = measured capacity of the central cylinder and electrometer,

V_1 = Potential of the central cylinder at start,

V_2 = Potential of the central cylinder after time T,

T = Time interval in which potential of central cylinder fell from V_1 to V_2,

r_a = Radius of outer cylinder,

r_i = Radius of inner cylinder,

n = Number of ions per c.c. of opposite sign to that given to the central cylinder,

e = Ionic charge,

v = Specific velocity of the ions,

l = Length of the inner cylinder.

From the above formula, the unipolar conductivity *nev* can be determined. The above formula has been based on the assumption that the force at a distance r from the inner cylinder with a charge E per unit length is $2\,E/r$ which is not strictly true as the length of the cylinder is short. Swann[11] has suggested the replacement of the factor

$$\frac{l}{2 \log_e \frac{ra}{ri}}$$

by C, the measured value of the capacity of the central cylinder and its connecting rod. Thus we get

$$C_1 \log_e \frac{V_1}{V_2} = 4\pi \, nev \, CT$$

If λ_p and λ_n are the conductivities due to positive and negative ions respectively

$$\lambda_p \text{ or } \lambda_n = \frac{C_1}{4\pi C} \log_e \frac{V_1}{V_2}$$

the total conductivity being

$$\lambda = \lambda_p + \lambda_n$$

With the experience gained in the use of the valve electrometer to measure potential gradients, it was felt that it could also be used with the Gerdien condenser to measure the conductivity of the air. The valve electrometer was coupled to the audio frequency modulated type of American radiosonde.

To examine the suitability of the valve electrometer to measure the conductivity of the air, preliminary tests were made on the ground with a Gerdien condenser manufactured by Günther and Tegetmeyer. Air was drawn through the condenser with a hand-operated fan. The central cylinder was connected to a bifilar Wulf electrometer, also made by Günther and Tegetmeyer. The rate of fall of potential was first measured with the Wulf electrometer and immediately the observations were repeated with the valve electrometer coupled to the audio frequency modulated radiosonde (Fig. 1). The signals from the radiosonde were recorded in the usual ground equipment

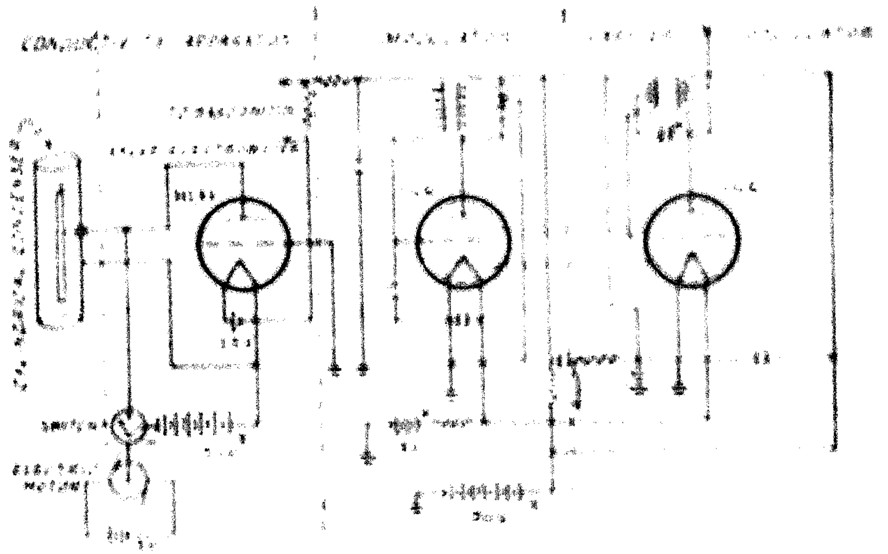

FIG. 1. Gerdien Conductivity Apparatus with Valve Electrometer and American Radiosonde

for the purpose. It was observed that the values of the rate of decrease of voltage of the central cylinder were same.

It was therefore decided to adapt this technique in a suitable and simple manner to measure the conductivity at various levels in the atmosphere.

The outer cylinder of the condenser was made of aluminised paper. It was reinforced with metallic rings at the top and bottom and with strips between the two rings. The dimensions of the cylinder were the same as that in the original Gerdien apparatus. The inner cylinder was made out of an aluminium tube, with its ends closed. It was supported in the centre of the outer cylinder by means of a thin steel wire passing through a piece of alkathene or polysterene insulating piece fixed on the side of the outer cylinder. The inner cylinder was charged to a known voltage (110 volts) at intervals. This was arranged by a battery operated (3 volts) small electric motor (Electrotor, type 240, manufactured by Rev Motors Ltd., Atherstone, Warwickshire, England) and a train of gears operating an alkathene or polysterene cylinder carrying the contracting arms. In one of the ascents the electric motor was replaced by a paper fan similar to that used in the F-type radiosonde.[12]

Before assembling the equipment for ascent the values of C_1 and C were measured in the laboratory. The capacitance of the HL 23 valve was found to vary from valve to valve. The Gerdien cylinder, the radiosonde with the valve electrometer and the switching arrangement to charge the central cylinder were assembled as shown in Fig. 2. The equipment was then calibrated with the radiosonde ground equipment by applying known voltages to the central cylinder, and obtaining a record of the corresponding audio frequency. The equipment was then released with a balloon.

During the flight, the Gerdien condenser is vertically placed and is therefore completely exposed to the vertical air current. The total weight of the equipment is of the order of 2,300 gm. and is lifted with two NR 575 balloons with a total free lift of 5,000 gm. (The Indian NR 575 balloons correspond to Darex 500). The balloons had a rate of ascent of approximately 16 km. per hour. The instrument was hung at a distance of 50 metres from the balloons. Polysterene insulators were employed between the balloons and the instrument.

Fig. 3 shows the records obtained on the 24th February 1953 and 4th March 1953. On the 24th February 1953, the charging of the central cylinder was made with a paper-fan operating during the rise of the balloon. On the 4th March 1953, the charging was effected with an Electrotor motor. On both these days the central cylinder was charged to a negative potential of 110 volts and 115 volts respectively. The conductivity of positive ions calculated from these two ascents is shown in Fig. 4.

Without discussing the details of variation of positive conductivity with height, it is encouraging to note that the values obtained from these ascents

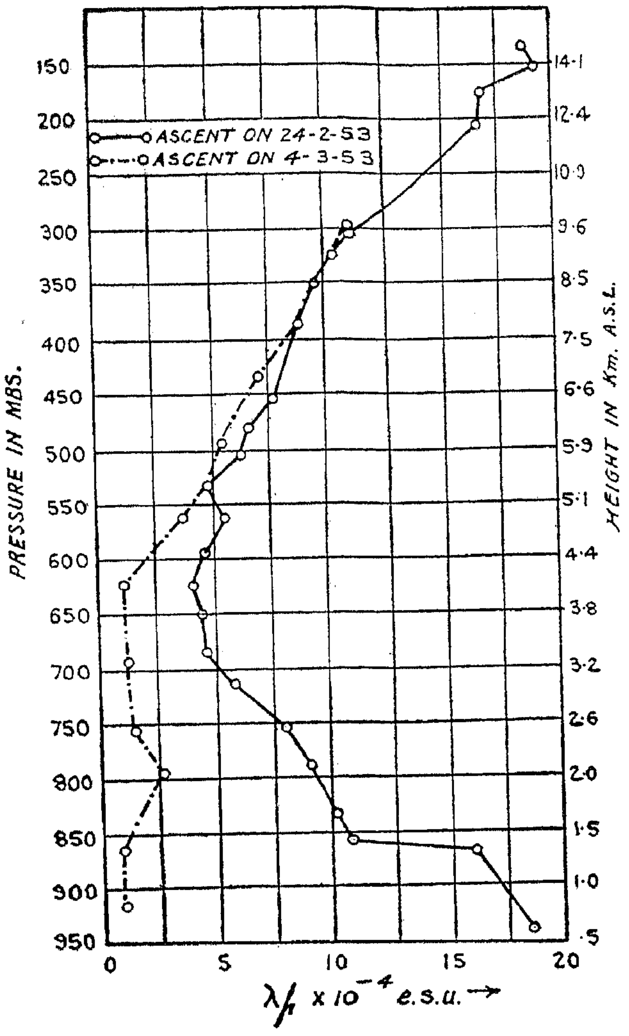

FIG. 4

are comparable with those obtained by Wigand or Gish and Sherman from Explorer II.

When the balloon is released the radiosonde ground equipment records the potential to which the central cylinder is charged and its variation due to leakage due to the positive ions. The baro-switch in the radiosonde also signals the value of the barometric pressure at different heights. One can calculate the conductivity of the air at different levels from the charging potential V_1 supplied by the battery meant for the purpose and V_2, the potential after discharge for a known interval of time measured in the chart. If due to bad reception the charging voltage is missed, the value of V_1 and V_2 can be taken from any points of the trace.

There has been considerable discussion regarding the most suitable voltage to which the central cylinder can be charged. Voltages 115 or 110 have been employed in the two ascents described in this paper. As the ground equipment gives a continuous record of the falling voltage in the central cylinder, any suitable value of V_1 and V_2 can be obtained for the calculation of the conductivity. As the air speed through the condenser is of the order of about 300 metres per minute, it appears that 115 volts is within the "Critical voltage" suggested by Hewlett.[13]

It would have been an improvement in the technique if a suitable funnel was fixed at the upper end of the outer cylinder, to reduce the effects of turbulence and it is hoped that it may be possible to design one in due course.

The technique described in this paper refers only to the measurements of the positive conductivity in the upper air. The method of adapting it to measure the negative conductivity is under examination.

Air conductivity depends upon altitude in a complicated way. Some of the factors that can affect it are:[14] (1) the intensity of cosmic radiation which increases with altitude, (2) for a given ionizing radiation, the rate of ion formation decreases directly as the air density, (3) the mobility of the ions varies inversely as the air density, (4) the rate of ion destruction in pure air of a given ion concentration decreases with altitude, (5) the concentration of radio-active matter exhaled from the earth over land decreases with altitude, and (6) the pollution of the atmosphere decreases with altitude. The last two factors will become insignificant at altitudes greater than one or two kilometres. In addition to the above it is likely that in the troposphere nuclei may tend to gather in layers especially near the boundaries of air masses or in the region of the stratosphere. It appears that the simple technique described in this paper may be useful to throw light on many of the above problems.

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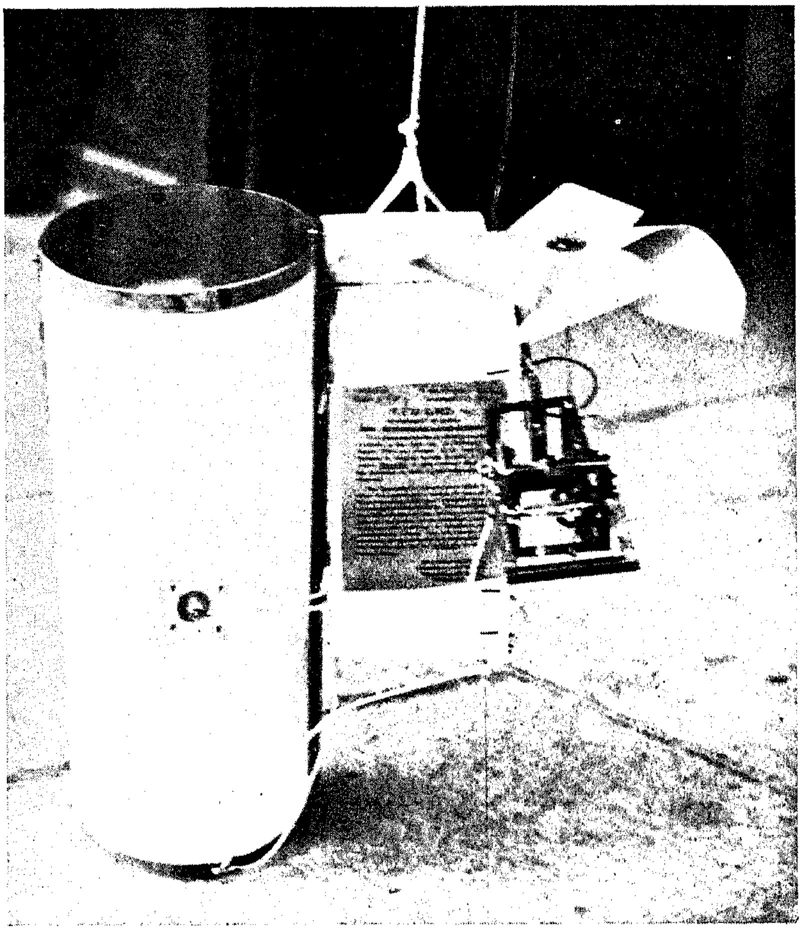

FIG. 2

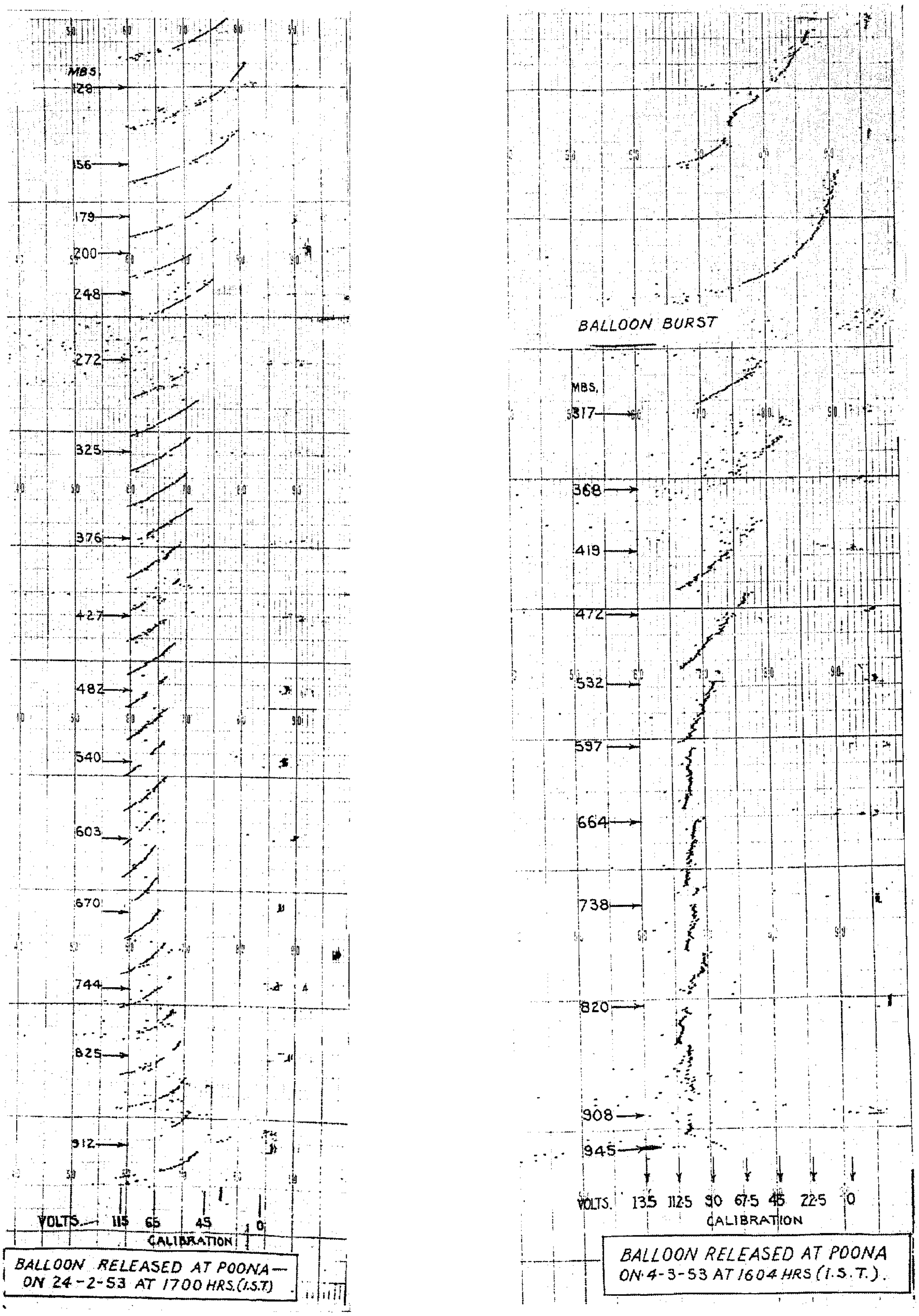
MBS.
128
156
179
200
248
272
325
376
427
482
540
603
670
744
825
912
VOLTS 115 65 45 0
CALIBRATION
BALLOON RELEASED AT POONA ON 24-2-53 AT 1700 HRS.(I.S.T.)
BALLOON BURST
MBS.
317
368
419
472
532
597
664
738
820
908
945
VOLTS. 135 112.5 90 67.5 45 22.5 0
CALIBRATION
BALLOON RELEASED AT POONA ON 4-3-53 AT 1604 HRS (I.S.T.).

FIG. 3

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