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Experimental Study of dc Corona at High Temperatures and Pressures

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Positive and negative corona characteristics of air and nitrogen are determined experimentally for coaxial cylindrical electrode geometry with gas temperatures from 300°K to 1100°K and with pressures from 0.1 to 8 atmospheres. Over this range, positive corona characteristics appear to be functions of gas density only. On the other hand, negative corona characteristics depend on gas temperature as well as gas density. At high temperatures both positive and negative coronas show instabilities which are pressure dependent.

INTRODUCTION

EXTENSIVE investigations have been reported on the properties of direct current corona in both low-pressure[1–3] and high-pressure[4,5] regions at temperatures to 600°K. Typical applications for this information have been in the design of Geiger counters,[6] high-voltage regulators,[7] and electrostatic precipitators.[8] Recent advances in the technology of materials have increased interest in corona characteristics at much higher temperatures, particularly as these characteristics apply to the design of high-temperature electrostatic precipitators.

This paper describes experimental data obtained for positive and negative corona in air and nitrogen at temperatures to 1100°K and pressures to 8 atmospheres. In all the work done coaxial cylindrical geometry was used.

APPARATUS AND PROCEDURE

The test cell is shown diagrammatically in Fig. 1. An outer vertical tube of stainless steel 36 in. in length and 3.36-in. inside diameter comprises the high-pressure, high-temperature vessel. This tube (except for its flanges) is surrounded by axially arranged silicon carbide heating rods appropriately enclosed in firebrick. The tube has steel housings bolted to both ends to support insulators and to provide access, gas inlets and outlets, and visual observation. The latter is provided by a high-pressure glass port. Inside the pressure vessel and arranged coaxially is a 2-in. inside diameter stainless tube in three sections. The two end sections are connected to the outer pressure tube and the center section (12 in. in length) is insulated from the rest of the cell by steatite washers. Between the outer pressure vessel and the center section of the inner tube are three chromel-alumel thermocouples arranged as shown. Connections from the thermocouples and the center section of the inner tube are brought out of the pressure vessel through high-pressure thermocouple glands. A discharge wire, supported at both ends by porcelain insulators, is centered coaxially in the test fixture and held taut by spring loading.

The gases used, both air and nitrogen, were commerically manufactured bottled gases. Two types of wire were used in the experiment, a 0.0319-in. diameter stainless steel wire and a 0.030-in. diameter platinum wire. No special treatment was used in preparing the wires except for cleaning with crocus cloth and carbon tetrachloride. The wires were "cleaned up" in the fixture by operating them for several days with high current negative corona discharge.[1]

The basic data taken were current-voltage readings at fixed temperatures and pressures. The current collected by the insulated 12-in. center section of the

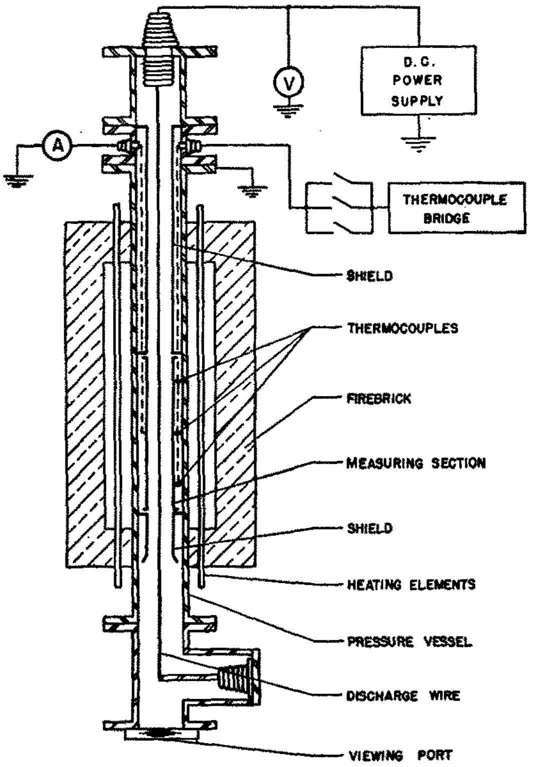

FIG. 1. Diagrammatic drawing of corona test cell.

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[1] C. G. Miller and L. B. Loeb, J. Appl. Phys. 22, 494 (1951).
[2] C. G. Miller and L. B. Loeb, J. Appl. Phys. 22, 614 (1951).
[3] C. G. Miller and L. B. Loeb, J. Appl. Phys. 22, 740 (1951).
[4] R. W. Lee and B. Kurrelmeyer, Trans. Am. Inst. Elec. Engrs. 44, 184 (1925).
[5] L. R. Koller and H. A. Fremont, J. Appl. Phys. 21, 741 (1950).
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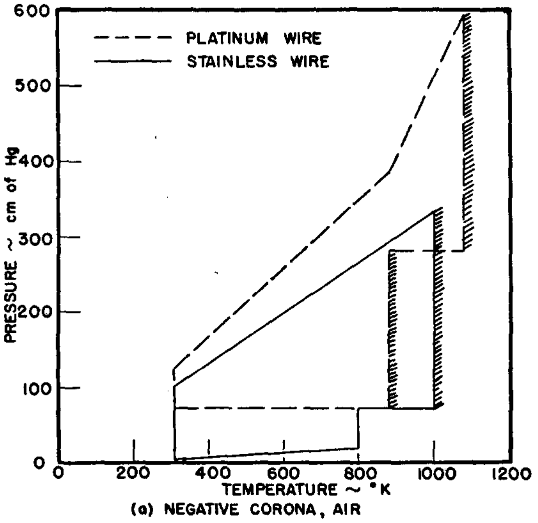
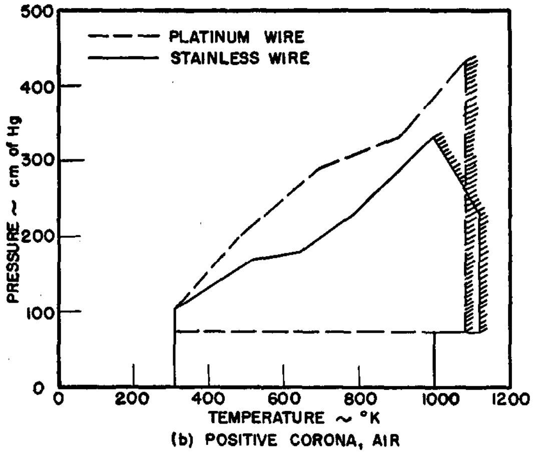
[7] F. A. Benson, *Voltage Stabilized Supplies* (Macdonald and Company, London, 1957).
[8] J. Lakey and W. Bostock, Trans. Inst. Chem. Engrs. (London) 33, 252 (1955).

inner tube was measured for a given potential difference between the wire and this collector tube. Temperature and pressure were varied in increments of approximately 150°C and 50 cm Hg, respectively. The curves shown in this report were obtained by cross plotting from the current-voltage characteristics.

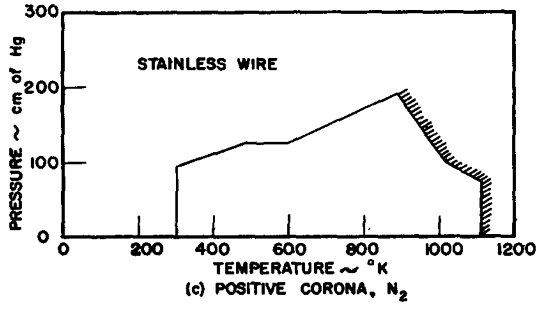
Since the maximum voltage available was 19 kv, it was not possible to obtain data at high pressures and low temperatures. The approximate temperature-pressure ranges over which reproducible data were collected are shown in Fig. 2. Qualitative observations were made at higher temperatures and pressures than indicated on Fig. 2 and are discussed later.



(a)



(b)



(c)

FIG. 2. Temperature-pressure regions over which reproducible data were obtained. Shading shows regions of instability.

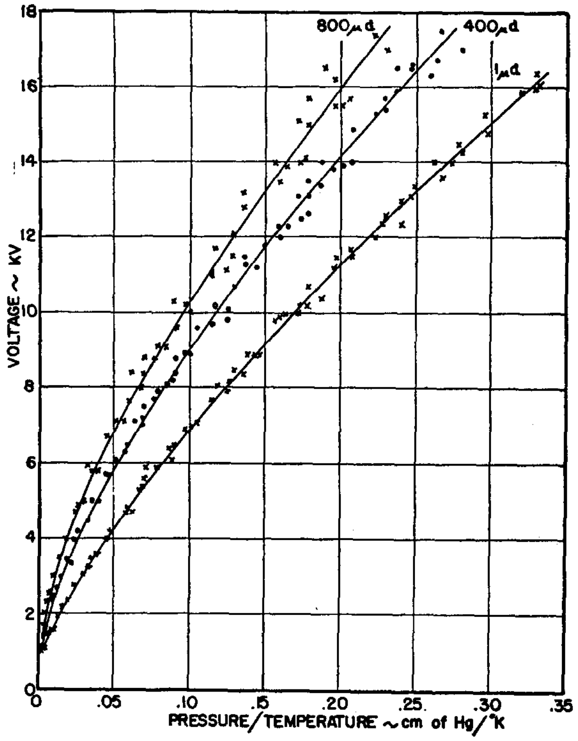


FIG. 3. Positive corona characteristics of air; stainless steel anode.

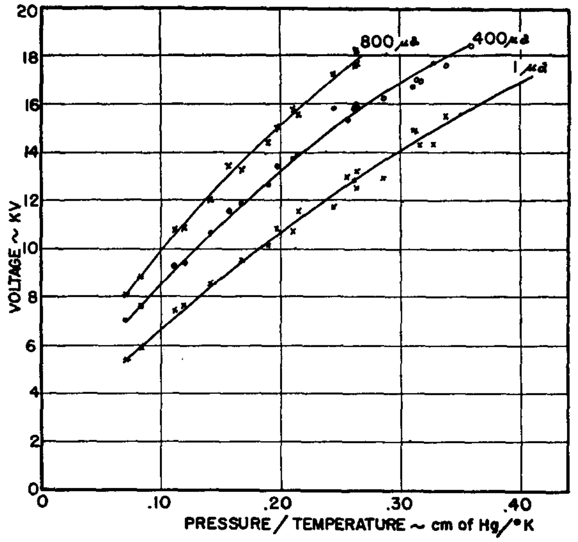
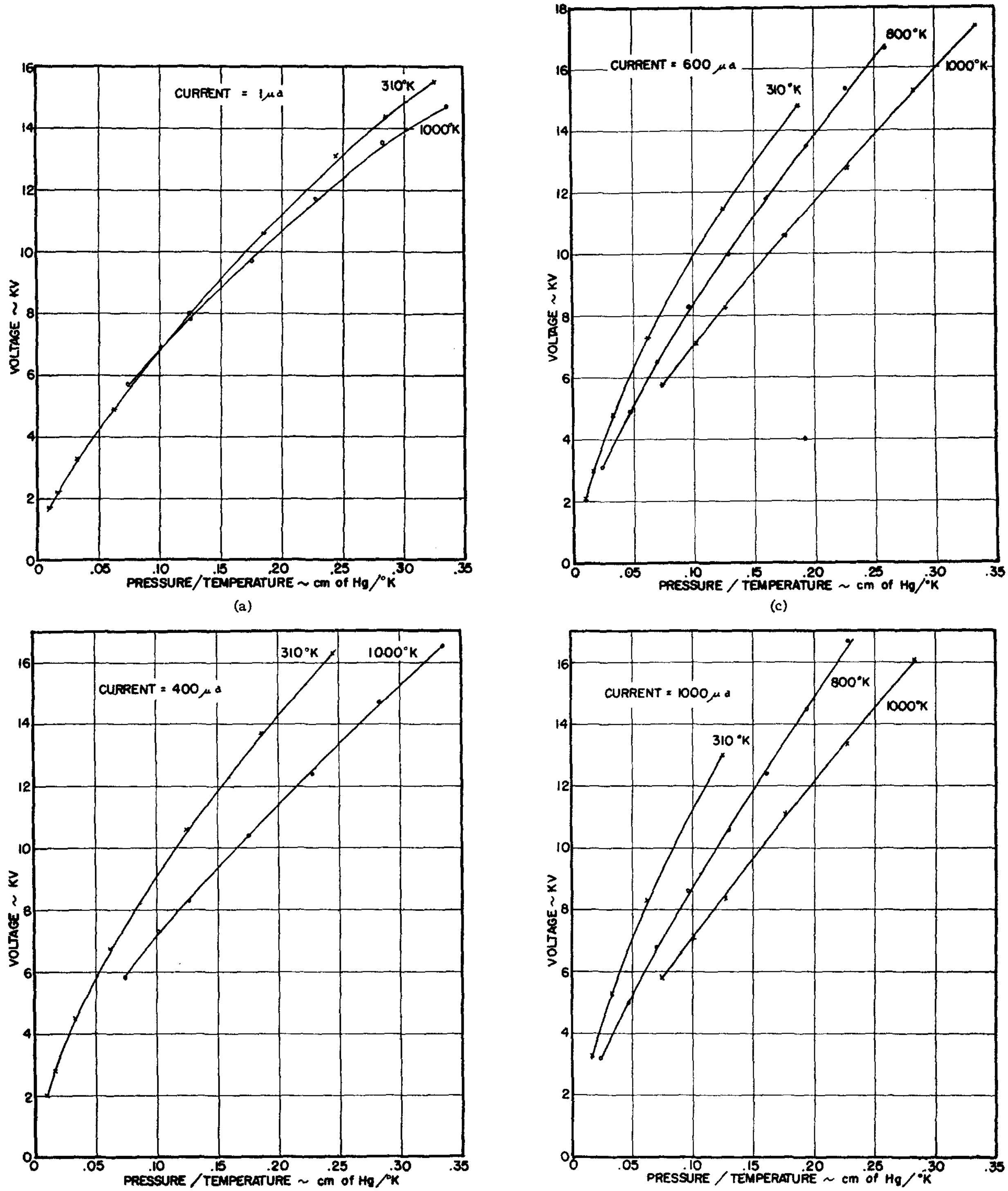


FIG. 4. Positive corona characteristics of air; platinum anode.

POSITIVE CORONA IN AIR

Figures 3 and 4 summarize the data obtained for positive corona in air for the stainless steel anode and for the platinum anode respectively. The temperature-



(a) (c)

(b) (d)

FIG. 5. Negative corona characteristics of air; stainless steel cathode.

pressure ranges over which the data for these figures were taken are shown in Fig. 2(b). The ordinate values of the curves of Fig. 3 are consistently higher than those of Fig. 4. A higher voltage was required to produce the same discharge current for the 0.0319-in. stainless steel wire as for the 0.030-in. platinum wire. The difference in voltage would be expected on the basis of the difference in wire diameters.[9]

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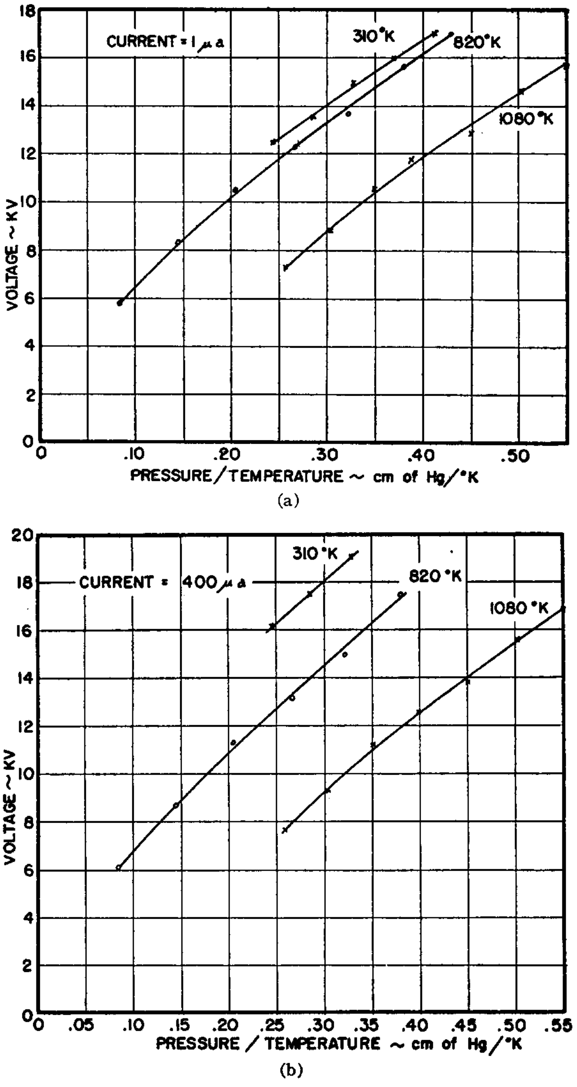
[9] F. W. Peek, *Dielectric Phenomena in High Voltage Engineering* (McGraw-Hill Book Company, Inc., New York, 1929), Chap. 4.

From a study of Figs. 3 and 4, it seems reasonable to conclude that positive corona characteristics are substantially independent of temperature and pressure individually but depend on the total mass of gas between the electrode structures. The different anode materials used had no appreciable effect on corona characteristics.

NEGATIVE CORONA IN AIR

Figures 5 and 6 summarize the data for negative corona in air for the stainless steel cathode and for the platinum cathode, respectively. The temperature- pressure ranges for these data are given in Fig. 2(a). It is apparent that negative corona characteristics for air are not dependent on gas density alone but are affected absolutely by temperature. With increasing current the effect of temperature is more pronounced. In terms of current-voltage characteristics, this means that, although the effect of temperature on starting voltage is not great for a fixed gas density, the slopes of the current-voltage curves change drastically with temperature.



(a)

(b)

FIG. 6. Negative corona characteristics of air; platinum cathode.

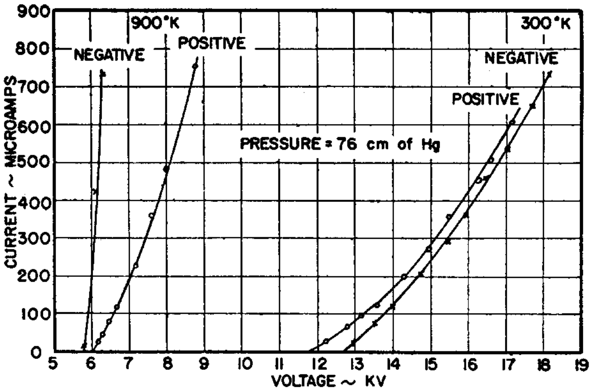


FIG. 7. Comparison of positive and negative corona characteristics of air; platinum wire.

There is some evidence that the cathode material has an effect on negative corona characteristics. Consider the 1-μa curves of Figs. 5 and 6. For the stainless steel wire cathode, essentially the same curve was obtained for all temperatures up to and including 820°K. It was necessary to go to a temperature of 1000°K before a separate curve could be distinguished clearly. On the other hand the curves separated at a lower temperature for the platinum wire cathode. However, this evidence cannot be considered too conclusive. Considerable difficulty was experienced in obtaining reproducible data with the stainless steel cathode at high temperatures. It was frequently necessary to lower the temperature and operate with high corona currents to "clean up" the wire.

COMPARISON OF POSITIVE AND NEGATIVE CORONA IN AIR

Figure 7 gives a comparison of the current-voltage curves for positive and negative corona in air at atmospheric pressure and at temperatures of 300°K and 900°K. The curves are for the 0.030-in. platinum wire. The salient feature of this comparison is the difference in slopes. At 300°K the curvatures of negative and positive curves are nearly the same. However, at 900°K, the negative curve has become extremely steep while the positive curve has not changed slope nearly so much. The starting voltages for negative and positive corona do not differ appreciably: nevertheless, at 300°K the starting voltage is higher for negative corona, while it is higher for positive corona at 900°K.

EXTENSION OF INVESTIGATION TO HIGHER TEMPERATURES AND PRESSURES

Attempts were made to extend the investigation to 1300°K and to higher pressures. Better results were obtained with platinum wire than with stainless steel wire, as is indicated by Fig. 2. However, difficulties were encountered with both wire materials. As the

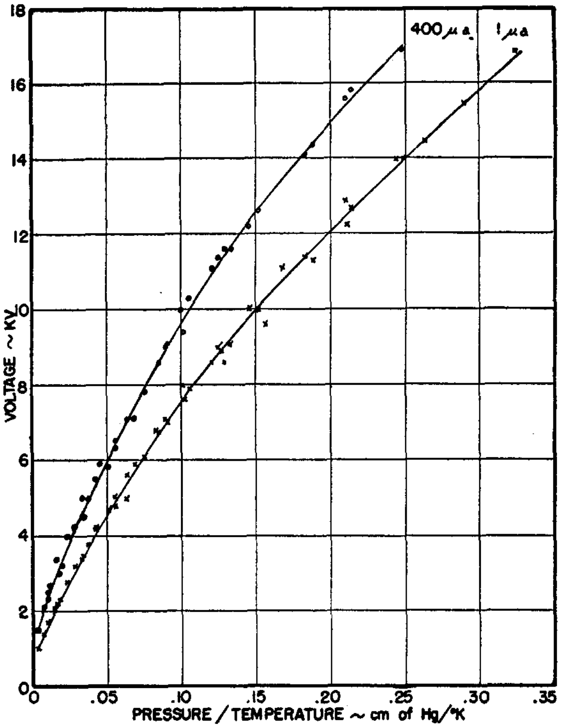


FIG. 8. Positive corona characteristics of nitrogen; stainless steel anode.

temperature was increased above 1100°K (or 1000°K in some cases), or as the pressure was increased into the instability regions shown in Fig. 2, the current-voltage curves became unreproducible and there was a more or less random occurrence of arcover along the current-voltage curve. These instabilities prevented the extension of the curves to higher temperature-pressure regions. Previous investigations[10–12] have described a somewhat similar instability for positive discharge in nitrogen. It is interesting to note that the instability regions are pressure sensitive and differ with the discharge wire material. These regions were not investigated closely enough for any conclusions to be formed as to their cause.

POSITIVE CORONA IN NITROGEN

Figure 8 summarizes the data taken for positive corona in nitrogen. Only a 0.0319-in. diameter stainless steel anode wire was used. The characteristics are similar to those of positive corona in air and are functions only of relative gas density.

At high temperatures the same instabilities as mentioned in connection with the tests on air were encountered. However, they began at lower pressures with nitrogen than with air. For example, at 990°K the maximum pressure at which stable corona could be maintained was 190 cm of Hg. At 1100°K stable operation could not be maintained above atmospheric pressure. The instability consisted of the random arcing mentioned before.

NEGATIVE CORONA IN NITROGEN

Figure 9 shows the current-voltage characteristics of negative corona in nitrogen at atmospheric pressure and at temperatures of 310°K and 840°K. There is a marked "hysteresis" effect which has been observed at low temperatures by other investigators.[4] It is interesting to note that this effect is less pronounced at high temperatures. Plots of voltage *vs* gas density were not made because of the multiple values of current for a given voltage. It should be noted that the currents are an order of magnitude higher than those obtained for positive corona in air or nitrogen and for negative corona in air.

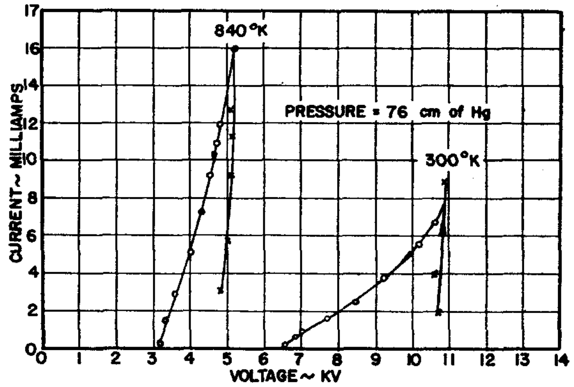


FIG. 9. Negative corona characteristics of nitrogen; stainless steel cathode.

CONCLUSION

This investigation indicates that temperature has an absolute effect on corona characteristics in air and nitrogen when the electrode geometry is asymmetrical. This effect is in addition to the dependence of gas density on temperature. For positive corona the result is an instability which is pressure and temperature sensitive. For negative corona the same instability exists and there is, in addition, a marked change in the slope of the current-voltage characteristic. The discharge electrode material appears to have little effect on positive corona characteristics, but may have an effect on negative corona characteristics.

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[12] I. Goldman, Tech. Phys. U.S.S.R. 5, 355 (1938).