ELECTRODELESS DISCHARGE: METHOD OF MEASURING INDUCED CURRENT, VARIATION OF CURRENT WITH PRESSURE FOR VARIOUS GASES

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Abstract

A special discharge tube has been designed which lends itself readily to the measurement of the *induced gaseous current in the electrodeless discharge.* This apparatus consists of a reentrant tube which describes a circle in the plane of the exciting coil and then goes out and describes a circle perpendicular to the plane of the exciting coil. Thus when a gaseous current is induced in the tube within the exciting coil it must pass through the outside turn before returning and completing the circuit. By placing a conductor of low resistance around the outside turn and connecting it to a radio-frequency ammeter, an induced current in it can be read off which is proportional to the induced gaseous current. This specially constructed tube was connected to an exhaust pump and a McLeod gauge, also to a system of connecting tubes for supplying different gases. The energy to the exciting coil was supplied by a highly damped high-frequency high-voltage source of constant strength, and pressure-current characteristics were obtained for six gases, namely, hydrogen, helium, nitrogen, oxygen, neon, and argon. Relative to these it was found that the induced gaseous current rose to the highest value in oxygen at a pressure of about 0.06 mm Hg; that the maxima in argon and neon were about the same, though for argon the maximum was sharp while for neon it was quite broad, the corresponding pressures being 0.05 and 0.2 mm Hg respectively; that helium and nitrogen were very similar to argon and neon in their behavior but rose to lesser current values with their maxima at about 0.035 mm; and that hydrogen proved to be the most critical of the gases studied, the pressure range was small (between 0.04 and 0.08 mm) and the maximum current 2.4 amperes, which latter is about one fourth that for oxygen. In none of the gases studied did the ammeter show even the slightest current except when there was a "bright glow" indicating that the intensity of the glow is qualitatively a measure of the current induced.

Introduction

The existence of two types of electrodeless discharge and their main differences in origin have been quite definitely determined.[1] The "dull glow" discharge has been shown[2,3,4,5] to be due to the strong electric field set up by the difference of potential that exists between the ends of the exciting coil. However the "ring" or "bright glow" discharge described by J. J. Thomson[6] has been shown[4,5] to be maintained electromagnetically. In this case the discharge is due, as is well known, to an alternating e.m.f. induced round the

[1] K. A. MacKinnon, Phil. Mag. **8**, 605 (1929).
[2] Townsend and Donaldson, Phil. Mag. **5**, 178 (1928).
[3] C. J. Brasefield, Phys. Rev. **35**, 1073 (1930); **37**, 82 (1931).
[4] C. T. Knipp, Phys. Rev. **37**, 756 (1931).
[5] Smith, Lynch, and Hilberry, Phys. Rev. **37**, 1091 (1931).
[6] J. J. Thomson, Phil. Mag. **32**, 321, 450 (1891); **4**, 1128 (1927).

periphery of the tube by the rapidly changing magnetic field within the coil. The shield experiments of Smith, Lynch, and Hilberry have shown the dependence of the starting of the "bright glow" on the "dull glow" or some ionizing agent. Thomson considered only the "ring" discharge; while Townsend and Donaldson, and Brasefield worked only with the "dull glow" discharge. MacKinnon, Knipp, and Smith, Lynch, and Hilberry have worked with both phenomena.

In this paper we are considering the current induced in the "ring" or "bright glow" discharge. The experiment of Thomson with two bulbs, one inside the other, in which the discharge in the outer bulb shields the inner gas from the inductive effect of the exciting coil, indicates that the gaseous current rises to a high value comparable with the current in the exciting coil. Again, the fact that the current in the exciting coil drops off considerably when the "ring" discharge gets fully under way, conditioned by the pressure

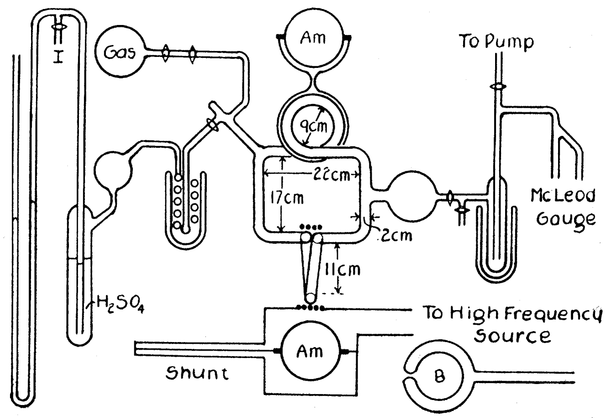


Fig. 1. Sketch of special reentrant electrodeless discharge tube with connections. The approximate dimensions are given. The planes of the two glass circles are at right angles to each other, thus the inductive effect of the energizing coil of four turns on the upper ammeter circuit is eliminated.

in the tube, shows also that the induced gaseous current rises to a high value, i.e., that a strong opposing e.m.f. is induced in the gas in the tube.

Apparatus and Procedure

A diagram of the complete set-up is shown in Fig. 1, and a photograph of the tube used, with the electrodeless discharge passing through it, is shown in Fig. 2. The discharge tube consists of a reentrant tube 2 cm in diameter which describes a discontinuous circle just inside the exciting coil (their planes being parallel to each other and perpendicular to the paper) and then leaves the coil and describes one turn in plane perpendicular to that of the exciting coil (i.e., in the plane of the paper). The total length of the discharge tube is about 155 cm. A heavy copper braid makes one turn round the upper circle of the glass tube and is connected to a Weston radio-frequency ammeter. The discharge tube is shown connected to a 500 cc expansion bulb and on through a liquid-air trap to a McLeod gauge and a mercury vapor pump. Gases are let in from the other side. Small gas samples in bulbs were connected as shown, while gases in tanks under pressure were let in through the intake *I* and allowed to bubble through sulphuric acid and a liquid-air trap before entering the discharge system.

As an energy source a motor-generator high-voltage high-frequency set was used, operating at a frequency of about 600 kc. The oscillations were highly damped. The energizing coil used was of 4 turns of copper tubing. Another ammeter is shown connected in a non-inductive shunt for determining the heavy current passing through the energizing coil. Currents as high as

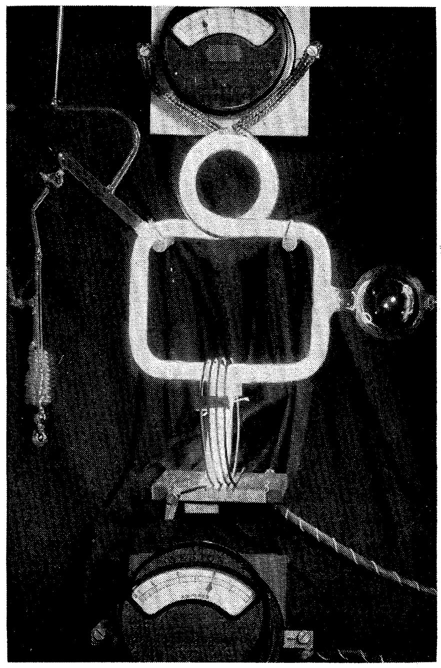


Fig. 2. Photograph of the reentrant electrodeless discharge completely formed by using an energizing coil of four turns. Residual air, pressure about 0.2 mm Hg. Illumination very intense. Time of exposure 6 seconds, followed by a photo-flash to get the apparatus. The energizing current through shunted ammeter shows 8 amperes, while the upper ammeter shows the induced current, due to the gaseous current acting as primary, as 2.6 amperes. The discharge does not enter the expansion chamber.

60 amperes were used. The photograph, Fig. 2, shows the actual deflection of each of the two ammeters as the discharge was passing.

The general procedure with each gas was to pump the system out to a very high vacuum and then wash it out successively with doses of the gas to be studied. After we were sure of the purity of the gas the system was pumped until a stage was reached at which the discharge would just begin (intermittently) to pass, whereupon the pump was shut off. Equilibrium in pressure throughout the system was soon reached after which the coil was again energized and allowed to continue until the two ammeter readings became steady. The pressure was read before and after the current reading. The system was then exhausted to a new pressure and the readings repeated. As the induced gaseous current increased (as indicated by the ammeter at the top) the current in the energizing coil was observed to decrease, but the frequency remained constant, therefore it was necessary to correct each reading to correspond to a constant energizing current. Following this procedure data for a number of curves were taken for each gas until we were able to reproduce the curves within the errors of observation.

The coupling factor of the upper turn of the discharge tube with the copper braid was investigated by substituting a similar tube filled with about 40 small insulated copper wires with their ends soldered together. It was thought that the wires thus placed would approach the distribution of the gaseous current through the tube. On sending known currents through this improvised primary the coupling ratio, which proved to be strictly linear, was

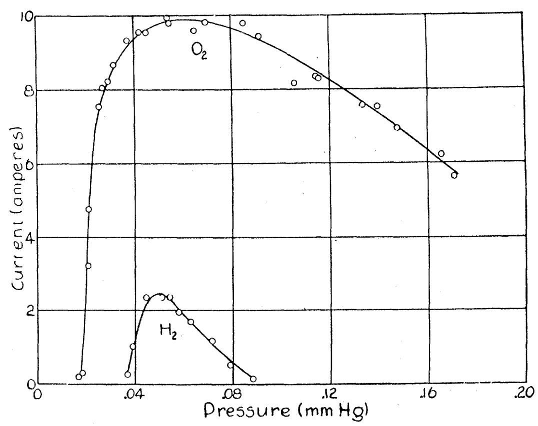


Fig. 3. Currents in the electrodeless discharge in oxygen and hydrogen as a function of the pressure. Exciting current 57 amperes.

found to be 2.84. The resistance of the secondary circuit including the ammeter was 0.033 ohm.

Experimental Results, Pressure-Current Curves

The curves shown are all corrected to a constant exciting current of 57 amperes. The ordinates are the values of the actual gaseous current flowing, obtained by the formula

$$I_p = 2.84 \times I_s.$$

Fig. 3 shows the pressure-current curves that were obtained for hydrogen and oxygen. Hydrogen was found to have the narrowest interval of excitation of any of the gases studied, and the maximum current for this gas was also found to be much smaller than that for any of the other gases, however this maximum was sharply defined. On the other hand the maximum current for oxygen was the largest that we observed for any of the gases. It was broad and its value nearly four times the maximum for hydrogen. Strange enough these two maxima occurred at nearly the same pressure. The oxygen curve that was obtained was unique in that at the high pressure end it started off very suddenly at a pressure of about 0.172 mm Hg and with an initial current of nearly 6 amperes. At slightly greater pressures the luminous discharge suddently ceased, the current having dropped to zero.

In general the two points at which any of the curves meet the pressure axis are points at which 57 amperes was the starting current for the "bright glow" for the given gas in this particular tube. It is proposed to use this apparatus for the study of the variation of the induced current with exciting current at constant pressure, to see whether the induced current reaches a saturation value as in the analogous case of the ordinary discharge tube with electrodes.

In Fig. 4 are shown the curves for argon and neon. Both rise to about the same current maxima which is about two amperes less than that for oxygen,

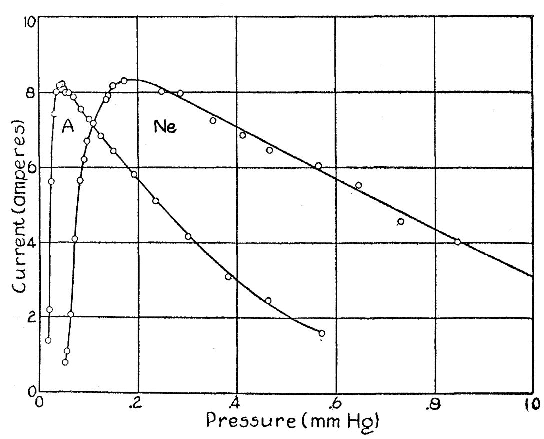


Fig. 4. Currents in the electrodeless discharge in argon and neon as a function of pressure. Exciting current 57 amperes.

however the pressure range is much greater for these two gases, that of neon being particularly large. Note that the maxima come at widely different pressures. To make the comparison with the other gases easier the maxima of these two gases are drawn to the same scale in Fig. 5. The current for neon dropped off to low values long before any of the other gases reached their maxima.

The curves obtained for nitrogen and helium are shown in Fig. 6. They are very similar to each other and in pressure range are similar to hydrogen though their current maxima are each about 2.5 times greater.

Table I gives the value of the maximum current for each gas, the pressure at the maximum, and the approximate pressure range of the "bright glow" discharge. The values tabulated are only useful as a means of comparing the gases since the actual currents and pressures depend on the size and shape of the tube, and on the nature of the source.

Additional interesting points are: Thomson early showed that the dis-

TABLE I. *Maximum current, gas pressure at maximum and pressure range in the electrodeless glow discharge in various gases. Exciting current 57 amp.*

Gas	Maximum current	Corresponding pressure	Pressure range of "bright glow"
Oxygen	9.9 amp.	0.060 mm Hg	0.020–0.172
Hydrogen	2.4	0.052	0.036–0.090
Argon	8.3	0.042	0.020–0.60
Neon	8.4	0.190	0.040–1.00
Nitrogen	5.54	0.032	0.018–0.090
Helium	5.8	0.033	0.017–0.10

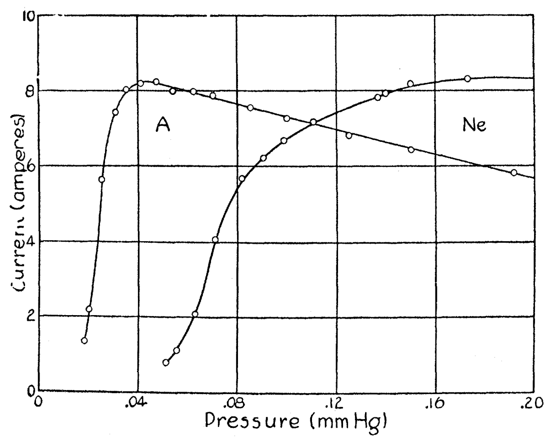


Fig. 5. Same as Fig. 4 except plotted to the same pressure scale as in Fig. 3.

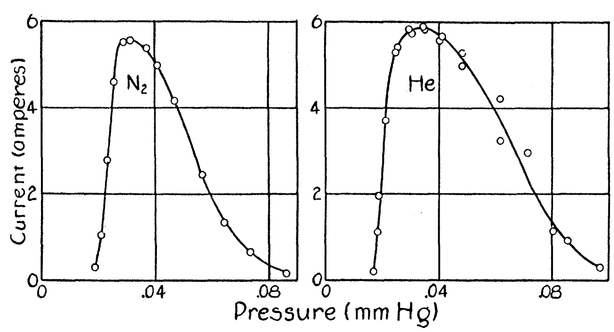


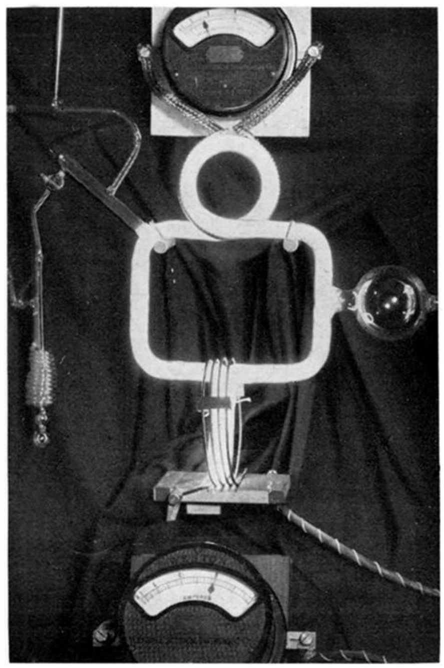
Fig. 6. Currents in the electrodeless discharge in nitrogen and helium as a function of pressure. Exciting current 57 amperes.

charge would pass only when the tube formed a closed path, i.e., when it was reentrant. This observation was confirmed by the use of a non-reentrant tube *B*, Fig. 1. When this tube and the long sinuous one were connected to the system so that each had the same pressure it was observed that a brilliant discharge passed through the reentrant one, but not, in turn, through *B*. The conditions for no current in the former may be approached by increasing its gas and inductive resistance, i.e., increasing its length. Thus the ease with which the induced gaseous current passes is inversely proportional to the length of the reentrant tube, and directly as the cross-sectional area. Hence reentrant tubes of this design should be of short length.

The character of the discharge as the exhaustion proceeded presented an interesting sequence. It began gradually by a succession of flashes that went all the way round the discharge tube. These became more frequent and more luminous as the pressure decreased, finally filling the entire circuit with a brilliant glow. As the exhaustion proceeded the brilliancy reached a maximum and began to fall off, slowly at first, then rapidly dropped to an occasional flash confined to the lower turn of the tube, in sharp contrast to the flashes that went all the way round at the beginning. It should also be mentioned that at no time was there any indication of a current in the upper ammeter except when a luminous discharge was observed. This indicates quite clearly, as was expected, that no current passed when the "dull glow" alone was observed in the tube.

Again, the discharge, even at its greatest brilliancy did not overflow into the expansion chamber or into the gas supply branch as may be seen by inspecting Fig. 2. Also at no time in the process of exhaustion, even in the case of nitrogen, was there any marked indication of an after-glow, which in itself is an indication of the purity of the gases studied. When the maximum induced gaseous current was allowed to pass for 4 to 8 seconds the reentrant tube warmed up quite preceptably throughout its length. When the upper ammeter was replaced by a 3 cm length of No. 30 nichrome wire it could readily be fused by the inductive effect of the gaseous current.

The oscillatory electrons do not show centrifugal tendencies at sharp bends and corners. A neon bulb previously sealed off at its most sensitive pressure will light up if inserted in the upper gaseous circle.



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