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TABLE OF CONTENTS

NOTES ON THE ELECTRICAL BEHAVIOR OF PORCELAIN AND GLASS AT MODERATELY HIGH TEMPERATURES.

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(Paper read at the Oberlin meeting of the Ohio Academy, Nov., 1913.)

The experiments described were carried on by the author during the fall and winter of 1912-1913.

They were suggested by an earlier experiment performed several years ago on the conduction of electricity through gases at high temperatures. During these earlier experiments certain gases were contained in glazed porcelain vessels and subjected to temperatures of 500° and 600° C. It was noted at that time incidentally that when the porcelain was subject to a high e. m. f., a current of some magnitude traversed the porcelain and that while the e. m. f. was steady the current through the porcelain steadily decreased with time.

Soon after this I suggested an experiment to Mr. Henderson, a student in Ceramics in the Ohio State University, and Mr. Geo. Weimar of the Electrical Engineering Department, which they undertook as a joint thesis. Their experiment consisted in applying a potential difference to porcelain bodies which were varied in temperature and determined the dielectric strength of the porcelain at different temperatures. They made a large number of such bodies, of different composition and of a form adapted for use in an electrically heated furnace. They measured the potentials required to break down such insulators.

In general when such a body breaks down under electric stress a mechanical puncture results and the body ceases to become an effective insulator when again subject to high potentials. Messrs. Henderson and Weimar found that when a temperature of 300° C. was reached, they had difficulty in building up a potential to a value where a definite and sharp break indicated a puncture of the dielectric. Instead of obtaining such a definite value a rather indefinite one was obtained in which a phenomenon somewhat similar to break down occurred. They discovered also that when these insulators were cooled to room temperatures that their insulating properties had not been impaired in the slightest. This indicated that instead of producing a mechanical break down of the material such as was attained at lower temperatures, the failure to insulate was due to a change in conductivity of the bodies.

Soon after this, experiments were reported by A. A. Sommerville of Cornell University and W. W. Stifler of the University of Illinois* on the resistance of similar bodies at high temperatures. The methods employed were the usual Wheatstone bridge methods for determining resistance in which a small e. m. f. was used.

Fleming, in his discussion of cable insulation, points out that such a method is open to serious objection on account of the polarization of the dielectric.

The effect of applying an e. m. f. develops a back e. m. f. and the condition for establishing a bridge balance becomes a function of the true resistance of the arm containing the specimen and the e. m. f. of polarization as well. The whole question of the resistance of such bodies is an open one. The transmission of current through such bodies has been regarded at

* Physical Review, April, 1911, p. 429.

times as similar to metallic conduction, at other times as electrolytic in character. It is possible that these ceramic bodies function in both manners.

The author undertook these experiments without expectation of answering this question, but to obtain some experimental data on the magnitude of the currents obtained by Henderson and Weimar in their experiments, also to find if possible whether one could give a true ohmic value to the resistance offered by the porcelain bodies at temperatures where they became very appreciable conductors. Henderson and Weimar had used periodic e. m. f's. from a 60 cycle source. The general plan here adopted was to employ the high potential storage battery in our laboratory for maintaining constant and fairly high potentials (up to 1,000 volts) and apply the potentials directly to the specimen at the same time measuring the current. Then from Ohm's Law we could infer the resistance

$$V_1 - V_2 = RI.$$

$V_1 - V_2$ = potential difference in volts.

I = current in amperes.

R = resistance in ohms.

Figure 1 shows the very simple arrangement of the circuits. The battery has one terminal earthed. The other terminal was connected to the specimen (S) through a high resistance (R). A Weston volt meter (V) with a multiplier (M) measured the potential difference between the upper face of the specimen and the earth. The regulating resistance (R) made it possible to maintain a constant potential if desired. The regulating resistance was a liquid contained in a tube 80 cm. long, 2 cm. in diameter.

The liquid is a solution 25% saturated of Cadmium Iodide in Amyl alcohol. The terminals are Cadmium. This gives a high resistance quite free from polarization and capable of carrying currents of 50 milliamperes.

The ammeter (A) introduced between the specimen and earth measured the current passing through the specimen only. This consisted of a resistance with a D'Arsonval galvanometer in shunt. Knowing the resistance of shunt and galvanometer one can calculate the fall in potential through the specimen for any values given by the voltmeter. Through the courtesy of the Ceramics Department, samples of porcelain were secured

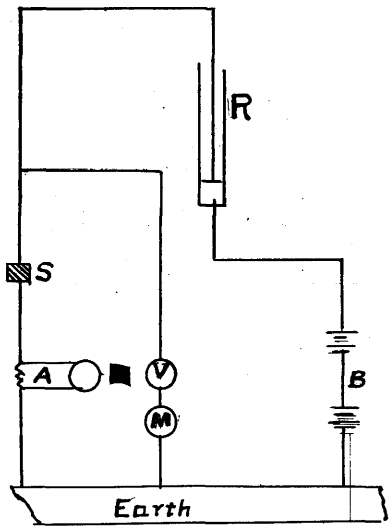


Fig. 1.

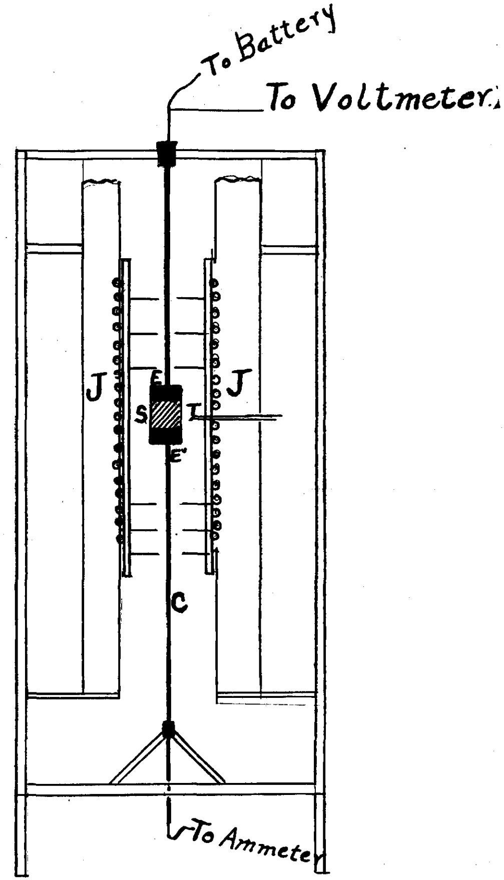


Fig. 2.

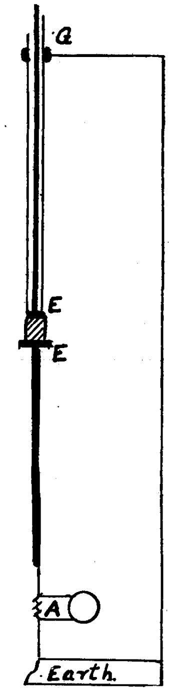


Fig. 3.

of the same kind as those used by Henderson and Weimar. These were moulded in the form of cylinders 2 cm. in diameter and 2 cm. in length. The ends were ground plane. The method of mounting and operating upon them is shown in Figure 2.

The furnace proper consisted of two porous battery jars with bottoms removed, placed end to end. Over this resistance wire was wound. This was covered with asbestos paste and baked on. The furnace was then placed in a section of asbestos steam pipe jacket. A thermo couple (T) projected into the chamber of the furnace. It was a Pt Rh-Pt couple which had been calibrated for other work.

A thick rod of copper (C) projected from below into the heating chamber. This rod had a copper cylinder (E) screwed to the top. The upper surface of the cylinder was covered with Platinum which was securely fastened to the copper cylinder both mechanically and electrically. This Pt surface served as an electrode which pressed against one face of the porcelain cylinder. Platinum was used because it would not oxidize at the temperatures attained. Above the specimen (S) a rod similarly terminated rested on the upper face of the cylinder. This rod had freedom of motion through guides. Changes in length due to expansion were provided for in this manner; it also insured that the specimen would be subjected to a constant pressure during the experiment. A series of mica vanes placed at intervals about the rod served to reduce heat losses due to convection.

Such a furnace can be regulated by hand, within reasonable limits. The large heat capacity and low conductivity of the materials entering into the construction serve to iron out small fluctuations of current strength. It was found that a steady temperature of 500° C. could be obtained five or six hours after turning on the current and that this could be maintained constant plus or minus 3° for a period of several hours. With such a device when a potential difference is applied, current flows through the ammeter. The specimen is so mounted that the stream lines of flow, such as we ordinarily consider, are perpendicular to the electrodes and parallel to the axis of the cylindrical specimen. The current we wish to measure is of this character. We will call this the Number One type. There are two other possibilities. Number two, a possible creepage or leakage from one terminal to another over the surface of the porcelain.

Number three, a current passing through the hot gases surrounding the body.

The third type is present if we raise the temperature to a point where the interior begins to glow and apply a sufficiently high potential. When an appreciable current passes through the gas it becomes luminous and is readily observed. It is characterized by appearing suddenly when a critical potential is attained and is large compared with the Number One type of current. The effect can be avoided only by operating over potentials which should be kept below 350 volts. This places a decided limitation in the form of apparatus shown in Figure 2.

Anticipating the results slightly it may be said that leaving out of account the gas discharge, the current passing through the ammeter and through the porcelain appeared to be separable into two parts, one which decreases rapidly with time and one which if it changes at all changes at a much lower rate. It was thought that this might be due to some alteration in surface condition and this was borne in mind while making the tests in porcelain. It did not seem feasible to alter the form of apparatus to prevent the possible surface leakage in the case of porcelain. It may be remarked also that while the values of current strength differed somewhat from different cylinders, all results were of the same general character.

The next step in the experiment was to make a glass cylinder of the same form as the porcelain cylinders previously described. Only one such cylinder was used and while it showed appreciable conduction at lower temperatures than did the porcelain, the general characteristics of current-time were the same, namely, a large initial current which decreased with time.

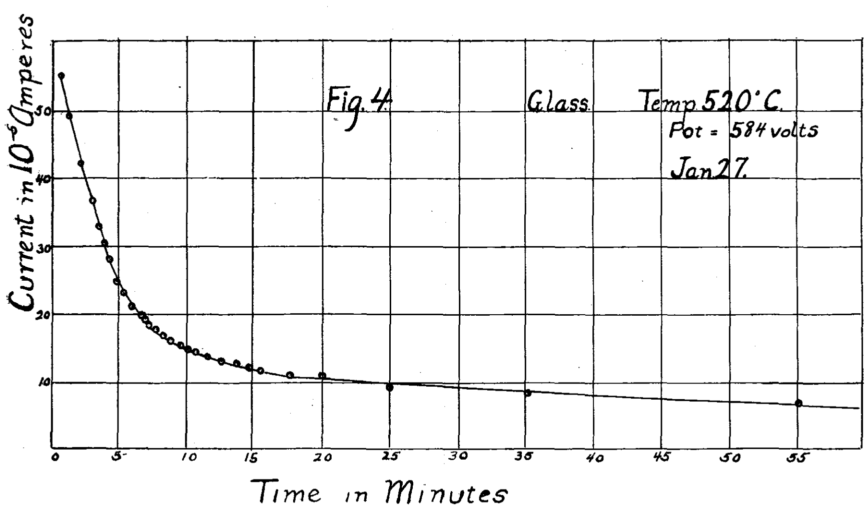
Next a glass cylinder of the form shown in Figure 3 was used. This was designed to eliminate both the possibility of gas conduction and leakage over the surface. The glass cylinder was continued at the upper edge by a glass tube which extended nearly the entire length of the copper rod. A guard ring shown in the figure (R) was wound around this tube and earthed. The rod inside the tube rested on the glass cylinder as before and was terminated with platinum. In this case if creepage over the surface occurred the leakage current would be diverted to earth and the ammeter would register only the current passing through the cylinder specimen, i. e., the Number One type. It was not convenient to make this cylinder of the same dimensions as the one previously used, but the characteristics of the current time curve were the same as in the previous cases. This would indicate that the characteristic curves of all were of the same kind and were due to the volume conduction of the specimens rather than leakage over the surface.

Discussion of Results.

A few preliminary trials indicated that it was not possible to fix the resistance of the porcelain or glass bodies by the simple application of the formula suggested earlier in this paper. The current strength was found to be a function of the material, dimensions, temperature and potential applied, also it depended upon the length of time of application of the e. m. f. The apparent resistance could have wide variations in value which seemed to be limited only by the time of application of the e. m. f. We are accustomed to think of the resistance of a conductor as having a definite and fixed value determined by the dimensions and temperature of the conductor. Our legal definition of the ohm is of this kind. In such a sense these ceramic bodies at temperatures where they become appreciably conducting have no definite resistance.

The usual method of study was to obtain a predetermined temperature and maintain it at a constant value through a single experiment. A potential was applied which was left constant and the current noted at time intervals. Figure 4 shows a typical curve. This was made on glass, with the guard ring arrangement, hence current values are for those which must pass through the glass.

The current decreases initially very rapidly with time and then at a much diminished rate. The units shown as ordinates are 10^{-5} amperes and on this scale the values may be shown over a long period. The first value shown in Figure 4 is one taken one minute after the potential was first applied. The earlier values are much larger and cannot be shown on this scale. The general procedure was to take current readings every 15 seconds during the early stage for say five minutes, then at minute intervals and finally at much greater intervals. When a new specimen is taken the initial currents are of the order of several milliamperes for a few seconds. Such measurements were made but it is difficult to obtain accurate current measurements where the values diminish so rapidly. The difficulty which Henderson and Weimar experienced in obtaining definite break down readings are, I think, a little better understood from the nature of these curves. In using a 60 cycle current a potential which increased from zero value to maximum value in 1-240 of a second was applied; this decreased

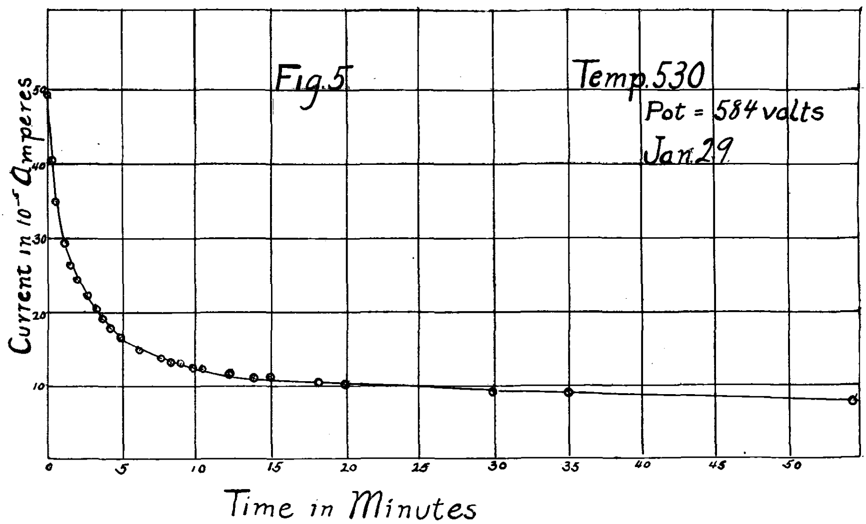


to zero and was then reversed in direction. In such intervals of time only a feeble back e. m. f. is developed and the current no doubt has a large value. Their difficulty in building up a definite potential was due to the fall in potential which occurs when a current passes. The continued decrease in current as time progresses is due undoubtedly to a back e. m. f. which may attain any value short of the applied e. m. f.

Persistence of the back e. m. f.—A considerable part of the experimental work in this connection was done in studying the ability of these bodies to retain an e. m. f. set up in them.

It was found for example that after the curve had been followed out to the flat portion, that the e. m. f. might be removed for a short time (say two minutes) and the curve taken up on reapplication of the e. m. f. without any discrepancy. If a half hour elapsed the first values would be somewhat larger than when the e. m. f. was withdrawn.

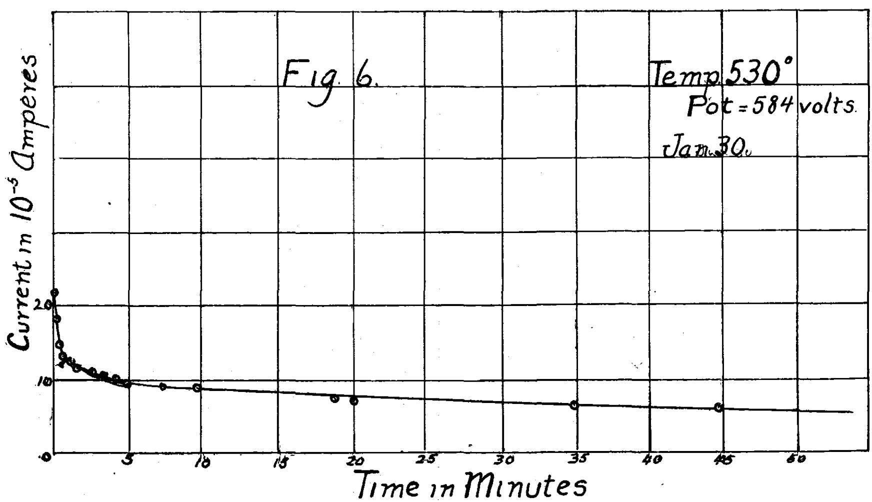
In some cases after application for a half hour in one direction the battery was reversed. The effect of this was to have the impressed e. m. f. of the batteries acting in the same direction as the previously generated back e. m. f. The time current curve showed this boosting effect, the initial values of the current were larger and the time taken for the curve to attain the flat portion was much longer.



This boosting effect was apparent even when the specimen was cooled to room temperature and reheated. The reversal was effected in two ways: First, by reversing the battery; Second, by taking the specimen out after cooling and turning it end for end. This latter process had the effect of reversing the specimen only leaving the terminals unaltered. The effect was the same and the effect of previous polarization was unmistakable.

Figures 5 and 6 are companion curves for Figure 4 and are introduced for the purpose of showing the retention of the polarized state. Figure 4 is the first run made in a glass cylinder which, so far as I had means of knowing, had never been treated electrically.

The first reading shown was taken one minute after the potential was applied. This was permitted to cool to room temperature and remain in that condition without the application of a potential for two days. The specimen was reheated to approximately the same temperature as before and the same potential applied. Figure 5 shows the result on the same scale. The first reading shown is smaller than the first one in Figure 4 and was taken 15 seconds after the potential was applied. The potential indicated was left on for four hours and the specimen then allowed to cool. It was reheated after 20 hours and the curve in Figure 6 obtained.



This and many similar experiments show that the resistance of bodies of this character cannot be determined in a satisfactory way by direct current measurements. The behavior of the body is determined in part by its previous history. In this respect it is analogous to the behavior of magnetic bodies. It would be of interest to put these bodies through a cycle such as is done in the study of magnetic hysteresis. In fact a possible way of throwing more light on the interesting and difficult subject of dielectric hysteresis might be carried out in this manner. The author had in mind attempting such a series of experiments, but the close temperature regulation required and the length of consecutive time required to take a series of observations did not appear feasible for one carrying a teaching schedule.

Physical Laboratory, Ohio State University, December, 1915.