

## STUDY OF RESISTANCE OF CARBON CONTACTS.

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WHILE engaged in some experimental work with telephone transmitters, it was found that the resistance of carbon contacts varied to a remarkable extent, not only with pressure and current, but also with the time and in a very regular manner.

The first two effects have been known for a long time, but the regular variation with time after eliminating the effect of change due to a rise of temperature, seems to have escaped notice—at least I have been unable to find any account of such work. To be sure it has been well known for a long time in telephone practice that oxidation and breaking down of contacts occur, but no attempts to show any regularity in such phenomena have been discovered.

The effects of pressure on contact resistance of carbon was investigated very thoroughly by Bidwell who also<sup>1</sup> investigated the effects of current strength on contact resistance. He found that the passage of a current through the contact caused the permanent change in resistance, sometimes decreasing it and sometimes increasing it, depending on the value of the current. In this connection, he found that if the current does not exceed a certain value, the resistance is decreased and more as the current is larger, provided the current does not rise above this value. On the other hand, if the current exceeds a certain value there is a permanent increase in the resistance.

At the time of the investigation described below, the writer did not have access to Bidwell's paper, consequently much of that work was repeated, but the regularity of the phenomena just described seems to be new and worth notice and such matters as are not mentioned in other researches are described below.

This paper is an account of an investigation of the time relations of changes in resistance in carbon contacts such as are commonly used in telephone transmitters. Experiments were made on carbon in the form of grains, balls and plates, always with the same results.

It will be convenient to divide carbon contacts into two classes, loose and tight. By a loose contact its mean one where the particles are held so that the contact is made under very slight pressure. In this case there

<sup>1</sup> Shelford Bidwell, "Elec. Res. of Carbon Contacts," Proc. Roy. Soc., XXXV., 1, 1883.

is no change of resistance due to expansion, which usually causes increased pressure, but the contact may break down, as will be seen below. By tight contact is meant one where the particles are held with sufficient firmness to maintain electrical contact even with large currents. In the first case, that is, loose contact, there are noticeable permanent changes in resistance. In the latter, tight contact, these changes are very slight. Microphonic action is not impossible in the case of tight contact. Indeed, the microphone is usually an example of tight contact in the sense explained above.

Loose contact was studied first by attaching a small carbon ball or a small grain of carbon to a thin phosphor bronze wire with a bit of a liquid cement, containing graphite and known as "clamp paste." This hardens in a few hours, is very strong and conducts well enough. In other experiments, the carbon balls and fragments were partially coated with copper electrolytically and then soldered to the phosphor bronze wire. Any other small wire possessing considerable elasticity would do equally well, but the phosphor bronze wire was at hand and served very nicely. The method of attaching the wire to the fragment seems to have no effect on the result. The wire was about 5 cm. long and was held by its end in a clamp so that the bit of carbon could be moved to touch another rigidly held piece of carbon. The circuit is shown in Fig. 1.

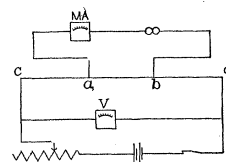


Fig. 1.

A 4-volt storage battery is arranged to send its current through a potentiometer wire, *cd*, and an adjustable resistance *R* in series. A sensitive voltmeter is applied at the ends of the wire, *cd*. The variable contacts *a* and *b* lead the current through a milliammeter and the experimental carbon contact in series. The milliammeter should be as near dead beat as possible. By moving *a* and *b* any required voltage may be applied and the current observed. It was found that when a small current is sent through the contact that there is a very regular decrease in resistance which if the contact is undisturbed seems to be permanent. The slightest jar, even that made by a wagon passing in the street outside, is sufficient to change the contact in such a way that the phenomenon repeats. Bidwell noticed that the resistance of such a contact is decreased by the current, but did not notice the regularity of the effect. Fig. 2 shows the manner in which the resistance changes. Here carbon balls  $\frac{1}{4}$ " in diameter were used. The time was measured by a metronome beating 40 beats to the minute. If a stronger current is used, the decrease is more noticeable, and if a strong current is followed by a weak

one, the weak one has no effect on the resistance. It is not absolutely certain that there is no recovery from this change of resistance, but

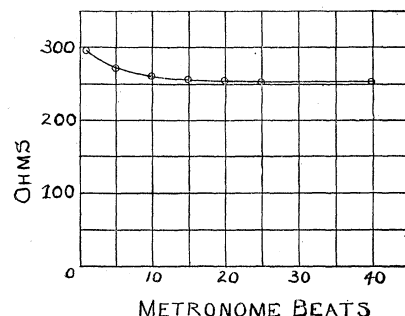


Fig. 2.

there is no experimental evidence to show that such a recovery occurs. Since there was no room available which could be made sound and jar proof, this point has not been carefully investigated. The sensitiveness of a loose contact to change in pressure is most extraordinary. When standing near the table on which the apparatus was placed, it was found that shifting the weight from one foot to the

other distorted the floor and table enough to change the pressure sufficiently to show a decided effect in the milammeter.

Table I. shows the result of several successive runs, beginning with a low E.M.F. and increasing to a value below the critical point. It will be seen that after the first run the resistance changes very little.

TABLE I.

E.M.F. in Volts.	I.	II.	III.	IV.
.4	445	308	296	296
.6	383	289	287	277
.8	254	222	236	236

If, as Bidwell points out, the E.M.F. passes a certain critical value, the phenomenon changes. There the resistance increases with the time and with remarkable regularity. As Bidwell noticed, the critical value depends somewhat on the pressure at contact. It also depends on contact area, so that the critical value probably depends on current density rather than on E.M.F. The higher the applied E.M.F., or better the higher the current density, the more rapid is the rise in resistance. Fig. 3 shows the phenomenon for two balls in loose contact when the applied E.M.F. is 1.6 volts.

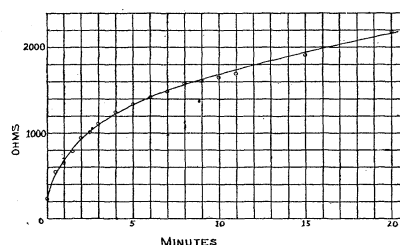


Fig. 3.

As will be seen, the resistance increases rapidly at first, then more slowly

and after about two minutes has increased to five-fold the original value. There is no evidence of recovery in this case. If the current be interrupted at any time and the circuit be left open for an hour or two and then closed, the resistance begins with the same value as when the current was interrupted and the curve is absolutely continuous, unless the contact has been jarred. With large E.M.F.'s but still so small that no visible arc forms, the resistance rises rapidly to infinity.

With smaller E.M.F.'s the change is very slow. If the initial value of the E.M.F. is near the critical value, it may happen that when the current is turned on the resistance falls for a moment, then rises. Apparently the fall in resistance gives rise to a current density in excess of the critical value and the second case is exhibited. Occasionally the resistance falls very quickly to a very low value and the contact then shows signs of cohesion, requiring a slight but unmistakable pull to separate the particles. Of course the contact is no longer loose. On the other hand, when the phenomenon of increase of resistance is observed and the particles are observed under a high power microscope, traces of a feathery adhering substance are sometimes seen, suggesting ash. This is not always visible and where seen may be small fragments abraded by rubbing, but the existence of ash is suggested.

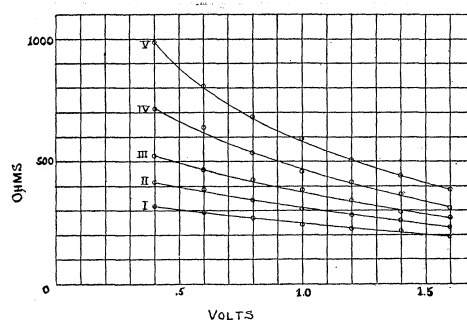


Fig. 4.

Table II. and Fig. 4 show the effect of successive passage of the E.M.F. beyond the critical value. Each such passage gives rise to an increase of resistance. In this experiment, the circuit was closed for as brief a period as possible. The longer the circuit is closed on the high value of the E.M.F. the higher the next curve of the family will rise.

TABLE II.

E.M.F.	I.	II.	III.	IV.	V.
.4	313	413	523	712	988
.6	290	382	462	635	808
.8	267	342	425	533	684
1.0	243	307	380	463	592
1.2	223	282	340	411	504
1.4	212	258	294	362	445
1.6	186	229	274	309	385

The phenomena observed are totally different when the pressure becomes great enough to break through the nonconducting layer, whatever it is. For example, a ball was held against a vertical disk of carbon with pressure produced by the elasticity of the phosphor bronze wire and

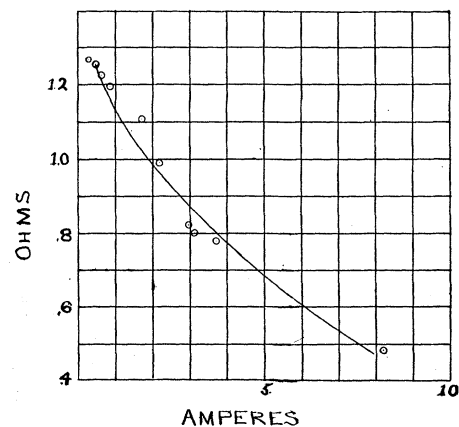


Fig. 5.

the phenomena of loose contact were observed. It was then placed on the same disk held horizontally, the pressure now being caused by the weight of the ball and the contact was tight. When the contact is tight there is no breakdown, even when the current is large enough to cause a bright arc. In another experiment, two thick carbon disks were placed near together in the same vertical plane and a small fragment of carbon dropped between them. Such a contact

may be loose or tight, behaving very erratically.

Fig. 5 shows the change in resistance due to different currents in the case of tight contact. In this experiment, a small ball was held against a carbon disk with moderate pressure. As will be seen from the readings in Table III., it is doubtful whether there is a decided change in resistance with time. The first column shows time in half minutes. The other columns show the resistances at these times for the applied electromotive forces given at the top of the columns.

TABLE III.

Time.	.06 Volt.	.21 Volt.	.4 Volt.	.56 Volt.	.72 Volt.	.83 Volt.	1.09 Volts.	1.60 Volts.	1.9 Volts.
0	4	3	2.9	3.4	3.2	2.82	2.66	1.54	1.29
½	4.8	3	2.9	3.38	3.18	2.77	2.68	1.55	1.23
1	4.4	3	3.2	3.3	3.25	2.99	2.6	1.54	1.23
1½	4.2	3	3.3	3.28	3.25	2.88	2.6	1.50	1.25
2	4.4	3	3.28	3.33	3.22	3.03	2.55		
2½			3.27	3.34	3.22	2.92			
3			3.26	3.34					

In some cases of tight contact, *e. g.*, a small ball against a disk under slight pressure, it has been found that the resistance decreases with time, but if the current be interrupted by opening the switch for a few minutes and closing it again, the resistance has a much smaller value than when

the switch was opened. The following data will make this evident. With an E.M.F. of four volts the resistance fell in four minutes from 158 to 146 ohms. After a rest of two minutes the resistance was 135 ohms and the circuit being closed for three minutes, no further change in resistance was observed. But a rest of two minutes brought the resistance down to 99 ohms, where it remained practically constant for three minutes. Another two-minute rest brought it to 91 ohms. In experiments like this each period of rest brought about a marked decrease in resistance. This phenomenon has been observed a number of times, but no satisfactory explanation has been suggested.

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