ON THE ACTION OF THE COHERER.

BY K. E. GUTHE.

I. THE CRITICAL VOLTAGE.

IN a former paper[1] Trowbridge and I have shown that a coherer with one contact shows quite a regular behavior, when cohesion is produced by a current flowing through it. Its P. D. during the passage of the current increases with the latter, finally reaching a constant value which is independent of a further increase of the current, or changes in the applied E.M.F. We have called this value the critical voltage of the coherer and have determined the same for a few metals.

It has seemed of interest to extend the investigation to a larger number of metals, and the present paper contains the results with coherers of silver, copper, zink, aluminium, cadmium, tin, iron, German silver, nickel and bismuth.

The coherer had practically the same form as the one described in the former paper. Instead of metal balls I used spherical surfaces stamped out of metal sheet. The coherer had one contact only and its resistance could be adjusted by means of a fine screw.

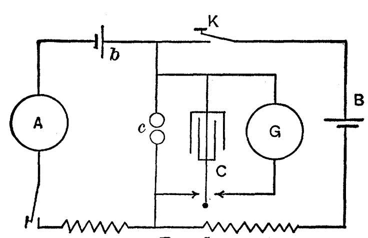

Fig. 1.

The method employed is illustrated by Fig. 1; in which *c* is the coherer. In order to estimate its original resistance it was connected with an auxiliary circuit containing a low E.M.F. (b = 0.4 V.) and a milliammeter (A). After adjustment to a high resistance, cohesion was produced by closing the key K; while the current was flowing, the condenser C was charged and discharged though the galvanometer (G) which had been previously calibrated by means of a stand-

[1] Guthe and Trowbridge, PHYS. REV., XI., p. 22, 1900.

ard cell. Thus the P. D. at the terminals of the coherer could easily be calculated from the deflection of the galvanometer. After opening the key K, the auxiliary circuit was closed again, to ascertain if a lowering of resistance had taken place. Since it was desired to determine the critical voltage only, no accurate measurements of the current were made, though I assured myself in every case by varying the current, that the critical voltage had been reached.

(a) Contact Between Surfaces of the Same Metal.

For each metal I took a series of 30 to 40 observations. The deflections due to the discharge of the condenser varied very little in each series. In the following table the mean values of the deflections (d) and the critical voltages (V) are given.

Table I.

	Ag.	Cu.	Zn.	Al.	Cd.	Sn.	Fe.	Germ. S.	Ni.	Bi.
d	13.7	21.6	22.2	54.3	25.1	21.9	51	32	46.9	42
V	0.062	0.094	0.096	0.236	0.109	0.095	0.222	0.139	0.204	0.183

It will be seen that the critical voltage varies appreciably where different metals are used; for German silver it lies between those of its constituent parts. The critical voltage seems to stand in a certain relation to the atomic weight of the metal. If we multiply the two together, we obtain the following results:—

Table II.

Ag.	Cu.	Zn.	Al.	Cd.	Sn.	Fe.	Ni.	Bi.
6.71	5.96	6.18	6.39	12.22	11.22	12.43	11.93	39.06

Ag, Cu, Zn and Al give practically the same product: 6.31; Cd, Sn, Fe, Ni, a value almost twice as large: 11.95, while Bi stands alone with a product six times larger than the smallest: $39.06 = 6 \times 6.51$. In the paper mentioned above we found for Pb, $V = 0.127$ volt which gives, multiplied by the atomic weight of Pb; $26.28 = 4 \times 6.57$. The first four metals are the best conductors of heat or electricity, while Pb and Bi stand alone in this respect also.

Interesting as this distinct division of the metals into three groups is, especially when we consider the great differences in the atomic weights of metals in the same group, there is not enough material on hand to form any definite hypothesis as to the reason for it.

(b) Contact Between Surfaces of Different Metals.

In the former paper a close agreement was noted between the formula expressing the P. D. of the coherer as a function of the current and the formula[1] which I have found to represent the polarization of Cu electrodes in $CuSO_4$ solution, and we were led to believe that we had to do with a phenomenon somewhat similar to the electrolytic conduction of electricity. We assumed that the existence of a critical voltage is due to the resistance of a layer of small metallic particles (ions or electrons) carried over by the current.[2] Supposing that these particles travel in the direction of the current, we might expect when working with a coherer, having different metals at the two sides of the contact, to obtain the critical voltage of the one or the other metal according to the direction of the current. That this is not the case is shown by the data in Table III. in which are given the critical voltages for a large number of combinations. The current is supposed to flow from the metal in the horizontal to that in the vertical line. The method of observation was the same as in the preceding experiments.

TABLE III.

From :

To:	Ag.	Cu.	Zn.	Cd.	Sn.	Fe.	Germ. S.	Ni.	Bi.
Ag.	0.0622	0.082	0.125	0.127	0.164	0.156	0.078	0.209	0.13
Cu.	0.086	0.094	0.135	0.142	0.170	0.252			0.13
Zn.	0.119	0.143	0.096	0.109	0.103	0.141			0.117
Cd.	0.118	0.131	0.105	0.109	0.087	0.174	0.091		
Sn.	0.166	0.179	0.089	0.087	0.095	0.210	*c* 0.2	0.152	*c* 0.13
Fe.	0.300	0.278	0.141	0.152	0.152	0.222	0.243	0.300	0.22
Germ. S.	0.078			0.10	*c* 0.20	0.261	0.139	0.170	0.165
Ni.	0.122				0.109	0.287	0.191	0.204	0.117
Bi.	0.26	0.261	0.196		*c* 0.22	0.304	0.209	0.196	0.183

[1] Guthe, PHYS. REV., VII., p. 193, 1898.

[2] It can easily be shown by a measurement of the resistance of the coherer, by means of an alternating current, that we have a *metallic* contact, after cohesion has taken place. Using the well-known Kohlrausch method for measuring electrolytic resistances, the value found agreed well with the one calculated from the P.D. and the current. The telephone could be adjusted to absolute silence which shows conlusively the existence of an actual metallic contact.

The deflections of the galvanometer were in general quite concordant; only with Al as one side of the coherer the results were so unsatisfactory that they have been omitted from the table.

We see that in general the direction of the current has no appreciable influence upon the critical voltage between different metals. Differences of considerable size were observed between Bi and Ni and between Fe and Sn only. The Peltier effect can hardly be adduced as the sole explanation for these differences, since they are in opposite direction for Bi and Ni and do not appear for German silver at all. We shall see under III. that the heating of the point of contact may have an influence upon the critical voltage and may possibly explain the observed differences due to the direction of the current.

II. The Negative Action of the Coherer.

Under "negative action" I understand the increase of resistance which can sometimes be observed in coherers when responding to an electrical influence. All the metals studied by me, especially the soft metals, show this behavior under certain conditions. Bose[1] has recently declared this negative action to be the normal one for certain metals. He supposes that each metal exists in two modifications, one with a high resistance (modification *A*) and another with a low resistance (modification *B*). The difference between these two, he thinks, is to be sought in the different arrangement of the molecules in the two cases. In certain metals, which he calls positive, *e. g.*, Fe, the modification *A* is the normal, in others, *e. g.*, K modification *B*. Under the influence of an electric wave the surface of the metal is supposed to change from its normal state into the other, and thus strains are produced in the metal. Though further action of the electric waves the new arrangement of the molecules may suddenly break down and the resistance of the coherer return more or less to its original value. Thus "oscillatory changes in the molecular structure are produced, which are evidenced by the corresponding electrical reversals."

Bose used in all his experiments the ordinary form of coherer, having a great number of contacts. Mizuno[2] investigating the in-

[1] Bose, Proc. Roy. Soc., 65, p. 166, 1899 and 66, p. 450, 1900.
[2] Mizuno, Phil. Mag., 50, p. 445, 1900.

fluence of repeated electrical impulses upon the resistance of such coherers, found curves of very similar character to Bose's for positive metals; even potassium showed a large final drop in resistance instead of an increase which should have been expected according to Bose's theory. In one case Mizuno used a one-contact coherer (two lead balls) and here the resistance fell after a few sparks of the oscillator to a constant minimum without showing any reversals at all.

It seems possible to arrive at an explanation of the negative action only from experiments with a coherer of a similar form. The phenomenon as observed by me, was as follows: On the first adjustment of the coherer the needle of the milliammeter showed quite irregular movements before it became steady. On closing the main circuit the resistance increased, but when, by opening key K the auxiliary circuit was closed, I observed an unsteady, slowly increasing deflection of the milliammeter showing that the low resistance was formed again. This corresponds perfectly to Bose's description "of the rumbling noise in the telephone due to the rearrangement of the surface molecules to a more stable condition."

It suggested itself immediately that a small, loose particle formed a conducting bridge between the coherer surfaces, which was thrown aside on the introduction of a higher E.M.F., but fell back to its original position, when only a low E.M.F. was in the circuit. This would be quite similar to the action of Nengschwender's anticoherer. The following observations showed this supposition to be true.

While under normal conditions a slight increase of pressure reduced the resistance almost to zero, it remained always relatively high in spite of an appreciable pressure, when the coherer showed negative action. The conducting particle remained between the surfaces.

The increase of resistance could be brought about many times in succession, if the coherer was left undisturbed. Sometimes the resistance became infinite and remained so. In such a case the surfaces had to be brought nearer together in order to make a new adjustment to a high resistance possible. After this the normal action took place. The particle had been thrown aside.

This shows that the negative action of the coherer is due to disturbing influences and cannot be considered a normal phenomenon, as Bose supposes. We shall not be able to understand the nature of the coherer unless we experiment with coherers of a form as simple as possible. The usual form, it seems, is not at all suited to the purpose.

In a paper, which has just appeared, Marx[1] describes his experiments with the so-called Schaefer anticoherer. The original resistance of this instrument is due to small particles forming a bridge between the two metallic ends. He observed under the microscope a distinct motion of the particles when an electric wave fell upon the apparatus, and a falling back into their original position when the electrical influence ceased.

III. The Influence which the Heating of the Contact has upon the Resistance of the Coherer.

It is well known that, after cohesion has taken place, a slight heating of the coherer restores the original high resistance; but it would be wrong to conclude from this that a coherer is less sensitive at higher temperatures. Considering the smallness of the contact, there can be no doubt that even with small currents a development of heat must take place at that point. With metals of low melting point I had observed the heating effect during the previous experiments. In general I was unable, when examining the contact by means of a microscope, before and after being used, to detect the slightest change on the metallic surfaces. But in the case of Bi and Sn, melting took place when the current was increased to more than one ampère. With the other metals I could not observe any change even with currents as large as four ampères.

In the course of my experiments on this subject I was led to the observation of a phenomenon, which, as I believe, was hitherto unknown. The method was practically the same as above. The coherer was slightly changed by using two fine wires of the same metal and at right angles to each other instead of the spherical surfaces. By a light pressure against one of them the loose contact was effected. Now I sent by means of a separate circuit a current of such

[1] Marx, Phys. Zeitschr., Jan. 26th, 1901.

strength through one of the wires that it—and consequently the point of contact too—became heated. While the heating took place the main circuit was closed and the P .D. of the coherer measured.

The higher the temperature of the contact, the lower appeared the resistance of the coherer under otherwise similar conditions and the resistance returned to its original high value when the heating ceased.

The following tables may serve to illustrate this phenomenon. In the first column I have given the deflections obtained by the discharge of the condenser when cohesion was produced before the contact was heated. In the second column follow the deflections obtained while the heating took place, and columns 3 to 5 give the corresponding deflections 10, 20 and 50 seconds after the heating had ceased. The coherer consisted of steel wires of 0.36 mm. diameter. Unit deflection corresponds to 0.00435 volt.

TABLE IV.

174	3	31	102	160
121	23	56	159	160

Even when the original resistance was infinite (this may be expressed by ∞) the phenomenon could be very distinctly observed.

TABLE V.

∞	18	292	∞	∞
∞	19	229	∞	∞

The results obtained when the current through the wire and consequently the temperature of the contact was varied, are given in Table VI. In the first column the heating current is given, the following columns have the same meaning as before. The values in the second column depend on the accidental original adjustment.

TABLE VI.

0.2 amp.	138	121	122	139	139
0.5 amp.	90	12	95	95	95
4.0 amp.	86	5	11	34	75

Similar results were obtained with copper wires. With them the heating seemed to have a still larger influence than with steel. The deflections were only two or three scale divisions during the heating, even in cases in which the original resistance had been infinite. The lengthening of the wire due to the higher temperature produced slipping and made the observations rather difficult, but this could easily be avoided by holding the wire in its original horizontal position with a fine vertical spiral.

Finally I used a contact between wires of different diameter. If we produce cohesion in such an instrument by sending a relatively large current through both wires, the thinner wire will be heated. The observations showed now a decided influence of the direction of the current. This can hardly be due to the different curvature of the wires, since Trowbridge and I have shown, at least for steel balls, that the diameter has no influence upon the critical voltage.

I select for illustration one example out of a great many. The thickness of the steel wires was 1.65 and 0.27 mm. respectively. When a current of three ampères was sent from the thicker to the thinner wire I obtained by discharging the condenser a deflection of 136 scale-divisions. If the current is smaller, the differences are smaller. The P. D. of the coherer is therefore lower if the electricity flows from the hotter to the colder side than if it flows in the opposite direction.

This may enable us to understand why different critical voltages were obtained according to the direction of the current, when contacts with different metals were used (Table III.). Bi showed the discrepancy most of all. If Bi forms one side of the coherer this side will be much warmer than the other, since this metal is a very bad conductor of heat. This would demand a small P. D. if the current flows from Bi to another metal. On the other hand when a current flows in this direction the point of contact is cooled and we might expect a higher critical voltage. These two influences are doubtless of a secondary nature and must be superposed. With Bi, as Table III. shows, the influence of the difference in temperature is by far the greater, while with Ni the Peltier effect seems to be the stronger.

I believe that in the action of the coherer the heating of the contact plays an important rôle. By it the first impulse to the lowering of resistance is given ; it may be called the first stage. We have to keep in mind that when the contact is not heated by the current passing *through* the coherer, the resistance very soon increases on cooling, while after actual cohesion has taken place, a metallic contact is produced and the resistance returns only very slowly to its high value.

PHYSICAL LABORATORY, UNIVERSITY OF BERLIN, January, 1901.