

POLARIZATION AND INTERNAL RESISTANCE OF
THE COPPER VOLTAMETER.

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MEASUREMENTS of electrolytic polarization may be divided into two general classes. In the first class may be placed all the measurements made with the direct current. This class includes the greater part of the determinations. In the second class the alternating current has been employed. The development of this method is a comparatively recent one, but promises to yield extremely important results. This method has also afforded measurements of electrode capacity, designated by "polarization capacity"—an expression which first appeared in a contribution by Kohlrausch.¹ This term suggests that the phenomenon is limited to the electrodes and to the solution immediately adjoining them. The enormous values obtained for the capacities,² indicate strata so thin as to be scarcely designated as finite. Their values are a reminder of the Helmholtz charged strata theory. However, the Warburg theory, which makes it a current conduction, and at the same time recognizes that both the electrodes and the solution play important parts, is more satisfactory. The process at the electrodes is frequently complicated. Gases may be deposited and cover parts of the electrodes and thus insulate parts of the surfaces, or the gases may be occluded and form an opposing gas battery. There may be an absorption of ions in the surface of the electrodes. The liberated products may form at the surface of the electrodes a new material or the same material in a different state of aggregation.

¹F. Kohlrausch, Pogg. Ann., 148, p. 443, 1872.

²M. Wien, Wied. Ann., 58, p. 37, 1896.

C. M. Gordon, Wied. Ann., 61, p. 1, 1897.

A. M. Scott, Wied. Ann., 67, p. 388, 1899.

E. Warburg, Wied. Ann., 67, p. 493, 1899.

E. Newmann, Wied. Ann., 67, p. 500, 1899.

The solution may act upon the electrodes either upon open or closed circuit—an action which may be normal or arise by reason of impurities, either in the electrodes or the solution. The character of the solution at the electrodes when carrying a current may be changed sufficiently to cause action. A concentration series always arises owing to the unequal rates of migration of the ions. Any of these changes give rise to a polarization. These deposits upon or in the electrodes are frequently small and a slight variation in their total quantity affects appreciably the electromotive force, when these deposits are present at the electrodes, before the current is started. Their ions are also present in the adjacent solution, and the current affects their magnitude; therefore, the concentration series in the solution is always affected. After removal of the current the electrodes and adjacent strata of the solution would tend to return to the former state of equilibrium, and the concentration series would be removed by diffusion. However the process of diffusion is a rather slow one and could only appear rapid when the concentration strata are minutely thin. If the current had suddenly been reversed, it must have aided the return to the original condition and quickly established the same phenomena as before, but at the opposite electrodes. This is what probably happens when alternating currents are used under proper conditions. This makes the phenomena reversible, and upon its reversibility depends the accuracy of the electrolytic resistance, by means of alternating currents.

The observations for electrolytic resistance by means of the direct current, unlike the observations by means of the alternating current, have never given uniform values. The resistance is always larger when the current is small. The method of measuring electrolytic resistance by direct current involves the measurement of three quantities, viz. electromotive force, E , at terminals of the electrolyte; the current, i ; and the polarization, P . The electrolytic resistance, r , is then calculated by the formula $r = (E - P) / i$. The determination of E and i is easy and accurate. However, P is not usually measured with the direct current still flowing. The circuit is broken and the voltmeter thrown upon an independent current. The process requires time and a residual part only of

the polarization as measured. Wiedeburg has given an experimental formula¹

$$P = \frac{P_1}{2} \left(1 - E^{-\frac{B_1}{S_1} q} \right) + \frac{P_2}{2} \left(1 - E^{-\frac{B_2}{S_2} q} \right)$$

where P is the total polarization. P and P' the maximum polarization at electrodes 1 and 2 respectively. s denotes surface of electrodes, B_1 and B_2 are constants depending upon the material of the electrodes, and q is the quantity of electricity which has passed.² Guthe has subjected the formula to an accurate experimental test. His experimental conditions made $P_1 = P_2 = P/2$, $B_1 = B_2$, $S_1 = S_2$ and the value of P so obtained, substituted in the simple formula above, gives the uniform values for electrolytic resistance. However, the actual measurement of P or an approximation to such a measurement is very desirable. As has been pointed out by several observers, the nearer the time from the opening the one circuit to the closing of the other approaches zero, the more accurate the values obtained for P , and therefore the more accurate the calculated value for r .

The object of the following experiments, is to emphasize these conditions and to show the growth of polarization upon closed and open circuit. It has therefore been necessary to employ the direct current. P has been measured between .00006 second, and .045 second after the polarizing electromotive force was removed. The latter has also been given wide ranges both in its value and in the time during which it was applied. The smallest time intervals, so far as could be learned, are ten times shorter than any previous experimenter has used.

Fig. 1 gives a diagram of the connections. The circuits were all made and broken by a swinging pendulum. The minute lateral motion of the pendulum was a troublesome factor until the steel cone pivots were drawn so tight that the pendulum ceased vibration after a few swings. The keys 1, 3 and 4 had micrometer screw attachments so that they could be adjusted accurately in the same plane as key 2. To obtain the deflection with the standard cell, B ,

¹ Wiedeburg, Wied. Ann., 51, p. 2, 302.

² Guthe, PHYS. REVIEW, Vol. VII., p. 193.

key 1 is fastened open with a strip of glass, keys 2 and 4 are set, the six-point switch is turned to the left and the key *b* is closed by hand about the instant the pendulum is released. This was necessary since the time period from key 3 to key 4 or from key 1 to key 4 was not long enough to allow the condenser to assume the potential of the standard, owing to the large internal resistance of this cell. To obtain the total deflection from the storage cell the

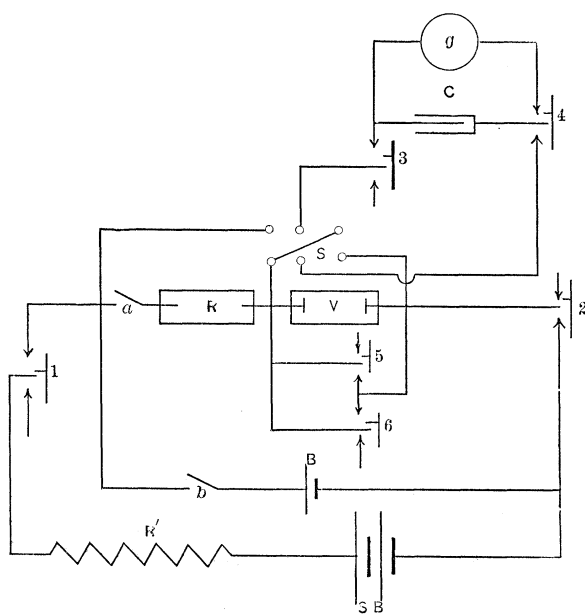


Fig. 1.

manipulation is the same except key 1 is used instead of key *b*. To polarize the voltmeter key *a* is closed and keys 1, 2, 3, 4, 5 and 6 are set. When the pendulum is liberated, it first meets key 5 and opens the voltmeter short-circuit. The detent to key 6 is overturned last of all and this again short-circuits the voltmeter. By this swing of the pendulum the galvanometer will give a deflection proportional to the fall of the potential over the resistance *R* or the voltmeter *V*, according as the six-point switch is turned to the left or right respectively. This fall of the potential over *V* will be the polarizing electromotive force, if keys 3 and 4 are released before key 2. It will be the polarization electromotive force if keys 3 and 4 are

released after key 2. The deflections over R and V are also proportional to the resistance R and the apparent resistance R_v of the voltmeter respectively. The deflection caused by the polarization of V , subtracted from the deflection produced by the applied electromotive force leaves a value proportional to the internal resistance r . Whenever deflections are thus compared it is necessary that the time intervals of charging be the same. For the apparent capacity of condensers vary when the time interval is very short.¹ The capacities of a one-third microfarad condenser and a one microfarad condenser were found to vary about four per cent. while a Stanley condenser varied three fold. Key 3 was placed so that it made the up contact after the detent to key 2 was released. The equation of motion of the pendulum and the distance key 4 was displaced from the plane of key 2, determines the time which has elapsed since the charging circuit was broken. To release keys 3 and 4 before key 2, a small hard rubber block was attached to the pendulum opposite keys 3 and 4. The current was determined from the total electromotive force of the storage battery and the total resistance of the circuit. When the currents were large it became necessary to measure the electromotive force of the storage cell upon closed circuit, since a concentration series² arises in that cell. A comparison of the deflections of the standard and storage cell gives the electromotive force of the storage cell. A deflection is then obtained from the storage when the time interval is short. Let this deflection be D' . Then, if d_r and d_v be the deflection on closed circuit over R and V when the condenser is charged the same length of time we have

$$(1) \quad D' = \frac{(d_r + d_v)(R + R_r + R')}{R + R_v}$$

where D' is proportional to electromotive force of the storage cell, and R' the resistance in series with R and R_v . The internal resistance of the storage cell is neglected. Farther (2) $R_v = R \frac{d_v}{d_r}$. This value of D' differs slightly from D for large currents. However, this correction was only made in the first experiment, and for the others the electromotive force of the cell on open circuit was used.

¹ PHYSICAL REVIEW, Vol. IV., p. 238.

² PHYSICAL REVIEW, Vol. IV., p. 353.

The adjustment of keys 2, 3 and 4 for a very short time interval was an extremely tedious task. Keys 2 and 4 were down contacts and the best method to adjust them was found to be by the sense of touch. The detents were held with the fingers against the spring contacts and the pendulum drawn back through an arc of about 2 to 5 mm., and allowed to fall against them. The time sense in the touch of the fingers is so delicate, that, by this method, a distance of .007 mm. could be detected. When the pendulum swung through its full arc the time required to pass through this distance at the lower point of the arc was .00002 second. The smallest time between keys 2 and 4 actually used was .00006 second, and in this time interval there is liable to be an error as large as twenty per cent., in a few cases. This error arises from the inaccuracy of the adjustment, temperature changes in the keys, lateral vibration in the pendulum, and any displacement of the keys due to pressure in making the settings. This setting could not be made one day and be found in adjustment the day following. Neither could it be made and key 3 adjusted to fall with its up contact between keys 2 and 4. Key 3 with an up contact had to be adjusted electrically and after much use it was found that its position would depend upon the electromotive force employed. The adjustment of keys 2, 3 and 4 for such a time interval requires three hours' work and then the adjustment could not be expected to remain over one half hour. After long trial, this short time interval was abandoned. A trial made it about .0005 second, revealed the fact that key 3 could be dispensed with so far as the polarization phenomena were concerned. The readings were the same, after allowing for difference in time interval of charging the condenser through the external resistance R , when key 3 was set as when it was allowed to remain against its up contact. In the latter case the condenser becomes charged to the polarizing electromotive force, and then upon open circuit discharges through the voltameter until it reaches the polarization electromotive force. This discharge would tend to maintain the polarization if the quantity is an appreciable part of the "polarization capacity" of the voltameter. Farther the electromotive force of the condenser would not have fallen to the polarization electromotive force if the time interval was sufficiently short. This time

interval must be determined from the equation of discharge of a condenser $q = (Qe^{-\frac{t}{RC}})$ or $d = (De^{-\frac{t}{RC}})$ where D is the total deflection of a galvanometer produced by a given electromotive force E applied to a condenser of capacity C , and d the deflection of the same galvanometer after the condenser charged to the same electromotive force has been allowed to leak through a resistance R for the time interval t . A test of this kind was applied by charging the condenser over the resistance R made approximately equal to the resistance of the voltmeter, and discharging it after leaking for an interval t . It was possible in this way to adjust the keys 3 and 4 so as to obtain an appreciable deflection, d . It was, however, not possible to obtain a deflection when the time interval was as long as .00006 second, provided the electromotive force of polarization was small. When the electromotive force was large the spring in .00006 second is not sufficiently far removed from the lower contact to break the primary circuit. This process therefore became an excellent independent method to use as a check upon the settings of the keys. When the condenser is charged by the polarization electromotive force, after the polarizing electromotive force is removed, it lowers the potential of the polarization electromotive force, if the charge in the condenser is an appreciable part of the total charge in the voltmeter, according to the law of divided capacities. For the time periods longer than .0006 second, a difference of two per cent. could be accounted for by experimental errors, but if there had been a difference of four per cent. in the readings, it could have been stated with some assurance that the capacity of the voltmeter was between twenty-five and one hundred times as great as the capacity of the condenser. No such difference was detected and key 3 was allowed to remain against the up contact for all the recorded measurements and was only set when it was desired to make a test for capacity. No such effect was ever found with certainty but it seems reasonable to anticipate capacity measurements when the surface of the electrodes is reduced considerable in magnitude. After omitting the setting of key 3 the adjustment of keys 2 and 4 was greatly facilitated, and it became again possible to set to .00006 second, when the electromotive force was small. Wires not shown in the figure also lead from the volta-

meter to an alternating current bridge where the electrolytic resistance was determined by the Kohlrausch method.

The density of the solution used was 1.1395 throughout the experiments. The evaporation from the surface was compensated by adding distilled water. The temperature varied about four degrees in the first experiment, but less in the others. All solutions, except the first, contained about one-tenth per cent. of alcohol. The object of the alcohol was to prevent oxidation of the electrodes, but in this proportion it was not a success. The solution was also boiled to free it of the contained oxygen. Fresh solution from a stock bottle was taken for each experiment. The results of the first experiment are contained in Tables I. and II., and Figures 2, 3 and 4. The copper plates had stood in the solution for an entire

TABLE I.

<i>i.</i>	<i>E.</i>	<i>R_v</i>	<i>i.</i>	<i>E.</i>	<i>R_v</i>
.00188	.106	56.44	.0274	.701	25.6
.003575	.236	66.	.0506	.9973	19.71
.00906	.435	48.	.0817	1.147	14.04
.01289	.5143	39.9	.1097	1.234	12.5
.01969	.6773	34.4	.2118	1.3765	6.5

TABLE II.

<i>T</i>	<i>E</i> = .236		<i>E</i> = .4349		<i>E</i> = .701		<i>E</i> = 1.147	
	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>r</i>
.00006			.2176	24.	.3570	12.6		
.00018	.0898	40.6	.136	33.			.2973	10.4
.000295					.2352	17.		
.00033	.0512	5.7	.0671	40.6				
.00053			.0634	41.	.1753		.1911	11.7
.00073			.0544	42.		19.2		
.00090	.285	58.						
.00100			.0364	44.				
.00680	.0215	60.	.0309	44.6	.1366	20.6	.1666	12.
.01400	.018	61.	.0245	45.3			.1503	12.2
.0800			.0182	46.				

week during preliminary tests, and the experiment itself continued through another week. At the end of this interval the plates were

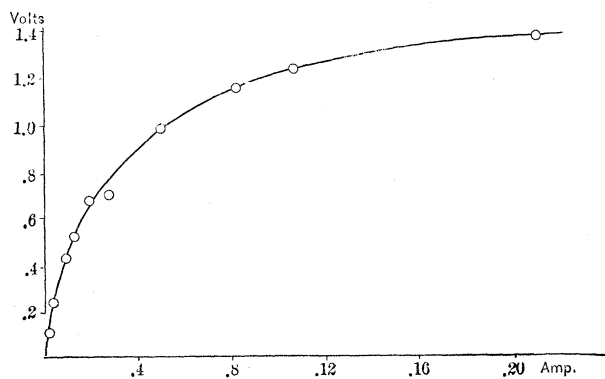


Fig. 2.

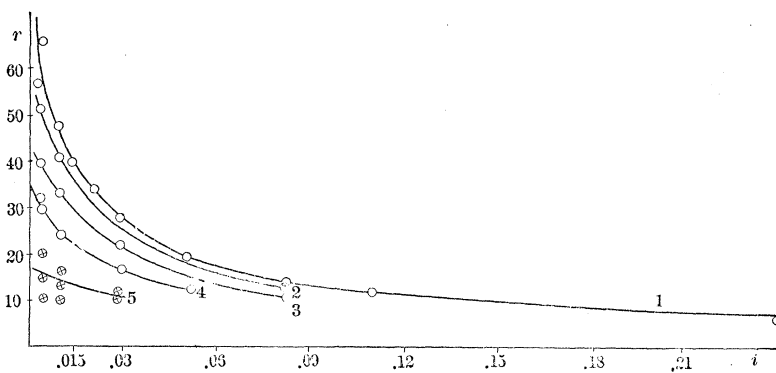


Fig. 3

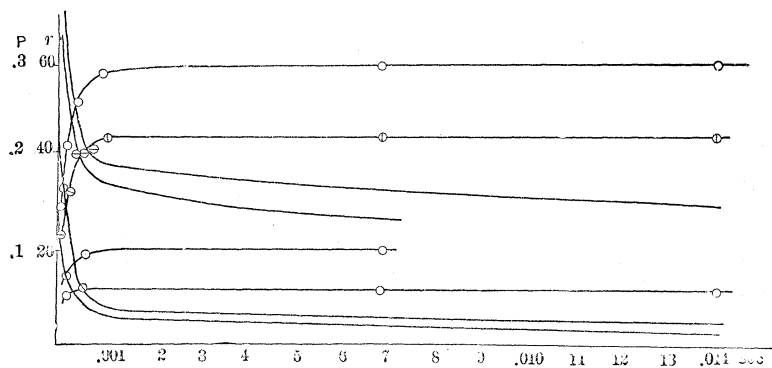


Fig. 4.

colored a dark green, but the uniformity of the readings indicate that the plates did not change throughout the experiment. The test of the resistance by the Kohlrausch method gave a value of thirty-three ohms, but the capacity effect was so large that the adjustment could not be made closer than about five per cent. The measurement of resistance by direct current indicated values much smaller than this. Later it appears that the direct current flowing only for a brief interval had an apparent temporary cleaning action upon the electrodes. The old plates were then thoroughly cleaned and immersed in the same vessel in another solution from the same stock bottle. The resistance now obtained by Kohlrausch's method was 3.9 ohms. The areas of each of these plates was 60 sq. cm. The primary circuit was closed approximately .08 of a second. Fig. 2 shows the relation of the polarizing electromotive force to the current. The ratio of these two quantities is the apparent resistance. In Fig. 3 resistances are plotted as ordinates and currents as abscissæ. The upper curve gives the apparent resistances. The other curves give resistances after allowing for the polarization measured after regular time intervals. The curve nearest the apparent resistance shows the resistance obtained when the polarization is measured, .00033 second after the removal of the polarizing electromotive force. This is the usual character of the curve obtained by the various experimenters, though the time period usually is several times longer than .00033 second. As this time interval is shortened, the resistances diminish and show less variation with changes of current. Some observations are shown on this curve for an unknown but very short time period, the data for which are not recorded. For more minute time period one could expect the curve for resistance to run parallel with the axis of abscissæ, *i. e.*, the resistance would be the same for all currents and probably the same as the electrolytic resistance. Fig. 4 gives the relation of polarization and of resistance to time for four different electromotive forces. As is apparent, the great changes all occur in the first one-thousandth of a second. There are also greater changes for small than for large electromotive forces.

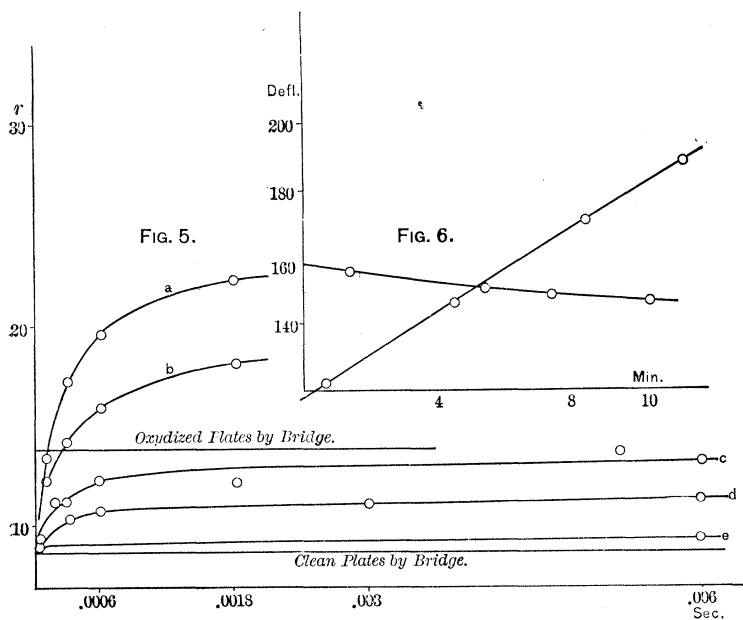
Table III. gives some results obtained with small copper plates with one-tenth the area of the previous plates. The electrolytic

resistance of the solution by the Kohlrausch method was 8.5 ohms when the plates were clean and 13.6 ± 0.4 when they had stood

TABLE III.

7×10^6	$R^0 = 73.5$ $i = .00186$ $E = .1367$		$R^0 = 51.4$ $i = .00535$ $E = .3576$	
	P	r	P	r
12	.1098	13.36	.209	12.36
30	.1049	17.10	.200	14.02
60	.1004	19.51	.190	15.86
180	.0955	22.14	.1825	17.91

in the solution for some time. In this experiment the plates had stood in the solution twenty-four hours. The results are shown graphically in curves *a* and *b*, Fig. 5.



Tables IV. and V. give results for plates of the same size as in Table III. The data, however, are for plates when first placed in the solution. Oxidation occurs so rapidly that it was impossible at first to get any consistent results. The resistance increased con-

tinually as indicated both by the potential and the bridge methods. In twenty minutes the plates would be appreciably colored and had to be recleaned. The fresh prepared plates would give new

TABLE IV.

R_v	i	E
16.11	.00050	.0081
15.2	.00193	.0283
13.12	.00454	.0596
12.55	.00587	.0737
12.6	.04580	.6771
11.	.08980	.9878

TABLE V.

	$R_v = 15.42$ $i = .00193$ $E = .0298$		$R_v = 12.71$ $i = .00587$ $E = .0745$		$R_v = 11.$ $i = .0898$ $E = .9878$	
	P	r	P	r	P	r
8	.0119	9.26	.0217	9.02		
18	.0083	11.11				8.8
30	.0083	11.11	.0147	10.21		
60	.0062	12.22	.0123	10.61		
180	.0064	12.1				
300			.0102	10.98		
600	.0054	13.15	.0087	11.22		9.2

values so different from the others that the difference could not be accounted for upon the ground of experimental error. Measurements were then taken at stated intervals and when these were extrapolated to zero time they became acceptably uniform. This indicated that the plates, if always cleaned with care and by the same method, would give almost the same resistance when first placed in the solution. The effects of oxidation increased the resistance fairly uniformly from this instant, but the effects were no two times alike and hence the above irregularities. It therefore became necessary to clean the plates for each determination. The circuits were then adjusted for the measurement of polarization, the plates dropped into the solution and about two seconds later the pendulum allowed to swing. The adjustments were then

made for drop over voltmeter, V , or over resistance, R of 30 ohms in series with V , and after a definite time interval the pendulum was again dropped. An example of the observations for fall of potential over V and R is given in Table VI. and shown graphically

TABLE VI.

T min.	Drop over 30 ohms.	Drop over V .
.75		122.2
1.5	27.6	147.
4.5		
5.5	270.	
7.5	268.4	
8.5		171.6
10.5	267.6	
11.5		189.

in Fig. 6. The intercept of these curves on the y axis is taken for the true drop over R and V . The plates were then recleaned and the keys set for another period of polarization and observations repeated. Any slight variation in voltmeter resistance gives a corresponding variation in applied potential, polarization and current. The mean of these values is recorded in Table IV. A more complete set of observations than given in Table V. is desirable, but, owing to necessity of cleaning the plates, to obtain such a set is an extremely tedious task. The data for resistance in Table V. are shown graphically in curves c , d and e of Fig. 5. Curves a and b arose from polarizing electromotive forces lying between the potentials causing the polarization d and e and that is where a and b should be expected to fall if the plates used in Table III. had been clean instead of being oxidized. We may therefore say that a large part of the effect in a and b arises from a change in the condition of the surface of the electrodes and consequent changes in adjacent solution and that the effect in c , d and e arises largely from the true concentration series.

In the next experiment the polarizing electromotive force varied from .0003 second to .1637 second. The copper plates were the same as in the previous experiment. The resistance external to voltmeter was constant. As the time of the applied electromotive

force increased the polarization also increased and there was, therefore, an increase in the terminal electromotive force. This occasions an increase in the apparent resistance of the voltameter and a corresponding decrease in the current. These results are shown in Table VII. For each polarizing period the polarization was measured at different intervals. The results obtained are given in Table VIII. Fig. 7 shows the results graphically. T_v represents the

TABLE VII.

T	i	R_v	E
.0003	.001954	16.84	.0329
.0030	.001927	23.12	.0430
.0240	.001914	38.10	.0729
.0634	.001895	48.64	.0923
.1637	.001885	54.13	.1010

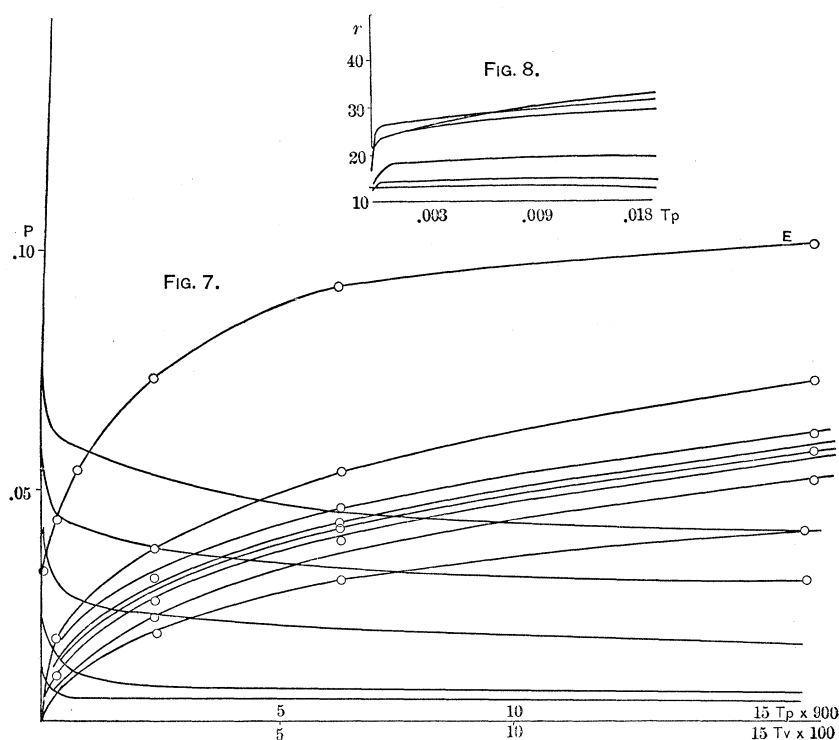
TABLE VIII.

T_p	$T_v = .0003$		$T_v = .003$		$T_v = .024$		$T_v = .0634$		$T_v = .1637$	
	P	r	P	r	P	r	P	r	P	r
.00012	.0077	12.90	.0181	13.71	.0367	18.94	.0529	20.44	.0725	15.66
.00030	.0067	13.24	.0152	15.21	.0302	22.32	.0453	24.46	.0611	21.71
.00060	.0058	13.89	.0123	16.72	.0274	23.81	.0425	25.96		
.00120	.0058	13.89	.0093	18.28	.0257	24.71	.0414	26.51	.0575	23.63
.00300	.0058	13.89	.0078	19.09	.0257	24.71	.0409	26.78	.0518	25.56
.00600	.0056	14.02			.0221	26.60	.0388	27.88	.0518	26.66
.01800	.0043	14.69	.0075	19.54	.0166	29.49	.0300	32.52	.0404	32.70

r by alternating current = 13.6.

time the voltameter was polarized and T_p the time elapsing between breaking the circuit and measuring of the polarization. The ordinates represent electromotive forces for both sets of curves. The curves with ordinates increasing with abscissæ each correspond to a constant T_p and variable T_v . For the remaining curves T_v is constant and T_p variable. The abscissæ are nine times larger for variable T_p than for variable T_v . The former show the decrease of polarization when the polarizing electromotive force is removed; the latter show the increase of polarization when the current is applied to the voltameter.

Fig. 8 shows the value of r as ordinates and T_p as abscissæ. They show no regularity as to each other. With more accurate measurements they possibly would be found to intersect the y axis at the point corresponding to the electrolytic resistance.



These observations show clearly the rapid formation of the polarization and that polarization arises for even minute current thrusts and for alternating currents. At first the current produces a change at the contact of solution and electrodes. It then effects deeper layers of the solution and the effect at the contacts of electrodes and solution increases, but less rapidly. This gives rise to further, but smaller increases in polarization. Diffusion diminishes the increase in polarization and after a time there is a constant potential between the terminals of the voltameter or equilibrium between the diffusion process and the increase in potential. On open circuit the diffusion still continues and affects most rapidly the strata nearest

the electrodes were in many cases a reaction occurs. Therefore at the electrode surfaces the changes are greatest. When all the strata affected by the concentration changes are extremely thin, then the polarization will decrease very rapidly. This effect is shown in the polarization curves and the rapid changes of the apparent resistance when the applied current was very small.

When the currents become larger there are concentration changes farther from the electrodes, and the greater the distance from the electrodes to the outlying concentration changes the less P will diminish in a short interval. Therefore, the values obtained for the true resistance when large currents are used, provided they are not so large as to complicate the phenomena, correspond more nearly to values obtained with alternating currents. Since the circuits were not closed long enough to establish a maximum of polarization, one might anticipate that the same effect would be produced by increasing the length of time, the polarizing electromotive force was applied. In Table VIII. it is seen the polarization does increase as T_v increases and that the residual polarization is more persistent on open circuit for the larger values of T_v . However, when the current is applied for a longer time the curve for apparent resistance does not become more nearly horizontal but becomes more bent. This would indicate that as the polarizing electromotive force increases and the current decreases the part of the polarization at the contact of the electrode and the solution increases more rapidly than the part farther removed from the electrodes. Therefore, there is a greater change in polarization for about the same current, when the time for the polarizing electromotive force is increased. This point, however, needs further investigation. The intercept on the y axis of the E curve divided by the current gives the electrolytic resistance as measured by the alternating current. The polarization curves with varying T_v all pass through the origin. The value of the polarization T_v for $T_p = 0$ would be difficult to extrapolate. These polarization curves approach nearer the E curve as time increases and makes r apparently increase and later decrease with increasing time. This may be due to some inaccuracy in the measurements, but it is not altogether impossible since the polarization is very persistent when the time is longer as indicated by the

curves where T_p is variable. The curves plotted with the last factor as variable indicate that there is a considerable part of the polarization very persistent. There is a part also which diminishes very rapidly, and which, by ordinary methods, has not been observed. The former probably concerns the strata of the concentration series more remote from the electrodes. The latter probably arises from the outer strata of the concentration series adjoining the electrode, where in the case of the oxidized plates reaction at once sets in. In case of clean copper plates this action would be scarcely noticeable, and therefore the slight variation of the c , d and e curves, Fig. 5. The curves and the data also indicate that if the true maximum value of P could be measured, the simple formula in ordinary use would give nearly the true resistance of the cell for all currents. That it should give the true electrolytic resistance when the measurements are very accurately measured should not be expected under all conditions. For concentration changes mean layers of different conductivity from the body of the solution. The heating of the electrodes may not be altogether negligible, particularly if either electrode is small and current density large. Gaseous products, and a change in the aggregation of the electrode surface also produce changes, since the current must either pass around or through them. Such phenomena as these together with the unmeasured part of the polarization, constitute what has been designated as a "transition resistance." It is always desirable to have as few complications as possible.

The time periods here used are so short one can estimate the polarization which would arise when an alternating current of slow frequency, like that used in electrolytic measurements, is applied. Let us assume a current alternating five hundred times to the second, having the same current strength as used in this experiment. Assume the average electromotive force to be seven-tenths of the maximum. Then the maximum would be reached in .001 second and the polarization would therefore be about .01 volt.

It is the author's intention to farther apply this method to thoroughly oxidized plates, and to clean electrodes, if oxidation of the latter can be prevented. Formaldehyde is recommended by some to prevent oxidation and will be tried. Farther tests for

capacity; and for other solutions and other electrodes are desirable. To diminish the time period much more will not be possible since the shortest time already is near the limit of the time for the condenser to acquire full charge. However, a change in the apparatus so as to obtain greater accuracy in the measurement of the time is very desirable. The method is also applicable to measurement of internal resistance and polarization in primary batteries.

UNIVERSITY OF NEBRASKA, June, 1899.