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SOME INDUCED POLARIZATION EFFECTS

BY

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The author also wishes to thank his wife for typing the manuscript and devoting a great deal of her time to reproducing the graphs.

## ABSTRACT

Some induced polarization effects were investigated in the laboratory. The effect of a metallic target in various electrolytes is described, and the following conclusions are reached: 1) the magnitude of the induced polarization potential is directly proportional to the resistivity of the electrolyte under a wide range of conditions, and seems to be only slightly dependent on the chemical nature of the electrolyte 2) the decay of the induced polarization potential is hyperbolic 3) the area under the decay curve increases hyperbolically with the excitation time 4) the area under the decay curve is directly proportional to the excitation voltage gradient under a wide range of conditions. The results are compared with D. F. Bleil's<sup>1</sup> work. Some of Bleil's results are found to disagree with the results described in this paper.

## SOME INDUCED POLARIZATION EFFECTS

SOCORRO, NEW MEXICO

### INTRODUCTION

If a metallic mass is placed in an electrolyte, and a current is passed through the electrolyte, the metallic mass becomes polarized. Since this induced polarization effect can be detected and measured by proper electrode configuration, it can be used as a method of geophysical prospecting.

Figure 1 shows the basic setup required to measure the induced polarization effect. The energizing current from some direct current source flows from electrode A to electrode A'. When switch  $S_1$  is opened, switch  $S_2$  is closed, and the decay of the induced polarization potential between electrodes B and B' is observed on some detecting device D. The induced polarity of the metallic mass is shown in the figure. The potential drop is from B to B' at all times.

Several publications relating to this method have appeared in the literature, the most recent of which is a paper by D. F. Bleil<sup>1</sup>. Bleil mentions other publications on the subject, and rejects most of their results. In the research discussed in this paper, only Bleil's work was referred to. All of the work was done in the laboratories

of the New Mexico Institute of Mining and Technology, Socorro, New Mexico.

The original plan was to investigate the effect of fine metallic particles disseminated in a sand matrix. It was soon discovered that disseminations up to five percent by weight gave practically no effect in clean quartz sand saturated with an electrolyte. Since the disseminated minerals found in nature are rarely as much as five percent by weight, this line of investigation was abandoned. At about the same time it was found that clays and other finely ground materials gave a pronounced induced polarization effect with no metal present. At that time Mr. Vacquier and Mr. Kintzinger undertook an investigation of this effect, while the author concentrated on a study of the effect produced by massive metallic deposits.

Bleil found that a given metallic target produced the same effect with or without pure quartz sand present in the electrolyte. This was verified in the present investigation. For convenience, all of the work discussed in this paper was done without the sand matrix.

During the initial stages of the research, all results and comparisons were taken from photographed decay curves. Two things could be readily ascertained from the photographs, 1) the comparative shapes of the decay curves 2) the maximum or peak induced polarization potential measured at time zero, when the energizing current was shut off. Using this information, a study was made of the effect produced by various numbers and sizes of steel ball targets, and the comparative effect of various mineral sample targets.

A better measurement proved to be the area under the decay curve. Collecting data in this manner, a study was made of area as a function of excitation time, excitation voltage gradient and electrolyte

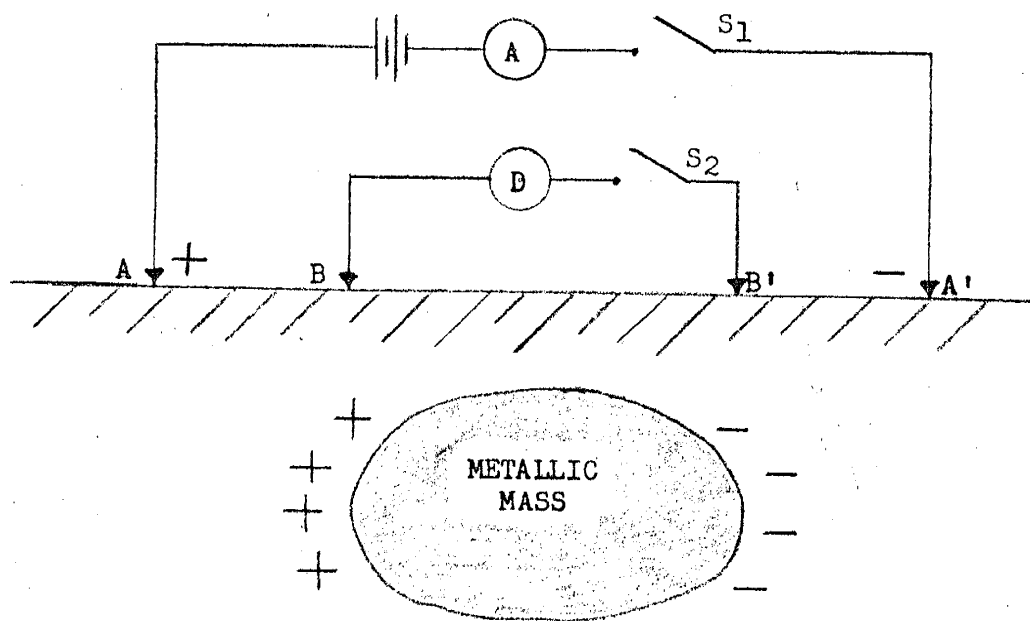


3.

resistivity, using a platinum foil target.

It was hoped that by gaining more information, the nature of the causal mechanism would be discovered. This goal was not realized, but several interesting results were obtained.

POLARIZATION OF A METALLIC MASS



D DETECTS INDUCED POLARIZATION DECAY  
A MEASURES ENERGIZING CURRENT

Fig. 1

## LABORATORY APPARATUS

The tube in which the various targets and electrolytes were placed in order to measure the induced polarization effect is shown in Fig. 2. This tube was open on top, and made of linen based bakelite. The energizing current electrodes were copper plates built into the ends of the tube. Following construction, the entire tube was soaked in hot ceresin wax. Two sizes were made, having inside cross sectional areas of 10.3 square cm. and 5.1 square cm. Both sizes were 45.1 cm. long. The detecting electrodes were small cups having a porous band 3 mm. wide on the bottom. The cups contained silver chloride paste with strips of pure silver embedded in them. The amplifier leads were clipped to these strips. The electrodes rested on top of the sample tube. These electrodes were very satisfactory, and were non-polarizing for electrolyte resistivities over about 100 ohm-cm. The bakelite tubes were also quite satisfactory, and were used with the above electrodes for all of the work described in this paper. The detecting electrodes were used at separations of 25 cm. and 10 cm.

A Model 205 Alinco Amplifier having an input impedance of 10,000 ohms was used together with a high input impedance pre-amplifier with a regulated power supply. This combination was later replaced

SAMPLE TUBE

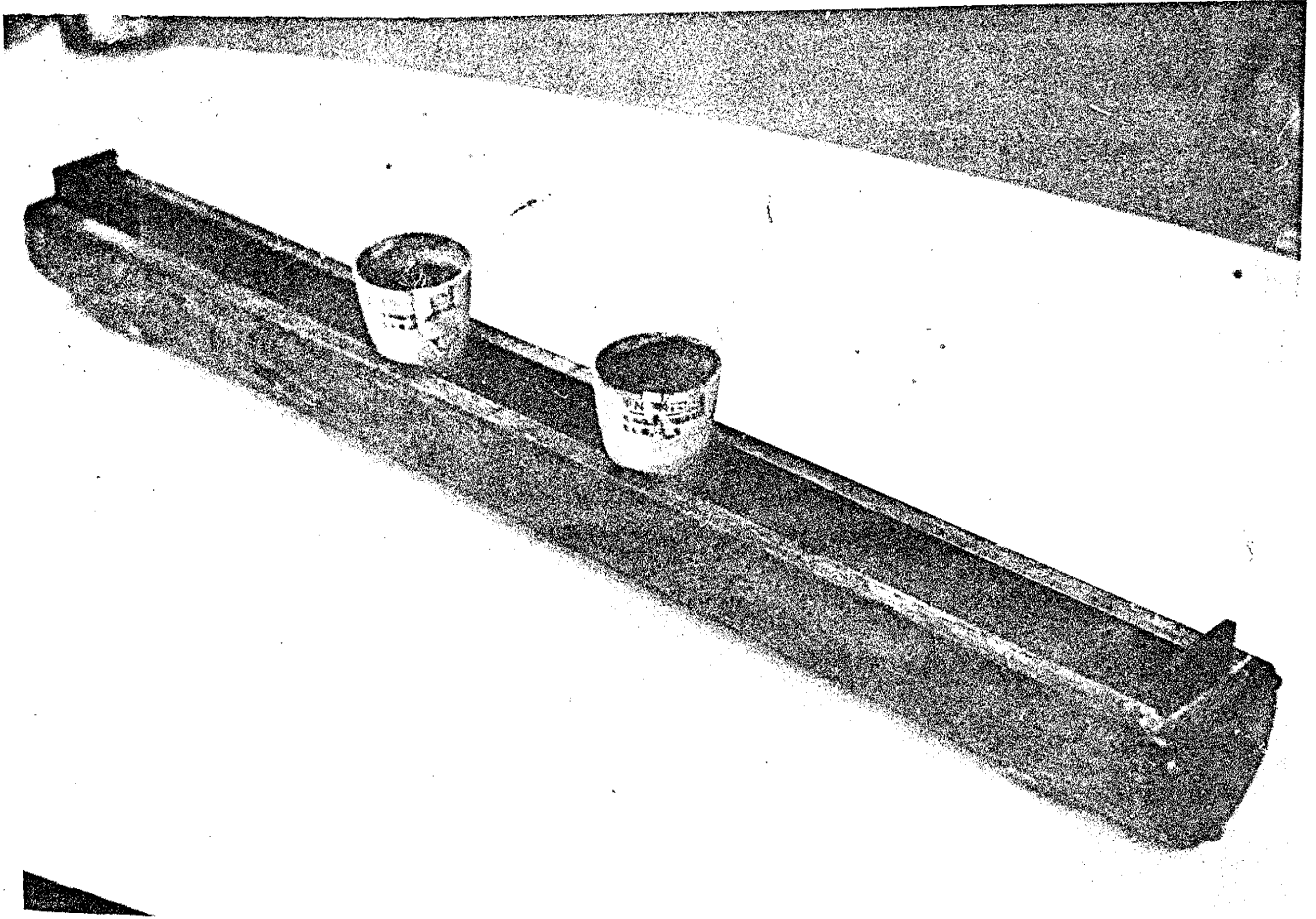


Fig. 2

by an American Electronics Laboratory Model 251A Wide Band Direct Coupled Amplifier with pre-amplifier. The power for these units was supplied by an American Electronics Laboratory Model 351 Dual Regulated Power Supply.

It was found that whenever there was a sample in the tube, a small potential existed between the detecting electrodes. In order to have zero input into the amplifier when there was no induced polarization potential, this small potential was balanced out. This was done by putting a variable potential device in series with the amplifier input.

An oscilloscope was modified so that the amplifier output could be applied directly to the deflection plates of the cathode ray tube. At first, data were recorded by photographing the decay curve on the oscilloscope screen with a Fairchild Polaroid Oscilloscope Camera. The Polaroid film was a considerable advantage since it could be developed for observation in one minute. A rough estimate of the peak induced polarization potential and of the time constant of the decay could be obtained directly from the photograph. Due to the non-linearity of the sweep, the area under the curve could only be obtained by plotting the decay curve on graph paper and using a planimeter. This was a laborious and time consuming job. Since the decay curves were all very similar in appearance, it was decided that the area under the curve was the best measurement to use for comparative purposes. The photographs were not well suited for this, so a new method of measurement was devised. The amplified signal was sent to an integrator, which contained a circuit that integrated the area under the curve. The output of the integrator was then

recorded on an Esterline Angus recorder. A key was used to short the integrator output when no induced polarization or calibration potentials were being measured. This method proved to be very convenient for measuring the area under the decay curve.

Fig. 3 is a block diagram of the final laboratory apparatus and Fig. 4 is a photograph of the equipment. The control box contained: 1) two 45 volt batteries used as the energizing voltage supply 2) the device used to null the amplifier input 3) two capacitors used to calibrate the Esterline Angus 4) two known constant voltage sources, used to calibrate the Esterline Angus and the oscilloscope picture 5) the two position switch which opened the detecting circuit when the energizing voltage was applied 6) a switch which shorted the milliammeter out of the detecting circuit 7) plugs for the Volt-Ohmyst which was used to measure the potential drop between the detecting electrodes, and 8) a potentiometer for controlling the energizing voltage.

To minimize 60 cycle interference, all of the equipment was enclosed in iron boxes, shielded cable was used for all leads between separate units, and the volt-Ohmyst was disconnected when not in use.

Electrolyte resistivities were measured with a conductivity cell and an impedance bridge. The resistivity of the sample could also be calculated from the expression:

$$\rho = R \frac{A}{l} = \frac{V}{I} \frac{A}{l} \quad (1)$$

A = cross sectional area of the sample tube in cm.<sup>2</sup>

l = length of the sample tube in cm.

R = resistance of the sample in the tube in ohms

V = potential drop across the tube in volts

$I$  = current through the sample in amperes

$\rho$  = resistivity of the sample in ohm-cm.

Both methods were used, and the agreement was within 5% in all cases.

The pH of the electrolytes was measured with a Beckman Model G pH Meter.

DIAGRAM OF THE APPARATUS

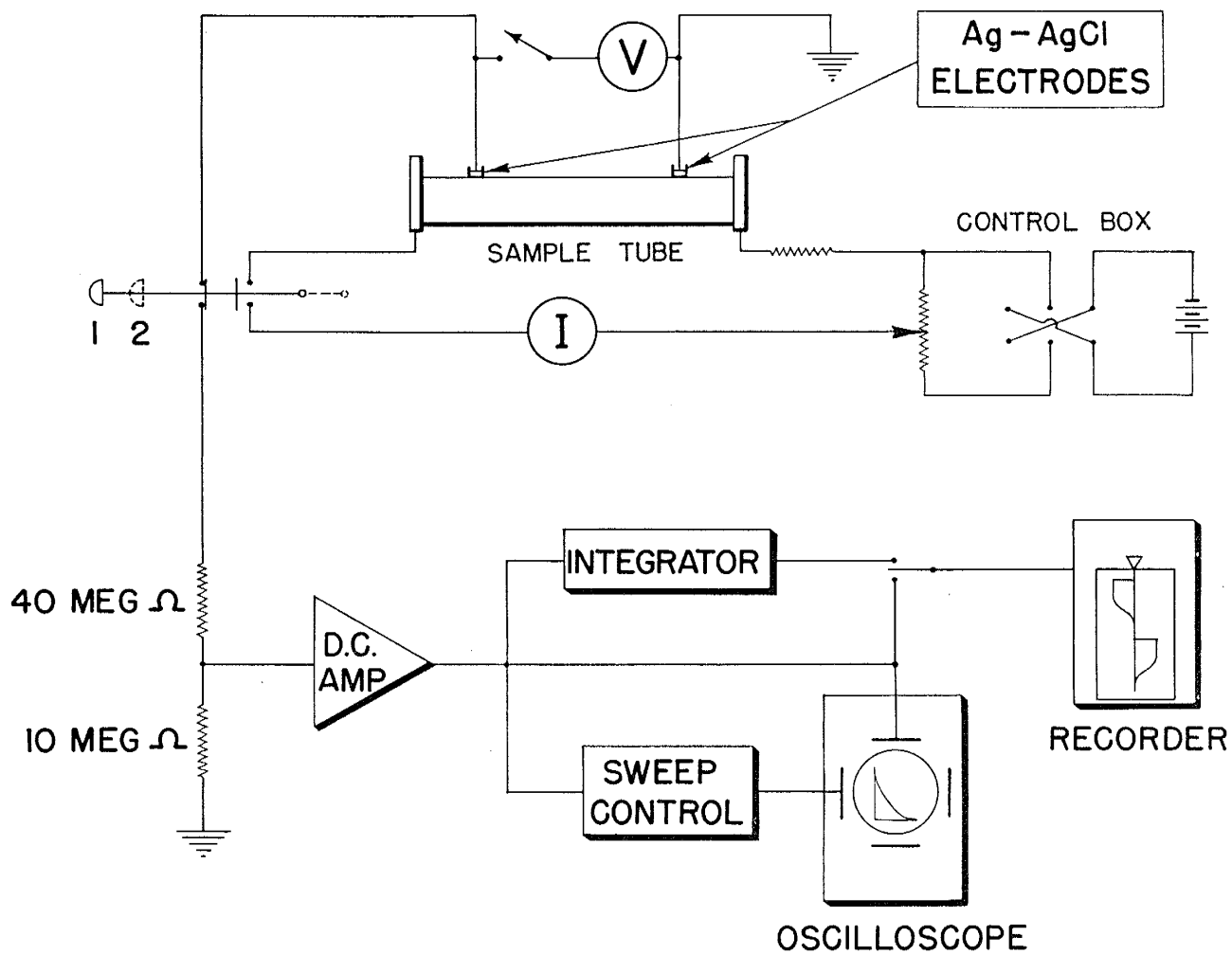


Fig. 3



LABORATORY APPARATUS

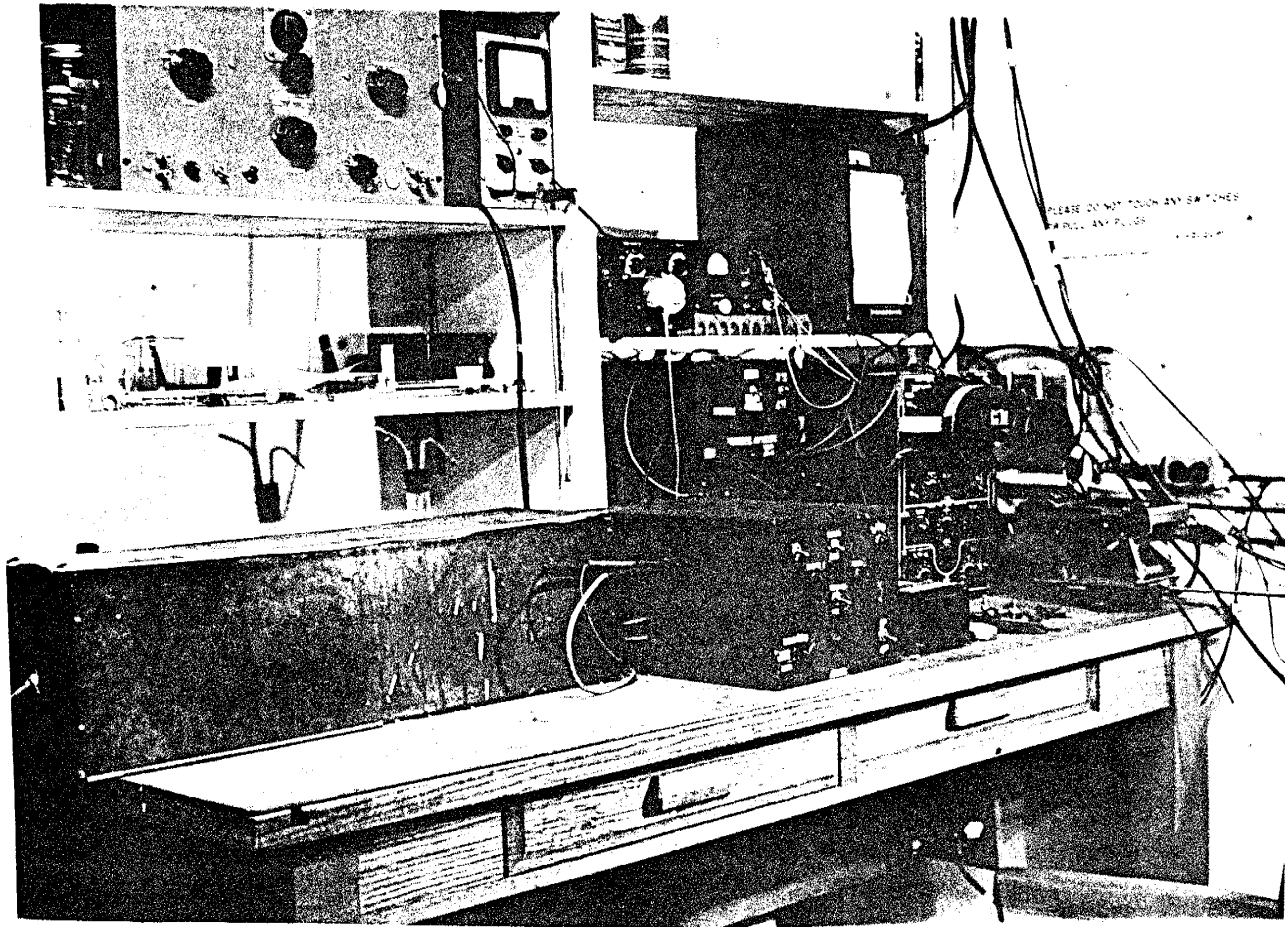


Fig. 4

## PROCEDURE AND RESULTS

### Peak Induced Polarization Potential

The peak induced polarization potential of different numbers of equal sized targets was investigated. The targets were polished steel balls,  $3/8$  inch in diameter. The electrolyte was tap water having a resistivity of 3100 ohm-cm., and the energizing current was applied for five seconds. The detecting electrodes were 25 cm. apart, and potential drop between them was .5 volt when the energizing current was being applied. One ball was centered in the tube between these electrodes, and the peak induced polarization potential measured. The same experiment was repeated for two balls, four balls and eight balls evenly distributed between the detecting electrodes. The peak induced polarization potential was directly proportional to the number of balls used. The same experiment was repeated with the potential drop between the detecting electrodes raised to one volt, and the same results were obtained. When the effect of two balls was measured at separations of two inches and four inches, the results were the same. These curves are shown in Fig. 5.

The peak induced polarization potential of polished steel balls

of different diameters was measured. The diameters ranged from 1/8 inch to 3/4 inch. The electrolyte was tap water having a resistivity of 3400 ohm-cm. The voltage drop between the detecting electrodes was one volt, and the energizing current was applied for five seconds. The detecting electrodes were separated by 25 cm. The measurements were made with one ball centered in the tube. A plot of ball diameter vs peak induced polarization potential is shown in Fig. 6. These points were also plotted on logarithmic graph paper. The last four points fell on a straight line, indicating an exponential relationship for diameters over about .35 of an inch. If  $d$  is the steel ball diameter in inches, and  $E_m$  the maximum induced polarization potential in millivolts, then the relationship is reasonably well expressed by  $E_m = 13.2 d^{2.2}$ . The exponent 2.2 indicates that  $E_m$  is not directly proportional to area ( $E_m \propto d^2$ ) or volume ( $E \propto d^3$ ), but may be some combined effect. A 3/4 inch brass ball was used as a target under the same conditions, and the effect was equal to that of the 3/4 inch steel ball within the limits of experimental error.

The measurements given in Fig. 5 and Fig. 6 may be distorted, since the high impedance pre-amplifier was not installed when the data were recorded. However, the character of the results was not affected.

An investigation was made into the effect produced by several different metallic targets. The targets used were: 1) 1/2 inch polished steel ball 2) chunk of pyrite ( $Fe S_2$ ), .78 cubic cm. in volume 3) chunk of galena ( $PbS$ ), .66 cubic cm. in volume 4) chunk of magnetite ( $Fe_3 O_4$ ), 1.8 cubic cm. in volume 5) a wax cylinder

PEAK INDUCED POLARIZATION POTENTIAL  
vs  
NUMBER OF 3/8 INCH STEEL BALL TARGETS

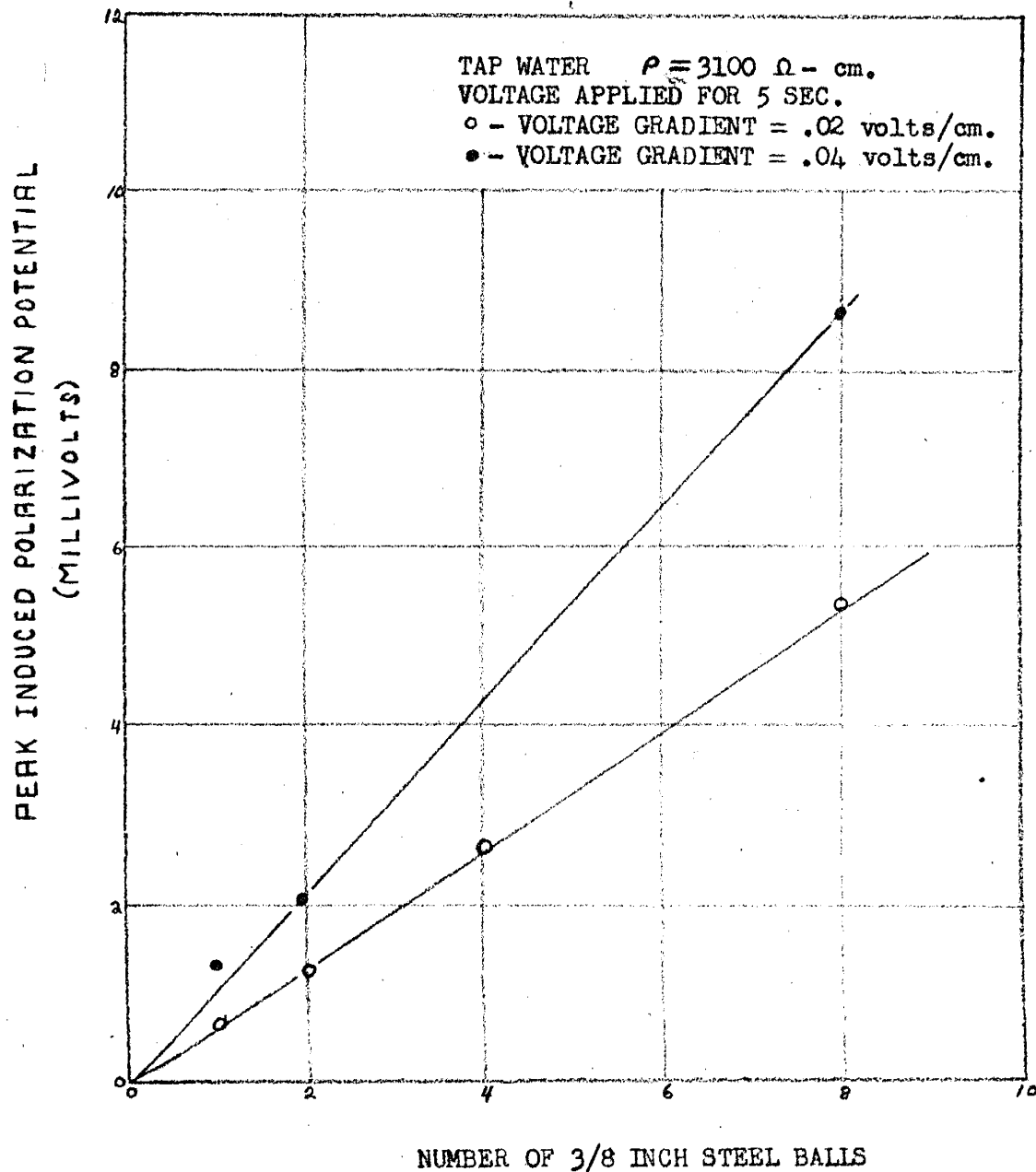


Fig. 5.

PEAK INDUCED POLARIZATION POTENTIAL  
VS  
STEEL BALL DIAMETER

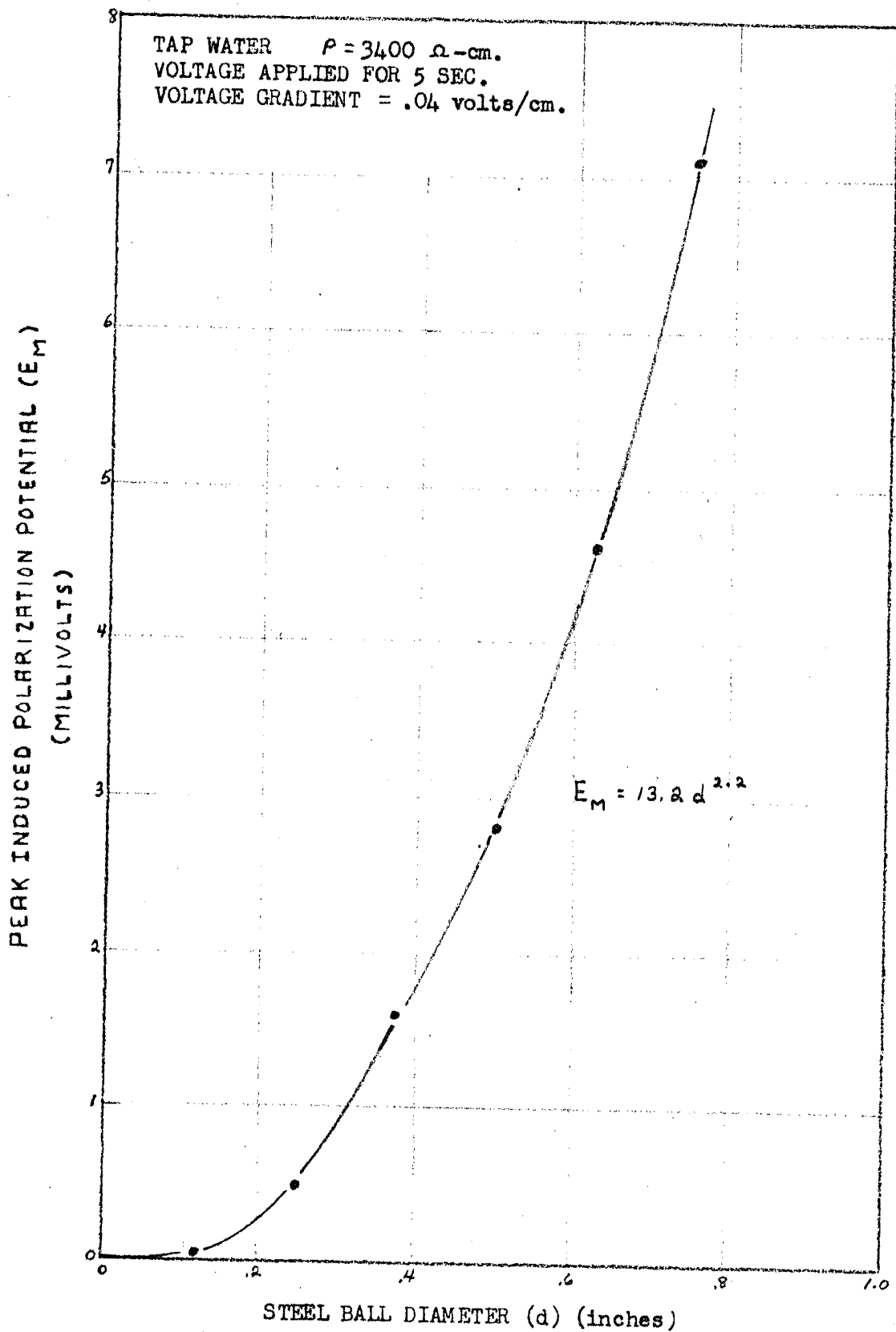


Fig. 6

TABLE 1

ELECTROLYTE	RESISTIVITY ohm-cm.	$\frac{1}{2}$ " steel ball	PEAK INDUCED POLARIZATION POTENTIAL			
			pyrite	galena	magnetite	platinum foil cylinder
Na Cl in H <sub>2</sub> O	600	8.4	10.0	9.8	0	11.7
Na Cl in H <sub>2</sub> O	2750	17.7	20.4	15.6	*	26.2
Na Cl in H <sub>2</sub> O	4300	22.7	29.6	20.5	5.2	57.7
Tap Water (25° C)	2900	19.2	18.3	17.1	*	29.2
Tap Water (38° C)	2100	16.4	15.4	14.2	*	25.6

100

Target Volumes (cc)                      1.1                      .78                      .66                      1.8                      1.44

Excitation Voltage Gradient of .04 volts/cm. applied for 5 seconds

\* Too small to be measured

PEAK INDUCED POLARIZATION POTENTIALS OF VARIOUS METALLIC TARGETS

wrapped in one layer of platinum foil, having a volume of 1.44 cubic cm., a length of  $\frac{1}{2}$  inch and a diameter of  $\frac{1}{2}$  inch. The thickness of the foil was .001 inch. The pre-amplifier was installed before this work began. The sample tube was filled with the electrolyte, and the decay curve was photographed for each of the targets centered in the tube. The results of these experiments are shown in Table 1, where the peak induced polarization potentials are tabulated for each target, along with the electrolyte and its resistivity. The results shown in the table are fairly consistent, and indicate that the effect increases with resistivity. The magnetite produced very little effect, despite the fact that it was the largest target used and the conductivity of magnetite is greater than pyrite. Other magnetite targets gave the same result, even after they were fractured to expose a fresh surface. The reason for this is not known, but this fact indicates that the effect depends on a property of the surface of the electronically conducting substance, and not just on its electrical conductivity. Tap water produced a larger effect at 25° C than at 38° C, probably because of the difference in resistivities, and not the temperature difference.

#### Shape of the Decay Curve

The same photographs used in the work just discussed were used to analyze the decay curves. The curves were compared by visual inspection and by superposing one curve on another. From the beginning, they looked very similar. Subsequent analysis verified this impression, and indicated that all of the decay curves might

be represented by the same general equation. A machinists microscope was used to determine the co-ordinates of a number of points on three of these curves. The photographs were mounted on a movable table under the microscope, and the displacement of the table was read directly from a scale. A plot of these curves is shown in Figs. 8, 9 and 10. As was expected, the points did not plot a straight line on logarithmic graph paper. The procedure used to find an equation to fit the data, was as follows. 1) An equation having unknown parameters, was assumed. 2) A number of points were selected from the original data, equal to the number of unknown parameters in the assumed equation. 3) These values were inserted in the assumed equation, and the resulting equations were solved simultaneously for the unknown parameters. 4) Various decay times ( $t$ ) were selected and used in this equation to solve for the induced polarization potential ( $E$ ). 5) These values were compared to the values taken from the curve. In this manner it was discovered that an equation of the form

$$E = \frac{1}{a+bt^c} \quad (2)$$

would fit all of the curves. The equations with their empirically determined parameters are shown on each graph. To simplify the solution of the three equations, the point  $t = 0$  was one of the three points used to determine these parameters. Thus:

$$a = \frac{1}{E_m} \quad (3)$$

where  $E_m$  is the peak induced polarization potential. The use of some other point would probably have given a slightly better fit, since the point  $(0, E_m)$  was the most difficult to measure accurately. It can be observed that as the resistivity of the electrolyte increases,  $b$  decreases and  $c$  increases. The fact that  $E_m$  (or  $\frac{1}{a}$ ) increases



with resistivity was mentioned before. It is interesting to note that if  $c$  is divided by the square root of the resistivity, about the same constant is obtained in all three cases. That is,  $c = k\sqrt{\rho}$ , where  $\rho$  is the resistivity of the electrolyte, and in this case  $k = .018$ . Since only three curves were analyzed, no attempt was made to draw any further conclusions from these equations. It was found that the equation

$$E = \frac{A}{(B+t)^K} \quad (4)$$

also fit the data fairly well, but not as well as expression (2).

The time constant ( $t_e$ ) defined as  $\frac{E_m}{e}$ ,  $e$  being the base of natural logarithms, was determined for each of the three curves. The value of  $t_e$  is recorded on each graph, and it can be seen that  $t_e$  decreases as the resistivity increases.

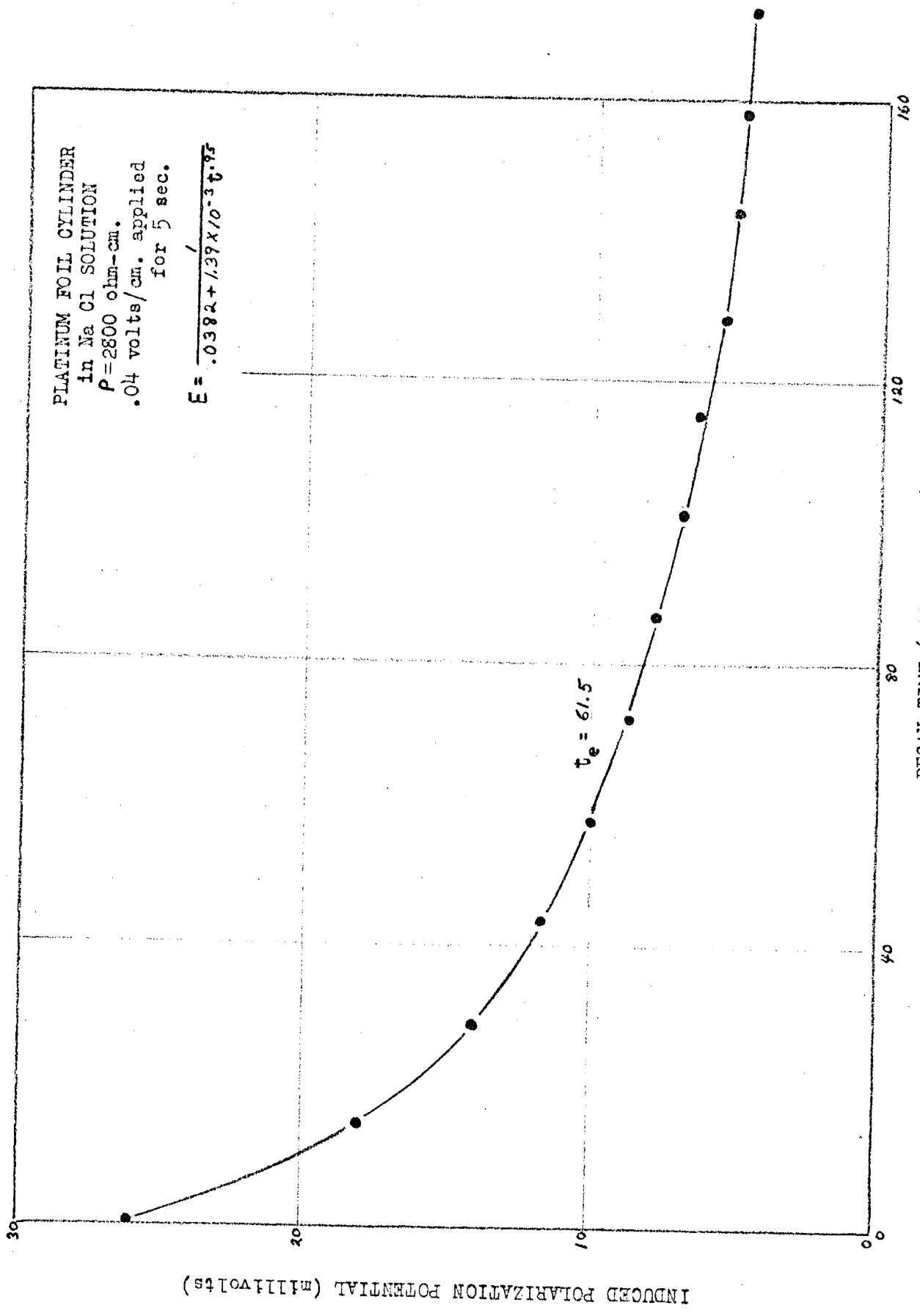
#### Area Under the Decay Curve

Some of the previous experiments were repeated with other equipment, measuring the area under the decay curve. When this was done, inconsistent results began to appear in the area measurements. When a steel ball or mineral sample was used as a target, the area increased if the target was left in the electrolyte. This made accurate comparative measurements of area practically impossible for those targets. In the previous work, only small inconsistencies were noticed in the measurement of peak induced polarization potential but in the area measurements, the change was considerable. In one case, the effect of a 3/4 inch steel ball was found to increase by a factor of three in 15 minutes. This indicated that the change was due to an increase

INDUCED POLARIZATION POTENTIAL  
 vs  
 DECAY TIME

PLATINUM FOIL CYLINDER  
 in Na Cl SOLUTION  
 $P = 2800$  ohm-cm.  
 $.04$  volts/cm. applied  
 for 5 sec.

$$E = \frac{1}{.0382 + 1.39 \times 10^{-3} t_e}$$



DECAY TIME (milliseconds)

Fig. 7

INDUCED POLARIZATION POTENTIAL  
vs  
DECAY TIME

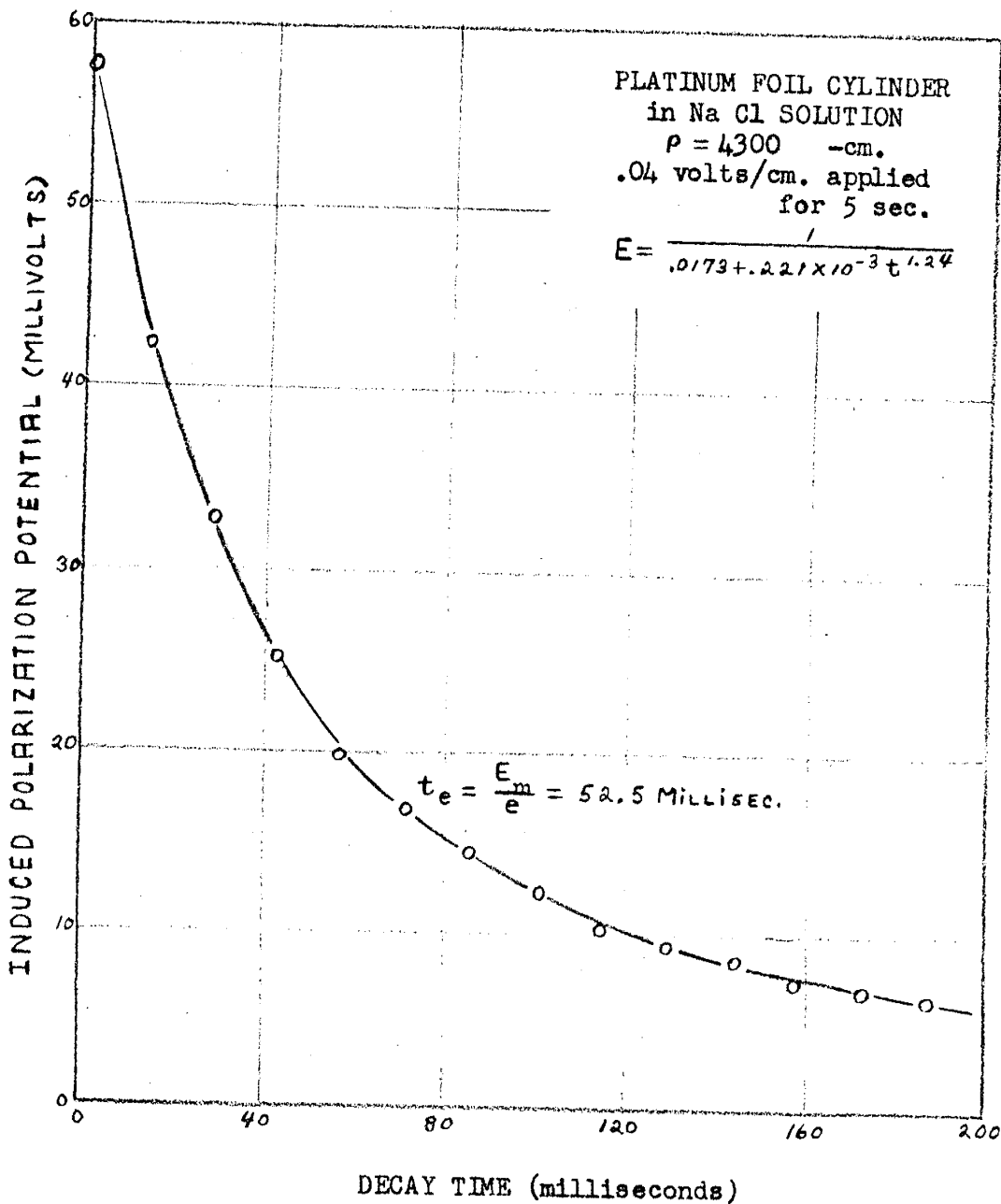
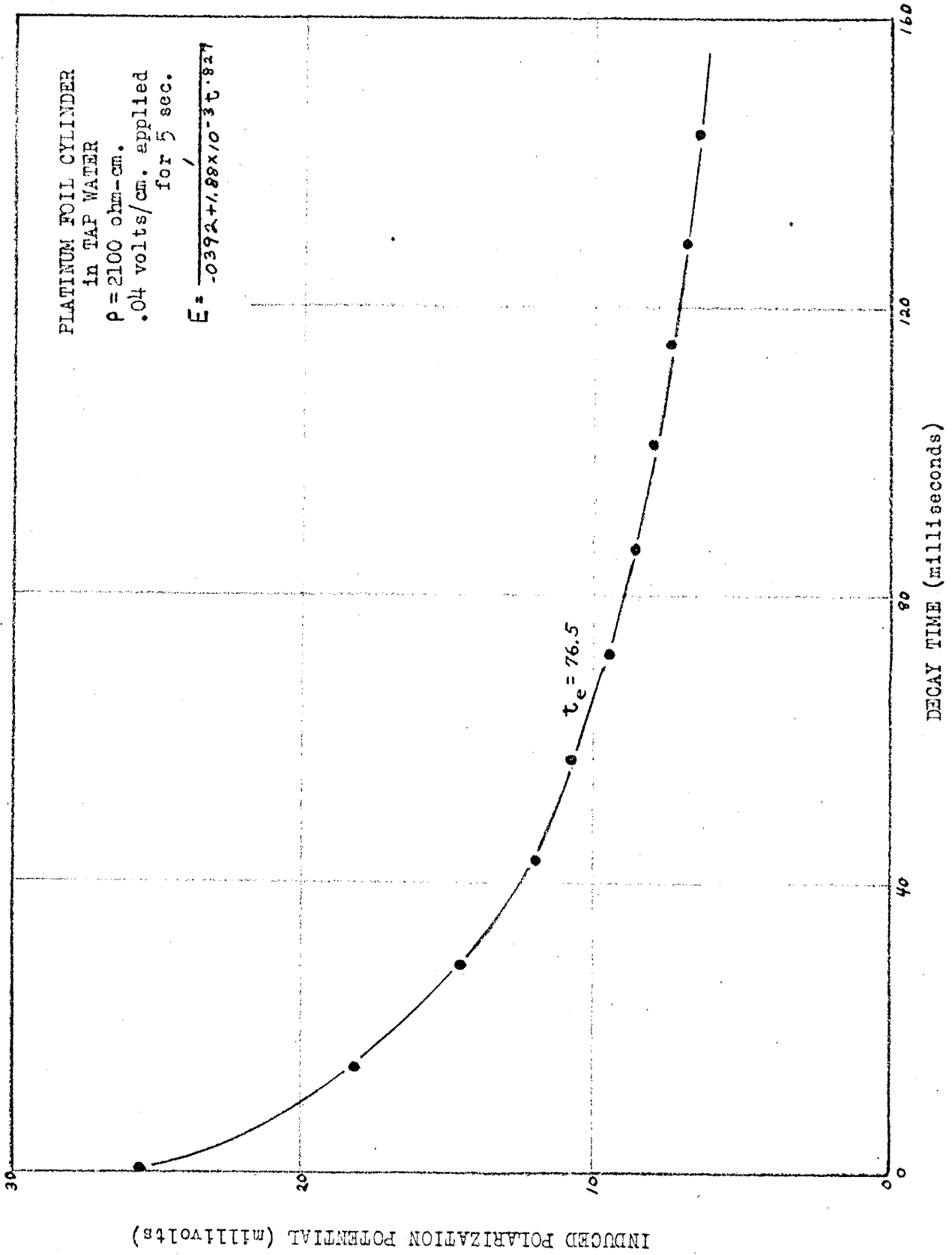


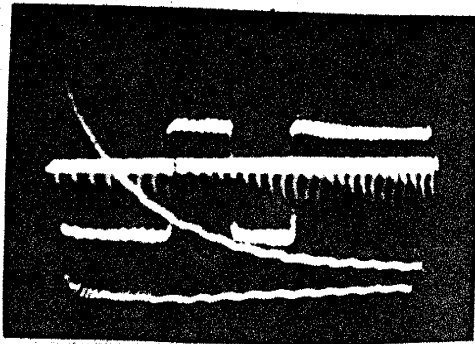
Fig. 8

INDUCED POLARIZATION POTENTIAL  
vs  
DECAY TIME

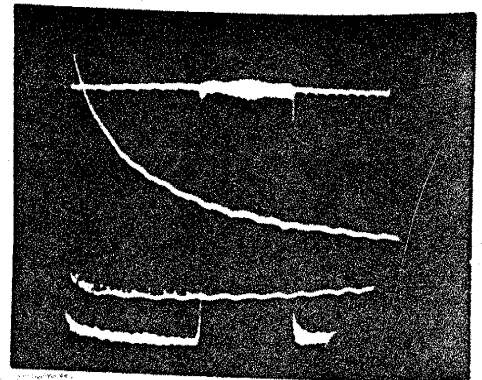


TYPICAL OSCILLOGRAPHES OF INDUCED POLARIZATION DECAY

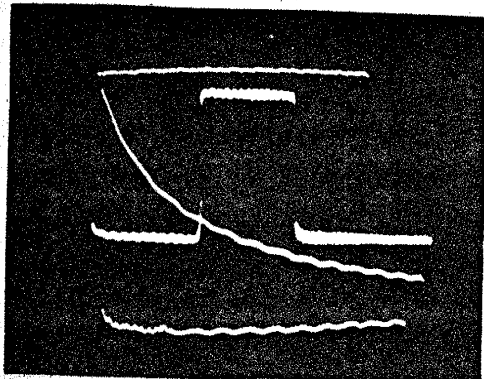
ENERGIZING VOLTAGE OF .01 volts/cm. APPLIED FOR 5 sec.



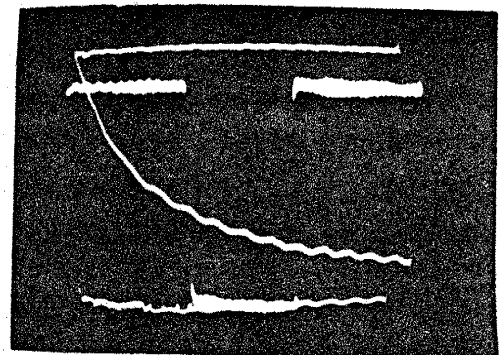
PYRITE IN Na Cl SOLUTION  
 $\rho = 4300$  ohm-cm.



GALENA IN TAP WATER  
 $\rho = 2100$  ohm-cm.



PLATINUM FOIL CYLINDER  
IN TAP WATER  
 $\rho = 2100$  ohm-cm.



$\frac{1}{2}$ " STEEL BALL  
IN Na Cl SOLUTION  
 $\rho = 2800$  ohm-cm.

Fig. 10

all along the decay curve, but not a large increase in the initial peak induced polarization potential.

#### Area as a Function of Excitation Time

Another measurement that might lead to the discovery of the mechanism causing induced polarization is the relations between excitation time and the area under the decay curve, and how chemically different electrolytes influence this relationship.

Fortunately, the effects from the platinum foil cylinder did not change with time. In the remainder of the work described here, the platinum foil cylinder was the only target used, and the word area refers to the area under the decay curve. The A.E.L. amplifier, pre-amplifier and power supply were used in obtaining the data.

The electrolytes used in this study ranged from 500 to 15,000 ohm-cm. in resistivity. This range was selected because it is the range likely to be encountered in field work and because the effect produced by these resistivities was large enough to be conveniently measured with the laboratory equipment used. Varying amounts of sodium chloride, hydrochloric acid, magnesium sulfate and sodium hydroxide were dissolved in distilled water to get different electrolytes having a range of resistivities. Salt water was chosen as an electrolyte since it is commonly found in nature. Hydrochloric acid and sodium hydroxide were used to represent an acid and a base having chlorine and sodium ions present. Magnesium sulfate was chosen to represent a neutral solution with low mobility magnesium ions. Tap water was also used. Table 2 gives a list of these electrolytes along with the

TABLE 2

CHEMICAL NATURE OF THE ELECTROLYTE	RESISTIVITY ohm-cm.	pH
	1100	7.0
	2000	6.8
Sodium Chloride in Distilled Water	3400	7.1
	7400	6.9
	11,100	6.9
	1400	2.8
	3200	3.3
Hydrochloric Acid in Distilled Water	5200	3.4
	7800	3.7
	11,700	3.9
	2800	6.7
Magnesium Sulfate in Distilled Water	5400	6.7
	10,000	7.0
	6500	9.6
Sodium Hydroxide in Distilled Water	15,000	9.8
Tap Water	3200	8.2

THE ELECTROLYTES

resistivity and pH of each.

The platinum cylinder was centered in the sample tube half way between the detecting electrodes, which were 10 cm. apart. The time of application of the energizing current was measured with a stop watch.

The data obtained in these experiments are shown in Figs. 11 to 14. Inspection of these graphs makes it clear that the area increases with time and that the relationship is not linear. The curves also indicate that some saturation value of area is approached as the application time increases, and that this saturation value is approached more rapidly for lower resistivities.

It is difficult to draw many conclusions from a qualitative comparison of the curves. An attempt to reduce all of the curves on one graph to one curve by multiplying by some simple function of resistivity was unsuccessful. Furthermore, the curves did not plot in a straight line on logarithmic graph paper. However, further analysis led to the discovery that the curves could be represented by an equation of the form:

$$A = \frac{t}{b+at} \quad (5)$$

A = area under the decay curve

t = time of application of the energizing current

a and b are empirically determined positive constants.

The verification of the above equation for all the curves was achieved by plotting  $\frac{1}{A}$  vs  $\frac{1}{t}$  for each curve, and noting that the plots lie on a straight line. It is obvious that this is adequate verification when (5) is rewritten:

$$\frac{1}{A} = a + \frac{b}{t} \quad (6)$$



AREA UNDER DECAY CURVE  
vs  
EXCITATION TIME

Na Cl in H<sub>2</sub>O  
EXCITATION VOLTAGE GRADIENT  
= .5 volts/cm.

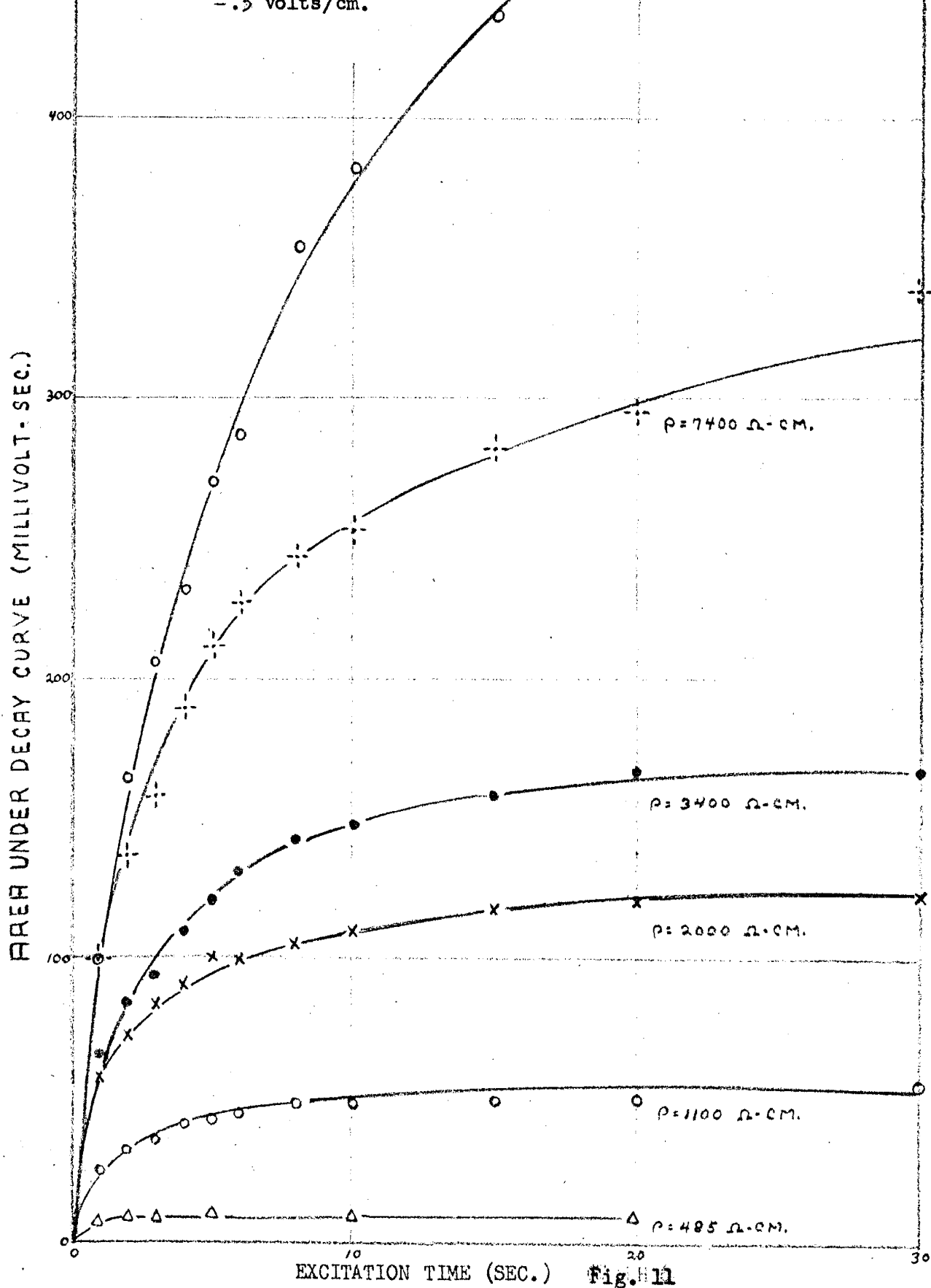
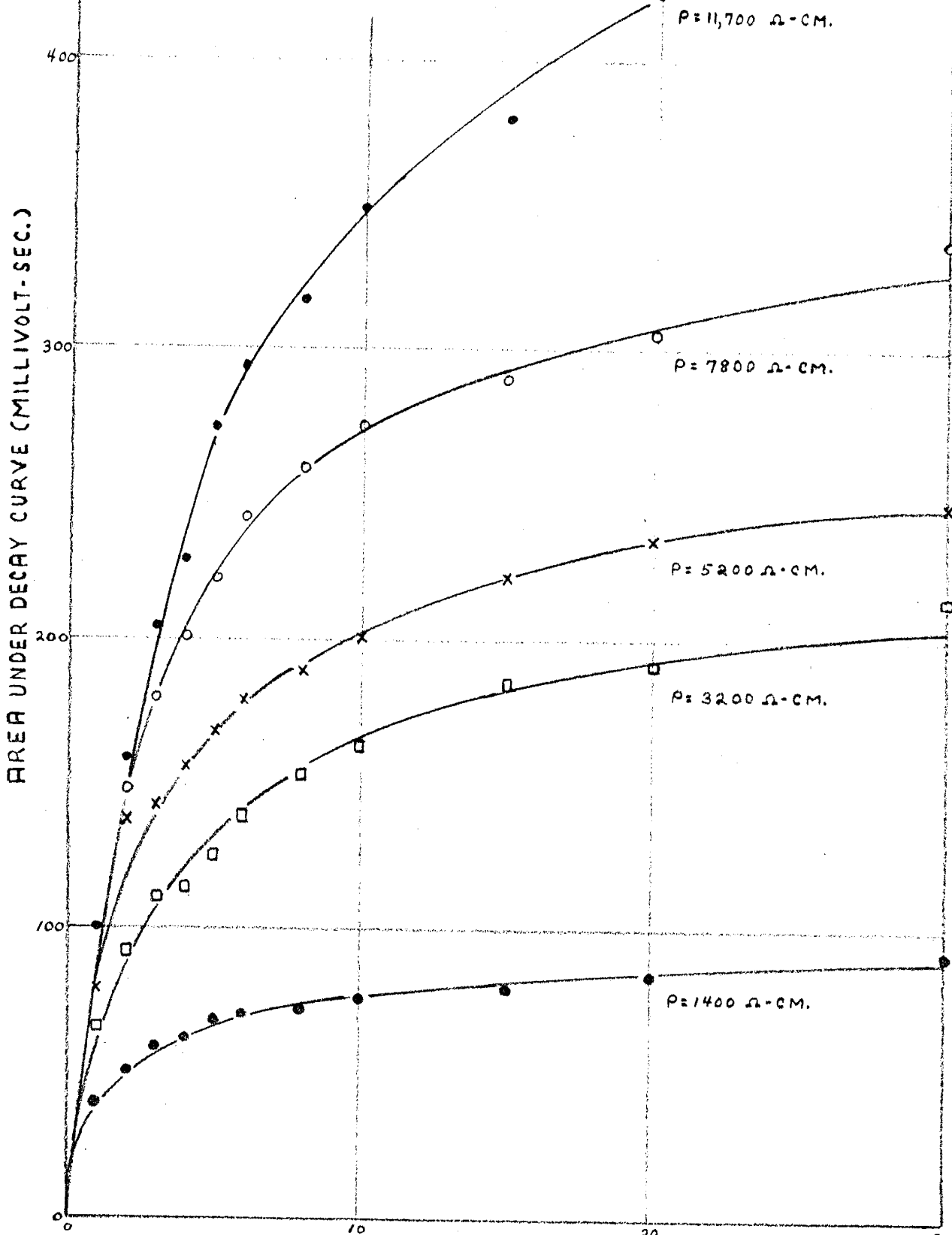


Fig. 11

AREA UNDER DECAY CURVE  
vs  
EXCITATION TIME

H Cl in H<sub>2</sub>O  
EXCITATION VOLTAGE GRADIENT  
= .5 volts/cm.



EXCITATION TIME (SEC.) Fig. 12

AREA UNDER DECAY CURVE

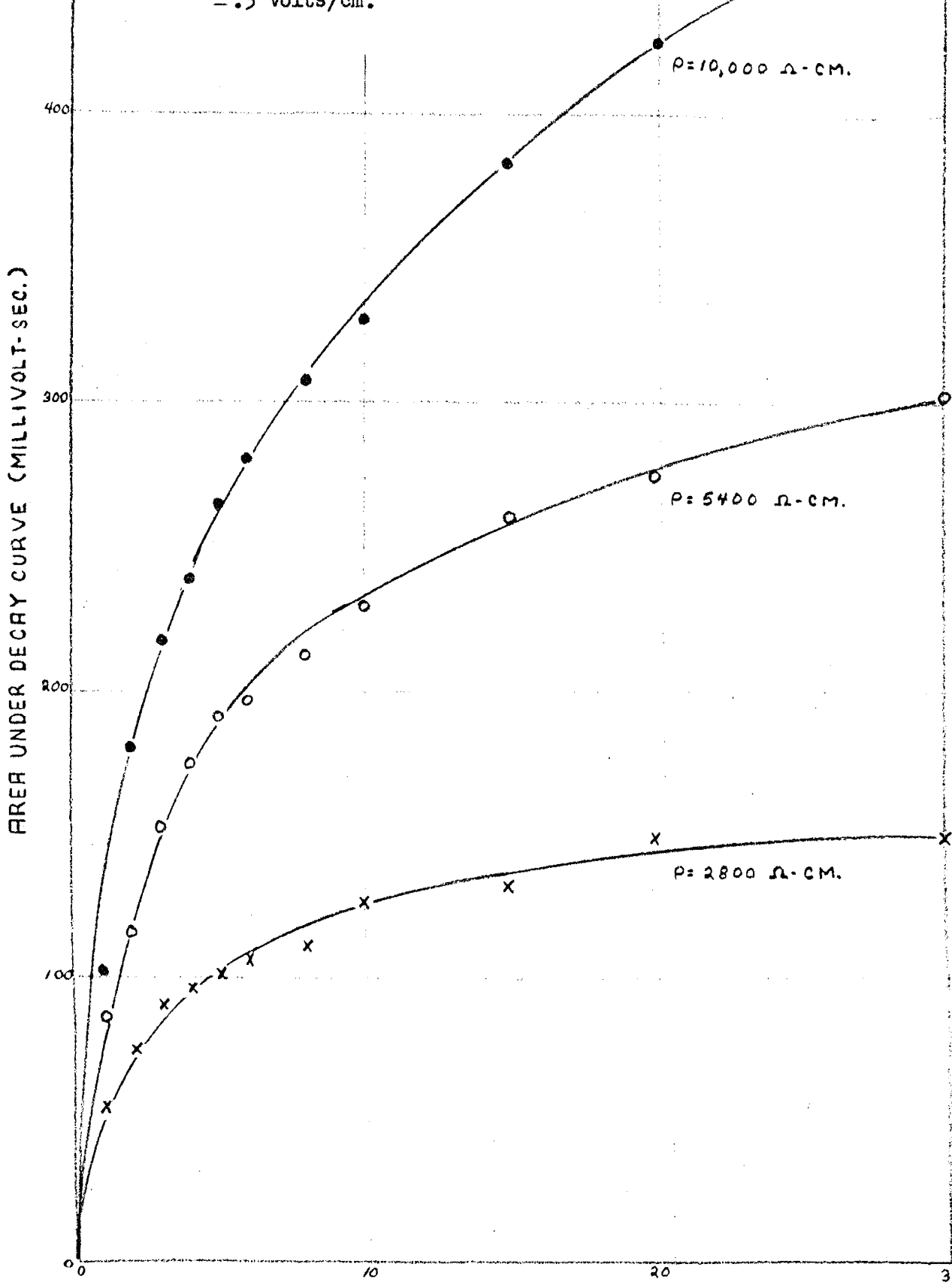
vs

EXCITATION TIME

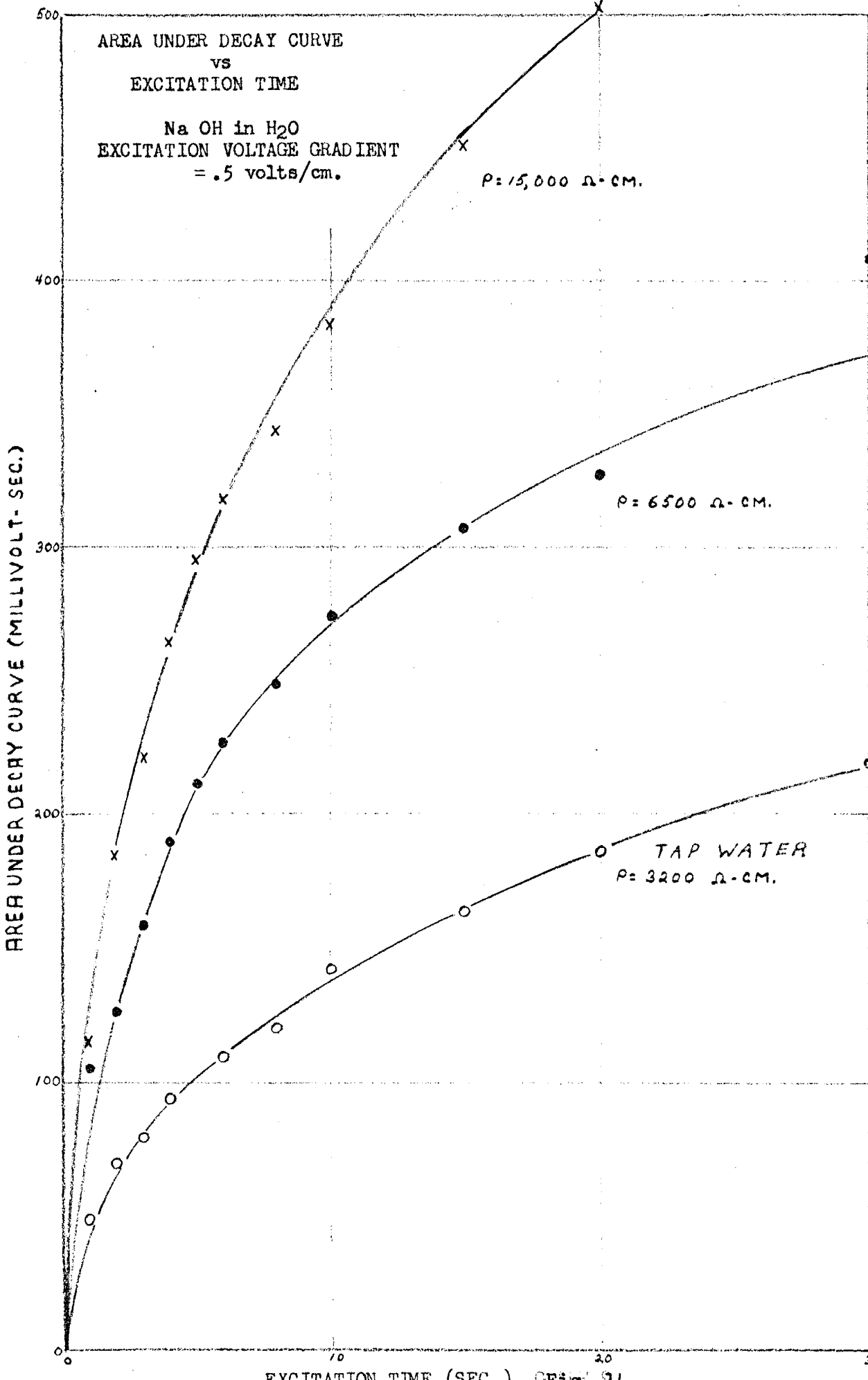
Mg SO<sub>4</sub> in H<sub>2</sub>O

EXCITATION VOLTAGE GRADIENT

= .5 volts/cm.



EXCITATION TIME (SEC.) (Fig. 13)



The points at  $t = 1$  and  $t = 2$  did not consistently fall on the straight lines. This may have been due to the fact that the percent error was large in measuring these short times with a stop watch.

The parameters  $a$  and  $b$  were obtained from the above plots,  $a$  being the slope of the line and  $b$  the ordinate intercept. Multiplying  $a$  by the resistivity yielded roughly the same number in every case, which implied that  $a = \frac{k}{\rho}$ , where  $\rho$  is the resistivity. In this case,  $k$  was about 17. From equation (5) it is evident that  $A \rightarrow \frac{1}{a}$  as  $t \rightarrow \infty$ , in which case the saturation value of  $A$  is  $\frac{\rho}{k}$ . Thus if equation (5) is true for all positive values of  $t$ , then  $A$  is directly proportional to  $\rho$  at saturation.

The parameter  $b$  also decreased as the resistivity increased, but no simple relationship relating  $b$  and  $\rho$  was discovered.

#### Area as a Function of Voltage Gradient Across the Target

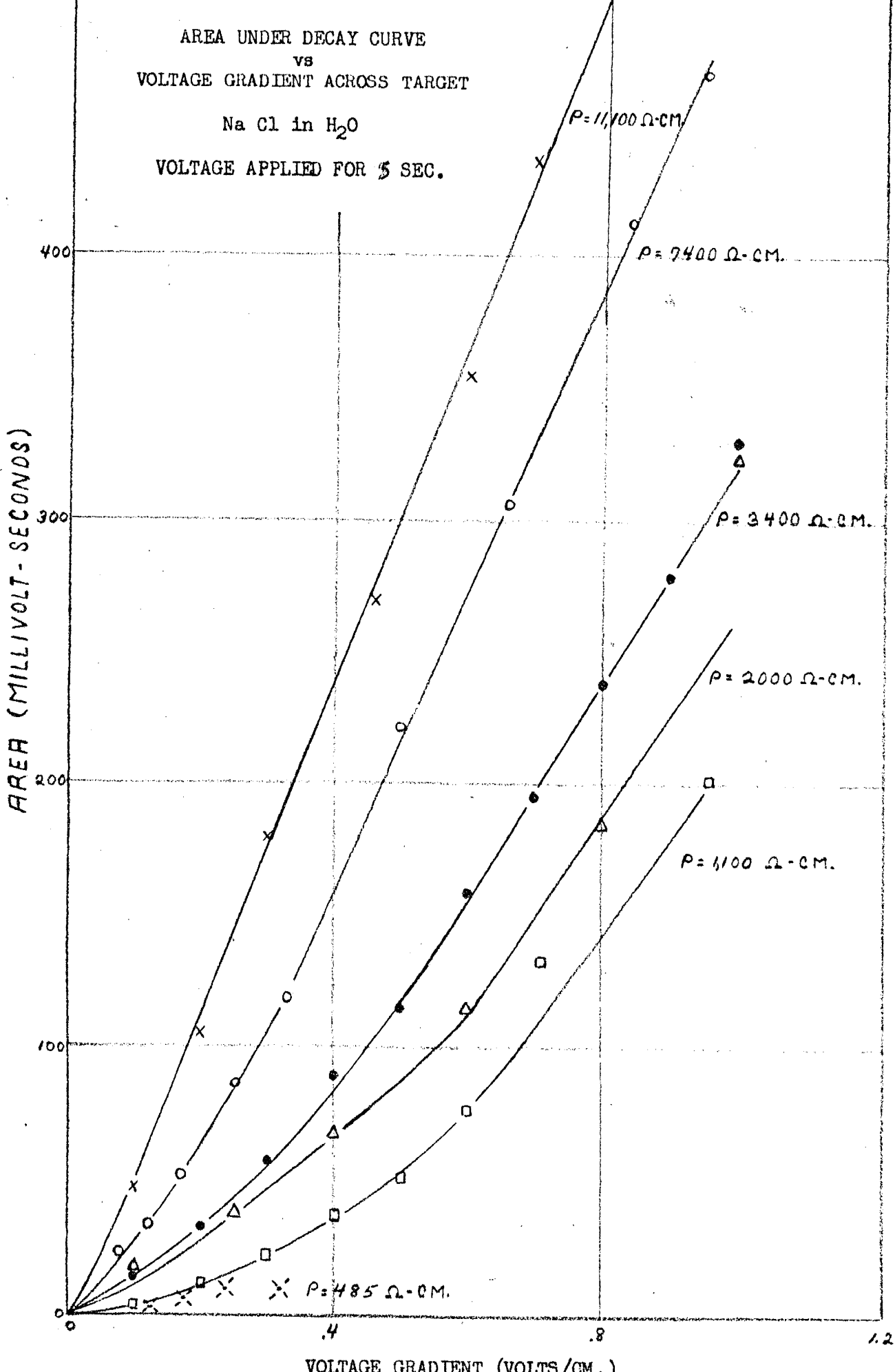
Another study was undertaken concurrently with the one just discussed. The purpose was to discover the relationship between area and the applied voltage gradient across the target, and how the various electrolytes of different resistivities affected this relationship. These data are plotted in Figs. 15 through 19. Each graph represents one particular electrolyte chemically, and shows the effect produced by various resistivities. The electrolytes were the same as those used in the previous study of energizing current as a function of area.

For the data shown on Figs. 15 through 18, the time of application

AREA UNDER DECAY CURVE  
vs  
VOLTAGE GRADIENT ACROSS TARGET

Na Cl in H<sub>2</sub>O

VOLTAGE APPLIED FOR 5 SEC.



AREA UNDER DECAY CURVE  
vs  
VOLTAGE GRADIENT

$Mg\ SO_4$  in  $H_2O$

VOLTAGE APPLIED FOR 5 SEC.

$\rho = 10,000\ \Omega\text{-CM.}$

$\rho = 5400\ \Omega\text{-CM.}$

$\rho = 2800\ \Omega\text{-CM.}$

AREA UNDER DECAY CURVE (MILLIVOLT-SECONDS)

400

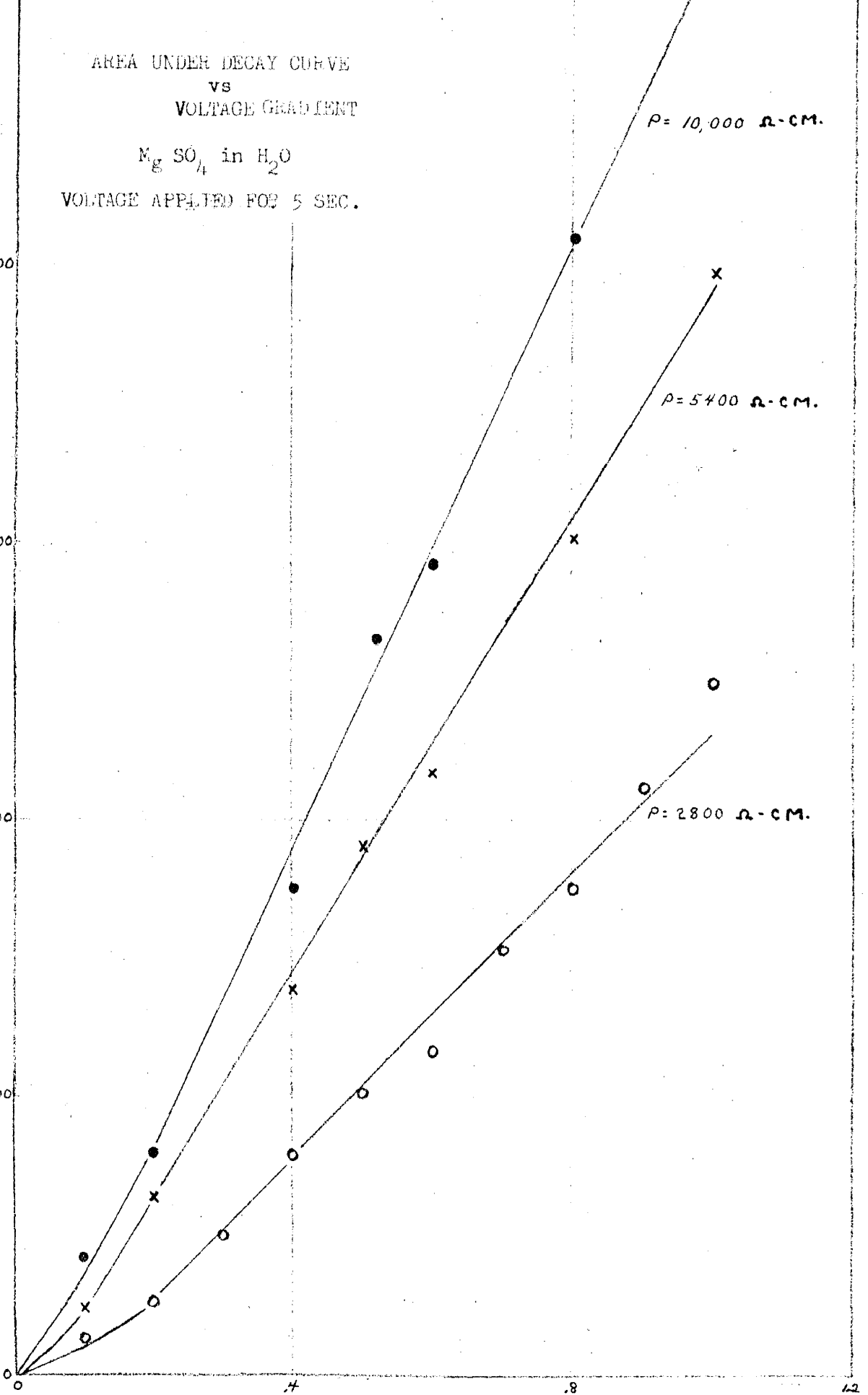
300

200

100

0

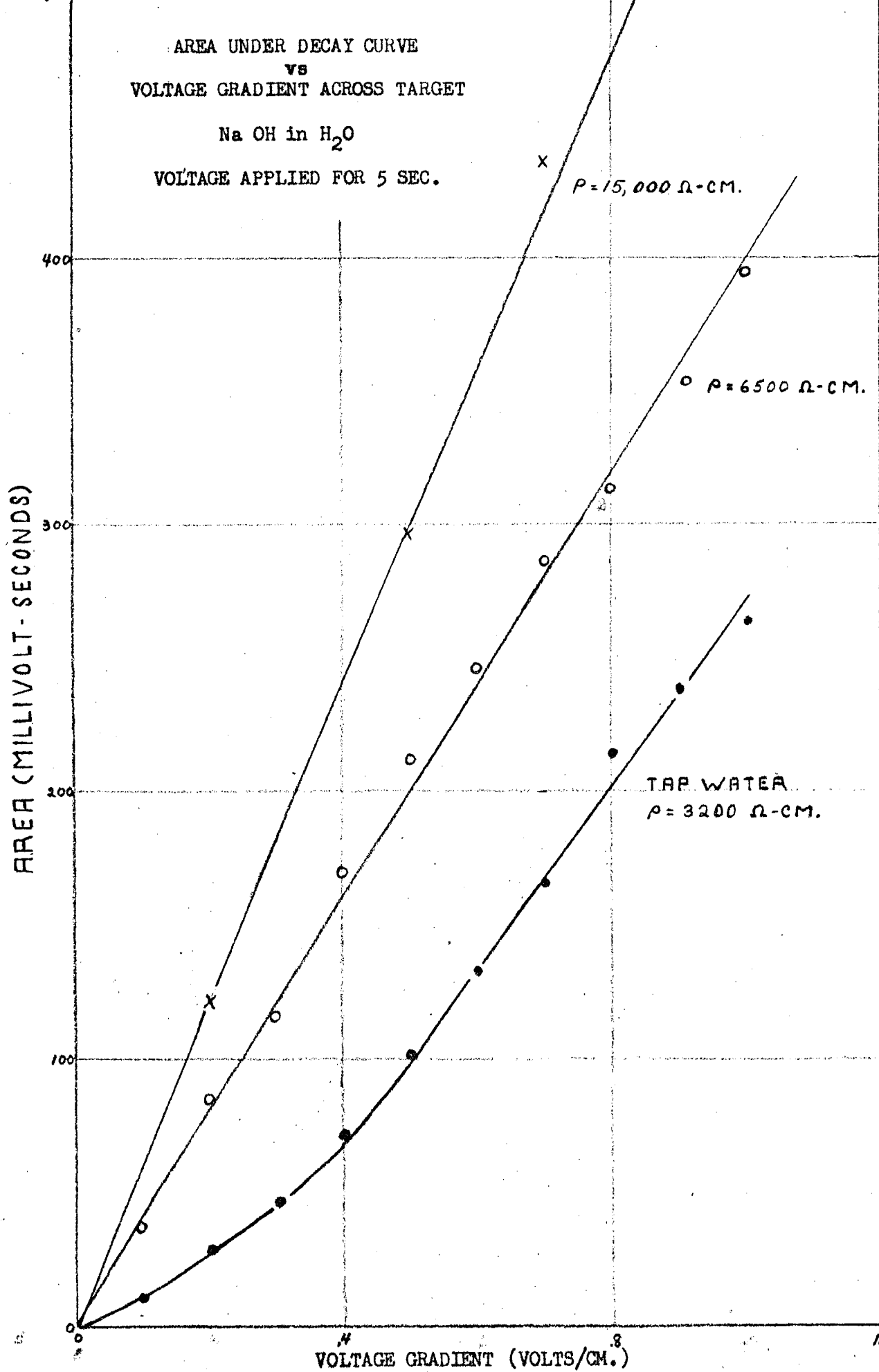
VOLTAGE GRADIENT (VOLTS/CM.)



AREA UNDER DECAY CURVE  
vs  
VOLTAGE GRADIENT ACROSS TARGET

Na OH in H<sub>2</sub>O

VOLTAGE APPLIED FOR 5 SEC.



$\rho = 15,000 \Omega\text{-CM.}$

$\rho = 6500 \Omega\text{-CM.}$

TAP WATER  
 $\rho = 3200 \Omega\text{-CM.}$

VOLTAGE GRADIENT (VOLTS/CM.)



AREA UNDER DECAY CURVE  
vs  
VOLTAGE GRADIENT ACROSS TARGET

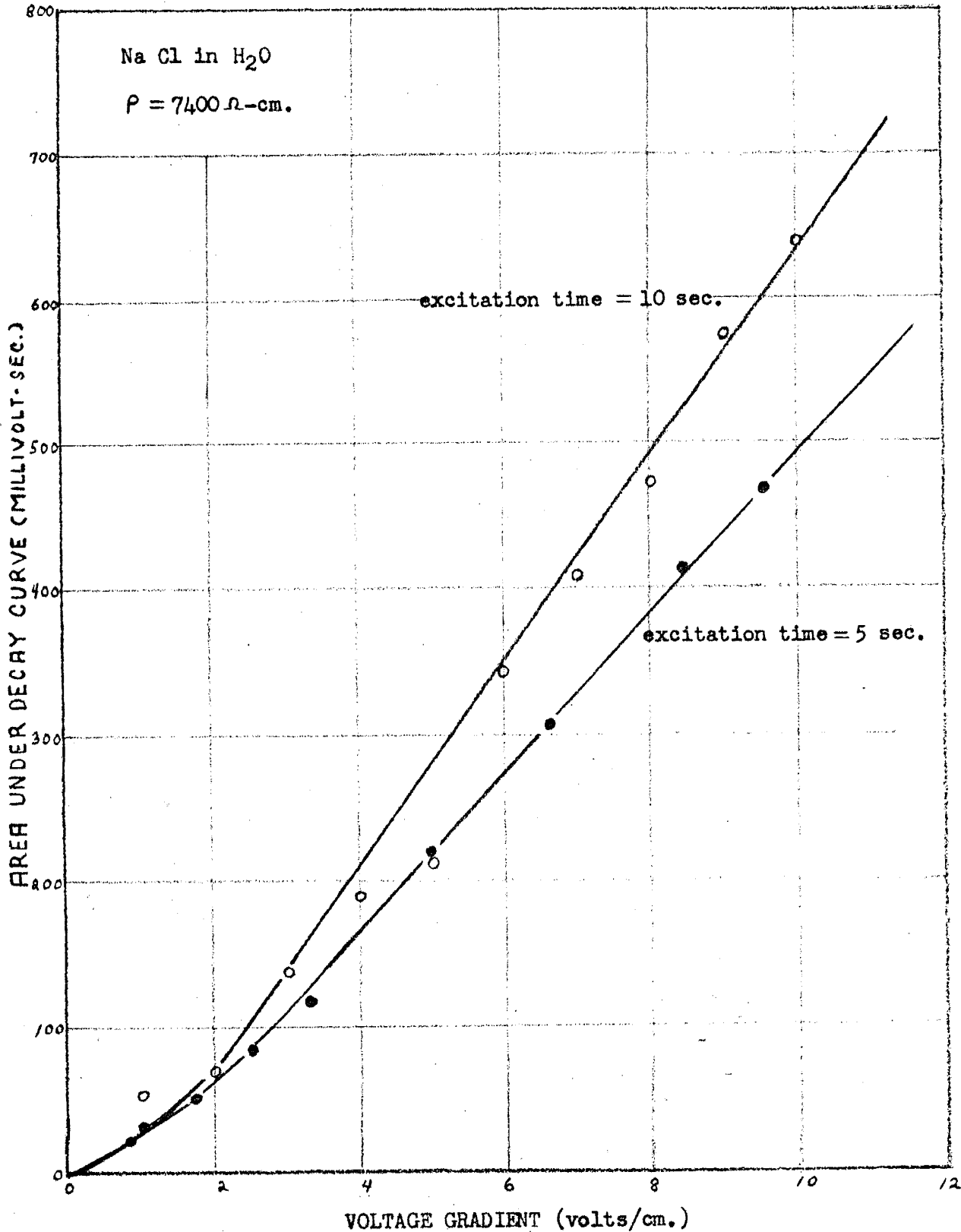
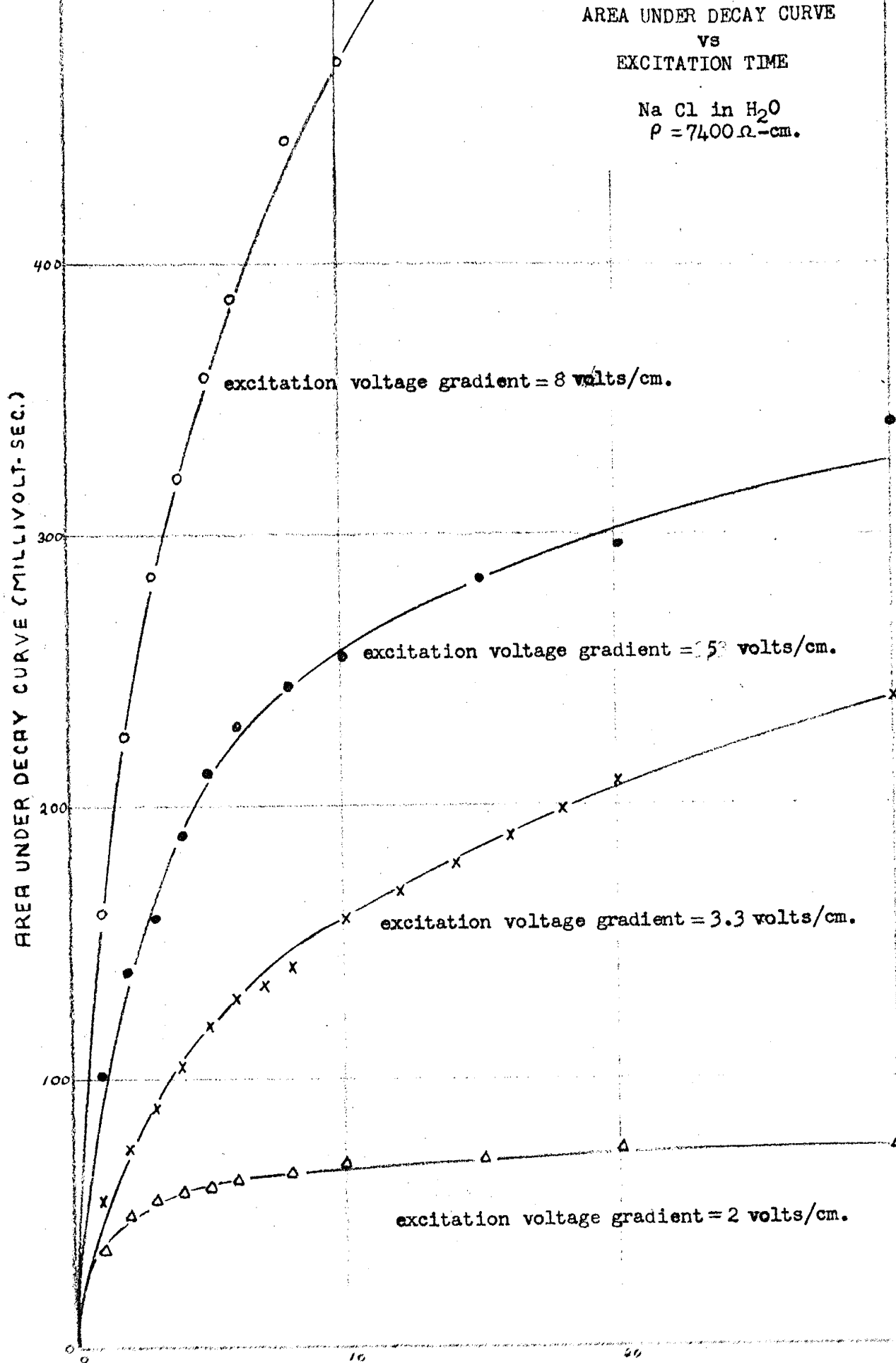


Fig. 11.9

AREA UNDER DECAY CURVE  
vs  
EXCITATION TIME

Na Cl in H<sub>2</sub>O  
 $\rho = 7400 \Omega\text{-cm.}$



EXCITATION TIME (SEC.) (Fig. 20)

of the energizing current was kept constant at five seconds. Inspection of these graphs shows that in every case the data plotted in a straight line for at least part of the curve. For the two salts, sodium chloride and magnesium sulfate (Figs. 15 and 17), the linear portions do not extrapolate back through the origin, but approach the origin with a curve of decreasing slope. The same is true for tap water. In all cases the curves are practically linear for higher resistivities. The hydrochloric acid shows a saturation effect for the 3200 ohm-cm. and 5200 ohm-cm. solutions.

The slopes of the straight line portions of all these curves were determined, and plotted against resistivity on rectangular coordinate graph paper. The change in slope was approximately linear for the sodium chloride and hydrochloric acid solutions, but the three slopes taken from the magnesium sulfate graph did not fall on a straight line. The two lines did not coincide, but intersected at about 13,000 ohm-cm. resistivity, the slope vs resistivity line for sodium chloride having the lesser slope.

Fig. 19 shows two curves, one for the five second energizing current time, and the other for a ten second application of the energizing current.

On Fig. 20, the excitation time has been plotted vs area for four different voltage gradients across the target. When a given energizing time was selected on this graph, and the areas at that time were plotted against their corresponding voltages, roughly a straight line resulted for all times up to thirty seconds. This suggests that the linear relationship between area and voltage gradient discussed in this section probably holds for all excitation

times up to thirty seconds.

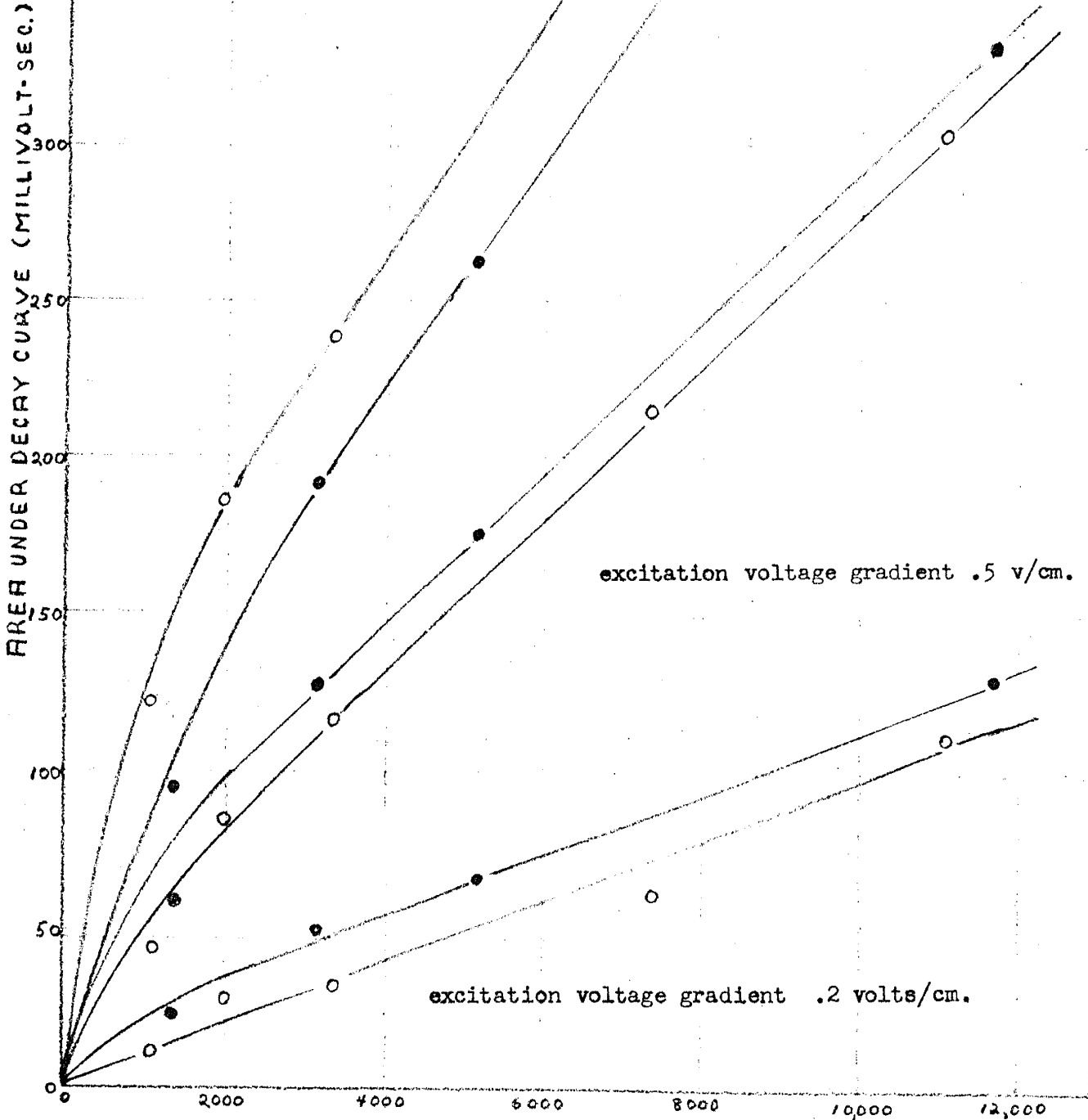
#### Area as a Function of Resistivity

In the two previous sections, a study was made of area as a function of time of excitation and of voltage gradient across the target. By selecting certain graphs discussed in those sections, it was possible to get a rough estimate of area as a function of resistivity. Figs. 11, 12, 15 and 16 each have at least four different resistivity curves plotted on them. At some fixed value of the abscissa on one of these graphs, the area varies as a function of resistivity. Points taken in this manner from Figs. 15 and 16 are plotted in Fig. 21. Voltage gradients of .2, .5 and .8 volts/cm. were selected on the abscissas of Figs. 15 and 16 to obtain these data. The interesting result brought out by Fig. 21 is that all of the curves are linear when the resistivity is greater than about 2000 ohm-cm. It is also noticeable that at the same voltage gradient, the two curves do not coincide, but they do have about the same slope. The equivalent points from Figs. 17 and 18 fall close to the lines plotted on Fig. 21.

The same procedure was repeated using Figs. 11 and 12 and excitation times of five and twenty seconds. Since the voltage gradient was .5 volts/cm., the five second case represented the same situation plotted on Fig. 21 when the voltage gradient was .5 volts/cm. The consistency of the data collected was born out by the fact that these curves practically coincided. The data for the twenty second case also plotted approximately in a straight line for resistivities over

AREA UNDER DECAY CURVE  
vs  
ELECTROLYTE RESISTIVITY

● H Cl in H<sub>2</sub>O  
○ Na Cl in H<sub>2</sub>O  
.5 volts/cm. applied for 5 sec.



RESISTIVITY (ohm-cm.) (Fig. 21)

about 2000 ohm-cm., the slope being somewhat greater than for the five second excitation time. The corresponding points from Figs. 13 and 14 fell close to these curves.

The above results thus indicate that area is directly proportional to electrolyte resistivity for the range of voltage gradients and excitation times used in these experiments. There is also some evidence that this proportionality may be slightly different for chemically different electrolytes.

## CONCLUSION

The original purpose of this investigation was to continue the work of D.F. Bleil who suggested that both massive and disseminated ore bodies could be detected by induced polarization. The plan was to make a systematic study of various disseminated minerals such as pyrite, galena, magnetite, etc. in different electrolytes, in the hope that some properties would be discovered that would be useful in prospecting. This line of investigation was unsuccessful and some of Bleil's conclusions seem to be unjustified, although the existence of the effect was confirmed in general.

The change in effect of metallic targets with time was overlooked by Bleil, and indicates a chemical reaction between target and electrolyte. However, in general, induced polarization does not depend on these reactions, since platinum and carbon targets gave rise to equally large effects but did not change with time.

This important result indicates that induced polarization is probably caused by redistribution of ions already present in the electrolyte in the vicinity of the target. An explanation of this type is given by A.A. Brant et. al. in U.S. Patent 2, 611, 004. Brant attributes the effect to a double electric layer formed on the surface of the conducting metallic body, which prevents current flow-

ing through the target once it is polarized. Bleil found that the current through his targets decreased to a certain steady value during polarization. The reason this was not zero was probably because of the target corroding in the electrolyte. Undoubtedly the current would decrease to zero in a platinum or carbon target once the double layer was built up.

When the energizing current is interrupted, the charge separated in the target disappears very rapidly, but the ionic charge in the electrolyte adjoining the target surface takes time to dissipate. This explains the slow decay, and why the total relaxation time (not rate of decay) is greater for higher electrolyte resistivities.

The rate of formation of the double layer also depends on the resistivity of the electrolyte. As expected, the greater the resistivity, the longer is the time required for induced polarization saturation. This could also be observed by noting the decay of the current through the target as a function of electrolyte resistivity.

Bleil made a serious mistake in stating that only metallic targets or disseminations give rise to induced polarization. Another group in this laboratory has been observing the relatively large effects produced by clays disseminated in moist sand. At present this effect is attributed to the surface conductivity of clay caused by the strong affinity of the surface for certain ions (usually negative). This property is common to both bentonites and kaolins which have very different properties in other respects.

Several experiments should be undertaken in order to establish more firmly the nature of induced polarization. 1) Using a target consisting of two pieces of carbon, insulated except on the end faces



and connected by a wire through a microammeter, study the current through the target during the induced polarization buildup and decay.

- 2) Repeat 1) using platinum foil instead of carbon.
- 3) Study the effect of electrolyte resistivity on the above current measurements.
- 4) Study the effect of powdered graphite disseminated in sand, and compare with the clay disseminations.
- 5) Study the effect of a cylindrical piece of carbon with its axis parallel to the sample tube axis.
- 6) Repeat 5) after insulating the curved surface with varnish, and compare the results.

It should be pointed out that there is no good reason to believe that metallic bodies in moist rock in nature give rise to the same effects observed in the simplified laboratory situation. If the effect is due to a double layer and the movement of ions, the lack of free water should have a pronounced effect. Bleil's work, along with the work described here, may thus have only a remote bearing on the effects observed from actual ore deposits.

#### REFERENCES

1. Bleil, D. F. (1953) "Induced Polarization: A Method of Geophysical Prospecting", *Geophysics*, vol. 18, pp. 636-661.

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