Summer 1939

A Study of The Effect of An Equal Energy Spectrum Upon Metallic Selenium In Vacuo

George Butler Scott
Fort Hays Kansas State College

A STUDY OF THE EFFECT OF AN EQUAL ENERGY SPECTRUM UPON METALLIC SELENIUM IN VACUO,

being

A thesis submitted to the Graduate Faculty of the Fort Hays Kansas State College in partial fulfillment of the requirements for the degree of Master of Science

by

George Butler Scott, B. S. in Education

Fort Hays Kansas State College

July 29, 1939 Approved: Harvey A. Zinszer
Date Major Professor

Acting F B Streeter
Chairman Grad. Council

TABLE OF CONTENTS

****

ACKNOWLEDGEMENTS

In appreciation, I wish to acknowledge my indebtedness to Dr. H. A. Zinszer for suggesting the problem and his continued interest and assistance during the course of the research; also to Mr. Roy Rankin, professor chemistry for the use of sundry apparatus.

HISTORICAL DATA AND INTRODUCTION

In a series of experiments on the effects of resonance between very rapid electric oscillations, Heinrich Hertz[1] in 1887, produced two electric sparks by the same discharge of an induction coil. One of these, the spark A, was the discharge spark of the induction coil and served to excite the primary oscillation. The second, the spark B, belonged to the induced or secondary oscillation. The spark-distance of the latter had to be accurately measured and since it was not very luminous, Hertz occasionally enclosed spark-gap B in a dark case so as more easily to make the observations. In so doing, Hertz observed that the maximum spark-length of spark B became decidedly smaller inside the case than it was before. On removing in succession the various parts of the case, it was seen that the only portion of the case which exercised this prejudicial effect was that part which screened spark-gap B from spark-gap A.

This simple observation led to Hertz's later[2] discovery of the phenomenon known today as photo-electricity.

---

1. Heinrich Hertz, Wiedemann's Ann., 31, p. 421, (1887).
2. Loc. cit., p. 983

What Hertz really found was that the passage of an electric spark between two clean, oppositely charged electrodes was facilitated when ultra-violet light was allowed to fall on them. However, his principal interest was in his researches on electromagnetic waves, and so he did no further work on this effect of light.

A year later, Hallwachs[3] found that an insulated, uncharged zinc plate, exposed to ultra-violet light from a carbon arc, acquired a positive charge as shown by a goldleaf electroscope. He also found that a charge on it, if negative, began to leak away as soon as the light was turned on. If, however, the plate had a strong positive charge, the light from the arc had no effect on it. Hallwachs suggested, as the probable reason for this puzzling behavior, that the incident light caused the emission of negatively electrified particles from the zinc plate and that they were prevented from escaping and revealing this effect only when the plate had a considerable positive charge.

The term photo-electricity has been coined from two Greek words, -phos meaning light and elektron meaning amber, the material used in the earliest recorded electrical experiments, as an appropriate term to properly express the phenomena in which electric charges are pro-

---

3. W. Hallwachs, Wiedemann's Ann., 33, p. 301, (1888).

duced by illumination with light. This phenomenon occurs under various conditions[4] each of which is known by a different name, such as photo-electric effect; photo-actinic effect; photo-conductive effect; and, photo-chemical effect.

The change of resistance of selenium when illuminated is in reality a photoelectric effect, and because it occurs within the substance it is to be recognized as belonging to the photo-conductivity group[5]. The photo-conductivity effect was discovered by Willoughby Smith[6] in 1873, who, being desirous of obtaining a suitably high resistance for use with submarine cables, instituted certain experiments on selenium in the course of which remarkable fluctuations of current were observed when the selenium was exposed to light. This effect is by no means confined to selenium but is shared by various other substances of which stibnite, molybdenite, and cuprous oxide are representative. An exhaustive experimental investigation of the effect was carried out by Adams and Day[7] in 1876. An enormous amount of literature relating to selen-

---

4. H. A. Zinszer, "Note on Photo-electric Phenomena," Proc. Indiana Acad. Sci., 40, p. 291, (1931)
5. Hughes and DeBridge: "Photoelectric Phenomena", p. 5 (McGraw-Hill, 1932)
6. Willoughby Smith: Jour. Soc. Telgh. Engrs. 2, 31 (1873)
7. Adams and Day: Phil. Trans. Roy. Sco. 167, 328 (1876)

ium has grown up, but, until quite recently, no progress whatever had been made in uncovering the really fundamental processes of photo-conductivity. According to Hughes and DuBridge[8], Gudden and Pohl and their collaborators began a systematical study of the whole question of photo-conductivity during the last decade, and in a series of remarkable experiments succeeded in discovering how, underlying the complicated phenomena frequently observed experimentally, there was a simple photoelectric effect easily explained in terms of the quantum theory.

An immense amount of work[9] has been done on the photo-conductivity of selenium. Doty[10] gives a list of 1536 articles on selenium and a list of 138 patents on its applications. It must be admitted, however, that all the published results--with but one important exception--have only an empirical value in the sense that they do not disclose any significant information to the fundamental photo-electric process which is believed to be the basis of photo-conductivity. The systematic work of Gudden and Pohl[11] shows that, only with specially selected

---

8. loc. cit.

9. Martin, R.E., "Bibl. of Lit. bearing on the Light-Sensitiveness of Selenium" Proc. Indiana Acad, 36, 163 (1926)

10. Doty, M.F., "Selenium, a List of References" (New York Public Library, 1927)

11. loc. cit.

single crystals, examined according to a certain procedure, is it possible to observe the true photoelectric current of electrons released directly by the light, without the superposition of secondary currents. Selenium is perhaps the outstanding example of a substance in which the secondary currents are of such magnitude and bewildering complexity as to mask completely the primary photoelectric current. The work of Gudden and Pohl is unique among all the investigations on selenium in that it shows that it is possible to observe a simple primary photoelectric current uncomplicated by the presence of any secondary current. Because of the fact that none of the other investigations on selenium give any information as to the fundamental photoelectric process, we shall summarize only a few typical results very briefly.

Selenium is peculiar among the elements in that it can exist in several allotropic forms. The crystals obtained from a solution of selenium in carbon disulphide are good insulators and are somewhat transparent to red light. Gudden and Pohl observed the primary photoelectric current in this form of selenium. Conducting crystals of selenium can be obtained by condensation of the vapor. Sieg and Brown[12] studied the photo-conductivity

---

12. Sieg and Brown, Phys. Rev. 4, 87 (1914); 4, 507 (1914) 5, 651 (1915).

of these crystals. Vitreous selenium, obtained by rapid cooling of molten selenium, is an insulator and shows no photo-conductivity. Finally selenium, which has been "annealed" after solidification for a considerable time at temperature between 100 and 217°C is slightly conducting in the dark, and shows considerable conductivity when illuminated. This is the kind of selenium used in "selenium cells".

When E. O. Dieterich[13] made an investigation of the conditions governing the shape of the sensibility curves for selenium it led to the production of several new types of cells, which may be classified into two general groups; those that have a maximum sensibility for wave-lengths longer than 640 mu mu, and those that show very little sensitiveness in this region, but have a maximum for wave-lengths shorter than 640 mu mu. The location of the maximum seems to be determined entirely by the method of "annealing" the cells. The samples annealed at "210°C., or higher, all show a maximum below 640 mu mu, and no maximum at all in the longer wave-lengths. Those annealed at lower temperatures, 180°C., all show a maximum at wave-lengths greater than 640 mu mu, which is higher than the broad, undefined maximum in the shorter wave-length.

---

13. Dieterich, E. O., Phys. Rev. 4, 467 (1914)

When the samples are annealed at temperatures between 180°C and 210°C., the height of the maximum in the red, relative to that in the blue, becomes less and less, until at about 210°C. it disappears.

Since little has been found in the literature, on the effect of actinic properties on the conductivity of metallic selenium and on its spectral response when possessing these properties, it was thought noteworthy to construct several silenium cells having low and medium dark resistances and to study them with a view of seeking some correlation between their conductivity characteristics and their prismatic response in vacuo.

44169

CONSTRUCTION AND ANNEALING OF CELLS

The cells, of which seven were constructed for this investigation, were all of the Bidwell type according to Dieterich[14], that is, two parallel wires were wound spirally around a form of mica. The cells were placed on a piece of iron whose temperature was just a little above the melting point of selenium, 207° C. After the cell had attained this temperature stick selenium was rubbed on one side in a thin layer and allowed to cool. If the selenium turned a dull gray on cooling they were then placed in an oven and annealed for eight hours at a temperature between 180° and 190° C. It was shown by Ries[15] that the higher the temperature to which the cells are heated during annealing the lower their resistance. In this investigation cells of high resistance were desired, therefore the temperature 180° to 190° C was used for the annealing temperature.

Dark and Light Resistance: It was essential to know the dark and light resistance of the cells which were be-

---

14. <u>loc. cit.</u>
15. Ries, C, "Das elektrische Verhalten des Kristallinischen Selens gegen warme und Licht", <u>Beibl. Ann Physik</u> 27, 1101 (1903).

ing investigated. A postoffice plug box bridge was used for determining the two above resistances. The cells were kept in the dark for twenty-four hours after which the resistance was taken. Then they were exposed to light and their resistance again determined, the latter being found to be much less. This phenomenon, when an emf is impressed on the cell, is known as the photo-resistance effect. Below is a table of the dark and light resistance of the various cells used in this experiment.

CELL	LIGHT INTENSITY	DARK RESISTANCE	LIGHT RESISTANCE
1	30 Ft-C	1,300,000 ohms	41,000 ohms
4	30 Ft-C	500 ohms	280 ohms
6	30 Ft-C	3,600 ohms	1,780 ohms
7	30 Ft-C	2,980 ohms	1,580 ohms

In the experiments three homemade selenium cells, No. 4, 6, and 7 and one commercial (McWilliams) cell No. 1 were tested. The dark-resistance of these cells tested as 500 ohms, 3600 ohms, 2980 ohms and 1,300,000 ohms respectively. The homemade cells were of the type according to Dieterich as previously stated. The commercial cell was purchased from the McWilliams Photo-Electric Company and will be known as McWilliams Cell No. 1 throughout the experiment.

In preparing the cells for evacuation, they were placed in glass tubes one end of which was sealed over with cortex glass. A small groove was filed in the glass to accomodate the lead wires. A large groove was cut in the edge of the tube to accomodate a glass tube for the purpose of evacuation. After the above were in place a piece of window glass was placed over the other end of the tube and sealed with DeKhotinsky cement. The tube was then sealed to the Hyvac pump and evacuated to within 1 cm of Hg. After 40 of 50 minutes of evacuation the cell was sealed off.

To determine the degree of evacuation a tube 100 cms long was placed in a beaker of Hg. This tube was connected by means of a "T" to the vacuum pump and to the cell, Fig. 1. By reading the atmospheric pressure on a Fortin barometer and measuring the height of Hg in the tube the degree of evacuation could be determined.

SKETCH OF EVACUATION APPARATUS

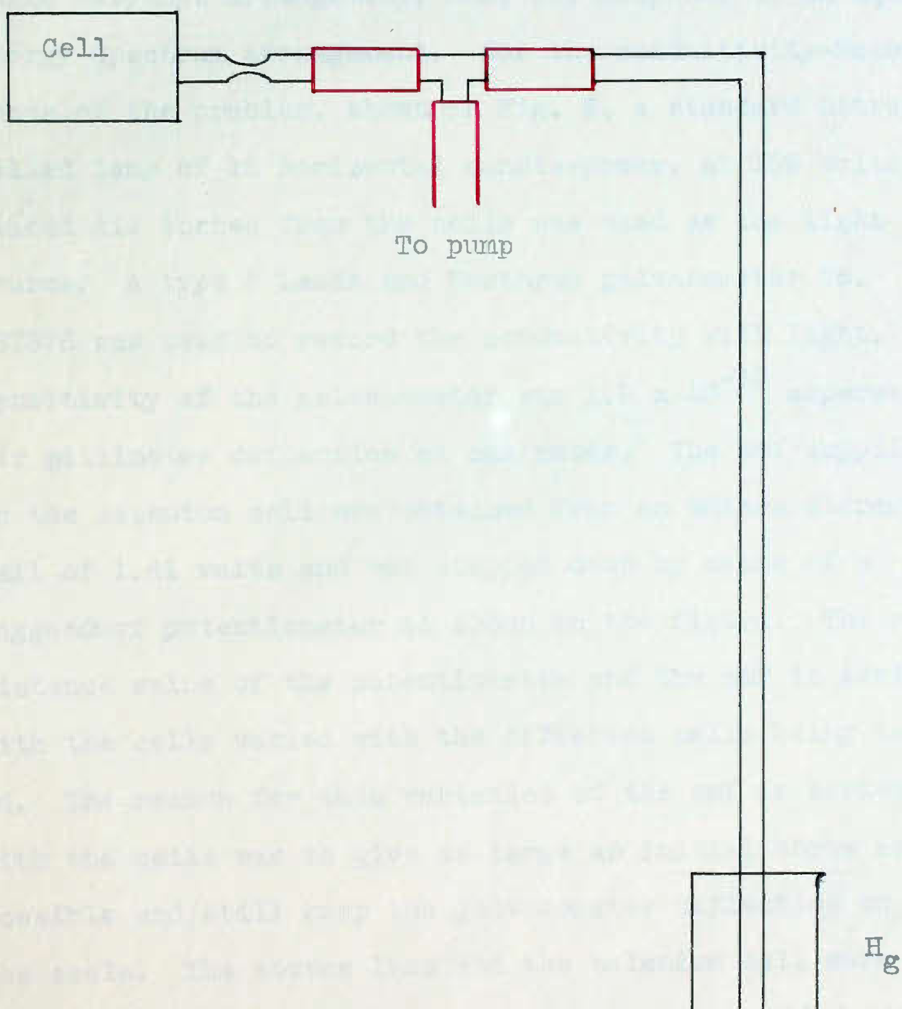
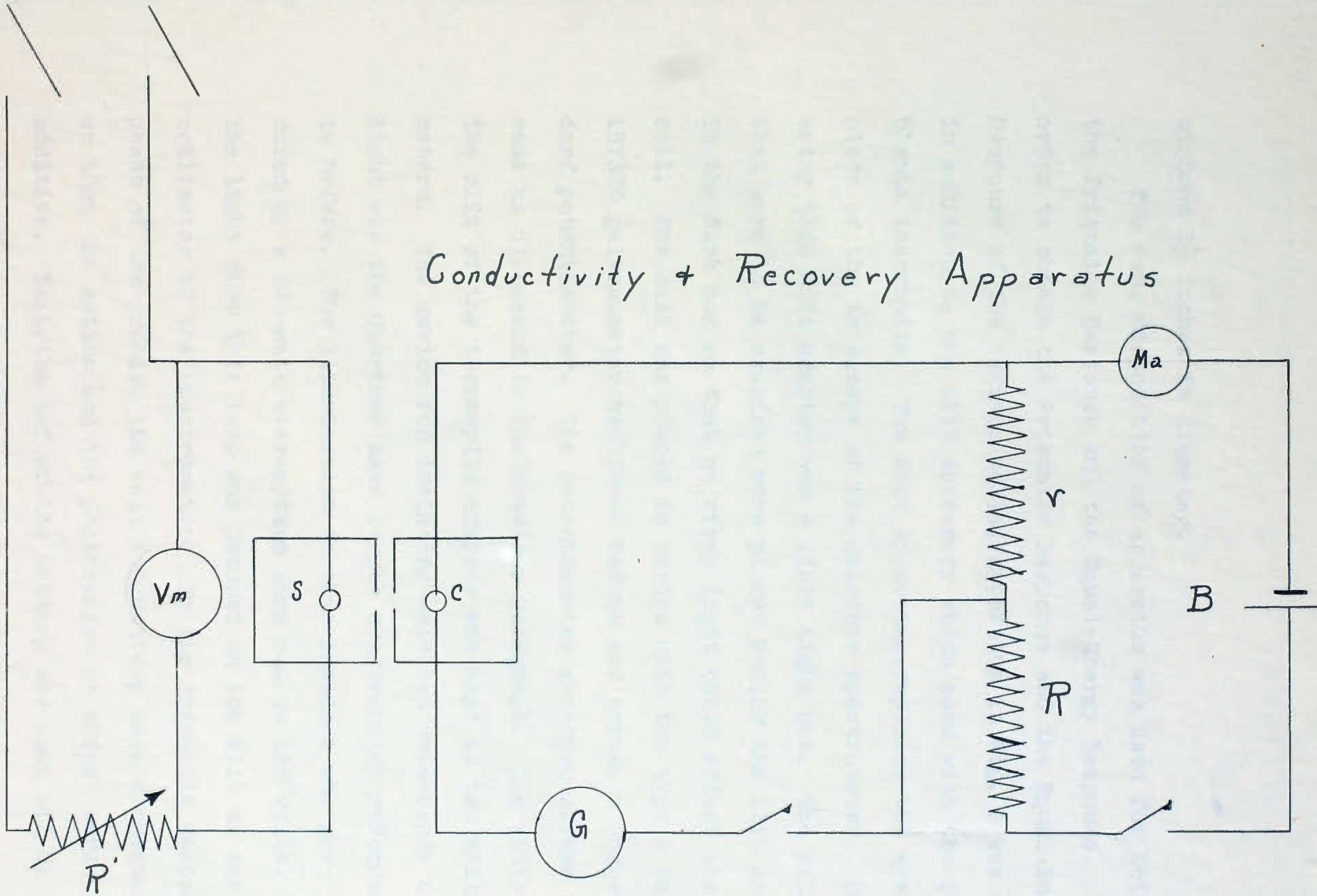


Fig. 1

DESCRIPTION AND ARRANGEMENT OF APPARATUS

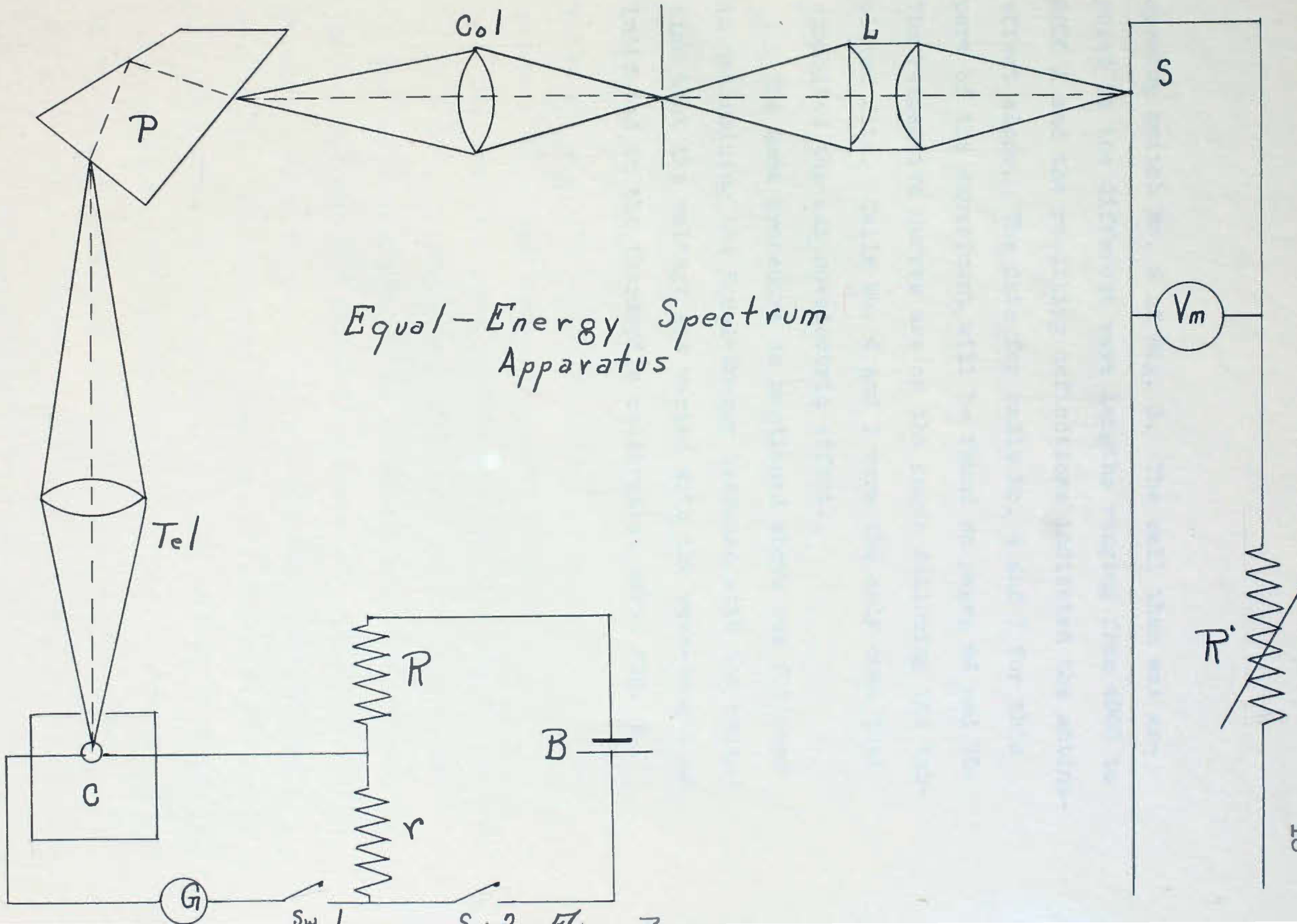
Three different arrangements of apparatus were used to carry out the three main divisions of this problem, namely: (1) Conductivity-Recovery arrangement; (2) Prismatic Response arrangement; and, (3) Response to an Equal-Energy Spectrum arrangement. For the conductivity-Recovery phase of the problem, shown in Fig. 2, a standard nitrogen-filled lamp of 16 horizontal candle-power, at 109 volts, placed six inches from the cells was used as the light source. A type P Leads and Northrup galvanometer No. 187376 was used to record the conductivity with light. The sensitivity of the galvanometer was 1.9×10^{-10} amperes per millimeter deflection at one meter. The emf supplied to the selenium cell was obtained from an Edison storage cell of 1.41 volts and was stepped down by means of a Poggendorf potentiometer as shown in the figure. The resistance value of the potentiometer and the emf in series with the cells varied with the different cells being tested. The reason for this variation of the emf in series with the cells was to give as large an initial throw as possible and still keep the galvanometer deflection on the scale. The source lamp and the selenium cell were placed in individual dark boxes which were provided with



Conductivity + Recovery Apparatus
Ma
r
Vm
S
C
B
R
G
R'

windows $1\frac{1}{2}$ inches in diameter.

The same disposition of apparatus was used for both the Prismatic Response and the Equal-Energy Response. In order to obtain the Prismatic Response and the Equal-Energy Response of the various cells, apparatus in Fig. 3 was used in addition to the slit accessory which came with the Coblentz thermopile. The slit apparatus replaced the eyepiece of the telescope of the Gaertner spectrometer. Covering this slit adapter was a light tight box. The cells that were to be examined were placed behind the slit and in the dark box so that no stray light could affect the cell. The cell was placed in series with the type P No. 187376 galvanometer mentioned before and across a Poggendorf potentiometer. The potentiometer arrangement was the same as discussed in the previous paragraph. The width of the slit of the thermopile adapter was kept at two millimeters. The device for isolating selected wave-bands of light was the Gaertner wave length spectrometer referred to before. The illumination in this instance was produced by a 500-watt stereopticon lamp run on 110 volts. The light from this lamp was focused on the slit of the collimator of the spectrometer. In the Prismatic Response phase of the problem the cell and battery were connected so that the actino and the photoresistant effect were additive. Next, the emf of the battery was shut off by


Col
L
S
P
Equal-Energy Spectrum
Apparatus
Vm
Tel
R
R'
B
C
r
G

opening switch No. 2 of Fig. 3. The cell then was exposed to the different wave lengths ranging from 4000 to 8250 A and the resulting deflections indicated the actino-effect alone. The data for calls No. 4 and 7 for this part of the experiment will be found on pages 66 and 70. The respective curves are on the pages following the tabulated data. Cells No. 4 and 7 were the only ones that exhibited the actino-electric effect.

The same procedure as mentioned above was followed in determining the Equal-Energy Response with the exception that the voltage was varied with the wave-length as indicated in the thermopile calibration curve Fig. 7.

PROCEDURE

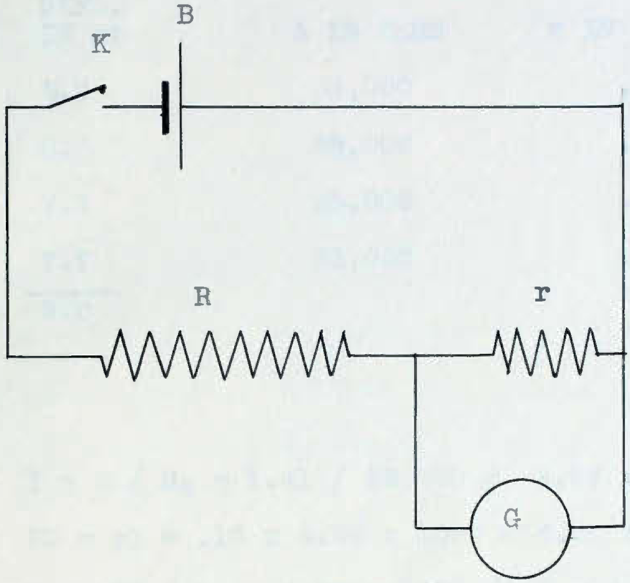
Determination of Galvanometer Sensitivity: The galvanometer used for determining the Equal Energy Spectrum was a "HS" Leads and Northrup D'Araonval galvanometer No. 2248. Its sensitivity came out as 2.5×10^{-11} amperes per millimeter at one meter's distance. Its ciruit resistance is 10 ohms and its period is 14.2 seconds.

In determining the sensitivity of this galvanometer, the customary Poggendorf potentiometer method was employed. A high resistance was placed in series with an Edison cell whose emf was 1.41 volts, and the galvanometer was bridged across a one-tenth ohm of the above resistance.

The data was taken as follows: The largexx resistance, R, was set at 33,000 ohms. The small resistance, r, of .1 ohm was placed across the galvanometer. The key was then closed and the deflections recorded. After the galvanometer came to rest several other deflection readings were taken. To make sure that the deflections were correct the battery wires were reversed and the average readings was used as the "$\bar{d}$" in the equation $K = i_g / \bar{d}$ which is one of the equations used in determining the sensitivity of the galvanometer. To check my first results 80,000 ohms was used for the large resistance R and .1 ohm for the small r. The deflections were taken as before and the sensitivity determined. The sensitivity obtained by the first calculation was $.26 \times 10^{-11}$ amps/mm at one meter by the second $.244 \times 10^{-11}$ amps/mm at one meter. A sketch showing the arrangement for this calibretion together with table of results follow.

DETERMINING THE SENSTIVITY OF THE GALVANOMETER

Diagram of Apparatus



B......Battery

K......Key

R......Large Resistance

r......Small Resistance

G......Galvanometer to be checked

Fig. 4

Table of Data and Mathematical Work
(trial one)

DEFL. IN mm	R IN OHMS	r IN OHMS
8.3	33,000	.10
8.3	33,000	.10
7.7	33,000	.10
7.7	33,000	.10
$\bar{d}$ = 8.0		

$I = E / R_t = 1.41 / 33{,}000 \doteq 4.27 \times 10^{-5}$ amps

$PD = rI = .10 \times 4.27 \times 10^{-5} = 4.27 \times 10^{-6}$ volts

$i_g = PD / R_g = 4.27 \times 10^{-6} / 10 = 4.27 \times 10^{-7}$

$K = i_g / \bar{d} = 4.27 \times 10^{-7} / 8 = 5.33 \times 10^{-8}$

$k = K / 2000 = 5.33 \times 10^{-8} / 2000 = 2.66 \times 10^{-11}$ a/mm

$k = 2.66 \times 10^{-11}$ amps / mm at one meter.

Table of Data and Mathematical Work (con)
(trial two)

DEFL. IN mm	R IN OHMS	r IN OHMS
3.8	80,000	.10
3.7	80,000	.10
3.7	80,000	.10
3.7	80,000	.10
3.5	80,000	.10
3.5	80,000	.10
3.5	80,000	.10
$\bar{d}$ = 3.6		

$I = E / R_t = 1.41 / 80,000 = 1.76 \times 10^{-5}$ amps.

$PD = rI = .1 \times 1.76 \times 10^{-5} = 1.76 \times 10^{-6}$ volt

$i_g = PD / R_g = 1.76 \times 10^{-6} / 10 = 1.76 \times 10^{-7}$

$K = i_g / \bar{d} = 1.76 \times 10^{-7} / 3.6 = 4.88 \times 10^{-8}$

$k = K / 2000 = 4.88 \times 10^{-8} / 2000 = 2.44 \times 10^{-11}$ a/mm

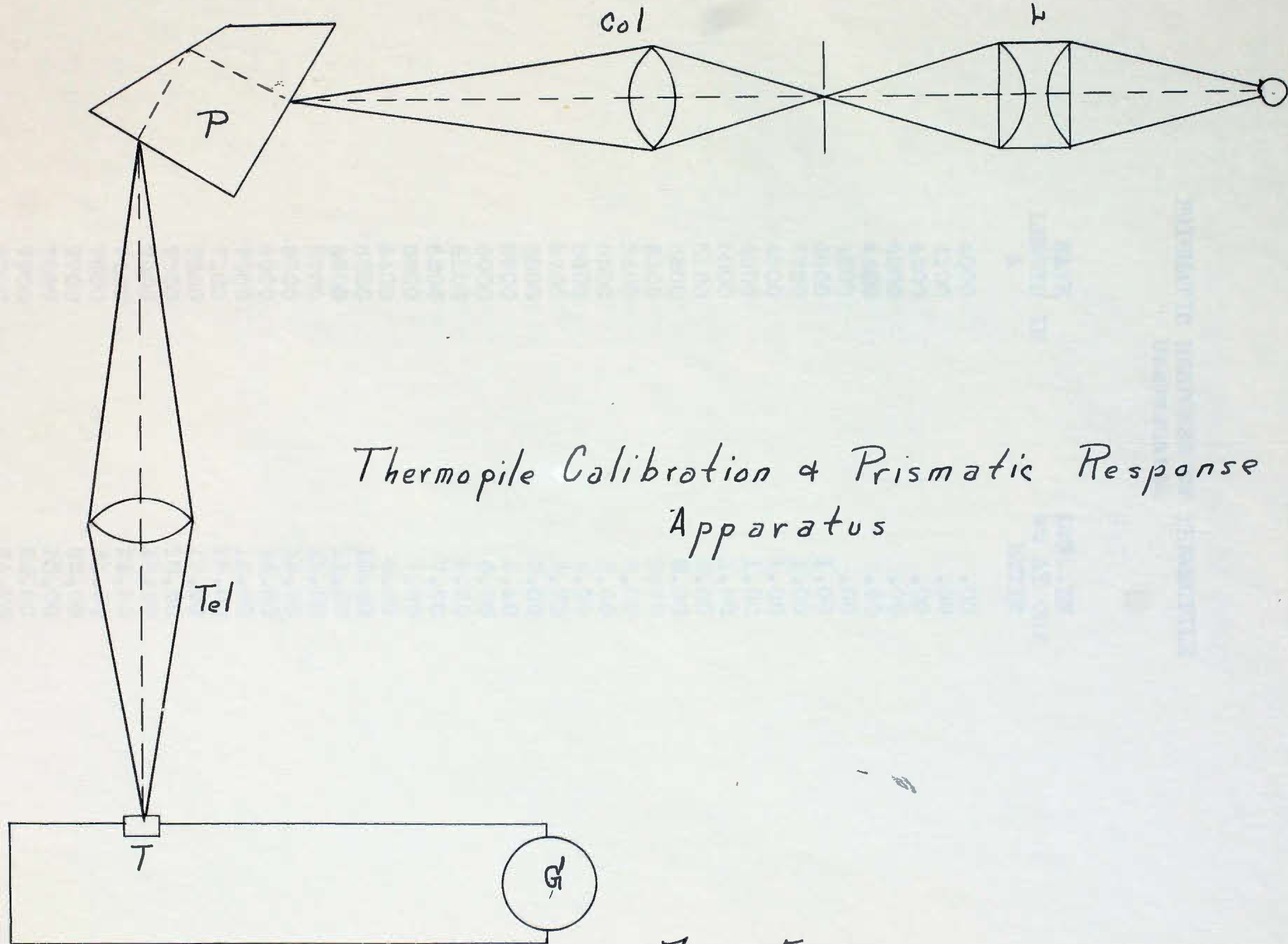
$k = 2.44 \times 10^{-11}$ amps/mm at one meter

Deflection for trial one 2.66×10^{-11} amps/mm at one m.
Deflection for trial two 2.44×10^{-11} amps/mm at one m.

Average deflection 2.55×10^{-11} amps/mm at one m.

PRISMATIC RESPONSE OF THERMOPILE

In determining the prismatic response of the thermopile, the disposition of apparatus in Fig. 5 was used. The galvanometer employed in this experiment was a "HS" Leads and Northrup D'Arsonval No. 2248. It was connected in series with a Ag-Bi Coblentz vacuum thermopile. It was necessary to have some device whereby a band of known wavelength of light could be secured. For the purpose a Gaertner constant deviation spectrometer having a range from 3900 to 8250 A was used. The objective of the telescope and the collimator had a focal length of 300 mm. A sodium flame was used for the calibration of the instrument. The thermopile was placed at the focus of the telescope of a Gaertner constant deviation spectrometer. The source of light, a 500-watt stereoptian lamp, was focused by means of condensing lens onto the collimater slit the latter being one millemeter in width. The source-lamp was operated at a constant voltage of 109 volts and the spectrometer was adjusted so as to include a wave band of 100 A at each setting. The entire range of the visible spectrum running from 3900 to 8250 A was investigated. The gålvanometer scale was placed at a distance of one meter from



Thermopile Calibration & Prismatic Response Apparatus

Fig. 5

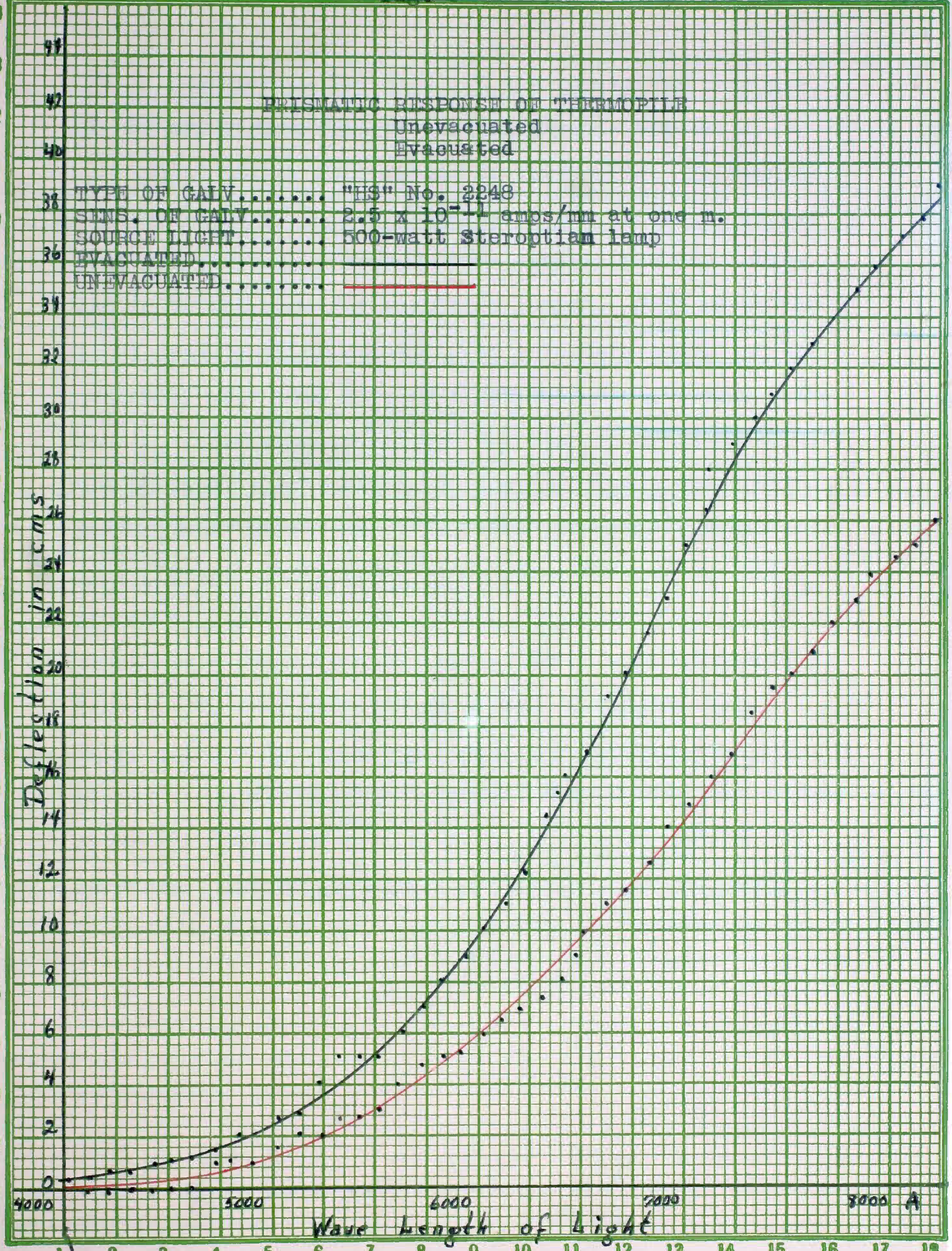
PRISMATIC RESPONSE OF THERMOPILE
Unevacuated

WAVE LENGTH IN A	DEFL. IN cm AT ONE METER
4000	.00
4100	.00
4200	.00
4300	.00
4400	.00
4500	.00
4600	1.00
4700	1.00
4800	1.00
4900	1.00
5000	1.50
5100	2.00
5200	2.00
5300	2.75
5400	2.80
5500	3.00
5600	4.00
5700	4.75
5800	5.00
5900	5.10
6000	6.00
6100	6.50
6200	7.00
6300	7.25
6400	8.00
6500	10.00
6600	11.00
6700	11.50
6800	12.75
6900	14.00
7000	15.00
7100	16.00
7200	17.00
7300	18.50
7400	19.50
7500	20.00
7600	21.00
7700	22.00
7800	23.00
7900	24.00
8000	24.75
8100	25.00
8200	26.00

PRISMATIC RESPONSE OF THERMOPILE
Evacuated

WAVE LENGTH IN A	DEFL. IN cm AT ONE METER
4000	.25
4100	.25
4200	.50
4300	.50
4400	.75
4500	1.00
4600	1.00
4700	1.25
4800	2.00
4900	2.00
5000	2.50
5100	2.75
5200	3.00
5300	5.00
5400	5.00
5500	5.00
5600	6.00
5700	7.00
5800	8.00
5900	9.00
6000	10.00
6100	11.00
6200	12.25
6300	14.50
6400	16.00
6500	17.00
6600	19.00
6700	20.00
6800	21.50
6900	23.00
7000	25.00
7100	28.00
7200	29.00
7300	30.00
7400	31.00
7500	32.00
7600	33.00
7700	34.00
7800	35.00
7900	36.00
8000	37.00
8100	38.50
8200	39.00

Fig. 6


PRISMATIC RESPONSE OF THERMOPILE
Unevacuated
Evacuated
TYPE OF GALV....... "HS" No. 2248
SENS. OF GALV...... 2.5 x 10^-11 amps/mm at one m.
SOURCE LIGHT....... 500-watt Steroptian lamp
EVACUATED..........
UNEVACUATED........
Deflection in cms
Wave Length of Light
4000
5000
6000
7000
8000 A

the galvanometer. The data and the curve, for this part of the experiment follows immediately, in Fig. 6.

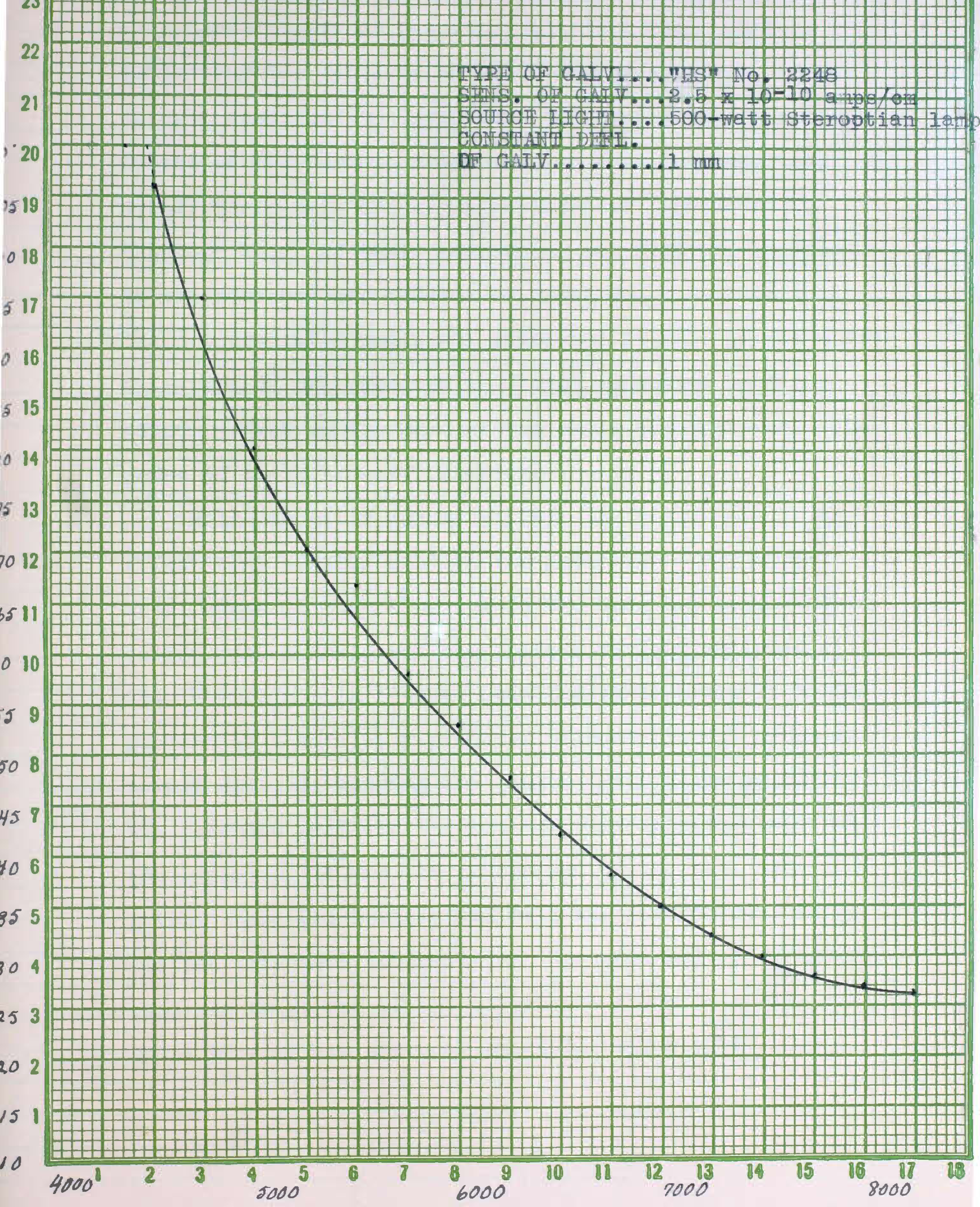
Equal Energy Calibration of Thermopile: In running the equal-energy response curves it was necessary to expose the cells to different wave lengths but the energy had to be the same for each wave length. Some means had to be used by which one could be sure this condition was achieved. For this purpose a Coblentz Bi-Ag Vacuum Thermopile of 6.2 ohms resistance was used in conjunction with the Gaertner spectrometer and the "HS" Leads and Northrup galvanometer previously mentioned. The source consisted of a 500-watt steropticon lamp. To secure an intense source of light at a small point the stereopticon lamp was placed in a projection lantern equipped with condensing lenses. To vary the voltage across the source lamp a large slide wire resistance used as a potentiometer was placed in parallel with the lamp. Fig. 5 mentioned before shows the disposition of apparatus for this part of the research. The Equal-Energy Calibration data and curve follows as Fig. 7.

EQUAL ENERGY CALIBRATION

DEFL. AT ONE METER	WAVE LENGTH IN A	E. M. F. IN VOLTS
1 mm	4000	-----
	4420	107.0
	4500	106.0
	4750	95.0
	5000	80.0
	5250	70.0
	5500	67.0
	5750	58.0
	6000	53.0
	6250	48.0
	6500	42.0
	6750	38.0
	7000	35.0
	7250	32.0
	7500	30.0
	7750	28.0
	8000	27.0
	8250	26.0

Fig. 7

EQUAL ENERGY CALIBRATION OF THERMOPILE



Conductivity vs Recovery; Actino Effect: Before subjecting the cells to an equal-energy spectrum, it was thought essential to learn more concerning the characteristics of the various cells used in this research than merely their dark and light resistance. Therefore, a thorough study of their conducting and recovery qualities in the presence and absence of light was made both in their unevacuated and their evacuated state. It was while this part of the research was being conducted that the actino effect on the part of the cells was discovered because of their erratic behavior.

Selenium cells rarely exhibit the actino-electric effect they usually exhibit the photo-resistant effect only. That is, when they are in the dark and connected in series with a small emf they have a certain resistance; then when light is flashed upon the cells there is a small current of electricity produced without the aid of an external emf. In running the conductivity response curves the selenium cell and the battery were so connected that the external emf and the actino emf of the cell were additive. Next the battery and cell was so connected that the two emfs were subtractive. The arrangement of apparatus for this part of the experiment appears in Fig. 2. These effects are shown on the following graphs.

CONDUCTIVITY CURVE

McWilliams Cell No. 1
Unevacuated

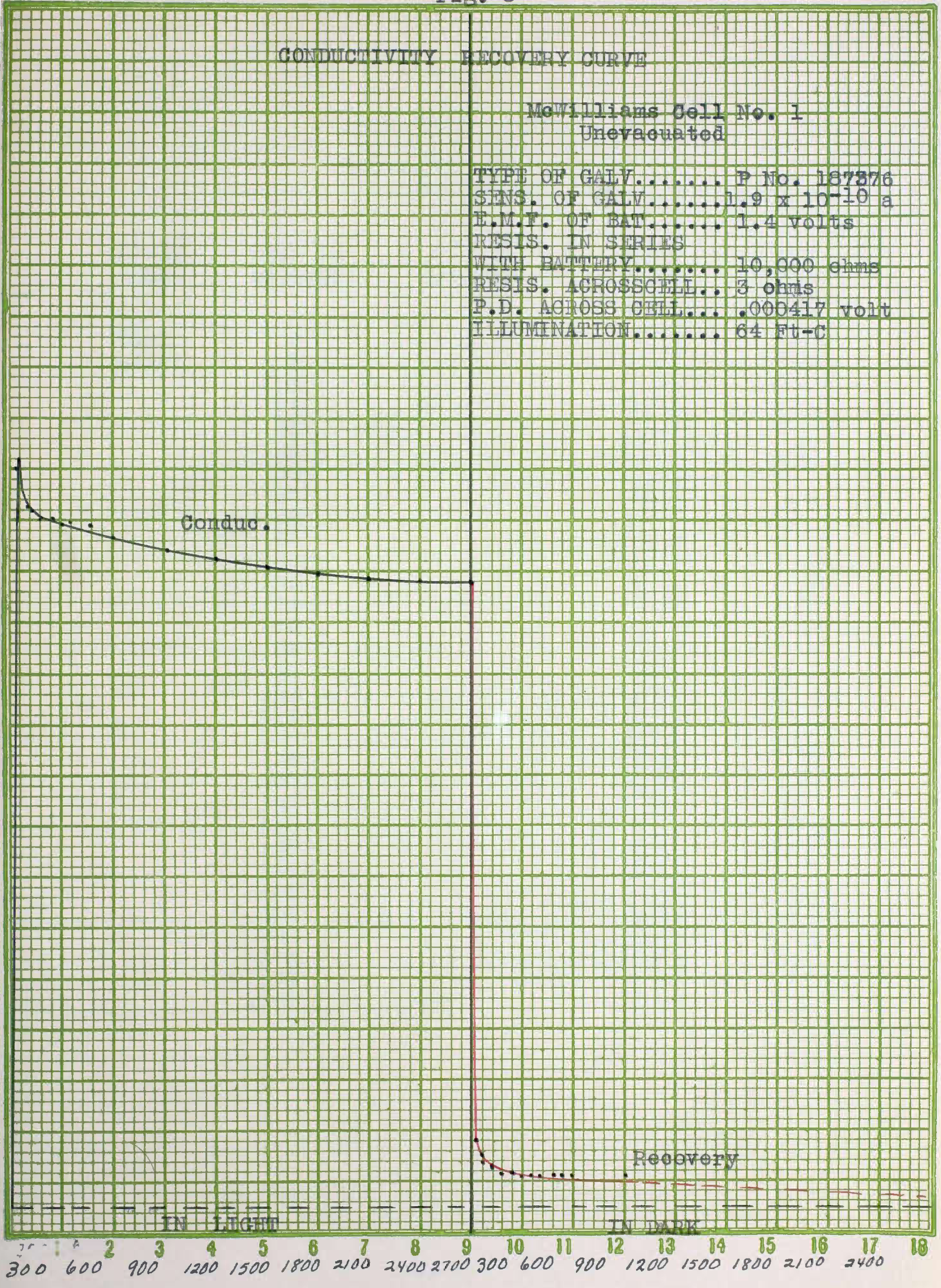
LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.20	.70	.50
Light	5		8.00	7.80
	10		15.00	14.80
	15		12.00	11.80
	20		13.00	12.80
	25		14.78	14.58
	30		15.20	15.00
	35		14.70	14.50
	40		14.30	14.10
	45		14.40	14.20
	50		14.50	14.30
	60		14.49	14.29
	70		14.40	14.20
	80		14.40	14.20
	90		14.40	14.20
	100		14.39	14.19
	110		14.35	14.15
	120		14.32	14.12
	150		14.30	14.10
	180		14.27	14.07
	198		14.25	14.05
	240		14.20	14.00
	300		14.17	13.97
	360		14.15	13.95
	480		14.00	13.90
	600		13.87	13.67
	900		13.60	13.40
	1200		13.40	13.20
	1500		13.20	13.00
	1800		13.10	12.90
	2100		13.00	12.80
	2400		13.00	12.80

RECOVERY CURVE

McWilliams Cell No. 1
Unevacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.20	----	----
	5		4.00	3.80
	10		3.00	2.80
	15		2.00	1.80
	20		3.00	2.80
	25		2.50	2.30
	30		1.90	1.70
	35		1.90	1.70
	40		2.00	1.80
	45		1.90	1.70
	50		1.90	1.70
	55		1.70	1.50
	60		1.70	1.50
	70		1.70	1.50
	80		1.60	1.40
	90		1.55	1.35
	100		1.50	1.30
	110		1.50	1.30
	120		1.45	1.25
	150		1.43	1.23
	180		1.30	1.10
	198		1.27	1.07
	240		1.20	1.00
	258		1.19	.99
	300		1.12	.92
	360		1.10	.90
	420		1.08	.88
	480		1.06	.86
	540		1.05	.85
	600		1.01	.81
	900		.97	.77

Fig. 8

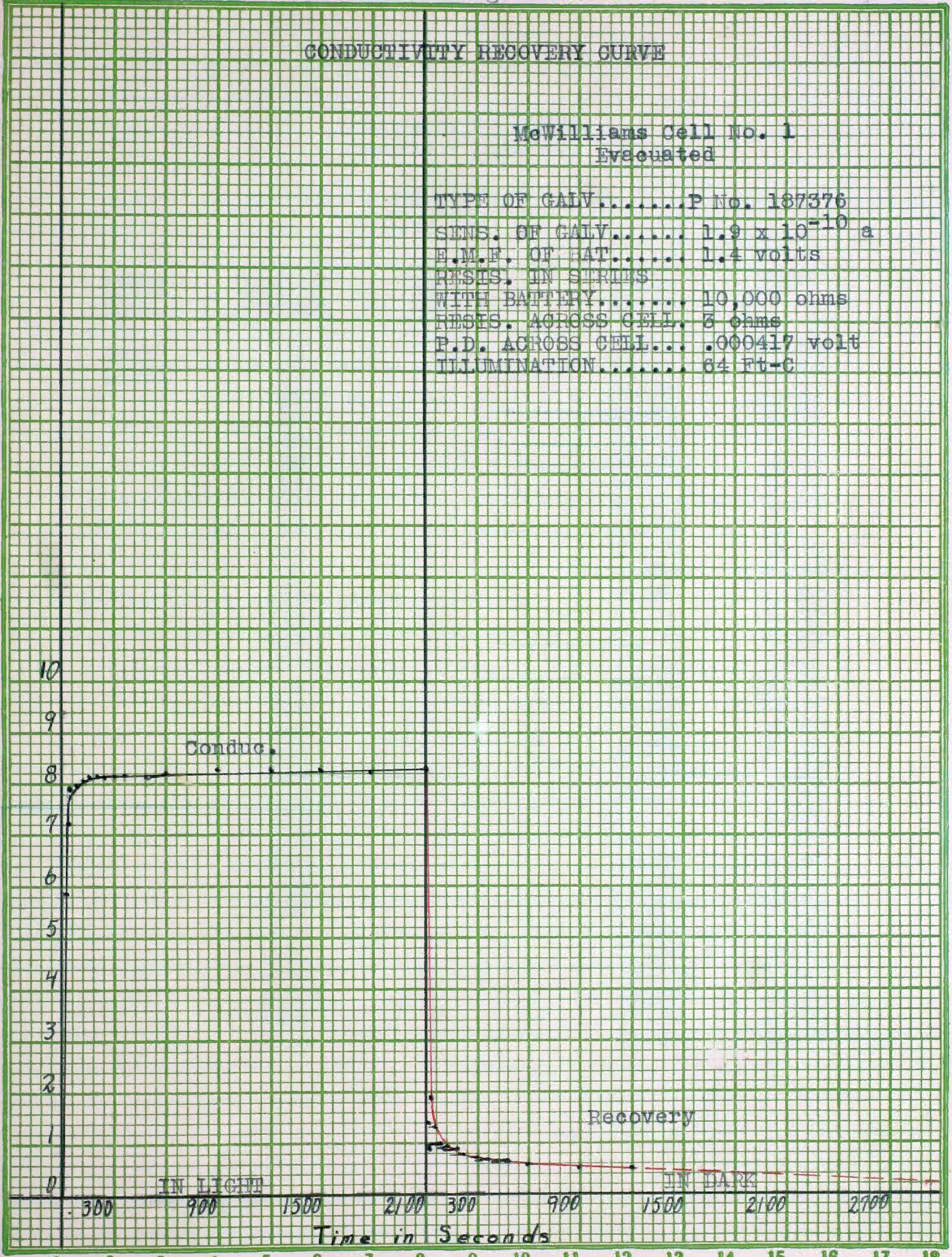

CONDUCTIVITY RECOVERY CURVE
McWilliams Cell No. 1
Unevacuated
TYPE OF GALV........ P No. 187376
SENS. OF GALV......1.9 x 10-10 a
E.M.F. OF BAT...... 1.4 volts
RESIS. IN SERIES
WITH BATTERY....... 10,000 ohms
RESIS. ACROSSCELL.. 3 ohms
P.D. ACROSS CELL... .000417 volt
ILLUMINATION....... 64 Ft-C
Conduc.
Recovery
IN LIGHT
IN DARK
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
300 600 900 1200 1500 1800 2100 2400 2700 300 600 900 1200 1500 1800 2100 2400

CONDUCTIVITY CURVE

McWilliams Cell No. 1
Evacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.10	.40	.30
Light	5		6.00	5.90
	10		9.50	9.40
	15		8.50	8.40
	20		7.50	7.40
	25		7.30	7.20
	30		8.00	7.90
	35		8.00	7.90
	40		8.00	7,90
	45		7,97	7.87
	50		7.97	7.87
	55		8.00	7.90
	60		8.07	7.97
	70		8.07	7.97
	80		8.10	8.00
	90		8.10	8.00
	100		8.12	8.02
	110		8.12	8.02
	120		8.15	8.05
	150		8.20	8.10
	180		8.20	8.10
	198		8.28	8.18
	240		8.20	8.10
	300		8.29	8.19
	360		8.29	8.19
	480		8.29	8.19
	600		8.30	8,20
	900		8.37	8.27
	1200		8.37	8.27
	1500		8.37	8.27
	1800		8.37	8.27

Fig. 9


CONDUCTIVITY RECOVERY CURVE
McWilliams Cell No. 1
Evacuated
TYPE OF GALV.......P No. 187376
SENS. OF GALV...... 1.9 x 10^-10 a
E.M.F. OF BAT...... 1.4 volts
RESIS. IN SERIES
WITH BATTERY....... 10,000 ohms
RESIS. ACROSS CELL. 3 ohms
P.D. ACROSS CELL... .000417 volt
ILLUMINATION....... 64 Ft-C
Conduc.
Recovery
IN LIGHT
IN DARK
0
1
2
3
4
5
6
7
8
9
10
300
900
1500
2100
300
900
1500
2100
2700
Time in Seconds

CONDUCTIVITY CURVE
(Actino + Conduc.)

CELL No. 4
Unevacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.30	12.20	11.90
Light	10		20.00	19.70
	20		21.50	21.20
	30		21.90	21.60
	40		21.85	21.55
	50		21.80	21.50
	60		21.70	21.40
	70		21.70	21.40
	80		21.70	21.40
	90		21.70	21.40
	100		21.70	21.40
	110		21.69	21.39
	120		21.60	21.30
	150		21.50	21.20
	180		21.35	21.05
	198		21.30	21.00
	240		21.27	20.97
	258		21.00	21.00
	300		21.30	21.00
	360		21.17	20.87
	420		21.10	20.80
	480		21.10	20.80
	540		21.06	20.76
	600		20.97	20.67
	900		20.80	20.50
	1200		20.70	20.40
	1500		19.60	19.30
	1800		19.50	19.20
	2100		19.45	19.15
	2400		19.30	19.00
	2570		19.20	18.90
	2700		19.20	18.90

RECOVERY CURVE

CELL No. 4
Unevacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.30	-----	-----
	10		15.00	14.70
	20		13.30	13.00
	30		13.00	12.70
	40		12.97	12.67
	50		12.92	12.62
	60		12.90	12.60
	70		12.90	12.60
	80		12.87	12.57
	90		12.85	12.55
	100		12.82	12.52
	110		12.80	12.50
	120		12.80	12.50
	150		12.77	12.47
	180		12.75	12.45
	198		12.72	12.42
	240		12.70	12.40
	258		12.67	12.37
	300		12.67	12.37
	360		12.65	12.35
	420		12.61	12.31
	480		12.60	12.30
	540		12.57	12.27
	600		12.56	12.26
	900		12.50	12.20
	1200		12.40	12.10
	1500		12.39	12.09

CONDUCTIVITY CURVE

CELL No. 4
Unevacuated

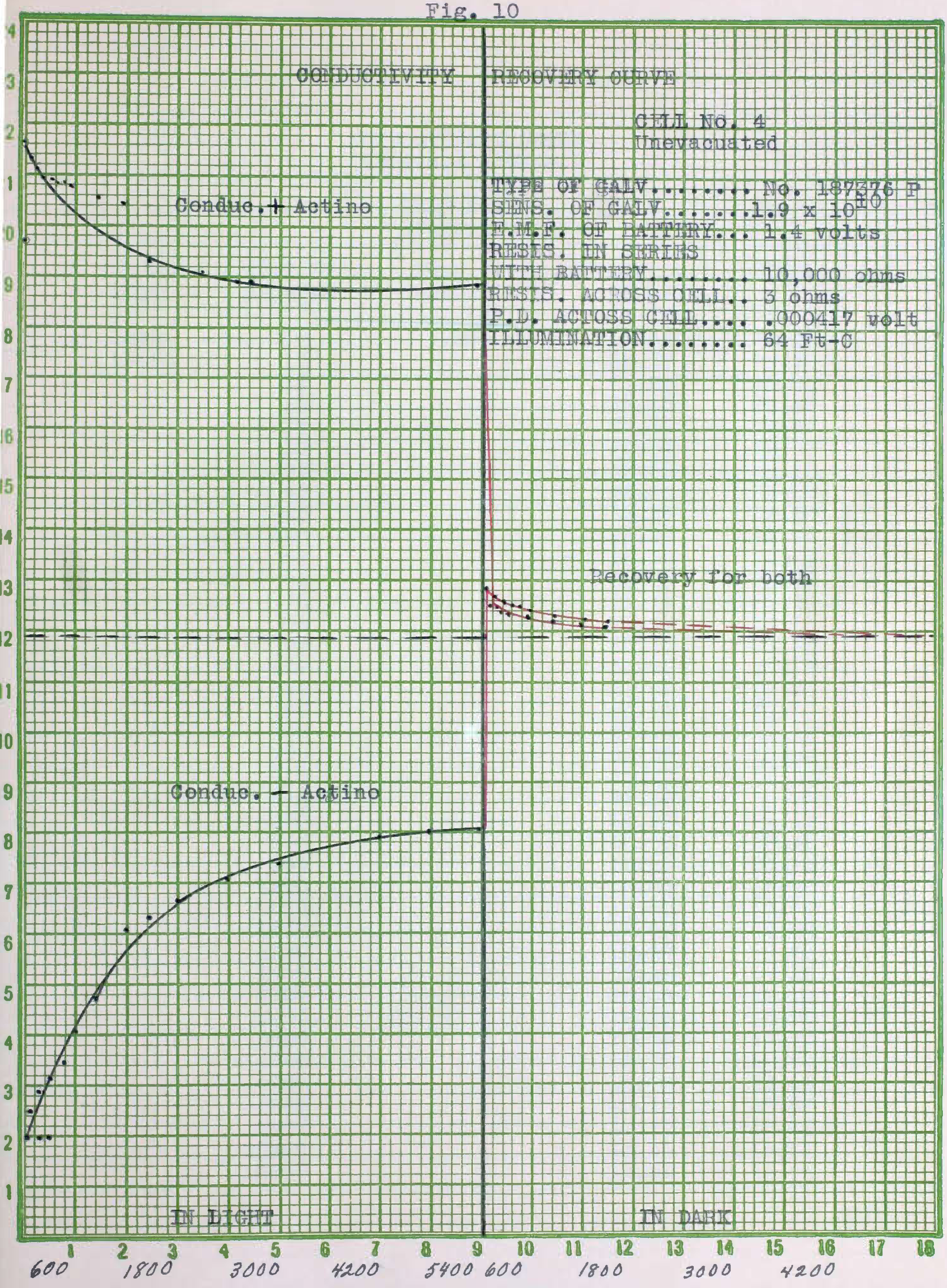
LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.50	12.30	11.89
Light	10		5.00	4.500
	15		3.30	2.80
	20		2.60	2.10
	25		2.50	2.00
	30		2.60	2.10
	40		2.65	2.15
	45		2.70	2.20
	50		2.75	2.25
	55		2.75	2.25
	60		2.90	2,40
	70		3.00	2.50
	80		3.02	2.52
	90		3.10	2.60
	180		3.40	2.90
	198		3.50	3.00
	240		3.50	3.00
	258		3.70	3.20
	300		3.75	3.25
	350		3.70	3.20
	480		4.10	3.60
	600		4.60	4.10
	900		5.20	4.70
	1200		6.60	6.10
	1500		7.00	6.50
	1800		7.25	6.75
	2400		7.60	7.10
	3000		7.90	7.40
	3600		8.17	7.67
	4200		8.40	7.90
	4800		8.50	8.00
	5400		8.60	8.10

RECOVERY CURVE

CELL No. 4
Unevacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.50	-----	-----
	10		12.40	11.90
	20		13.20	12.70
	30		13.35	12.85
	40		13.35-	12.85
	50		13.30	12.80
	60		13.30	12.80
	70		13.30	12.80
	80		13.25	12.75
	90		13.22	12.72
	100		13.21	12.71
	110		13.20	12.70
	120		13.19	12.69
	150		13.17	12.67
	180		13.15	12.65
	198		13.10	12.60
	240		13.10	12.60
	250		12.07	12.57
	300		13.05-	12.55
	360		13.00	12.50
	480		12.97	12.47
	600		12.90	12.40
	900		12.80	12.30
	1200		12.70	12.20
	1500		12.65	12.15

Fig. 10


CONDUCTIVITY RECOVERY CURVE
CELL No. 4
Unevacuated
TYPE OF GALV........ No. 187376 P
SENS. OF GALV.......1.9 x 10^10
E.M.F. OF BATTERY... 1.4 volts
RESIS. IN SERIES
WITH BATTERY........ 10,000 ohms
RESIS. ACROSS CELL.. 3 ohms
P.D. ACROSS CELL.... .000417 volt
ILLUMINATION........ 64 Ft-C
Conduc. + Actino
Recovery for both
Conduc. — Actino
IN LIGHT
IN DARK
600 1800 3000 4200 5400 600 1800 3000 4200

CONDUCTIVITY CURVE
(Conduc.+ Actino.)

CELL No. 4
Evacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.10	12.45	12.35
Light	10		21.00	20.90
	15		21.00	20.90
	20		22.50	22.40
	25		22.50	22.40
	30		22.50	22.40
	35		22.20	22.10
	40		22.20	22.10
	45		22.20	22.10
	50		22.20	22.10
	55		22.20	22.10
	60		21.90	21.80
	70		21.90	21.80
	80		21.80	21.70
	90		21.80	21.70
	100		21.80	21.70
	110		21.80	21.70
	120		21.70	21.60
	150		21.60	21.50
	180		21.59	21.49
	210		21.45	21.35
	240		21.30	21.20
	300		21.27	21.17
	600		20.70	20.60
	900		20.20	20.10
	1200		19.80	19.70
	1500		19.80	19.70
	1800		19.40	19.30
	2100		19.40	19.30
	2400		19.20	19.10
	2700		19.20	19.10
	3000		19.00	18.90
	3600		18.80	18.70
	4200		18.70	18.60
	4800		18.75	18.65
	9000		18.95	18.85
	9600		18.95	18.85
	10200		18.95	18.85
	10800		18.95	18.85

RECOVERY CURVE

CELL No. 4

Evacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.10	-----	-----
	10		15.00	14.90
	15		14.00	13.90
	20		13.70	13.60
	25		13.65	13.55
	30		13.60	13.50
	35		13.60	13.50
	40		13.50	13.40
	45		13.50	13.40
	50		13.50	13.40
	55		13.50	13.40
	60		13.47	13.37
	70		13.45	13.35
	80		13.42	13.32
	90		13.41	13.31
	100		13.00	12.90
	110		13.00	12.90
	120		13.40	12.90
	150		13.37	13.27
	180		13.35	13.25
	240		13.30	13.20
	360		13.26	13.16
	600		13.18	13.08
	1200		13.00	12.90
	1800		12.90	12.80
	2400		12.89	12.79

CONDUCTIVITY CURVE
(Conduc. — Actino.)

CELL No. 4
Evacuated

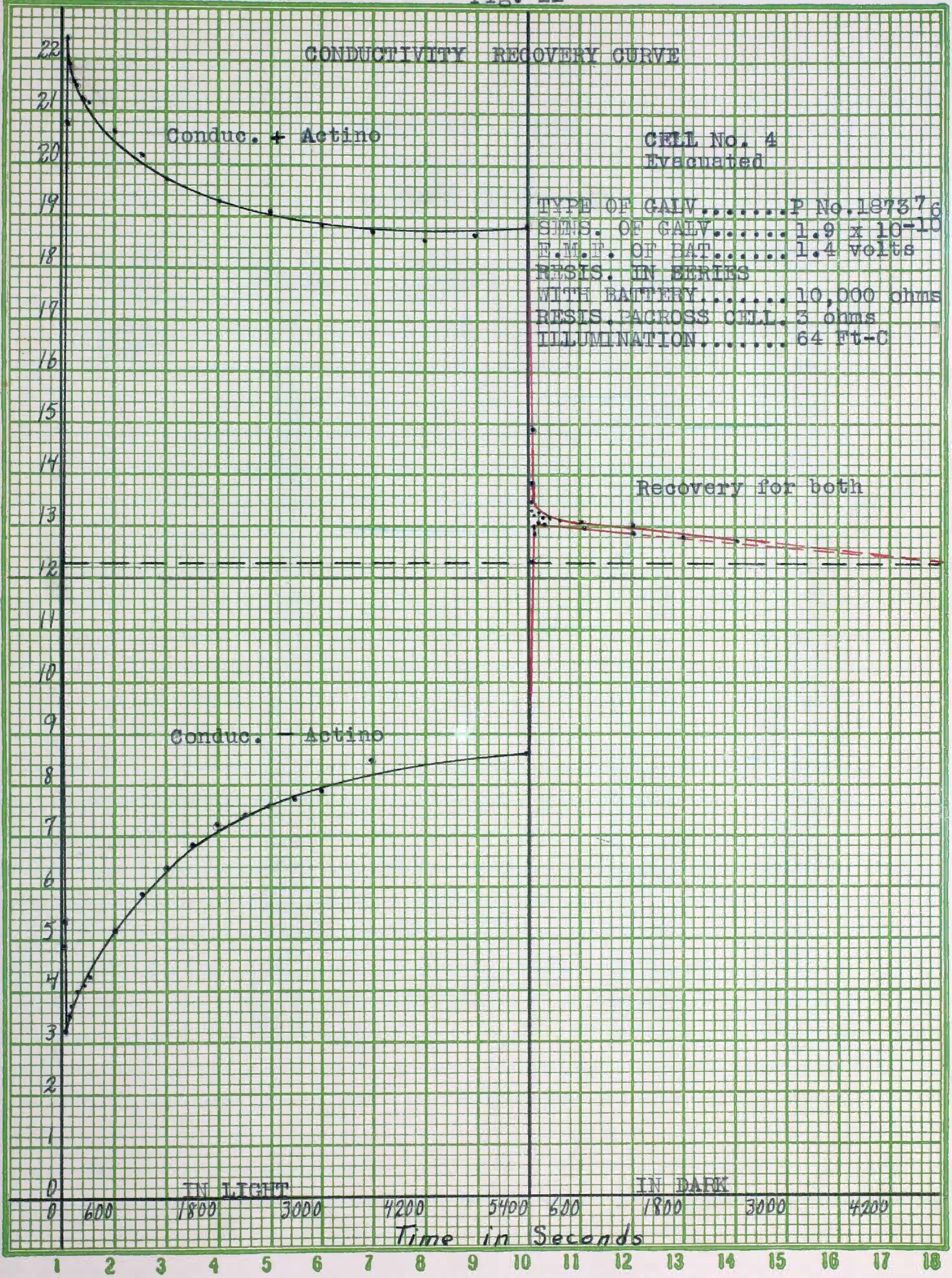
LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.10	12.10	12.00
Light	10		5.50	5.40
	15		4.00	3.90
	20		3.50	3.40
	25		3.30	3.20
	30		3.30	3.20
	35		3.40	3.30
	40		3.50	3.40
	45		3.50	3.40
	50		3.60	3.50
	55		3.60	3.50
	60		3.65	3.55
	70		3.70	3.60
	80		3.70	3.60
	90		3.70	3.60
	100		3.70	3.60
	110		3.80	3.70
	120		3.80	3.70
	150		4.00	3.90
	180		4.10	4.00
	198		4.12	4.02
	240		4.20	4.10
	300		4.35	4.25
	600		5.30	5.20
	900		6.00	5.90
	1200		6.55	6.45
	1500		6.90	6.80
	1800		7.20	7.10
	2100		7.50	7.40
	2400		7.70	7.60
	2700		7.85	7.75
	3000		8.50	8.40
	3600		8.60	8.50
	5700		8.70	8.60
	7200		8.90	8.80
	9000		9.10	9.00

RECOVERY CURVE

CELL No. 4
Evacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.10	-----	-----
	10		12.40	12.30
	15		13.10	13.00
	20		13.20	13.10
	25		13.20	13.10
	30		13.45	13.35
	35		13.45	13.35
	40		13.40	13.30
	45		13.40	13.30
	50		13.40	13.30
	55		13.40	13.30
	60		13.37	13.27
	70		13.37	13.27
	80		13.37	13.27
	90		13.30	13.20
	100		13.30	13.20
	110		13.30	13.20
	120		13.28	13.18
	150		13.28	13.18
	180		13.25	13.15
	240		13.25	13.15
	360		13.10	13.00
	600		13.00	12.90
	1200		13.00	12.90
	1800		13.00	12.90

Fig. 11


CONDUCTIVITY RECOVERY CURVE
Conduc. + Actino
CELL No. 4
Evacuated
TYPE OF GALV.......P No.1873 7 6
SENS. OF GALV......1.9 x 10-10
E.M.F. OF BAT......1.4 volts
RESIS. IN SERIES
WITH BATTERY.......10,000 ohms
RESIS. ACROSS CELL. 3 ohms
ILLUMINATION.......64 Ft-C
Recovery for both
Conduc. — Actino
IN LIGHT
IN DARK
0 600 1800 3000 4200 5400 600 1800 3000 4200
Time in Seconds

CONDUCTIVITY CURVE

CELL No. 6
Unevacuated

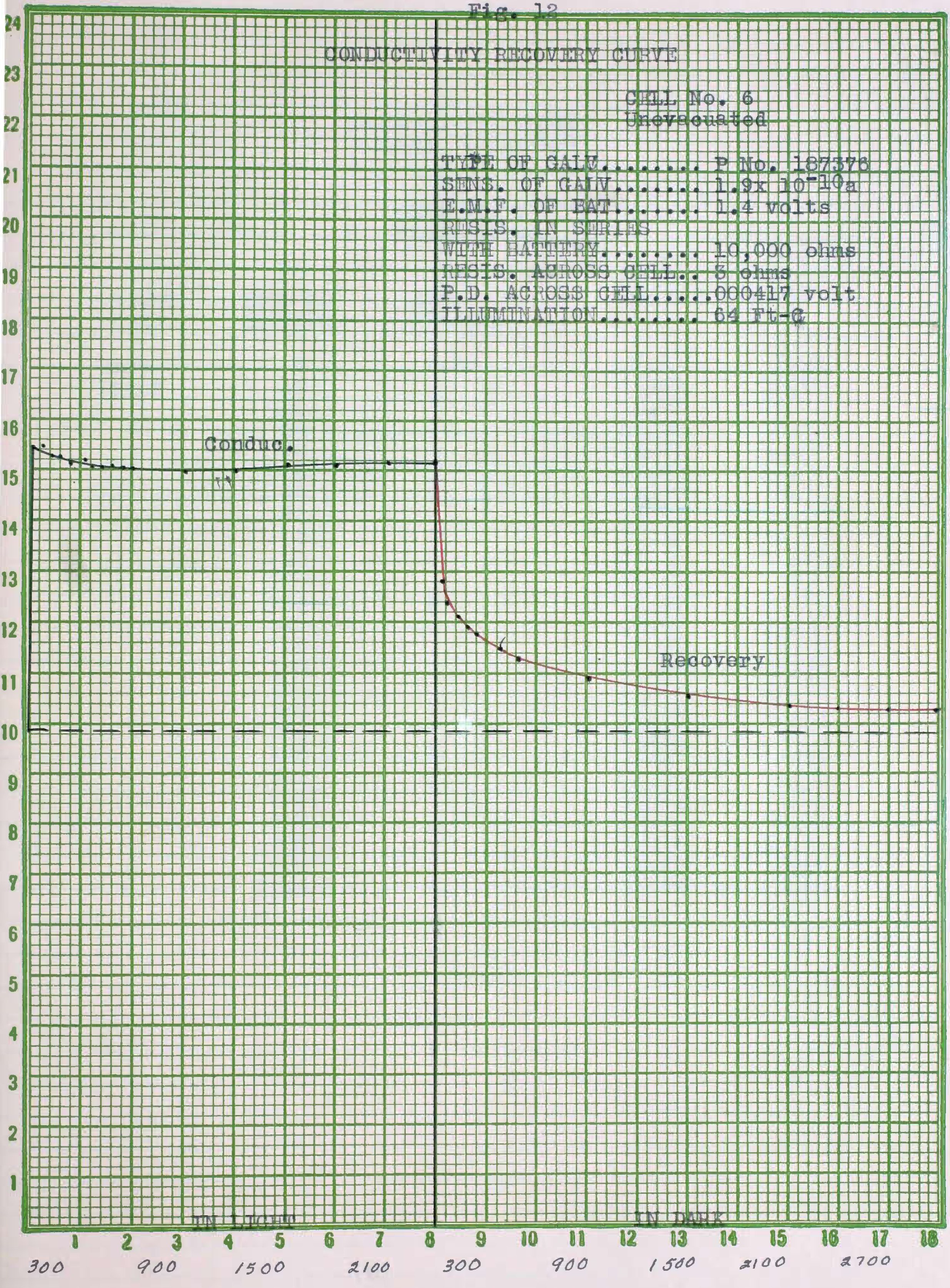
LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.10	10.05	9.95
Light	5		12.00	11.90
	10		14.50	14.40
	15		15.60	15.50
	20		15.50	15.40
	25		15.50	15.40
	30		15.50	15.40
	35		15.50	15.40
	40		15.50	15.40
	45		15.50	15.40
	50		15.50	15.40
	55		15.50	15.40
	60		15.50	15.40
	80		15.40	15.30
	100		15.40	15.30
	120		15.35	15.25
	150		15.30	15.20
	180		15.30	15.20
	198		15.30	15.20
	240		15.20	15.10
	258		15.20	15.10
	300		15.20	15.10
	360		15.10	15.00
	420		15.10	15.00
	480		15.10	15.00
	540		15.07	14.97
	600		15.05	14.95
	900		15.00	14.90
	1200		15.00	14.90
	1500		15.00	14.90
	1800		15.15	15.05
	2100		15.20	15.10

RECOVERY CURVE

CELL No. 6
Unevacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.10	-----	-----
	10		13.80	13.70
	15		13.20	13.10
	20		13.00	12.90
	25		12.90	12.80
	30		12.80	12.70
	35		12.70	12.60
	40		12.65	12.55
	45		12.60	12.50
	50		12.50	12.40
	55		12.47	12.37
	60		12.40	12.30
	80		12.30	12.20
	100		12.17	12.07
	120		12.10	12.00
	180		11.95	11.85
	198		11.80	11.70
	240		11.75	11.65
	360		11.55	11.45
	480		11.40	11.30
	600		11.35	11.25
	1200		10.90	10.80
	1800		10.62	10.52
	2400		10.50	10.40
	3000		10.40	10.30
	3600		10.35	10.25

Fig. 12


CONDUCTIVITY RECOVERY CURVE
CELL No. 6
Unevacuated
TYPE OF GALV........ P No. 187376
SENS. OF GALV....... 1.9x 10-10a
E.M.F. OF BAT....... 1.4 volts
RESIS. IN SERIES
WITH BATTERY........ 10,000 ohms
RESIS. ACROSS CELL.. 3 ohms
P.D. ACROSS CELL.....000417 volt
ILLUMINATION........ 64 Ft-C
Conduc.
Recovery
IN LIGHT
IN DARK
300
900
1500
2100
300
900
1500
2100
2700

CONDUCTIVITY CURVE
(Conduc. + Actino)

CELL NO. 7
Unevacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.25	7.45	7.20
Light	10		14.00	13.75
	20		15.00	14.75
	30		15.00	14.75
	40		14.95	14.70
	50		14.95	14.70
	60		15.00	14.75
	70		14.95	14.70
	80		14.95	14.70
	90		15.00	14.75
	100		15.00	14.75
	110		15.00	14.75
	120		15.00	14.75
	150		15.00	14.75
	180		15.00	14.75
	198		15.00	14.75
	240		15.00	14.75
	300		15.00	14.75
	360		14.95	14.70
	420		15.00	14.75
	480		15.00	14.75
	540		15.00	14.75
	600		15.00	14.75
	900		15.00	14.75
	1200		15.00	14.75

RECOVERY CURVE

CELL No. 7
Unevacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.25	-----	-----
	10		10.50	10.25
	20		9.80	9.55
	30		9.70	9.45
	40		9.60	9.35
	50		9.50	9.25
	60		9.40	9.15
	70		9.32	9.07
	80		9.30	9.05
	90		9.25	9.00
	100		9.20	8.95
	110		9.20	8.95
	120		9.10	8.85
	150		9.02	8.77
	180		8.95	8.70
	198		8.90	8.65
	240		8.82	8.57
	258		8.80	8.55
	300		8.77	8.52
	360		8.70	8.45
	420		8.65	8.40
	480		8.57	8.32
	540		8.52	8.27
	600		8.50	8.25
	900		8.30	8.05
	1200		8.17	7.92
	1500		8.10	7.85
	1800		8.02	7.77

CONDUCTIVITY CURVE
(Conduc. — Actino)

CELL No. 7
Unevacuated

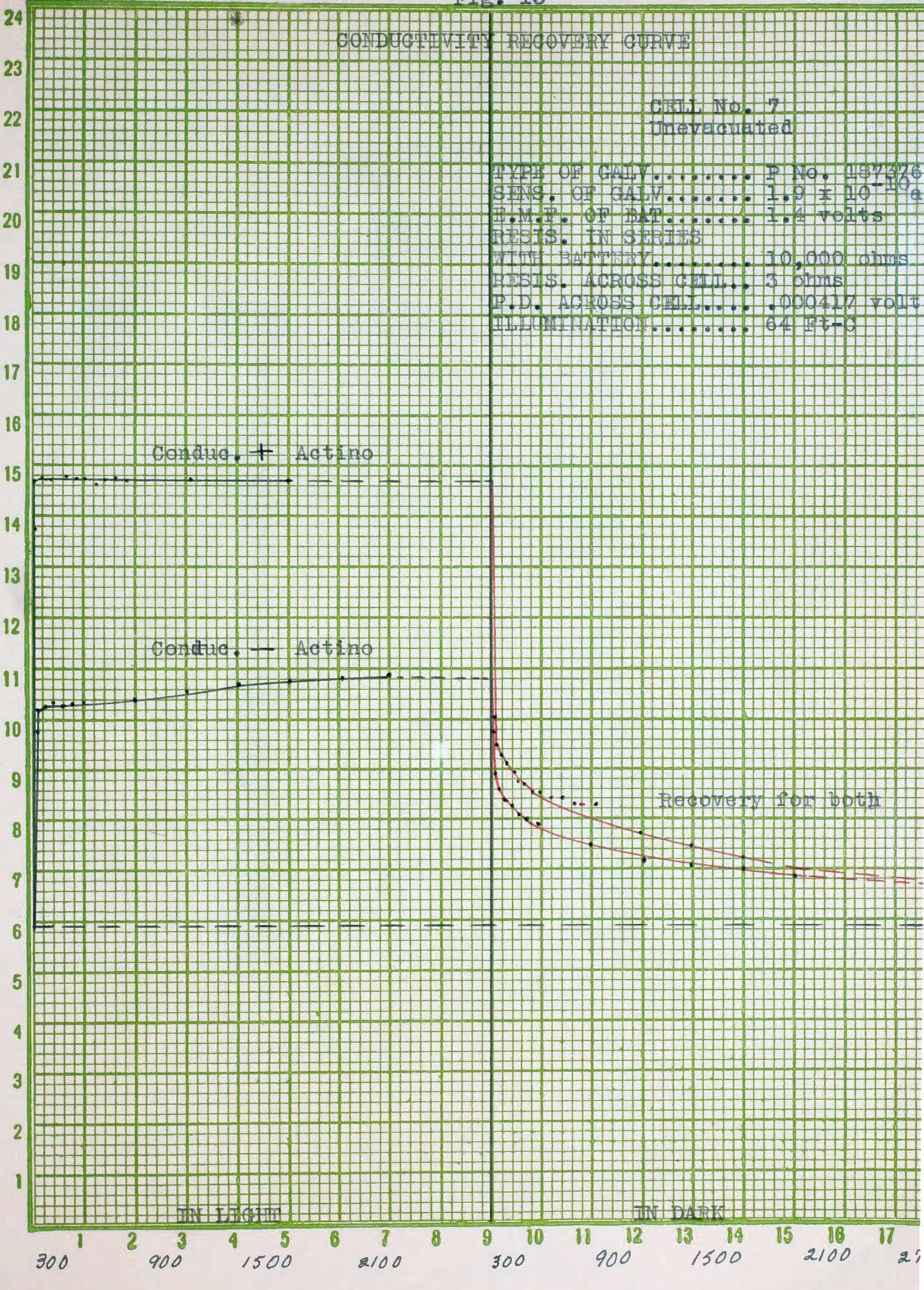
LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN.cm	DIFF.
Dark	0	.50	6.40	5.90
Light	10		10.20	9.70
	15		10.70	10.20
	20		10.75	10.25
	25		10.75	10.25
	30		10.75	10.25
	35		10.75	10.25
	40		10.75	10.25
	45		10.75	10.25
	50		10.75	10.25
	55		10.76	10.26
	60		10.76	10.26
	70		10.77	10.27
	80		10.78	10.28
	90		10.78	10.28
	100		10.78	10.28
	110		10.79	10.29
	120		10.79	10.29
	150		10.80	10.30
	180		10.80	10.30
	198		10.81	10.31
	240		10.84	10.34
	300		10.87	10.37
	600		10.95	10.45
	900		11.07	10.57
	1200		11.20	10.70
	1500		11.25	10.75
	1800		11.35	10.85
	2100		11.40	10.90

RECOVERY CURVE

CELL No. 7
Unevacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.50	-----	-----
	10		10.20	9.70
	15		10.20	9.70
	20		9.50	9.00
	25		9.50	9.00
	30		9.40	8.90
	35		9.35	8.85
	40		9.30	8.80
	45		9.35	8.85
	50		9.20	8.70
	55		9.25	8.75
	60		9.10	8.60
	70		9.00	8.50
	80		8.90	8.40
	90		8.88	8.38
	100		8.85	8.35
	110		8.80	8.30
	120		8.75	8.25
	150		8.67	8.17
	180		8.60	8.10
	198		8.50	8.00
	240		8.45	7.95
	300		8.35	7.85
	600-		8.00	7.50
	900		7.72	7.22
	1200		7.60	7.10
	1500		7.50	7.00
	1800		7.40	6.90

Fig. 15



CONDUCTIVITY RECOVERY CURVE
CELL No. 7
Unevacuated
TYPE OF GALV.......... P No. 187376
SENS. OF GALV......... 1.9 x 10^-10 a
E.M.F. OF BAT......... 1.4 volts
RESIS. IN SERIES
WITH BATTERY.......... 10,000 ohms
RESIS. ACROSS CELL... 3 ohms
P.D. ACROSS CELL..... .000417 volt
ILLUMINATION......... 64 Ft-C
Conduc. + Actino
Conduc. — Actino
Recovery for both
IN LIGHT
IN DARK
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
300 900 1500 2100 300 900 1500 2100

CONDUCTIVITY CURVE
(Conduc. + Actino)

CELL No. 7
Evacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.30	-----	-----
Light	10		7.90	7.60
	20		15.00	14.70
	30		16.55	16.25
	40		16.56	16.26
	50		16.56	16.26
	60		16.52	16.22
	70		16.50	16.20
	80		16.47	16.17
	90		17.52	16.22
	100		16.50	16.20
	110		16.50	16.20
	120		16.40	16.10
	150		16.45	16.15
	180		16.50	16.20
	198		16.45	16.15
	240		16.40	16.10
	258		16.40	16.10
	300		16.37	16.07
	360		16.25	15.95
	420		16.25	15.95
	480		16.10	15.80
	540		16.07	15.77
	600		16.05	15.75
	900		15.77	15.47
	1200		15.70	15.40
	1800		15.70	15.40

RECOVERY CURVE

CELL No. 7
Evacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.30	-----	-----
	10		11.10	10.80
	20		10.60	10.30
	30		10.45	10.15
	40		10.30	10.00
	50		10.20	9.90
	60		10.10	9.80
	70		10.05	9.75
	80		9.97	9.67
	90		9.90	9.60
	100		9.85	9.55
	110		9.80	9.50
	120		9.79	9.49
	150		9.67	9.37
	180		9.60	9.30
	198		9.50	9.20
	240		9.46	9.16
	258		9.40	9.10
	300		9.36	9.06
	360		9.27	8.97
	420		9.20	8.90
	480		9.10	8.80
	540		9.05	8.75
	600		9.00	8.70
	900		8.77	8.47
	1200		8.60	8.30
	1500		8.45	8.15
	1800		8.35-	8.05

CONDUCTIVITY CURVE
(Conduc. — Actino)

CELL No. 7
Evacuated

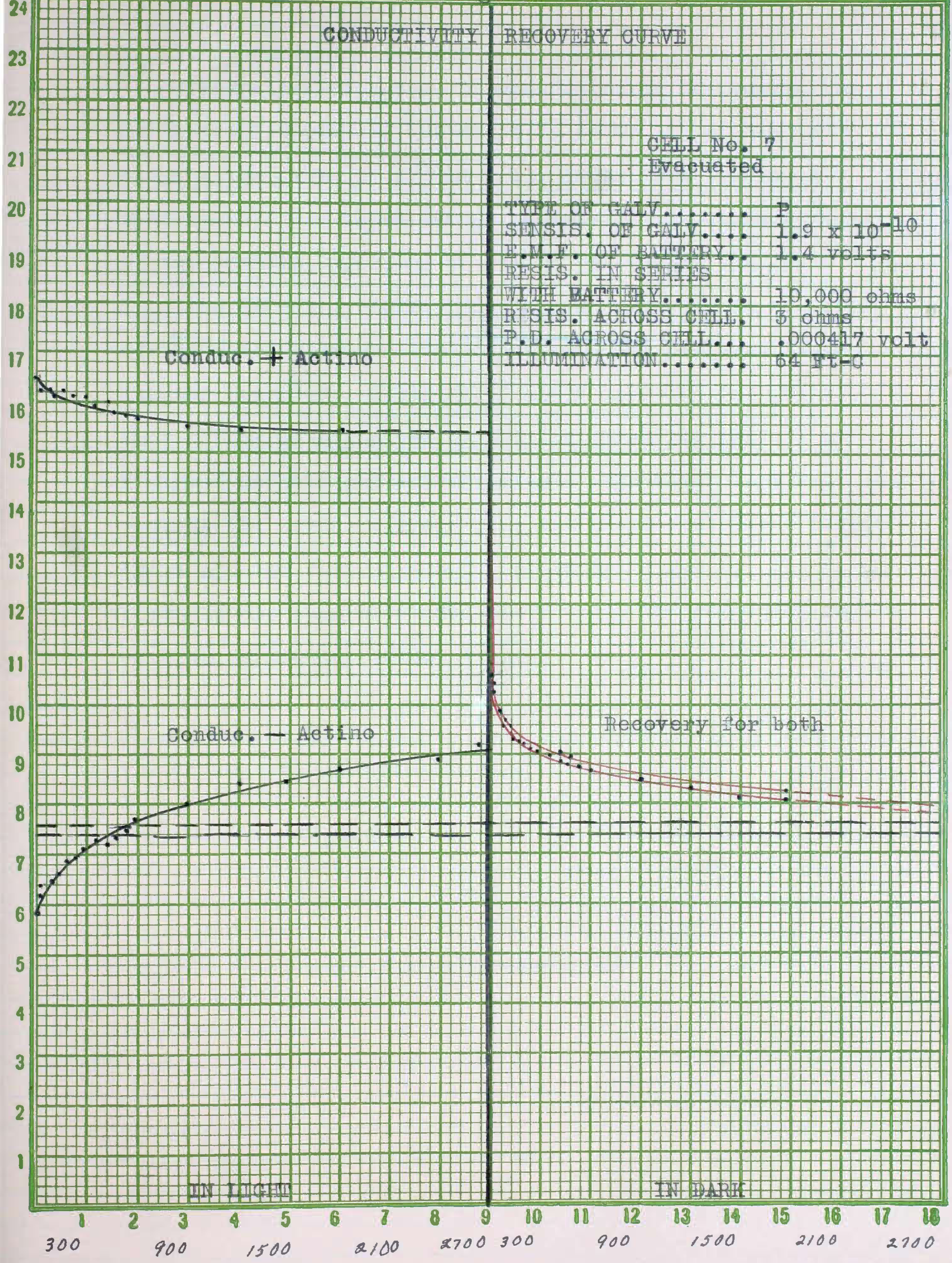
LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.30	7.70	7.40
Light	10		6.25	5.95
	20		6.40	6.10
	30		6.50	6.20
	40		6.65	6.35
	50		6.75	6.45
	60		6.75	6.45
	70		6.80	6.50
	80		6.87	6.57
	90		6.89	6.59
	100		6.90	6.60
	110		6.95	6.65
	120		6.97	6.67
	150		7.10	6.80
	180		7.20	6.90
	198		7.35	7.05
	240		7.39	7.09
	300		7.42	7.12
	360		7.60	7.30
	420		7.60	7.30
	480		7.70	7.40
	540		7.85	7.55
	600		7.96	7.66
	900		8.30	8.00
	1200		8.70	8.40
	1500		8.87	8.47
	1800		9.05	8.75
	2400		9.27	8.97
	3300		9.50	9.20

RECOVERY CURVE

CELL No. 7
Evacuated

LIGHT COND.	TIME IN SECONDS	ZERO READING	DEFL. IN cm	DIFF.
Dark	0	.30	-----	-----
	10		10.90	10.60
	20		10.70	10.50
	30		10.50	10.20
	40		10.35	10.05
	50		10.35	10.05
	60		10.17	9.87
	70		10.10	9.80
	80		10.05	9.75
	90		10.00	9.70
	100		9.95	9.65
	110		9.90	9.60
	120		9.85	9.55
	150		9.77	9.47
	180		9.69	9.39
	198		9.60	9.30
	240		9.55	9.25
	258		9.50	9.20
	300		9.41	9.11
	360		9.41	9.11
	420		9.30	9.00
	480		9.20	8.90
	540		9.10	8.80
	600		9.06	8.76
	900		8.85	8.55
	1200		8.67	8.37
	1500		8.52	8.22

Fig. 14


CONDUCTIVITY RECOVERY CURVE
CELL No. 7
Evacuated
TYPE OF GALV....... P
SENSIS. OF GALV.... 1.9 x 10-10
E.M.F. OF BATTERY.. 1.4 volts
RESIS. IN SERIES
WITH BATTERY....... 10,000 ohms
RESIS. ACROSS CELL. 3 ohms
P.D. ACROSS CELL... .000417 volt
ILLUMINATION....... 64 Ft-C
Conduc. + Actino
Conduc. — Actino
Recovery for both
IN LIGHT
IN DARK
24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
300 900 1500 2100 2700 300 900 1500 2100 2700

Prismatic Response: It was desirable to observe the prismatic response of the cells in order to be able to compare the behavior of the cells under this treatment with that of the equal-energy radiation. For this part of the problem apparatus in Fig. 5 was used. The light from the 500-watt stereopticon lamp was focused on the slit of the collimator and the deflections for different wave-lengths recorded. Cells No. 1 and 6 have but one graph each. This is explained by the fact that the cells 1 and 6 showed no actino-electric effect. The black line represents the actino voltage plus the photo resistance effect. There are two curves each for cells No. 4 and 7. The black curve is the same as stated above while the red curve represents the actino effect alone.

PRISMATIC RESPONSE

McWilliams Cell No. 1
Evacuated

E. M. F. IN VOLTS	WAVE LENGTH IN A	DEFLECTION IN cm
106	4000	4.20
	4250	5.90
	4500	7.60
	4750	10.50
	5000	12.20
	5250	14.10
	5500	16.00
	5750	17.70
	6000	19.80
	6250	24.60
	6500	28.90
	6750	30.40
	7000	29.10
	7250	25.60
	7500	22.10
	7750	18.50
	8000	15.80
	8250	13.70

Fig. 15


PRISMATIC RESPONSE
Deflections in cms
Wave Length of Light
4000
5000
6000
7000
8000
Å
McWilliams Cell No. 1
Evacuated
TYPE OF GALV. No.187570P
SENS. OF GALV. . . . . 1.9 x 10^{-10}
E.M.F. OF BATTERY. . . . 1.4 volts
RESIS. IN SERIES
WITH BATTERY. . . . . 10,000 ohms
RESIS. ACROSS CELL. . . 40 ohms
P.D. ACROSS CELL. . . . . .00556 volt
READING OF M.A. . . . . . . .15 ma.

PRISMATIC RESPONSE

CELL No. 4
Evacuated

E. M. F. IN VOLTS	WAVE LENGTH IN A	A + V DEFL. IN cm	A DEFL. IN cm
106	4000	.10	.05
	4250	130	.20
	4500	.70	.60
	4750	1.45	1.20
	5000	2.50	2.15
	5250	3.40	3.40
	5500	4.70	4.60
	5750	5.50	5.40
	6000	4.70	4.60
	6250	2.90	2.55
	6500	2.50	2.00
	6750	3.70	3.10
	7000	5.20	4.40
	7250	6.21	5.30
	7500	7.00	5.90
	7750	7.70	6.40
	8000	7.90	6.90
	8250	8.30	7.40

Fig. 16

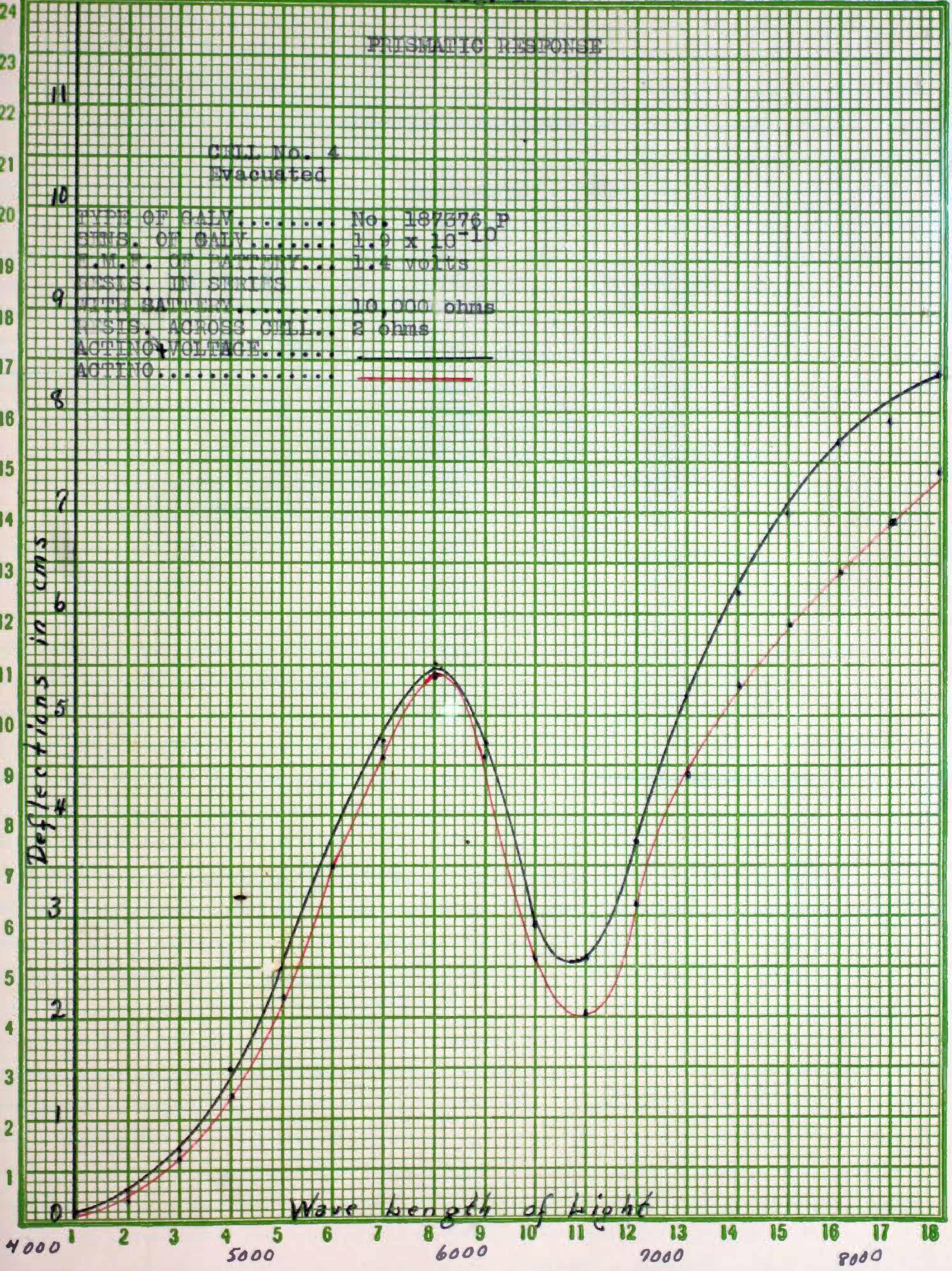
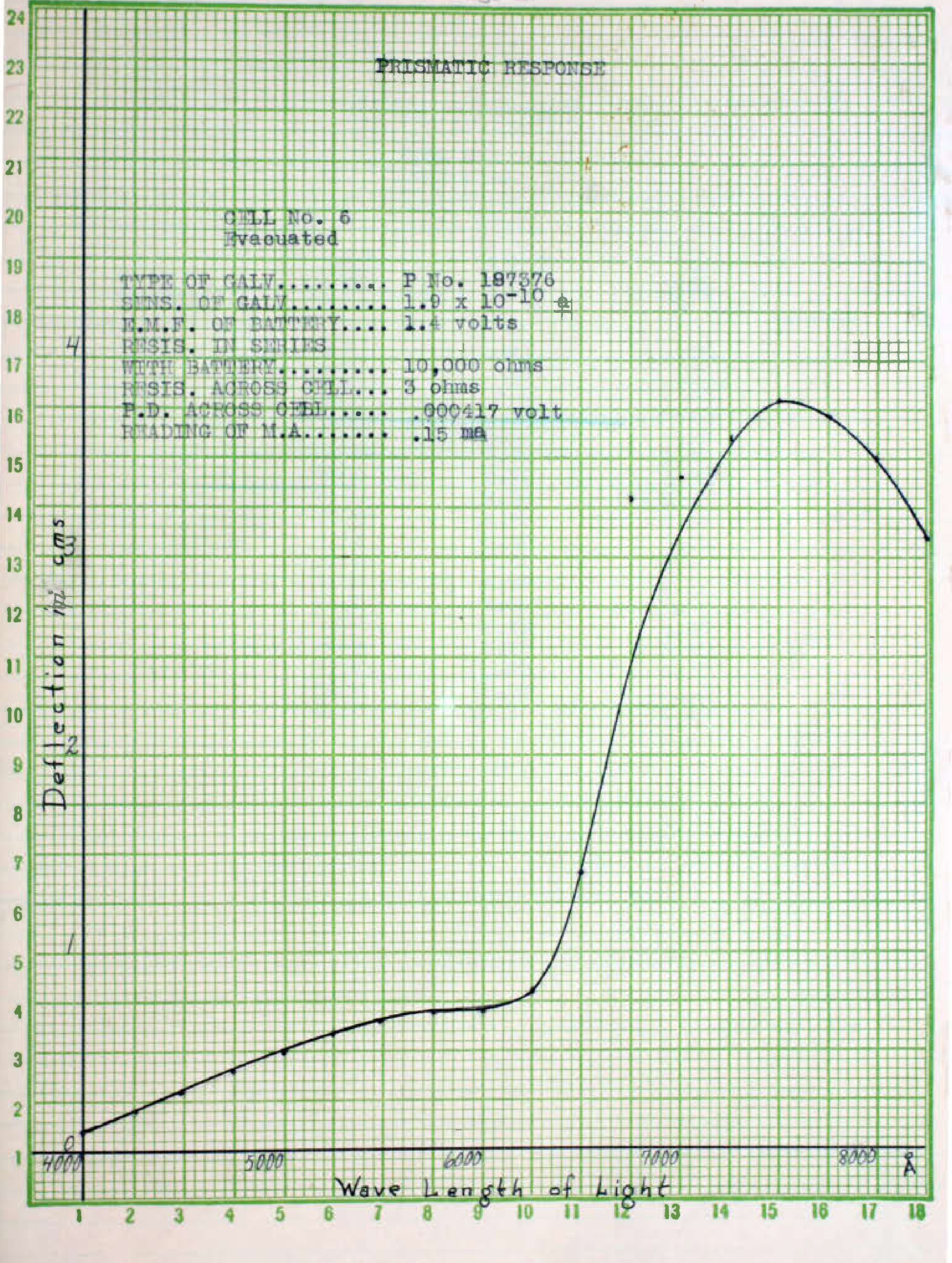

PRISMATIC RESPONSE
CELL No. 4
Evacuated
TYPE OF GALV........ No. 187376 P
SENS. OF GALV....... 1.9 x 10-10
E.M.F. OF BATTERY... 1.4 volts
RESIS. IN SERIES
WITH BATTERY........ 10,000 ohms
RESIS. ACROSS CELL.. 2 ohms
ACTINO VOLTAGE......
ACTINO..............
Deflections in cms
Wave length of Light
4000
5000
6000
7000
8000

Fig. 17


PRISMATIC RESPONSE
CELL No. 6
Evacuated
TYPE OF GALV.......... P No. 187376
SENS. OF GALV......... 1.9 x 10-10
E.M.F. OF BATTERY.... 1.4 volts
RESIS. IN SERIES
WITH BATTERY.......... 10,000 ohms
RESIS. ACROSS CELL... 3 ohms
P.D. ACROSS CELL.... .000417 volt
READING OF M.A....... .15 ma
Deflection in cms
Wave Length of Light
4000
5000
6000
7000
8000
Å

PROSMATIC RESPONSE

CELL No. 7
Evacuated

E. M. F. IN VOLTS	WAVE LENGTH IN A	A + V DEFL. IN cm	A DEFL. IN cm
106	4000	.10	.10
	4250	.25	.20
	4500	.50	.30
	4750	.87	.60
	5000	1.37	.90
	5250	2.00	1.40
	5500	2.70	2.00
	5750	3.55	2.60
	6000	4.00	2.90
	6250	4.20	3.00
	6500	3.55	2.40
	6750	2.90	1.60
	7000	3.00	1.50
	7250	4.20	2.50
	7500	6.15	3.00
	7750	7.90	4.20
	8000	9.25	5.15
	8250	10.10	5.90

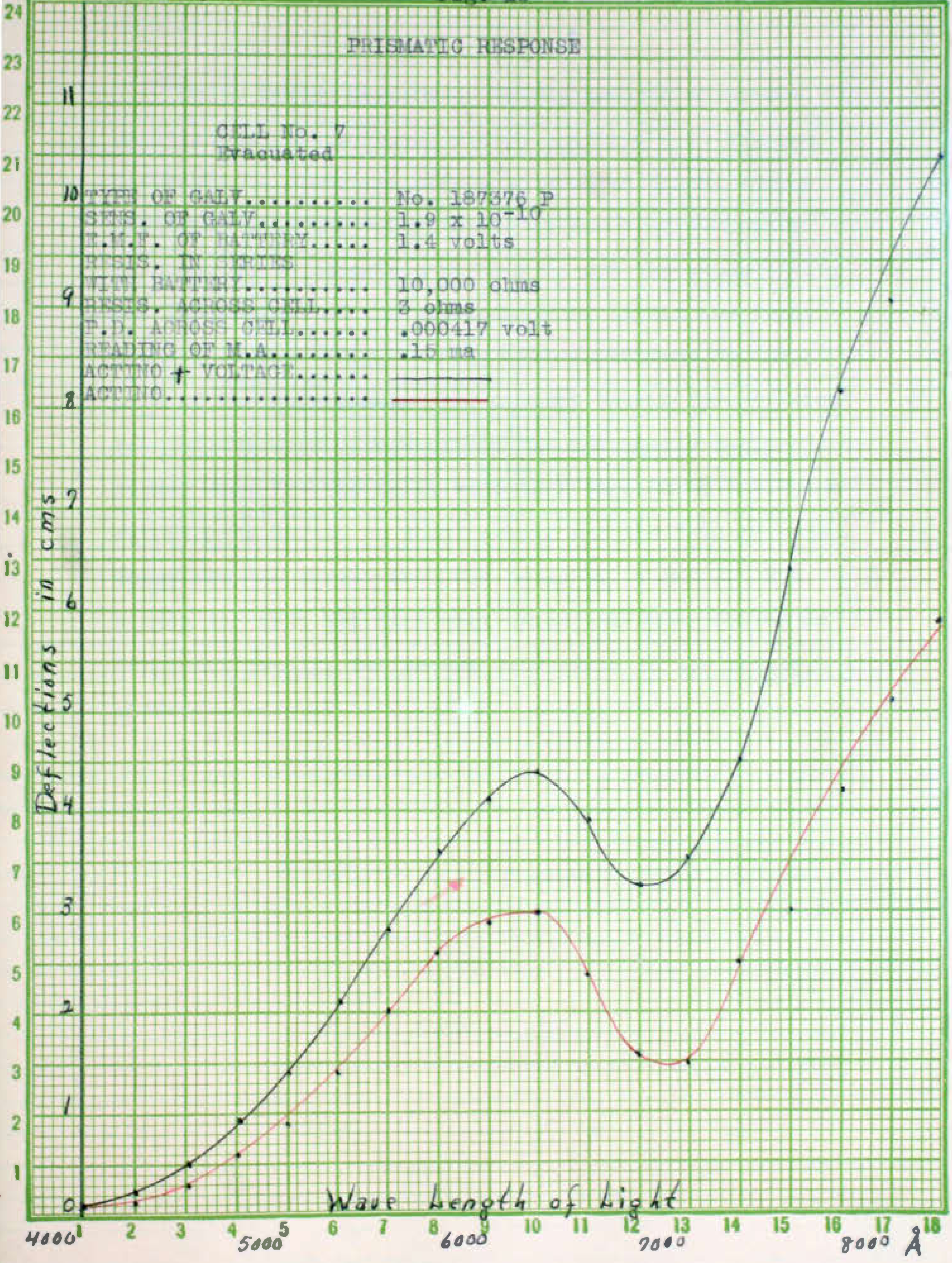

PRISMATIC RESPONSE
CELL No. 7
Evacuated
TYPE OF GALV.......... No. 187376 P
SENS. OF GALV......... 1.9 x 10^-10
E.M.F. OF BATTERY..... 1.4 volts
RESIS. IN SERIES
WITH BATTERY.......... 10,000 ohms
RESIS. ACROSS CELL.... 3 ohms
P.D. ACROSS CELL...... .000417 volt
READING OF M.A........ .15 ma
ACTINO + VOLTAGE......
ACTINO................
Deflections in cms
Wave Length of Light
4000
5000
6000
7000
8000
Å

Fig. 18

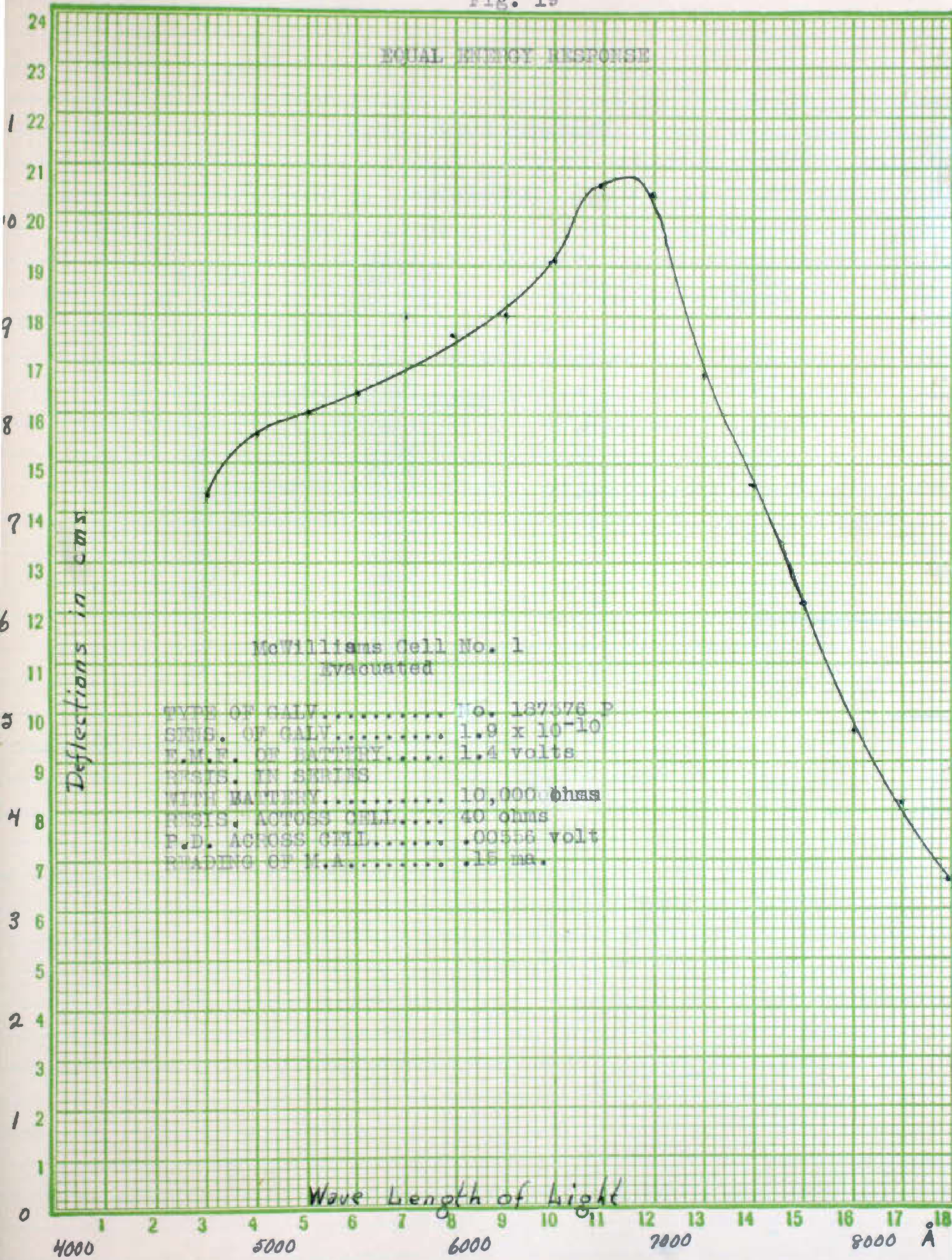
Equal Energy Response: Having secured a current calibration for an "equal energy spectrum", it was now desirable to study the effect of such an "equal energy spectrum" upon the conductivity of the selenium cells in question to ascertain whether or not the conductivity was independent of the wavelengths of light, the cells being in vacuo. Fig. 3 shows the connections for this part of the experiment. The current values for different wavelengths were picked off of the thermopile calibration curve, Fig. 7. The cells were then exposed to different wavelengths having an equal energy and the data recorded. There are two curves each for cells No. 4 and 7. The reason for this has also been explained under Prismatic Response, namely, due to the occurrence of the actino effect.

EQUAL ENERGY RESPONSE

McWilliams Cell No. 1
Evacuated

E. M. F. IN VOLTS	WAVE LENGTH IN A	DEFLECTION IN cm
106	4500	7.15
95	4750	7.82
80	5000	8.00
70	5250	8.20
67	5500	9.00
58	5750	8.80
53	6000	9.00
48	6250	9.60
42	6500	9.80
38	6750	9.70
35	7000	8.40
32	7250	7.30
30	7500	6.10
28	7750	4.80
27	8000	4.10
26	8250	3.30

Fig. 19

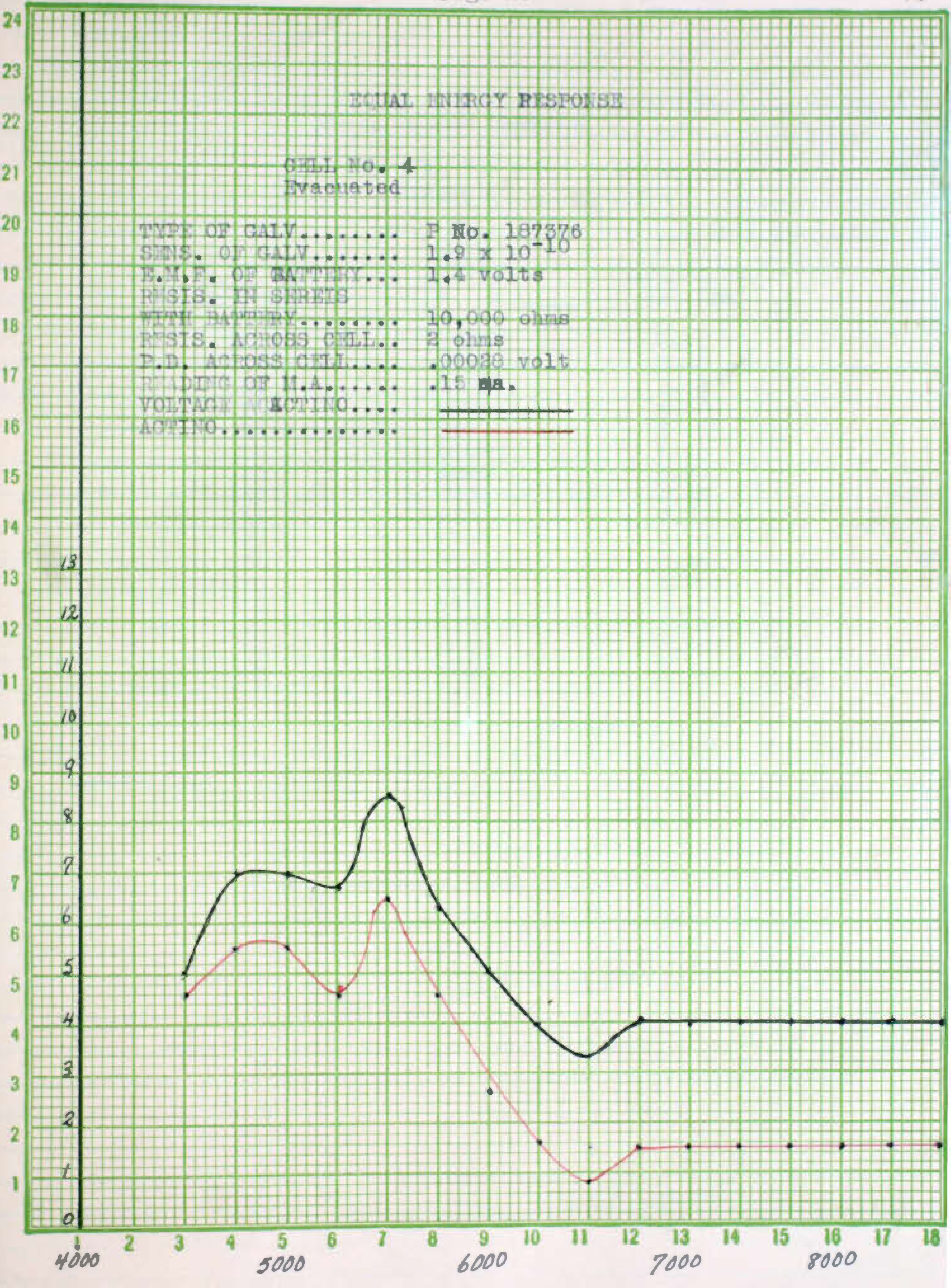

EQUAL ENERGY RESPONSE
McWilliams Cell No. 1
Evacuated
TYPE OF GALV.......... No. 187376 P
SENS. OF GALV......... 1.9 x 10-10
E.M.F. OF BATTERY..... 1.4 volts
RESIS. IN SERIES
WITH BATTERY.......... 10,000 ohms
RESIS. ACROSS CELL.... 40 ohms
P.D. ACROSS CELL...... .00556 volt
READING OF M.A........ .15 ma.
Deflections in cms
Wave Length of Light
4000
5000
6000
7000
8000
Å

EQUAL ENERGY RESPONSE

CELL No. 4
Evacuated

E.M.F. IN VOLTS	WAVE LENGTH IN A	A + V DEFL. IN cm	A DEFL. IN cm
106	4500	.50	.45
95	4750	.70	.55
80	5000	.70	.55
70	5250	.67	.45
67	5500	.85	.65
58	5750	.62	.45
53	6000	.50	.27
48	6250	.40	.15
42	6500	.32	.08
38	6750	.40	.15
35	7000	.40	.15
32	7250	.40	.15
30	7500	.40	.15
28	7750	.40	.15
27	8000	.40	.15
26	8250	.40	.15

Fig. 20

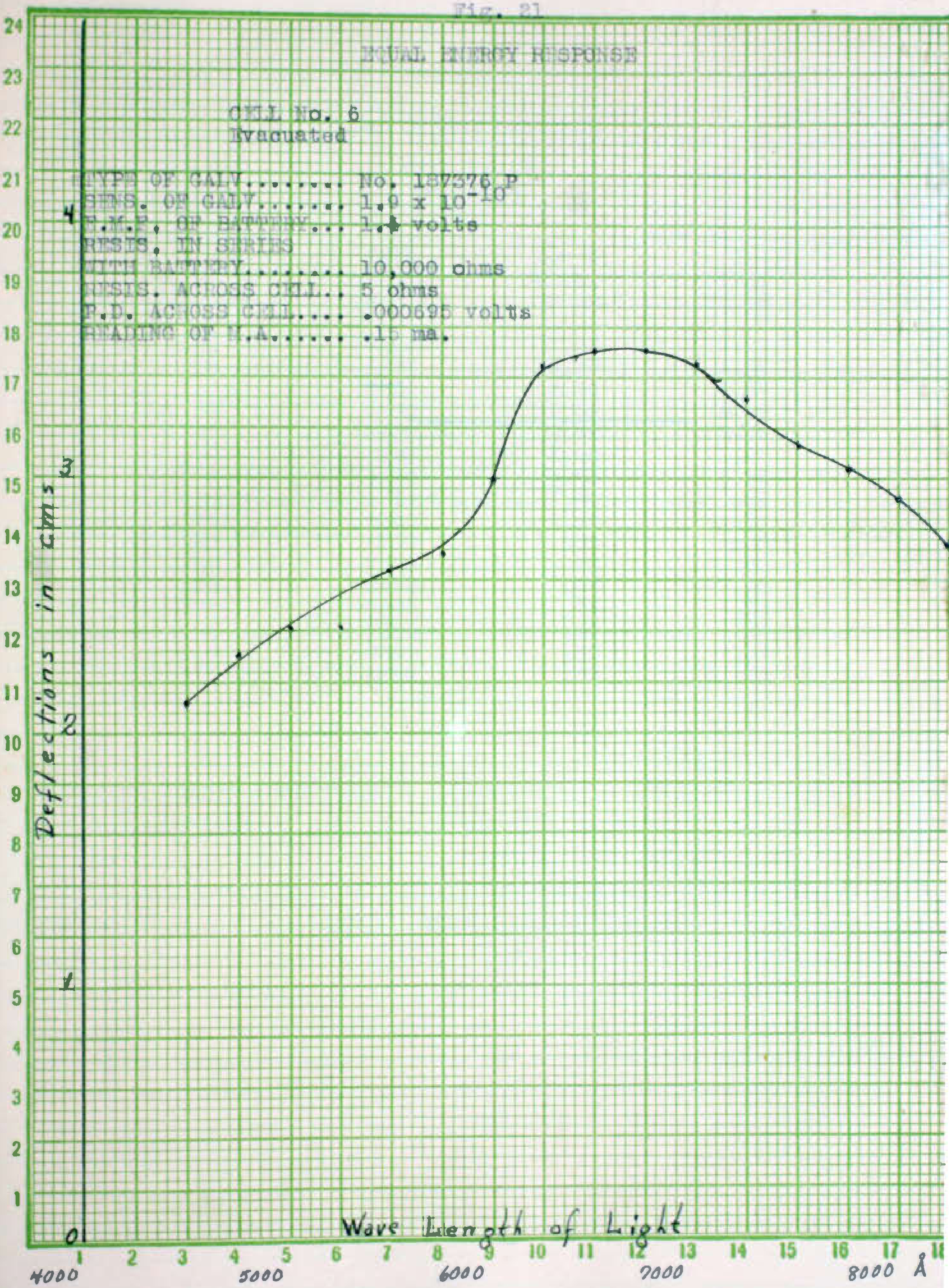

EQUAL ENERGY RESPONSE
CELL No. 4
Evacuated
TYPE OF GALV........ P No. 187376
SENS. OF GALV........ 1.9 x 10^-10
E.M.F. OF BATTERY... 1.4 volts
RESIS. IN SERIES
WITH BATTERY........ 10,000 ohms
RESIS. ACROSS CELL.. 2 ohms
P.D. ACROSS CELL.... .00028 volt
READING OF M.A....... .15 ma.
VOLTAGE N ACTING....
ACTING..............
4000
5000
6000
7000
8000

EQUAL ENERGY RESPONSE

CELL No. 6
Evacuated

E. M. F. IN VOLTS	WAVE LENGTH IN Å	DEFLECTION IN cm
106	4500	2.15
95	4750	2.35
80	5000	2.45
70	5250	2.45
67	5500	2.65
58	5750	2.70
53	6000	3.05
48	6250	3.45
42	6500	3.55
38	6750	3.55
35	7000	3.45
32	7250	3.35
30	7500	3.15
28	7750	2.85
27	8000	2.75
26	8250	2.58

Fig. 21


EQUAL ENERGY RESPONSE
CELL No. 6
Evacuated
TYPE OF GALV.......... No. 187376 P
SENS. OF GALV......... 1.9 x 10-10
E.M.F. OF BATTERY... volts
RESIS. IN SERIES
WITH BATTERY.......... 10,000 ohms
RESIS. ACROSS CELL.. 5 ohms
P.D. ACROSS CELL.... .000695 volts
READING OF M.A........ .15 ma.
Deflections in cms
Wave Length of Light
4000
5000
6000
7000
8000 Å

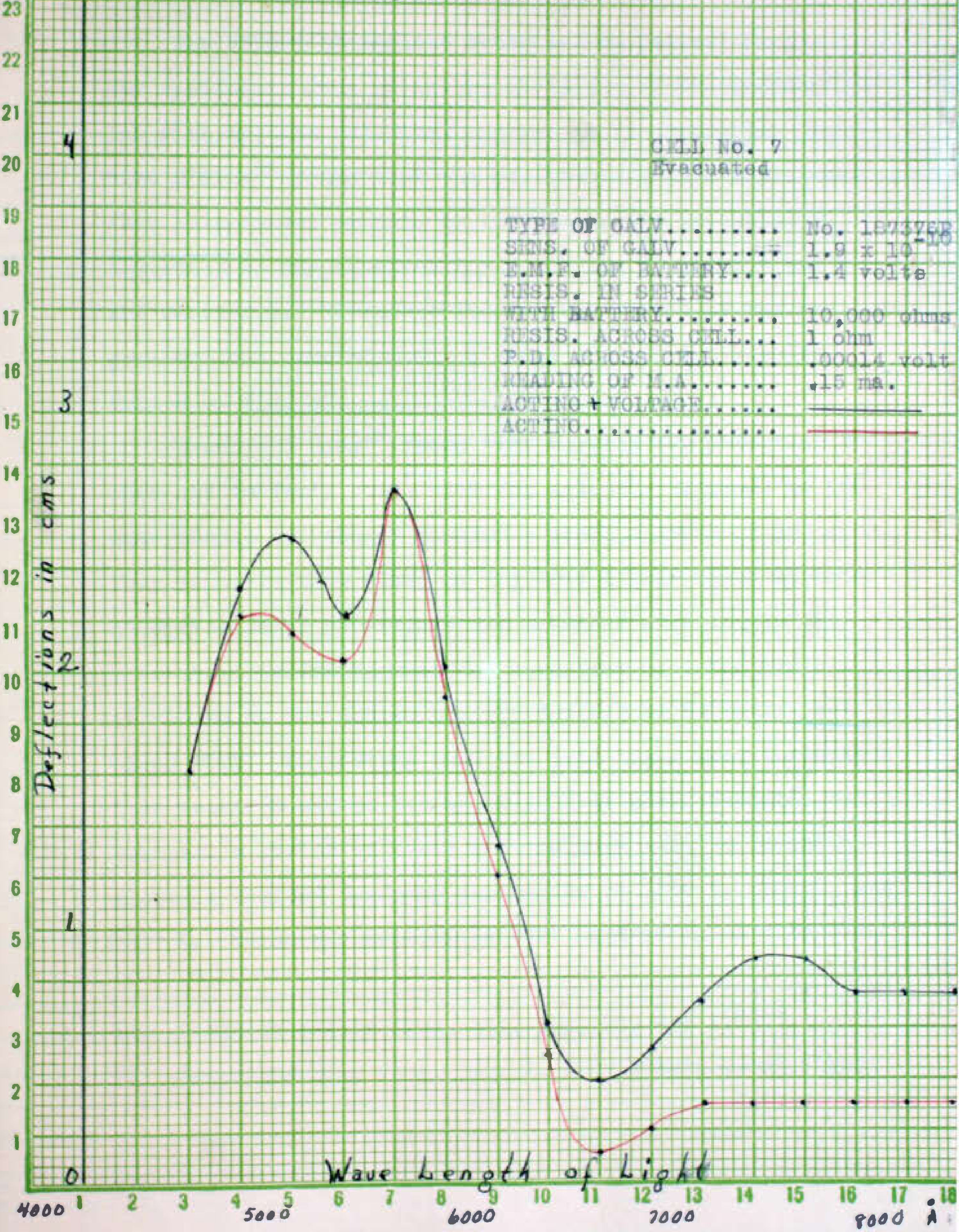
EQUAL ENERGY RESPONSE

CELL No. 7
Evacuated

E. M. F. IN VOLTS	WAVE LENGTH IN Å	A + V DEFL. IN cm	A DEFL. IN cm
106	4500	1.60	1.60
95	4750	2.30	2.25
80	5000	2.50	2.07
70	5250	2.20	2.10
67	5500	2.70	2.70
58	5750	2.00	1.95
53	6000	1.35	1.20
45	6250	.60	.50
42	6500	.40	.11
38	6750	.55	120
35	7000	.70	.30
32	7250	.75	.30
30	7500	.75	.30
28	7750	.65	.30
27	8000	.65	.30
26	8250	.65	.30

Fig. 22

EQUAL ENERGY RESPONSE



The Effect of Applied Potential on Cells: Hardly any systematic data as to the variation of photoconductivity with applied potential appears to be available. Fournier d'Albe[16] found that the resistance R of a cell, whether illuminated or not, depended upon the potential V according to the equation $R = a - b \log V$, where a and b are constants. Therefore the following part of the experiment was carried out. A graph showing the results follow as Fig. 23.

Brown and Sieg[17] found that varying the potential from one to forty volts with the selenium "exposed to the same bundle of energy" yielded a broad maximum at 800 mu mu. They repeated this phase of the work a year later at considerable lower potentials and obtained practically the same characteristics with the exception that the maximum at 800 mu mu was not as clearly defined as in their previous work. Suspecting that the potentials used throughout this research was so low as to inhibit characteristic responses, a series of tests were made on cell No. 4 which showed a decided tendency for maxima at 5000 A, 5750 A, and 8000 A. While our potentials were necessarily low in order

---

16. Fowinier d'Albe <u>Proc. Roy. Inc.</u> 86, 452 (1902)

17. Brown and Sieg <u>Phys. Rev.</u> 2, 491 (1913); 4, 55 (1914)

to keep the galvanometer reading on the scale, further tests will be made on this phase of the work using much higher potentials and a protective shunt around the galvanometer at some later date.

EFFECT OF APPLIED POTENTIAL

CELL No. 4
Evacuated

E.M.F. VOLTS	WAVE LENGTH	A VOLT DEFL.	B VOLT DEFL.	C VOLT DEFL.	D VOLT DEFL.
106	4500	.30cm	.40cm	.50cm	.70cm
095	4750	.47cm	.50cm	.70cm	1.00cm
80	5000	.40cm	.50cm	.65cm	1.00cm
70	5250	.39cm	.47cm	.77cm	.90cm
67	5500	.50cm	.60cm	.80cm	1.10cm
58	5750	.40cm	.50cm-	.70cm	.97cm
53	6000	.32cm	.49cm	.70cm	.97cm
48	6250	.29cm	.40cm	.60cm	.87cm
42	6500	.20cm	.31cm	.50cm	.80cm
38	6750	.12cm	.30cm	.50cm	.80cm
35	7000	.12cm	.30cm	.50cm	.80cm
32	7250	.15cm	.35cm	.55cm	.90cm
30	7500	.17cm	.35cm	.55cm	.90cm
28	7750	.17cm	.35cm	.55cm	.90cm
27	8000	.17cm	.35cm	.55cm	.90cm
26	8250	.17cm	.35cm-	.55cm	.90cm

A P.D. across cell = 1.27×10^{-4} volt

B P.D. across cell = 2.54×10^{-4} volt

C P.D. across cell = 3.81×10^{-4} volt

D P.D. across cell = 5.08×10^{-4} volt

Fig. 23


VOLTAGE RESPONSE
CELL No. 4
Evacuated
GALV.USED.....No. 187376 F
VOLTAGE ACROSS CELL
A..000127v. C..000381v.
B..000254v. D..000508v.
D
C
B
A
Deflections in cms
Wave Length of Light
4000
5000
6000
7000
8000
Å

SUMMARY AND DISCUSSION OF RESULTS

As cited before, the cells used in this investigation consisted of one commercial cell with a sensitivity (ratio of dark to light resistance) of 32, and three homemade Bidwell cells with a sensitivity of 2. A comparison of the conductivity-recovery curves reveals the fact that, in all cases, evacuation of the cell produced more smooth and symmetrical responses both in darkness and in light. However, in the case of high-sensitivity cell No. 1, the evacuated conductivity was found to be practically halved compared with the unevacuated conductivity; while on the other hand, the evacuated conductivity of cell No. 4 did not change appreciably from that of the unevacuated conductivity. Whether or not, the fact that cell No. 4 possessed an actino response while cell No. 1 did not, was the reason for this difrerence in behavior is difficult to say. Of the four cells, cells No. 4 and No. 7 only exhibited a photo-actino effect. This photo-actino effect is sometimes called the "primary current" in the literature and it is unidirectional.

Comparing Figs. 16 to 18, it is easily observed that the cells possessing the actino characteristics reacted similarly one with the other but entirely different to the prismatic radiation, than those cells not possessing this characteristic; the difference in response being that the actino cells exhibited a double maximum near 6000A and again near 8000A, while those not possessing this characteristic exhibited a single maximum at about 7000 A.

The critical stage of our analysis of this experiment consists in a comparison of Figs. 19 to 22, for after all the purpose of this research was to study the effect of an equal-energy spectrum on selenium cells in vacuo, all the other data being incidental and merely for the purpose of becoming informed as to the individual characteristics of each cell.

Here again in Figs. 19 to 22, we observe the decided difference between the response of the actino cells and those not possessing this characteristic. The equal-energy response of non-actino cells No. 1 and No. 6 followed very closely their prismatic response shown in Figs. 15 and 17 respectively. The maximum of the equal-energy response for these cells, No. 1 and No. 6, remained at approximately the same wavelength but were considerably broadened. The response in toto was necessarily diminished because of the restricted energy of the source.

As far as actino cells No. 4 and No. 7 are concerned, they tended to follow their prismatic response shown in Figs. 16 and 18 respectively. In Figs. 20 and 22, a tendency toward a triple maximum is noticeable, the actino current following closely after the conductivity current.

This being an investigation in pure physics as compared with applied physics, it is difficult at this time to prophesy with any degree of certainty what the practical applications of the results might be. It is customary for investigators in pure science to concern themselves not so much with possible practical applications of their findings as with a reasonable theory for the behavior of the phenomena observed.

However, this investigation indicates that selenium cells devoid of the actino characteristic possess their sharpest sensibility in the region of 7000A and have no sharp fluctuations; while the actino cells possess their sharpest sensibility in the region of 5000A and undergo sharp fluctuations especially toward the red end of the spectrum. Here then, are two types of cells each responsive to a different portion of the spectrum. This finding appears to refute an earlier investigation[14], the report of which states that "the location of the maximum seems to be determined entirely by the method of 'annealing' the cells". If one were to grant that the presence or absence of the actino effect was entirely due to the method of "annealing" then the claims of Dieterich are justified.

---

14. Dieterich, E. O., Phys. Rev. 3, 498 (1914).

BIBLIOGRAPHY

Dieterich, E. O. "The Influence of Annealing on the characteristics of Light-Sensitive Selenium". (In Physical Review, Vol. 4, p. 467, Nov., 1914).

An article on the annealing of selenium cells.

Brown, F. C. and Sieg, L. P. "Wave-Length Sensibility Curves for Light Sensitive Selenium and their Significance". (In Physical Review, Vol. 4, p. 48, July, 1914).

An article explaining the sensibility curves of selenium.

Nicholson, P. J. "The Physical Properties of Selenium" (In Physical Review, Vol. 3, p. 1, Jan., 1914).

An article on the physical properties of selenium.

Dieterich, E. O. "The Control of the Wave-Length-Sensibility Curves for Selenium". (In Physical Review, Vol. 3, p. 498. 1914; vol. 8, p. 191, July 1916).

Coblentz, W. W. "Positive and Negative Photo-Electrical Properties of Molybedenite and Several other Substances". Washington, Government Printing Office, 1920, Scientific

Paper No. 398, United States Bureau of Standards.

Explanation of positive and negative photo-electricity of molybedenite and several other substances.

Coblentz, W. W. "Various Photo-Electrical Investigations" Washington, Government Printing Office, 1922, Scientific Paper No. 462, United States, Bureau of Standards.

An article on the various photo-electrical investigations their procedure and technique.

Martin, R. E. "Bibliography of Literature Bearing on the Light-Sensitiveness of Selenium". (The Procedings of the Indiana Academy of Science), 36, 163, (1926)

This article was used to select other articles that had a bearing on light-sensitiveness of selenium.

Hughes, A. L. and DuBridge, L. A. Photo-Electric Phenomena. New York, McGraw-Hill, 1932.

Explanation of the photo-Electrical Phenomena.

Zinszer, H. A. "Note on Photo-Electrical Phenomena" (In Indiana Academy of Science Proceedings, 1931, XL, 291)