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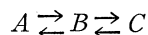
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## THE NATURE OF LIGHT ACTION IN SELENIUM.

BY F. C. BROWN.

IN a paper by Brown and Stebbins<sup>1</sup> it was shown that the light-sensitiveness of a certain selenium cell was a function of its resistance whether that resistance was conditioned by temperature, pressure, light or other agencies. This conclusion, together with the results of recent investigations, has led me to formulate an hypothesis for explaining the changes in the electrical conductivity occurring in light-sensitive selenium. The statement and the discussion of this hypothesis together with the results of investigations pertinent to this hypothesis will form the material of this paper. As the amount of data that must be correlated is quite large indeed, particular attention will be given only to the various effects produced by light.

The hypothesis is that all light-positive and light-negative varieties<sup>2</sup> of selenium consist of various mixtures of three kinds of selenium which we will call *A*, *B* and *C*, and that under the action of light *A* is changed into *B* and *B* is changed into *C*, according to the reaction,



and that the changes in both directions are proportional at all times to the amounts of the changing material. The principal argument that is offered for proposing such an explanation is that it seems to be consistent with the experimental facts under a variety of conditions, and that as is generally recognized previous theories do not explain many of the recently observed phenomena.

That the effect of illumination on certain varieties of light-positive selenium is to produce a genuine change in the selenium itself has not

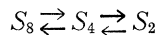
<sup>1</sup>PHYS. REV., 26, p. 273, 1908.

<sup>2</sup>For the meaning of this terminology see PHYS. REV., XXXII., p. 237, 1911.

been questioned since Pfund<sup>1</sup> and Berndt<sup>2</sup> showed that selenium cells made by using selenium of the highest purity and carbon electrodes were sensitive to light. By studying the conductivity at different temperatures Marc<sup>3</sup> concluded that certain varieties of selenium consist of two allotropes *A* and *B* in equilibrium. Montén<sup>4</sup> by observing the resistance in the dark at pressures between 0 and 3,000 atmospheres concluded that the selenium cells that he used consisted of at least two allotropes *A* and *B* in equilibrium under the given pressures.

More recently Kruyt<sup>5</sup> has made density measurements that indicate that in light-sensitive selenium there are two components that are in equilibrium according to the reaction  $A \rightleftharpoons B$ .

This paper will not attempt to define the three components whose existence is supposed nor will it consider the particular reasons why the components have different rates of change under the same external conditions. But since Biltz and Preuneur<sup>6</sup> have found three components in sulphur changing under the influence of pressure and temperature according to the reaction



it would not be surprising to find later that the three components of light-sensitive selenium may be identified and studied as separate allotropic forms.

#### THEORY.

In order to obtain conditions which are easily subject to theoretical treatment we will suppose that the sensitive layer of selenium may be so thin that the impinging light may be of practically uniform intensity throughout the layer, and that temperature, pressure and all other conditions except that of illumination that affect the conductivity remain constant; further suppose that the conductivity of the *A* kind is zero, while that of the *B* kind approaches that of the metals and that the conductivity of the *C* kind is so much smaller than that of the *B* kind that it may be neglected. Part of the experimental evidence in favor of neglecting the conductivity of the *C* kind will be brought out in this paper but the most direct evidence will be presented in a later paper concerning the recovery of selenium. Let  $\alpha_1$  and  $\beta_1$  be the respective rates of change of *A* into *B* and *B* into *C* for a given set of conditions and  $\alpha_2$  and  $\beta_2$  the

<sup>1</sup>Phil. Mag., 7, p. 26, 1904.

<sup>2</sup>Phys. Zeit., 5, p. 121, 1904.

<sup>3</sup>Zeit. anorg. Chem., 48, p. 5, 1906.

<sup>4</sup>Archiv. för Matematik, Astronomi och Fysik, 4, p. 1, 1908, also dissertation on "The Influence of Pressure on the Electrical Resistance of Selenium and Silver Sulphide."

<sup>5</sup>Zeit. für anorg. Chemie, 64, p. 305.

<sup>6</sup>Zeit. Phys. Chem., 39, p. 323.

corresponding reverse changes of  $C$  into  $B$  and of  $B$  into  $A$ . Let  $A_0$ ,  $B_0$  and  $C_0$  represent the initial amounts of the respective kinds before illumination. By illumination the constants  $\alpha_1$  and  $\beta_1$  increase in value and are probably accompanied by small changes in  $\alpha_2$  and  $\beta_2$ , so that after a time  $t_1$ , the respective amounts of the three kinds are  $A_1$ ,  $B_1$  and  $C_1$ . Nothing will be said concerning the homogeneity and uniformity further than that the way in which the three components are mixed shall not to any great extent affect the following expression for the conductivity,

$$i = K_1 B. \quad (I)$$

Then the changes take place in accordance with the following equations:

$$dA/dt = \alpha_2 B - \alpha_1 A, \quad (2)$$

$$dB/dt = \alpha_1 A - \alpha_2 B + \beta_2 C - \beta_1 B, \quad (3)$$

$$dC/dt = \beta_1 B - \beta_2 C, \quad (4)$$

$$A + B + C = K, \quad (5)$$

$$dA/dt + dB/dt + dC/dt = 0. \quad (6)$$

From these equations we obtain the differential equation,

$$[\ddot{B}] + (\mu + \alpha_1)[B] + (\alpha_1\mu - \alpha_2\lambda)B - \beta_2\alpha_1K = 0, \quad (7)$$

where

$$(\alpha_1 - \beta_1) = \lambda,$$

$$\alpha_2 + \beta_2 + \beta_1 = \mu.$$

This equation is of the form,

$$[\ddot{B}] + M[B] + NB - L = 0.$$

The solution of the equation is

$$B = L/N + c_1 e^{+m_1 t} + c_2 e^{m_2 t}, \quad (8)$$

and

$$C = \frac{L\beta_1}{N\beta_2} + \frac{\beta_1 c_1 e^{m_1 t}}{\beta_2 + m_1} + \frac{\beta_1}{\beta_2 + m_2} c_2 e^{m_2 t}, \quad (9)$$

where

$$L = \alpha_1 \beta_2 K, \quad (10)$$

$$N = \alpha_1 \beta_1 + \alpha_1 \beta_2 + \alpha_2 \beta_2, \quad (11)$$

$$m_1 m_2 = \alpha_1 \beta_1 + \alpha_1 \beta_2 + \alpha_2 \beta_2, \quad (12)$$

$$m_1 + m_2 = -(\alpha_1 + \alpha_2 + \beta_1 + \beta_2), \quad (13)$$

$$B_0 = L/N + c_1 + c_2, \quad (14)$$

$$C_0 = L/N \times \beta_1/\beta_2, \quad (15)$$

for equilibrium in the light,

$$B_1 = \frac{L}{N} = \frac{(\alpha_1\beta_2)K}{\alpha_1\beta_1 + \alpha_1\beta_2 + \alpha_2\beta_2}, \quad (16)$$

$$C_1 = \frac{L}{N} \times \frac{\beta_1}{\beta_2} + \frac{\beta_1}{\beta_2 + m_1} c_1 + \frac{\beta_1 c_2}{\beta_2 + m_2}, \quad (17)$$

$$\frac{\alpha_2}{\alpha_1} B_1 + B_1 + \frac{\beta_1}{\beta_2} B_1 = K, \quad (18)$$

and the value of the constants in equation (8) are

$$c_1 = \left[ \frac{C_0}{\beta_1} + \left( \frac{L}{N} - B_0 \right) \frac{1}{\beta_2 + m_2} - \frac{L}{N\beta_2} \right] \left[ \frac{(\beta_2 + m_2)(\beta_2 + m_1)}{m_2 - m_1} \right], \quad (19)$$

$$c_2 = \left[ \frac{C_0}{\beta_1} + \left( \frac{L}{N} - B_0 \right) \frac{1}{\beta_2 + m_1} - \frac{L}{N\beta_2} \right] \left[ \frac{(\beta_2 + m_2)(\beta_2 + m_1)}{m_1 - m_2} \right]. \quad (20)$$

Since the conductivity depends only on the amount of the  $B$  kind present, our problem is to determine how the amount of the  $B$  kind should

TABLE I.

Case.	1	2	3	4	5
After illumination {					
$a_1$	.13	.13	.03	10	10
$a_2$	10.	10.	.40	.13	.13
$\beta_1$	2.66	2.66	.40	2.66	2.66
$\beta_2$	.05	.05	.3	.05	.05
$m_1$	-10.39	-10.39	-.7	-2.65	-2.65
$m_2$	-.058	-.058	-.2	-10.19	-10.19
$A_0$	14,890.	121,000.	290.	12,880.	2,220.
$B_0$	1.0	1.0	10.	10,000.	10,000.
$C_0$	1.0	10,000.	10.	85,120.	95,760.
$A_1$	9,320.	77,000.	265.	30.	30.
$B_1$	120.	1,000.	20.	2,000.	2,000.
$C_1$	6,360.	53,000.	25.	106,000.	106,000.
$K$	15,900.	131,000.	310.	108,000.	108,000.
$L/N$	120.	1,000.	20.	2,000.	2,000.
Per cent. $A_0$	90.	92.	90.	12.	2.
Per cent. $B_0$	.06	.008	3.2	9.0	9.0
Per cent. $C_0$	10.	8.	7.	79.	89.0
Before exposure {					
$a_1/a_2$	$.67 \times 10^{-4}$	$8 \times 10^{-5}$	.035	.8	5.0
$\beta_1/\beta_2$	1.0	$10^3$	1.0	8.5	9.5
After exposure {					
$a_1/a_2$	.013	.013	.075	77.	77.
$\beta_1/\beta_2$	50.	50.	1.2	53.	53.

vary with the time of illumination, as specified in equation (8), when different initial conditions are considered. To do this we must first determine the constants  $m_1$  and  $m_2$  and  $c_1$ ,  $c_2$  and  $L/N$ . These constants depend on the rates of change and the initial amounts of the  $A$ ,  $B$

and  $C$  components. The rates of change must be positive quantities under all conditions. In accordance with equations (12) and (13) this obviously requires that  $m_1$  and  $m_2$  shall always be of negative sign. Also the amount of the three components  $A$ ,  $B$  and  $C$  must necessarily be positive quantities, and it seems reasonable to expect that the ratios  $\alpha_1/\alpha_2$  and  $\beta_1/\beta_2$  should always be increased by the action of light. This last presumption would further require that during illumination the amount of the  $C$  kind must always be increased and that at the same time the  $A$  kind must be decreasing. The  $B$  kind may obviously either increase or decrease depending upon the relative amounts of change in the  $A$  and  $C$  kinds. These are all the conditions that it seems wise to impose at present. Further experimentation may show that not only do the rates of change vary according to simple laws with changes in the intensity but that the ratios of the rates also vary according to correspondingly simple laws.

By a method of approximations and guesses I have found specimen arbitrary values for the rates of change, which when taken with appropriate values of the other constants will establish the characteristic ways in which the conductivity,  $i$ , will vary with the time of exposure to light. All the constants must be in harmony with the twenty equations given and also must satisfy the other necessary conditions. The equation as obtained from (1) and (8) shows the relation between the conductivity and the time of exposure to be

$$i = K_1(L/N + c_1e^{m_1t} + c_2e^{m_2t}). \quad (21)$$

Certain values of the constants and other information is given in the accompanying Table I. This table furnishes the values for the constants in the above equation, the graphs of which are shown in Fig. 1. The equations of the curves are as follows;

curve 1,	$B = 120 - 138e^{-10.39t} + 19e^{-.058t}$ ,
curve 2,	$B = 1000 - 1160e^{-10.39t} + 160e^{-.058t}$ ,
curve 3,	$B = 20 - 4.872e^{-.7t} - 5.12e^{-.2t}$ ,
curve 4,	$B = 2000 - 3250e^{-10.59t} + 11250e^{-2.65t}$ ,
curve 5,	$B = 2000 + 5670e^{-2.65} + 2340e^{-10.59t}$ .

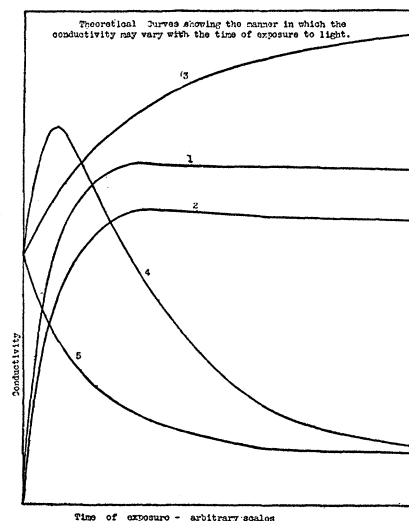


Fig. 1.

The main points that are essential to the theory may be understood most easily by studying the curves. In (1) and (2) the initial conductivity is very small and it rises rapidly to a maximum and then falls off slowly to a constant limiting value. The equilibrium value of the conductivity in the light to that in the dark is of the ratio 1,000 to 1. Curve (3) shows the conductivity in the dark to be greater than that shown in (1) and (2). The increase of conductivity due to illumination is always positive. It increases most rapidly at first. In the fourth case the conductivity rises rapidly by illumination to a maximum, that is, relatively to the initial conductivity not very large and then falls off quite rapidly to a value which may be even less than the initial conductivity. Curve (4) shows the manner of variation although it does not show the fact that the initial conductivity is much larger than prevails in the first three cases.

In what is called case 5 the conductivity begins to decrease at once when the light acts on the selenium and it falls rapidly compared to the rate of decrease in the other four cases noted.

Considerable importance is attached to the fact that the decrease of resistance becomes more and more rapid as the conditions change from those required in case 1 on down to those required by case 5, and that in all the cases except No. 5 there are changes in the conductivity in both directions shown in an unmistakable manner; also to the fact that as we shift from cases 1 to 5 the initial or dark conductivity increases.

Case 2 is regarded as a highly improbable one in that the rates of change between *B* and *C* compared to the reverse changes between *C* and *B* are greater before illumination than afterwards.

The theory proposed is simple and attractive in so much as it rather implies that all the agencies that affect the conductivity of selenium produce the same kind of a change in the selenium, namely a variation in the rates of interchange. Or stated in other words the selenium is in equilibrium under a variety of conditions. Each agency merely acts in a way to alter the equilibrium by changing the rates. Whether or not every agency changes the rates in accordance with the same laws after the units have been properly adjusted is a matter that will have to be determined by experiment. Any variety of selenium which shows a marked increase of conductivity at first and then is followed by a decrease when acted on by light should in all probability show the same two changes when acted on by other agencies, but this conclusion is clearly not required. For example, a Giltay or a high sensibility selenium cell which by illumination rises to a maximum conductivity, say 100 times as great as the conductivity in the dark, and then falls to only 30 times the

dark conductivity, might reasonably be expected to rise to the same maximum and then to fall to the same limiting value 30 to 1, if there were a sudden application of mechanical pressure of the right amount. The same argument would apply to the agencies of temperature and differences of electric potential.

A mechanical interpretation of the theory may be proposed as follows: The *A*, *B* and *C* varieties because of their rates of interchange are in equilibrium. When the selenium is illuminated new rates are established and consequently new equilibrium values for the amounts of the *A*, *B* and *C* kinds. We may regard the selenium as distorted from its equilibrium condition, and the study of the change of conductivity as merely a study of one of the processes taking place while the new equilibrium is being established. In fact experiment shows that it is possible to distort the selenium system, if it may be called such, so that the amount of any kind may be either greater or less than is required for equilibrium. So far as the *B* kind is concerned the distortion may be either positive or negative in at least one variety of selenium, while the condition of light or darkness is changing in only one direction. Or suppose any variety of selenium in equilibrium in the diffuse light of a room; the selenium may be distorted in one direction by imposing the condition of darkness. It may be distorted in the opposite direction by imposing the condition of intense illumination. By increasing the intensity of illumination the amount of the *C* kind increases and by decreasing the illumination the amount of the *C* kind decreases. The following argument will illustrate what general behavior is expected. Suppose a selenium cell in equilibrium in the dark in a condition which we will call  $\phi$ . Next expose it to intense light and as a result of the existing distortion it changes according to certain laws toward a new equilibrium condition which we may call  $\theta$ . The changes can be shown by curves. Finally remove the selenium to the dark and again due to the distorted condition of the selenium it will return to its former dark condition  $\phi$ . The changes from  $\theta$  to  $\phi$  can also be represented on curves. The general movement of the change in the first case may be said to be in the positive direction and in the second case it may be said to be in the negative direction. The changes in the negative direction as shown by the second set of curves may be said to be the reciprocal of the changes in the positive direction and the time taken for the selenium to go from  $\theta$  to  $\phi$  should be of the same order of magnitude as the time required for the selenium to go from  $\phi$  to  $\theta$ . Where there is a rapid change and a slow change going in one direction there should in general be both the rapid and the slow changes in the reverse process.

In a recent paper<sup>1</sup> given before the American Physical Society was developed an equation for the conductivity on the assumption that the reverse changes  $\alpha_2$  and  $\beta_2$  were at all times small compared to the direct changes, and that the conductivity of the *C* kind was one half as large as that of the *B* kind. It was stated that these assumptions were only tentative. As certain facts are brought out both by the agreement and by the disagreement of the experimental results with the equation developed,

$$i = k_1 \left\{ \frac{A_0 \alpha_1}{\alpha_1 - \beta_1} (e^{-\beta_1 t} - e^{-\alpha_1 t}) + B_0 e^{-\beta_1 t} \right\} \\ + k_2 \left\{ \frac{A_0}{\alpha_1 - \beta_1} [\alpha(I - e^{-\beta t}) - \beta(I - e^{-\alpha t})] + B_0(I - e^{-\beta_1 t}) + C_0 \right\}$$

two families of curves taken from this equation are shown in Fig. 2 and Fig. 3. The theoretical objection that is urged against these

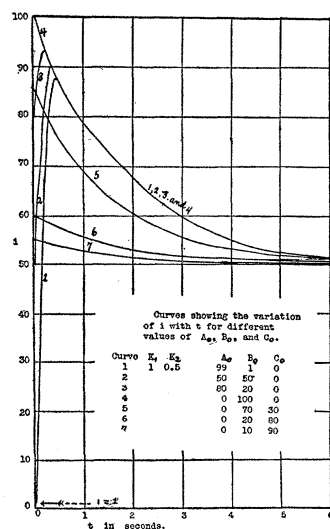


Fig. 2.

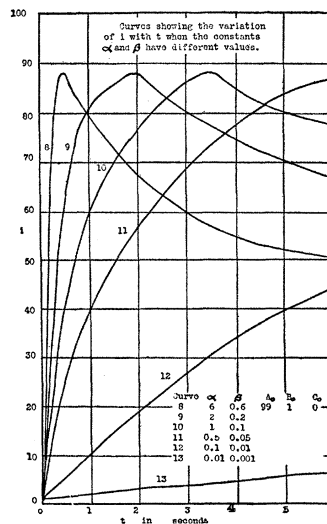


Fig. 3.

special assumptions is that there is no method of accounting for the initial amounts of the three kinds in the dark, and consequently no satisfactory way of explaining the recovery of the selenium after the light is removed. Wherein the experimental results show that the special assumptions are not warranted will be brought out in the discussion of the results.

<sup>1</sup> PHYS. REV., Vol. XXXII., p. 237, 1911.



## GENERAL CONSIDERATIONS.

Some time ago I observed a striking relation between the resistance of selenium and its sensibility to light. In this instance, sensibility is used in the sense of the ratio of the conductivity in the light to the conductivity in the dark, when the selenium was exposed directly to sunlight or its equivalent for about 5 minutes. The relation observed was that the higher the resistance the greater was the sensibility or conversely the lower the resistance the less the sensibility and finally when the resistance became very low the sensibility became of the negative sign. The accompanying Table II. shows the observations that were made. However it must be remembered that the values represent only orders of magnitude. The specific resistance is not in all cases proportional to the measured resistance of the selenium. Further as the sensibility was measured without any intention of making such comparisons as here noted, the sensibility also is subject to a large error. Nevertheless the relation mentioned is very clearly shown.

TABLE II.

Kind of Selenium.	Resistance.	Sensibility.
High sensibility selenium cell,	10 <sup>9</sup>	200 to 1
Giltay selenium cell,	400,000	30 to 1
Ruhmer selenium cell,	90,000	10 to 1
Home made, 1904,	100,000	10 to 1
Home made, 1904	160,000	4 to 1
Home made, 1904,	30,000	2 to 1
Home made, 1904,	17,000	1.1 to 1
Home made, 1904,	12,000	1.0 to 1
Home made, 1904,	3,500	1.0 to 1
Light negative selenium,	400	-1.002 to 1
Light negative selenium,	20	-1.15 to 1
Light negative selenium,	1	-1.5 to 1

Since making these observations I have learned that Pochettino and Trabacchi<sup>1</sup> and also J. W. Giltay have made observations that show this same relation existing between resistance and sensibility. Giltay in one of his trade circulars on selenium cells, says that he makes high resistance selenium cells of high sensibility and low resistance selenium cells of low sensibility and adds that "low resistance and high sensibility simply do not go together."

As an example of diverse facts concerning selenium, which do not seem to any conclusion we may note the laws of change of conductivity with light intensity as given in Table III., where *m* represents the

<sup>1</sup>According to Ries in his book on Die Elektrischen Eigenschaften und die Bedeutung des Selens für die Electrotechnik.

change of conductivity,  $i$  represents the light intensity,  $R$  the resistance, and the other quantities constants.

TABLE III.

Law.	Authority.
$i = cm^2$	Rosse, Adams, Berndt.
$i = cm^3$	Hopius.
$i = m(m-a)b$	Athanasiadis.
$i = b^m - 1$	Hesehus.
$R_a/R_b = (b/a)^a$	Ruhmer.
$I = cm$	Stebbins. <sup>1</sup>

Without doubt all the variations in the results of the above investigators can be explained on the ground that the conditions were widely different in many cases. The varieties of selenium were not the same; the intensity ranged between different limits; and no doubt the time of exposure was different in each case. Other legitimate reasons might be sought for in the construction of the cell form and the thickness of the selenium on this form. The facts in this table are presented merely to demonstrate the futility of search for a simple universal law connecting the conductivity of a selenium cell and the intensity of illumination. It is obviously necessary to look to other relationships than the one mentioned if we wish to connect the facts by simple laws.

The properties of the known varieties of selenium are summed up in Table IV., so far as information has been obtained. The purpose here is to call attention in a more general way more particularly to the diverse properties of selenium.

TABLE IV.

Variety of Selenium	Change of Conductivity by Light.	Conductivity in the Dark.	Direction of Change of Conductivity.			
			By Temperatures.	By Pressure.	By Electrical Diff. Potential.	By Moisture.
High sensibility cell . . . .	+ followed by -	$10^{-9}$	-	?	+	+
Giltay cell . . . . .	+ followed by -	$10^{-6}$	+	+	+	?
Ruhmer cell . . . . .	+	$10^{-5}$	+	+	+	+
Ries's "abnormal cell" . . .	+ followed by -	?	?	?	?	+
Light-negative cell . . . .	-	$10^{-2}$	+	?	+ or -	-

It is not certain how many of these diverse properties may be in part due to impurities in the selenium. Also we are very much in doubt as

<sup>1</sup>Proved by Stebbins for faint illumination by two independent methods in connection with his work on the Measurement of the Light of Stars by a Selenium Photometer, in *Astro-Phys. Jour.*, 32, p. 185, 1910. However his results are not published.

to what is the depth of penetration of selenium by light. Before the proposed theory can be put to a rigid test it will be necessary to answer the last question but not the first. But this question cannot be answered at present. We may now proceed to call attention to experiments with the above varieties of selenium.

#### EXPERIMENTS WITH LIGHT-POSITIVE SELENIUM.

In most of the experiments with light-positive selenium, a selenium cell designated Giltay No. 2, which was made by Giltay of Delft, Holland, was used. For somewhat more than a year previous to its use for the experiments described in this paper it has been left in paraffin oil in a glass tube of about 4.5 cm. diameter and 25 cm. length. With the exception of a space left for a window, the tube had been black enameled on the exterior surface. This tube was surrounded by a second similar tube. When the second tube was so turned that the two windows were together, the cell could be illuminated. The temperature of the oil in which the cell was placed was read from a thermometer projecting through a rubber cork down into the oil. In the dark at 25° C. the cell had a resistance of about 490,000 ohms.

Whenever changes in the conductivity were investigated that occurred during short intervals of time, a pendulum and a ballistic galvanometer were used in connection with a Wheatstone's bridge circuit. This method of measuring such changes of resistance is discussed elsewhere.<sup>1</sup> It will be sufficient to state here that the average conductivity of the selenium during any interval is a function of the deflection of the galvanometer, which function can be determined either by experiment or calculation. The method of illumination was to place a tungsten lamp in the same dark box in which the selenium cell was placed and to regulate the time of illumination by opening and closing keys controlling the current through the lamp. If the period of illumination desired was a fraction of a second, the keys were manipulated entirely by the pendulum which threw in the ballistic galvanometer. It was assumed that the light reached a constant value at once and no correction was made for the fact that the candle-power of a tungsten lamp decreases perceptibly after the current is turned on.

The change of conductivity varies with the time of illumination. In all high sensibility selenium cells the conductivity first rises rapidly to a maximum and then it falls off fairly rapidly at first and then more slowly. This is shown for the Giltay No. 2 in curve 14 of Fig. 4, where the cell was exposed to a 16-cp. lamp at about a distance of a meter.

<sup>1</sup>See paper by Brown and Clark, *PHYS. REV.*, 1911.

The maximum conductivity is reached in about 50 sec. and is about seven times greater than the conductivity in the dark. In curve 15 is shown the variation of conductivity with time for a very intense illumination. The intensity was approximately that of a 32-cp. lamp at a distance of 7 cm. It will be noted that the maximum conductivity is reached in .35 sec.

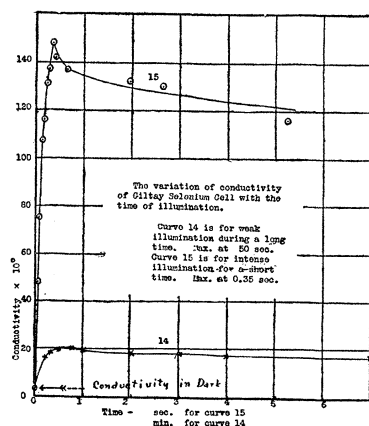


Fig. 4.

A fair sample of the observations taken to obtain the data for such a curve is given in the following Table V. The first key closes the storage battery circuit through a tungsten lamp. The second key throws the ballistic galvanometer in circuit and the third key again opens the galvanometer circuit.

There are three sources of error in obtaining these observations which for our present considerations are of minor importance. The first arises from the fact that the intensity of illumination of a tungsten lamp does not become constant at once when the current is turned on. The second error was in the current itself. The storage battery used did not

TABLE V.

Observations on the Change of Conductivity of Selenium Cell Giltay No. 2 with Time by Use of Pendulum and Ballistic Galvanometer.

Temp.	Resistance in Dark.	Distance Apart of Second and Third Keys.	Time of Exposure.	Mean Corrected Time.	Deflection.	Conductivity $\times 10^6$ .
28° C.	370,000		0	0	0	2.7
		.1 sec.	0.1 sec.	0.050	28	48
		.05	0.1	0.075	35	75
		.05	0.15	0.125	41	107
		.05	0.2	0.175	45.5	116
		.05	0.25	0.225	50.8	131
		.05	0.30	0.275	52.5	137
		.05	0.35	0.325	56.5	148
		.05	0.40	0.375	52.5	137
		.05	0.40	0.375	53.1	141
		.05	0.65	0.625	52.4	137
		.05	2.65	2.62	48.9	130
		.05	2.0	1.97	48.1	129
		.05	5.25	5.22	45.0	115
		.05	9.4	9.4	41.	107

furnish an unvarying E.M.F. After a few seconds use there was observed several times a slight decrease in the current. If however the lamp was connected in the regular lighting circuit substantially the same results were obtained as when the storage battery was used. The third error arose from incomplete recovery between readings. Practically from 1 minute to 1 hour was considered sufficient time, the time depending upon the intensity and duration of exposure and the temperature. For reasons which will be given later, we shall see that the reaching of the initial dark resistance does not necessarily require that the equilibrium condition shall be reached for a particular temperature or light condition. But equilibrium does require a particular resistance, under given conditions.

The amount of the decrease of conductivity in the Giltay cell is by no means pictured in curve 15. Other sets of observations were made where the time of illumination extended over a period of 15 minutes, *i. e.*, about one hundred and fifty times as long as in the instance just discussed. A Siemens and Halske needle galvanometer was placed in series with the cell and the conductivity was determined directly from the readings. The intensity of illumination was approximately the same as that for the short exposure. The decrease of the conductivity was extremely large as will be readily seen by referring to curves 16 and 17 of Fig. 5. In these cases the maximum conductivity was probably reached in 0.4 sec. At the temperature of  $17^{\circ}$  C. the conductivity was of the order of one hundred times that of the conductivity in the dark and at  $41^{\circ}$  C., the maximum ratio of the two conductivities was about 30 to 1. It may be observed from the curves that these ratios decreased after 10 minute exposures to 60 to 1 and 12 to 1. These last ratios probably represent very nearly the condition of equilibrium with the given intensity of light compared with equilibrium in the dark for the two temperatures stated. It is significant however that the equilibrium is approached with equilibrium in the dark for the two temperatures decidedly more rapidly at the higher temperature. The first deflection of 40 recorded in curve 17 is no doubt somewhat too high, due to the inertia of the galvanometer needle system.

The remarkable decrease in the conductivity of the Giltay cell is just as remarkable as is the enormous increase at first. Certainly it is of just

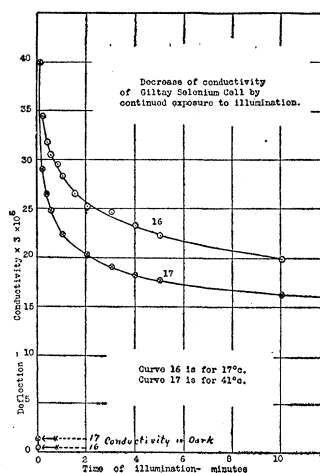


Fig. 5.

as much importance theoretically. First of all it is quite necessary to know if this decrease in the conductivity represents a genuine change in the selenium or if it is a polarization phenomenon. This question is a particularly legitimate one in view of the fact that many selenium cells show extreme polarization under the action of light and the electric current. I wish to state at the outset that none of the phenomena I have observed recently in light-positive and light-negative selenium arise from polarization by the current. My reasons for making such deductions with regard to the Giltay cell are as follows:

(a) First the selenium cell was balanced in a Wheatstone's bridge circuit after being intensely illuminated for several minutes. Then the battery circuit was broken. There was not the slightest deflection of the galvanometer by this procedure. This showed that no appreciable back E.M.F. was produced by the combined actions of the light and the electric current.

(b) Again the cell was connected in one arm of the bridge illuminated and balanced. The battery current was then quickly reversed by a reversing key. There was no apparent change of resistance. If there had been any polarization practically its whole effect would have had to disappear in less than a second. This might have been regarded as sufficient proof of the non-existence of polarization. (c) Next a test was made to see if the decrease of conductivity in the Giltay cell took place independent of the action of the current during the period of illumination. It was found, for example, that the conductivity at any time after the cell had been illuminated for 2 min. 10 sec. was that shown in curve 17 whether the current was flowing through the cell during the first two minutes or not.

At another time two series of observations were taken, one with the current acting all the time and the other with the current off during the first 60 seconds. The results are shown in the following table, where the conductivity in the dark is represented by unity, and where the observations were taken in the order enumerated by the sets.

Remembering that the current flowing through the selenium cell when the above observations were made was from 20 to 100 times larger than it was during the previous observations when the pronounced decrease of conductivity in the Giltay cell by light was noted, and allowing for the inconstancy of the light source, it may be concluded that the light action is independent of the current.

(d) Fearing that some might raise the question as to whether the 10 seconds allowed for the resistance determination might not be sufficient time for the current to produce the decrease under discussion, a further

TABLE VI.

*Conductivity of Selenium Cell after Being Exposed to Light.*

Time of Exposure.	Conductivity without Current Flowing in Cell.	Conductivity with Current Flowing in Cell.
	Av. of Sets II. and IV.	Sets III.
70 sec.	32.7	32.3
90 sec.	31.9	31.2
2 min.	30.7	30.3
	Set IV.	Av. of Sets III. and V.
70 sec.	30.5	30.7
90 sec.	29.9	30.0
2 min.	29.2	29.1
	Av. of Sets I. and III.	Sets II.
90 sec.	34.1	33.2
2 min.	32.9	32.2

test was made in which the mean time that the current flowed through the cell was 0.06 second. The pendulum before mentioned in this paper was used to first close the battery circuit for lighting the tungsten lamp when desired, then to close the battery circuit through the selenium cell and Wheatstone bridge circuit, and 0.01 sec. later to close the galvanometer circuit for a period of 0.1 sec. The resistance of the cell was 640,000 ohms and the fall of potential across it was about 0.1 volt. The following are the observations:

Time of Exposure, Seconds.	Deflection without Current Acting.	Deflection with Current Acting.
0.5	43.0	43.3
1.5	67.5	66.9
2.5	68.8	66.9
3.5	70.1	—
5.5	66.9	67.5
10.5	64.9	65.3 and 63.2

As in the previous observations the conductivity is a function of the deflection. The slight differences in the deflections with and without the current acting can be explained by assuming that the selenium had not recovered by the same amount for all the observations.

It may now be considered definitely settled that the decrease as well as the increase of conductivity in the Giltay selenium cell no. 2 represents a genuine change in the selenium or what is supposed to be selenium and not what is ordinarily termed polarization.

It has been shown by a great many investigators that the sensitiveness of selenium decreases with increase of temperature. However it has not been shown to my knowledge how the conductivity for different times of exposure varies with the temperature. As questions in the theory are involved in such information, I have obtained data at different tem-

peratures for time conductivity curves. Such curves are shown in Fig. 6. While the observations are not very accurate, and the range of temperature is not very great, yet it is safe to draw certain conclusions. The conductivity in the dark is more than four times larger at  $46.5^{\circ}\text{C}$ . than it is at  $11^{\circ}\text{C}$ ., and yet the maximum conductivity under the influence of intense illumination has nearly the same value. This is of course in agreement with the well established fact that the sensibility of certain selenium cells decreases greatly with rise in temperature. The maximum

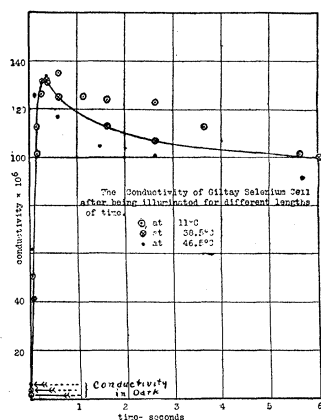


Fig. 6.

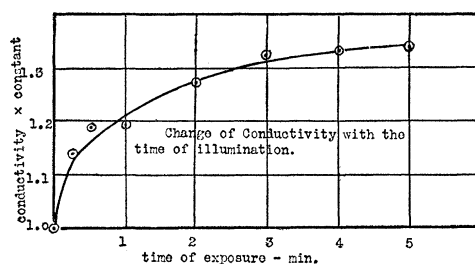


Fig. 7.

seems to be shifted toward the conductivity axis at higher temperatures. However there is reason for believing that the intensity of illumination was slightly less at the higher temperature than at  $11^{\circ}\text{C}$ .

Another class of light-positive selenium continues to increase in conductivity when it is illuminated. The selenium in the Bidwell and also the Ruhmer cells belong to this class. In Fig. 7 is shown how the conductivity varies with the time of exposure for a selenium cell of the Bidwell type. In this particular cell the resistance was only 8,000 ohms, and the sensibility was very low. The cell was not surrounded by a liquid while the readings were being taken; consequently a part of the observed change of conductivity may have been due to temperature. In

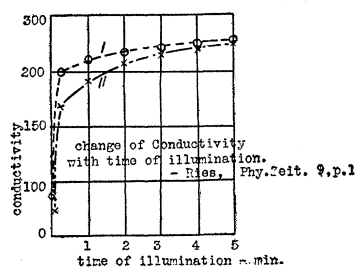


Fig. 8.

Fig. 8 are shown similar curves for two other cells of this class.<sup>1</sup> Curve I is for a cell that was slowly cooled in the making process, and curve II is for one that was quickly cooled in

<sup>1</sup> These are taken from a paper by Ries, Phys. Zeit., 9, p. 9, 1908.



the making. He does not state the resistance of the cells or what was the intensity of illumination. For the cell referred to in Fig. 7, the intensity was that of a 16-cp. lamp at a distance 20 cm. When the intensity was greater than this the rise of the conductivity was more rapid at first and the final value was somewhat larger. In fact any light-positive selenium shows that the equilibrium value of the conductivity to increase with the intensity of illumination. Whether this equilibrium value varies in the same manner as does the conductivity for a very short period of illumination has not been investigated. Aside from the manner in which the "conductivity-time of exposure" curves differ in the two classes of selenium, there are two additional characteristic differences. The sensibility is much lower in the second class and the initial dark resistance is lower. At this time no special importance can be attached to the fact that the changes take place more slowly in the second class than in the first. The depth of the selenium and the intensity of illumination should be alike in order that such comparisons should be of particular value.

#### EXPERIMENTS WITH LIGHT-NEGATIVE SELENIUM.

Because of the difficulty of manufacture of selenium that decreases its conductivity upon exposure to light, I have not been able yet to determine the exact treatment of selenium that produces this so-called light-negative variety. In fact it took just as long and just as much patience to make the fifth sample as it did the first one. We shall therefore confine our attention to an analytical study of the behavior of these samples, particularly under the influence of light.

The general characteristics of this variety are not rigidly defined, except on a few points. The resistance is always small, and when the sample is first prepared it is very unstable. The smaller the resistance the greater is the sensibility, *i. e.*, the greater is the percentage change of resistance by light. Usually the amount of decrease of conductivity increases with increased illumination, but many times I have observed that a weak illumination such as the diffuse light of the room produces practically as great a change as does an intensity one hundred times as great. Generally the selenium recovers quickly when the light is removed, but after many exposures it may become fatigued and not recover for hours or at all. If the recovery is only partial then the sensibility is reduced. A few times and without any warning the selenium has for a single exposure become light-positive instead of light-negative. This was usually when the resistance was unsteady and when the selenium had been repeatedly illuminated. With one exception this reversal of effect has occurred only in newly prepared samples.

The following table will show the regularity of the increase of resistance of two samples which were about a year old. Unless otherwise specified the illumination was quite intense.

TABLE VII.

*Table Showing by Successive Readings the Decrease of Conductivity in Two Samples of Light-Negative Selenium.*

Sample No. 9. Time of Observation.	Resistance in Ohms.	
	In Dark.	In Light.
3:09	107	107.2 in diffuse light.
3:14	107.6	108.6 intense illumination.
3:17	107.6	108.6
3:25	107.6	108.4
3:32	107.6	108.7
3:54	107.6	108.7
4:06	107.65	108.7
4:21	107.6	

No. 2.		
	18.9	22.8 in diffuse light.
	21.8	24.0 in diffuse light.
	22.0	24.7 in diffuse light.
		25.2 20 cm. from 16-cp. lamp.
	22.7	23.2 20 cm. from 16-cp. lamp.

When first made these samples showed the same amount of increase usually, but not only did the resistance in the dark shift very suddenly and irregularly, but the amount of the change in the light was very irregular and at times zero. The irregularities were made more pronounced by sudden changes of temperature or by very intense illumination. Table VIII. shows how the resistance gradually increased as the temperature was successively changed.

TABLE VIII.

Resistance in Dark, Ohms.	Temperature, Degrees Cent.
117	20
123	5
153.5	-10
148	0
157	20
191	3
189	4.5
196	-7
190	2
181	8
167	20
154	39
183	45

From this table it is observed that the general tendency is for the resistance to decrease by raising the temperature and for it to increase by lowering the temperature, but that the net result is an increase of resistance. Not only is the process not a reversible one, but often a change of temperature in either direction increases the resistance. The irregularities were exaggerated by extreme or rapid changes of temperature. All that has just been said however applies only to samples that have been newly made. The increase of resistance of sample no. 1 at the above temperatures was of the order of 1 ohm. By suddenly changing the temperature up and down as indicated in the above table and by tapping the selenium with a thermometer the resistance was further increased to 481 ohms at  $24^{\circ}$  C. It was then exposed to the light of a well lighted room for several months during the summer. All the time it was immersed in paraffin oil in a similar manner to that described previously as in use for the Giltay cell. At the end of the summer the selenium had increased in resistance to 6,200 ohms and it was not measurably sensitive to light. But this was not the most surprising thing. After being removed to the dark for a period of about a month its resistance fell back to 675 ohms, where it was somewhat unsteady and after the current was allowed to flow through it for an hour it fell still further to 67 ohms. It was then light-sensitive as before and has remained so for several months.

The way that the conductivity of these light-negative samples vary with the time of exposure is shown in Fig. 9. The lower curve is for

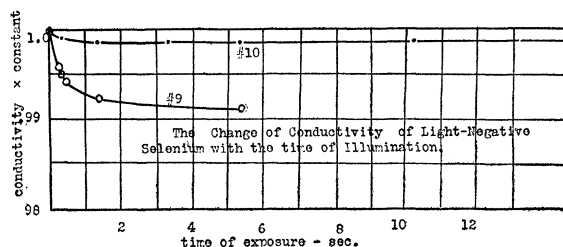


Fig. 9.

sample no. 9, which had a resistance of 107 ohms. The resistance of this sample was perhaps the most steady at all times of any that I have made. The upper curve applies to sample no. 10, which had a resistance of 312 ohms. It should be noted that almost all of the change takes place in less than a second. The intensity of the light was not much different from that used on the light-positive selenium which gave the results show in curves 15, 16 and 17. The rate of decrease in the latter

case is about 200 times greater than it is in the Giltay cell. Further experiments should be carried on with this light-negative variety, in order to determine the conditions of stability and instability.

#### RIES'S "ABNORMAL SELENIUM CELLS."

Ries in his paper on the "Effect of Moisture on the Electrical Properties of Selenium"<sup>1</sup> discusses a most peculiar variety of selenium which he has produced. When illuminated these abnormal selenium cells first rise to a maximum very quickly and then fall off slowly to a minimum value, very much as noted for the Giltay selenium cell. Sometimes the conductivity would even decrease below the conductivity in the dark.

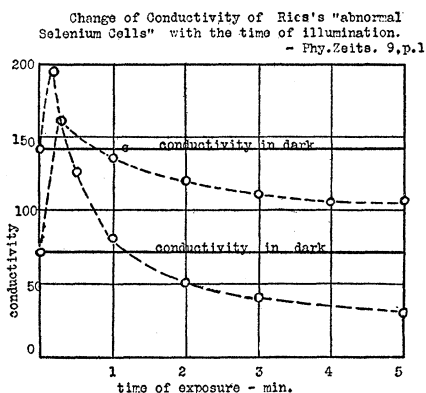


Fig. 10.

Two of his curves are shown in Fig. 10. The conductivity of these samples never increased much above that of the dark conductivity. The initial resistance and the intensity of illumination are not stated. He regards the decrease of resistance as a spurious effect which merely counteracts the positive light-action. His experiments indicate that moisture plays an important part in the formation and persistence of this variety.

I have not yet succeeded in reproducing his so-called "abnormal selenium cells," but this is no doubt because I have not duplicated the exact necessary conditions. I should prefer however to call this variety a third or modified type of the light-positive variety.

#### THE APPARENT FAILURE OF OHM'S LAW.

Ohm's law states that in an electrical conductor the current flowing is proportional to the difference of potential, assuming of course that all other conditions remain fixed. In all varieties of light-sensitive selenium this law apparently does not hold. As the voltage across the selenium is increased the current usually increases at a more rapid rate than it should. The amount of the change in the specific conductivity is sometimes very large. The curves in Fig. 11 show how the variation differs in the two classes of light-positive selenium. It is noted that in the Ruhmer cell the amount of variation is almost proportional

<sup>1</sup>Phys. Zeit., 9, p. 1.

to the voltage, while in the Giltay cell the variation decreases as the voltage is increased. The different high potentials were applied from 20 seconds to 1 minute before each observation was taken. It was suspected that the falling off of the effect in the Giltay cell was due to a decrease of the conductivity by the high potential much the same as is produced by light. This suspicion was strengthened by leaving the potential of 116 volts on the cell about a minute before taking the observation. It is seen that this point is below the curve. In other words, just as in the case of light the change of conductivity is a function of the time of application of the changing agent. The way that the decrease takes place is shown by the observations recorded in Fig.

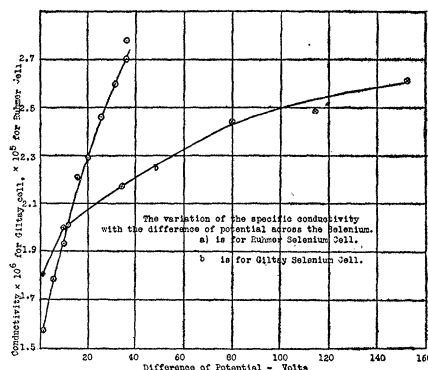


Fig. 11.

12. This curve tells its own story when it is compared with the curves 16 and 17 in Fig. 5. There can be little doubt but that just as light produces a rapid change in the positive direction followed by a slow change in the negative direction, so are there corresponding changes produced by difference of electrical potential. In order to be certain that

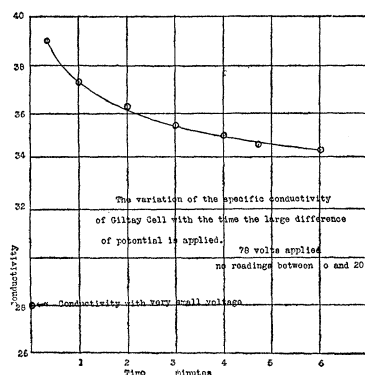


Fig. 12.

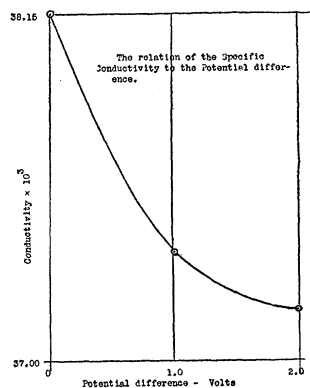


Fig. 13.

the variation first increased rapidly and then decreased slowly, the pendulum and ballistic galvanometer previously referred to were used. First the selenium cell was balanced in the Wheatstones bridge circuit where the fall of potential was two volts. Then the pendulum was

arranged to throw 120 volts instead of the 2 volts into the circuit for varying intervals of time. The galvanometer was in circuit during the last 0.1 sec. of the intervals. The deflection was a function of the change of resistance as usual. The relation of the change of resistance to the deflection may be estimated from the following:

$$\Delta x = 600,000 \text{ ohms,} \quad d = 3.5 \text{ mm.}$$

$$\Delta x = 650,000 \text{ ohms,} \quad d = 5.3 \text{ mm.}$$

$$\Delta x = 700,000 \text{ ohms,} \quad d = 23.5 \text{ mm.}$$

The following table, IX., shows that the maximum conductivity was reached in about 0.1 sec. The increase is rapid and large in amount and the decrease is small and slow in taking place.

TABLE IX.

Time of Application.	Deflection, mm.	Time of Application.	Deflection, mm.
.01 sec.	1.0	.10 sec.	27.3
.02	5.0	.10	26.0
.05	10.9	.20	24.2
.01	1.5	.50	22.5
.02	2.5	7.0	3.5
.02	5.0	10.0	2.7
.01	1.2	60.0	2.5
.05	22.5	60.0	2.0
.10	27.1		

The variation of the specific conductivity of light-negative selenium takes place within quite a different range of potentials than it does for the light-positive selenium. Between two and ten volts I could not detect any variation whatever with certainty. But between 0.001 and 2.0 volts the effect of the variation of the potential difference was unquestionable. The curve in Fig. 9 shows the effect of varying the voltage on light-negative no. 9. The readings were taken after the potential had been applied about a minute. There was evidence that the change was a function of the time also. However this change was so small that it could not be clearly distinguished from a possible temperature effect. The important conclusion is that the electrical difference of potential changes the specific conductivity and in the same direction as the change by light. I have one low resistance sample of selenium that continues to show the light-positive characteristics at times. Also its specific conductivity increases with increase of voltage. Further experiments must be carried on with this sample.

#### DISCUSSION OF RESULTS.

On the basis of our explanation we have deduced four particular characteristic equations, which show the relations existing between the time

of exposure and the conductivity. These relations are shown in the curves in Fig. 1. Experimental results bearing on these relations with all the known varieties of selenium are recorded. The thickness of the selenium varied between 0.1 mm. and 1 mm. While the thicknesses are unquestionably greater than is permitted by the theory because of the absorption of light by selenium, nevertheless it seems that the general form of the conductivity-time curves should not be materially different from what it would be if the layer were very thin. Experiments have not yet been completed for the determination of the depth of penetration of selenium by light, but the indication is that the light penetrates much deeper than is generally supposed, particularly in the light-positive varieties.

The results showed, that the Giltay cell gave curves very similar to 1 and 2, that the cells of the Bidwell type gave data for a curve like no. 3, that the light-negative selenium led to curves of the character of no. 5, and that Ries's "abnormal selenium cells" led to a curve like no. 4. I may state that I found data for curves of no other character to be obtained, either from the theory or from any variety of selenium that has come to my notice. I regard the striking similarity between these experimental and theoretical curves as important evidence in favor of the proposed theory. It seems a waste of time to try to fit the comparison curves more accurately until further information is obtained concerning the depth of penetration of selenium by light.

The curves in Fig. 4 show that with increased intensity of illumination the maximum conductivity occurs sooner, that the maximum is much greater, and that the equilibrium value of the conductivity is correspondingly greater. Any view of the theory requires that the rates of change shall be a function of the light intensity. The curves in Fig. 3 show how the maximum should be shifted if the reverse changes were small in comparison with the direct changes. The form of the curves agrees with the experimental curves, and the maximum occurs quicker with increased intensity. Also for faint illumination the change of conductivity is almost proportional to the time of exposure. This agrees with the relation of the conductivity to the time of exposure as determined by Stebbins. But there is disagreement on two fundamental points, viz., this assumption will not account for the different values of the maximum conductivity or for the different values of the equilibrium conductivity, for different values of illumination.

The curves in Fig. 2 show the manner in which the conductivity should vary with the time for a given intensity of illumination when there are different amounts of the three components. This is again on the assump-

tion that the reverse changes are small. All the forms of curves obtained with the different varieties of selenium are included in these curves. Also there is agreement in the fact that the highest sensibility selenium is that of the highest resistance and that of the negative variety is that of the lowest resistance. There are no disagreements between experiment and theory so far as these curves are concerned, unless we introduce a fact to be explained in a later paper, *i. e.*, that the conductivity of the *C* kind is small in comparison with that of the *B* kind.

Knowing the nature of the disagreement between experiment and theory when the reverse changes were supposed to be small, one can see at a glance that the particular disagreements should be removed if the reverse changes were not neglected. By taking into account the reverse changes as explained in the theory we not only removed the above discrepancies and obtained the curves showing all the characteristics required by the experimental results, but we also had a method of explaining the initial amounts of the three components and for explaining the recovery of selenium. Just what the agreement between the sign and the magnitude of the ratio of the sensibility to the initial conductivity may be cannot be defined further than is shown in Tables I. and II. There is no evidence of disagreement on this point. Satisfactory proof is lacking however in that Table I. does not consider all the possible relations. Theory and experiment agree on the following with regard to selenium of the variety found in the high sensibility of Giltay cells; the maximum conductivity occurs quicker with intense illumination than with faint; the maximum increases in value as the intensity increases; the equilibrium value of the conductivity increases with the intensity; for faint illumination the change of conductivity is almost proportional to the period of exposure.

There are some instances where no relation can be traced between theory and experiment. The ordinary effect of a rise of temperature is to produce a change in the conductivity in the same direction as that by light. But in the high sensibility cell the change by temperature is opposite to that by light. But since the temperature effect is in the same direction as in the pure metals and of about the same magnitude, we may say that the temperature effect is metallic in nature and refuse to explain it further. It is well known that the temperature effect in selenium cells is extremely large ordinarily. The curves in Fig. 6 illustrate this. It may be that the negative temperature effect exists in all selenium cells and that it is sometimes concealed by the much larger reaction temperature effect in the opposite direction. However the greatest difficulty in this line is with the light-negative variety of



selenium. The change by heat is opposite to that by light and also to that in metals by heat. I have no explanation to offer further than to say that the indication is that the light and temperature produce entirely different effects in this variety of selenium, and the same effect in light-positive selenium.<sup>1</sup>

It is a noteworthy fact that in the Giltay cell a large potential difference produces a rapid increase in the conductivity which is followed by a decrease, almost identical to the changes produced by light except that the effects are not so large. As the two changes by light in the Giltay cells were found to be independent of the magnitude of the current one would naturally suppose that the large potential difference affects the conductivity as a result of electrical stresses in the selenium rather than as a result of the electric current. On this view the electrical forces would function in the dynamic equilibrium of the selenium.

Our experiments with selenium under pressure and those of Montén previously referred to show both a rapid and a slow change as noted for light and for high potentials. But the two changes here are difficult to measure accurately because of the simultaneous action of temperature. The equilibrium of selenium under pressure and temperature should be studied more carefully.

This dynamic equilibrium theory, if it satisfactorily explains all the observed phenomena, will still leave the whole subject in an unsatisfactory condition from one point of view. It will still remain to be explained why different varieties should have different rates of change. It may turn out that these different initial rates of change may arise from impurities which act as catalytic agents, or it may be if peculiar initial arrangements of the components are once established in the process of making, that there is an accompanying pressure or potential effect which maintains that peculiar arrangement. Some varieties of selenium do not have a fixed permanent stable equilibrium condition at once. They tend very slowly toward a new condition. In some cases moisture has been known to be the cause of such change but in others there is reasonable doubt. A semi-stable condition seems to exist in the light-negative selenium.

The way that light-sensitive selenium recovers when it is disturbed from its equilibrium condition by any agency is perhaps the strongest evidence in favor of the proposed dynamical theory. With the exception of some light-negative varieties of selenium, the selenium always recovers the conductivity that it possessed in the dark before illumination, and further

<sup>1</sup>On the similarity of the light and temperature effects, see paper by Miss L. S. MacDowell, *PHYS. REV.*, 31, p. 524, 1910.

the two changes that appear during the direct action also appear in the reverse process. The conductivity time curves may be called the reciprocals of the same curves for the action of light.

If the view is accepted that the conductivity changes only when the amount of the conducting variety is changed, then there is obviously no discrepancy in Ohm's law.

#### CONCLUSIONS.

1. That light produces two changes in the conductivity of opposite sign in all light-sensitive selenium.
2. That the amount of the change is a function of the time of illumination as well as the intensity and character of the illumination.
3. That the selenium in the Giltay cell shows the same two changes under the action of high potential differences that it shows under the action of light.
4. That the character of the conductivity curves for the four known varieties of light-sensitive selenium can be explained by assuming the existence of three components in dynamic equilibrium, under given illumination, temperature, pressure and electrical potential differences.
5. That the effect of any agency that affects the conductivity of selenium is of the nature that it alters the rates of interchange between the components.
6. That the experimental results can be explained to a first order approximation on the assumption that only the *B* kind is conducting, of the three components which are in equilibrium according to the reaction  $A \rightleftharpoons B \rightleftharpoons C$ .
7. That if we accept the view here proposed the failure of Ohm's law becomes only an apparent and not a real failure.

PHYSICAL LABORATORY,  
STATE UNIVERSITY OF IOWA.