# CHARACTERISTICS OF CONTACT RECTIFICATION WITH A SILICON CARBON CONTACT.

BY RALPH C. HARTSOUGH.



## INTRODUCTION.

During the last thirty-five years much experimental evidence has been brought to bear upon the phenomenom that a large current will pass in one direction and small current, if any at all, in the opposite direction, through contacts of certain dissimilar solids.[1] Though the greater part of these investigations have been valuable, there are many unsettled and disputed problems connected with the phenomenon of contact rectification. The question as to whether we are dealing with a film effect, the chemical or physical structure of certain materials, or the mere ease of giving up electrons, has received more or less attention. There has been some disagreement as to the area of contact in its effect upon the rectifying property. Some investigators have had much difficulty with the uncertainty of the rectifying properties of the contacts used. Among these uncertainties three are very much in evidence: (1) the direction of flow of rectified current was different with various voltages; (2) at various places on the materials used there would be lacking a rectifying property and often different places on the same specimen would rectify

[1] Ferdinand Braun, Pogg. Ann., 153, p. 556, 1874; 157, p. 350, 1878. F. Streintz, Akad. Wiss. Wein. Sitz. Ber. III., 2a, p. 345, 1902. P. G. Nutting, PHYS. REV., 19, p. 1, 1904. L. W. Austin, Bull. Bur. Standards, 5, 1, p. 133, 1908. G. W. Pierce, PHYS. REV., 28, p. 153, 1909. 29, p. 478, 1909. A. E. Flowers, PHYS. REV., 3, p. 25, 1914. R. H. Goddard, PHYS. REV., 34, p. 423, 1912.

in opposite directions; (3) the rectifying property would be lost by increasing the voltage a very slight amount.

These difficulties and many more of a minor character have greatly hindered the bringing of conclusive evidence to bear upon this most interesting phenomenon.

## Experimental Work.

After a careful consideration of all the former experiments on the phenomenon of contact rectification, it seemed that to make any subsequent and real additions to previous investigations, a more perfect pair of contacts would have to be found. It seemed from the standpoint of convenience and accuracy that, if a rectifying contact could be found which would stand up against from five to ten volts and give 0.5 to 1.0 ampere rectified current, we should then be in a better position to study its characteristics. Also a very important feature for this proposed contact would be durability of its surfaces as well as permanency of the adjustment of contact of its surfaces. Durability here calls for absence of any change, physical or chemical, which would alter its rectifying action. By the durability or permanency of adjustment of the contact is meant that a certain pressure would remain the most efficient in the rectifying action under given conditions.

A systematic search was begun with the above conditions in mind. With all the better contacts used by former experimenters and a long list of metals and non-metals, a selective and sorting arrangement was devised.[1] About one hundred different metals, alloys and non-metals were included in this process, which was essentially as follows: All which apparently allowed more current to pass from than to the substance were put in class *A* and the opposite in class *B*. Those which were uncertain in their action were placed in another series. After these three series had been carefully worked over, a cross-testing process was carried on involving the use of both alternating and direct current in each of about one thousand pairs of contacts tested. It was found that a silicon carbon contact most nearly fulfilled the proposed ideal conditions for a contact as outlined above. However, after much careful investigation with various grades of silicon, furnished through the courtesy of The Carborundum Co., of Niagara Falls, New York and many grades of arc carbon furnished through the courtesy of the National Carbon Co., of Cleveland, Ohio, it was found that the purer material up to a certain point gave the best results. A grade of silicon and carbon was found which admirably filled all the hoped-for essentials.

[1] Some of this work was done in Nebraska Wesleyan University.

### Construction of Contact and Methods of Connection.

In Fig. 1 is given a sectional view of the arrangement of the contact. *S* is the silicon mounted in molten type metal and allowed to cool. *C* is arc carbon, insulated and held in place away from the brass cup container *g*, by a hard rubber ring *D*. *E* is a pressure adjusting screw.

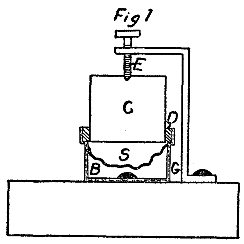


Fig. 1.

To connect the rectifier so as to obtain a total effect of the a. c. current as d. c. Two methods of connection were experimented with. In Fig. 2 is essentially the aluminum valve rectifier connection. This arrangement requires no auxiliary devices and is not bothersome from that standpoint. However, to get the most efficient effect, all contacts should be adjusted to work the same under like conditions. In Fig. 3 is shown

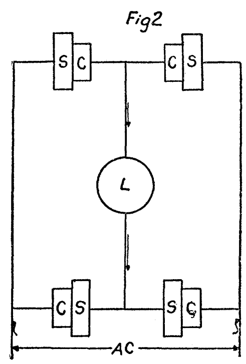


Fig. 2.

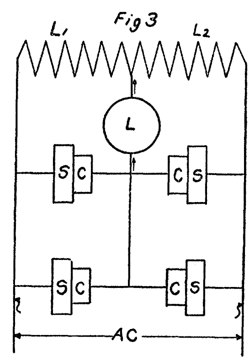


Fig. 3.

rectifier connected after the manner of a mercury arc rectifier. All together the writer had better satisfaction from this connection than from the previous one in Fig. 2.

### Effect of Temperature and Low Air Pressure.

A slight unsteadiness was noticed when the temperature was about 300° C., but aside from this, temperature seemed to have no effect whatsoever. There is reason to believe that the unsteadiness observed was due to expansion in the metals and thereby a change in pressure. No effect was noticed when the contact was placed in a vacuum of one mm. pressure. It apparently worked as well as when in the normal air pressure.

### Discussion of Surfaces.

The surfacing and finishing as well as a suitable mounting of the silicon received not a little attention. The grinding was done on a carborundum wheel, but the finishing, a most important part, was accomplished on a thick plate glass, using alcohol and carborundum powder to bring it to as perfect a plane surface as could be obtained. It was found best not to put a high polish on this silicon surface. The surfacing of the carbon was essentially the same as that of the silicon. All surfaces were made chemically clean and dried thoroughly.

It is very hard to make even a good estimate of the amount of surface in contact after using the best of care in preparation and manipulation. However, two points applied gave approximately twice the magnitude of rectified current that one point gave. Also, two pairs of surface areas, surfaced exactly the same way, one area being only a little over twice that of the other, gave very approximately twice the rectified current. We are led to conclude that the magnitude of the rectified current is approximately proportional to the area of contact.

*Ratio of Contact Areas.*

Observer: R. C. H. March 30, 1914.

Conditions:

1. All carbons surfaced by same process.
2. Same voltage used throughout test (5.0 volts, a. c.).
3. Same surface of silicon used throughout test.

| Carbon, Area $\overline{Cm.}^2$ | Force in Grams. | Rectified Current, Amperes |
|---|---|---|
| One point[1] | 30 | 0.050 |
| Two points[2] | 30 | 0.095 |
| 1.34 | 50 | 0.115 |
| 3.44 | 100 | 0.050 |

## Discussion of Photographs of Surfaces.

The character of the surface of both the silicon and the carbon is so closely allied with efficient rectification that a very thorough study of these surfaces was carried on. Many degrees of fineness of grinding compounds was experimented with to ascertain if possible to what extent the smoothness of surface affected the rectifying property. In photograph No. 1, is shown the best rectifying surface of silicon magnified to 400 diameters. No. 3 is the best rectifying surface of carbon (same magnification). No. 2 is a highly polished surface of silicon and No. 4 is a polished surface of carbon. Both No. 2 and No. 4 are magnified 400 diameters. Below is given a summary of the action of these photographed surfaces in experiment.

[1] Point of same order as knitting needle.

[2] Thirty grams force on each point.

Observer: R. C. H. April 21, 1914.

Conditions:

1. Same voltage throughout test (5.0 volts a.c.).
2. Same method used for surfacing throughout test.

| Surfaces. | Contact Area $\overline{Cm.}^2$ | Degree of Rectification. | Pressure per $\overline{Cm.}^2$ |
|---|---|---|---|
| No. 1 and No. 4 | 1.87 | slight | 300 grams |
| No. 1 and No. 3 | 3.44 | complete[1] | 40 grams |
| No. 2 and No. 3 | 3.44 | fair[2] | 60 grams |
| No. 2 and No. 4 | 1.87 | poor | 500 grams |

*To Show Forming Process.*

Observer: R. C. H. April 14, 1914.

Conditions:

1. Started freshly surfaced silicon and carbon.
2. Same surfaces kept in contact throughout test.
3. Used 3.44 cm.[2] area carbon and silicon surface with 30 grams per sq. cm.

| Time. | P.D. Contact. | Approximate Rectification Ratio.[3] | Rectified Current Amperes. |
|---|---|---|---|
| 9.15 A.M. | 3.8 | 35 : 1 | 0.23 |
| 9.17 A.M. | 5.8 | 50 : 1 | 0.64 |
| 9.20 A.M. | 6.1 | 40 : 1 | 0.86 |
| 9.22 A.M. | 6.3 | 100 : 1 | 1.10 |
| 9.23 A.M. | 3.6 | 300 : 1 | .56 |

After looking into the results of the different grades of surfacing and after carefully studying the photographs of surfaces, we are led to think that the contact rectification takes place through the action of small points. There is no doubt in the writer's mind that the "forming effect," mentioned above, is a bringing of more points on the surface into activity. In the photographs No. 1, a good rectifying surface of silicon shows a large number of points as compared to No. 2, a poor rectifying surface of the same silicon. Surface No. 2 was afterward made a good rectifying surface by finishing as No. 1 was surfaced. The size and number of these projections are vitally tied up with the rectifying property. Pressure would bring more points into contact, theoretically, but we find that increased pressure does not increase the rectifying properties of a surface. Pressure evidently has a crushing effect on the points of the surface, thereby destroying the property of rectification. The writer's theory is that in the "forming processes" there are points which

[1] These surfaces could be formed so as still to give complete rectification with an applied voltage of 10–12 volts and rectified current of 1.0 to 1.5 amperes.

[2] These surfaces would not form. By "Forming" we mean that a better rectifying surface resulted from certain manipulation as given below.

[3] Rectification ratio is the area of the current curve above compared to that below the zero line. The current curves were studied by the use of the oscillograph.

are very close yet not active as rectifiers and an increase in voltage causes an arc across these points bringing them into contact. This theory is compatable with the fact that two surfaces which have been "formed," when separated have to be "re-formed" again the same as the first time. This shows that there is no chemical formation and that this forming is evidently a point phenomenon. A surface once "formed" will hold constant as a rectifier as long as it is undisturbed. With the carbon surfaces the same conclusions are drawn. No. 3, a good rectifying surface, shows more point area than No. 4, a poor rectifying surface. All surfaces were illuminated from the side in photographing them.

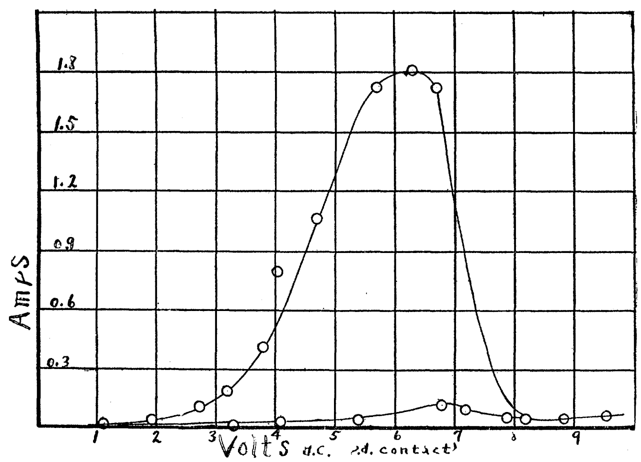


Fig. 4.

## Current E.M.F. Data.

It was in this part of the experimental work that an effect was noticed which started a long search for a time element in the rectifying action. This effect was the fact that a rectifier which would give complete rectification with an alternating E.M.F., would allow, with equivalent value of direct E.M.F., as much as fifteen per cent. to twenty per cent. of the current to pass in the high resisting direction. Fig. 4 shows current E.M.F. curved with the direct current. The contact used

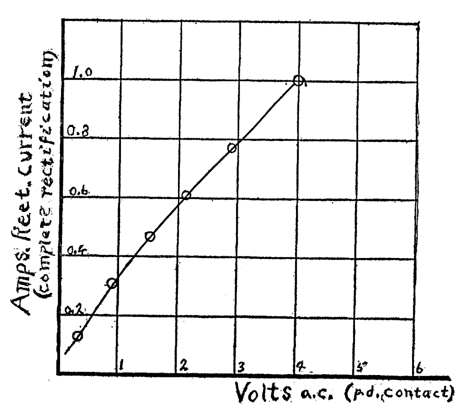


Fig. 5.

gave complete rectification with alternating E.M.F. at 5.0 volts. The upper curve gives the current when the voltage was applied from silicon to carbon, the lower curve, the corresponding current when the voltage

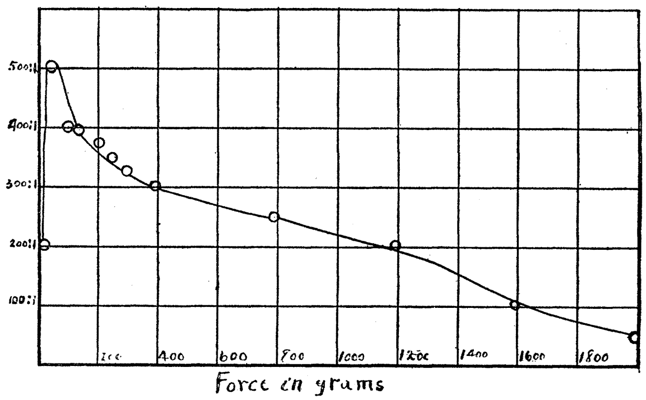


Fig. 6.

was applied in the reverse direction. These results could be repeated time after time. Here is given a set of readings very much like the readings from which the curve in Fig. 4 was plotted.

*Direct Current Applied to Contact.*

Observer: R. C. H. March 27, 1914.

| Silicon to Carbon. | | Carbon to Silicon. | |
|---|---|---|---|
| Volts (P. D. Contact.) | Amperes. | Volts (P. D. Contact.) | Amperes. |
| 1.14 | 0.013 | 1.15 | 0.004 |
| 2.03 | 0.067 | 2.04 | 0.02 |
| 2.87 | 0.114 | 2.93 | 0.018 |
| 3.1 | 0.162 | 3.2 | 0.018 |
| 3.9 | 0.30 | 4.0 | 0.01 |
| 4.7 | 0.455 | 4.85 | 0.017 |
| 5.0 | 0.50 | 5.4 | 0.017 |
| 6.0 | 0.70 | 6.1 | 0.017 |
| 6.8 | 0.2 | 6.9 | 0.018 |
| 7.2 | 0.007 | 7.2 | 0.007 |
| 8.1 | 0.024 | 8.2 | 0.011 |
| 9.0 | 0.018 | 9.0 | 0.013 |
| 9.3 | 0.018 | 9.3 | 0.013 |
| 10.4 | 0.018 | 10.4 | 0.018 |

(Storage Battery used)

Fig. 5 is a current-voltage using alternating E.M.F.

## Current Pressure Data.

That pressure is closely related to the rectifying property has been pointed out by almost every experimenter, but I believe not one has

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Fig. 1.

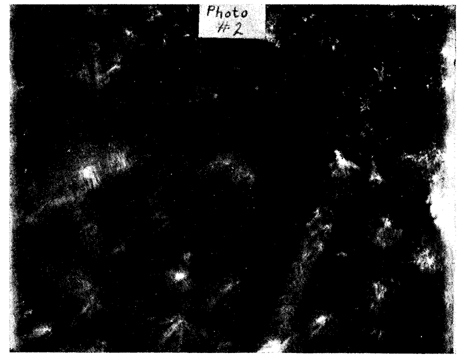


Fig. 2.

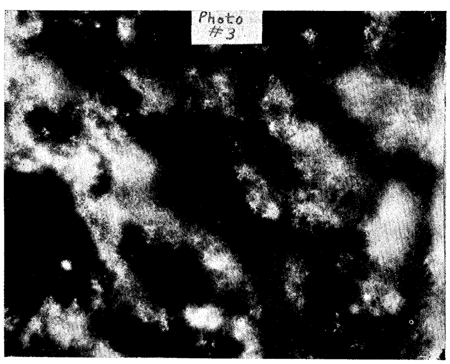


Fig. 3.

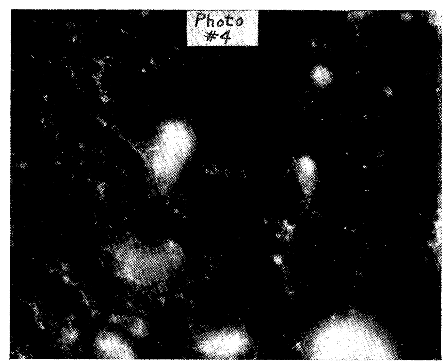


Fig. 4.

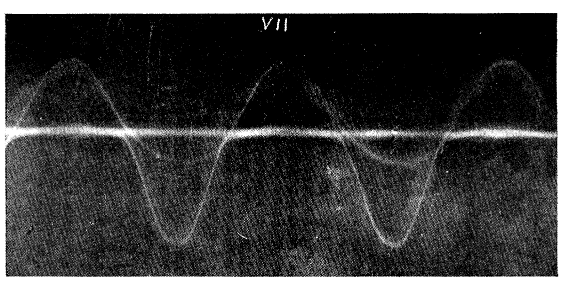


Fig. 7.

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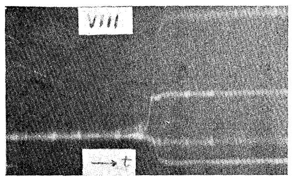



Fig. 8.

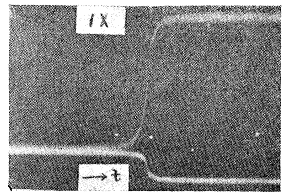



Fig. 9.

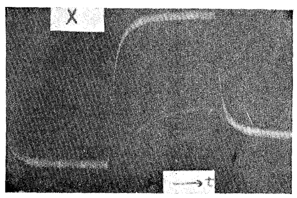



Fig. 10.

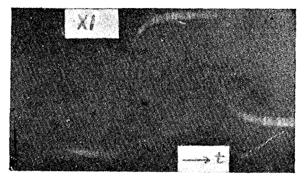



Fig. 11.

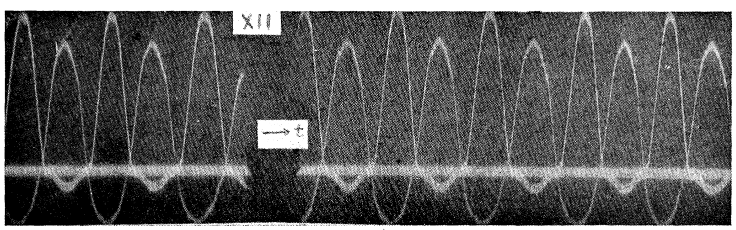



Fig. 12.

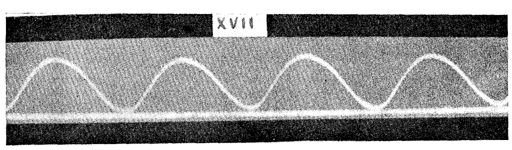



Fig. 17.

RALPH C. HARTSOUGH.

shown the exact relation. The following readings are characteristic of many taken. They show the effect of pressure, not only upon rectification but also upon the potential drop.

Observer: R. C. H. April 22, 1914.

Conditions:

1. Same voltage throughout experiment (5.0 volts a.c. applied).
2. Same contact area (3.44 $\overline{\text{cm.}}^2$).

| Volts P.D. Contact. | Estimated Rectification Ratio. | Forces in Grams. |
|---|---|---|
| 4.25 | 200 : 1 | 25 |
| 3.85 | 500 : 1 | 50 |
| 3.70 | 400 : 1 | 100 |
| 3.65 | 400 : 1 | 150 |
| 3.60 | 375 : 1 | 200 |
| 3.55 | 350 : 1 | 250 |
| 3.50 | 325 : 1 | 300 |
| 3.40 | 300 : 1 | 400 |
| 3.15 | 250 : 1 | 800 |
| 3.00 | 200 : 1 | 1,200 |
| 2.80 | 100 : 1 | 1,600 |
| 2.25 | 50 : 1 | 2,000 |

Fig. 6 is a curve plotted from these results.

## Discussion of Oscillograph Curves.

Of the many investigators who have used the oscillograph in studying the peculiarities of contact rectification we believe none have reported the fact before mentioned—that a rectifier giving complete rectification, as in Fig. 7, will allow, with direct E.M.F., some current to pass in the high resisting direction. It was thought that by the sudden application of direct E.M.F. in the high resisting direction a building up process, if present, would be detected by a lag in the current curve. Fig. 8 is a result of such manipulation, while Fig. 9 is the result of an equivalent non-inductive resistance replacing the rectifier. No difference in slope of the two curves can be detected. Then the apparatus was arranged to get the current curve from zero to low current value, reversed to high current value, finally to zero, which is shown in Fig. 10. The heavy line is the current curve, the lighter one the E.M.F. This total change on reversal of current occurred in about 1/100 of a second. Fig. 11 represents the same manipulation having the rectifier replaced by an equivalent non-inductive resistance. No difference was detected in the two curves.

Alternating current was now resorted to as offering an explanation of the time element in the rectifying action. In Fig. 12 is given a curve of

60-cycle current beginning with the instant of application to the rectifier. Within the twelve inches of film which revolved on the drum at a speed of 600 R.P.M., a reducing of the current curve in the high resisting direction is noticable. There are $1\frac{1}{2}$ cycles missing on the print as the twelve-inch film was too long for the paper. Time goes from the break toward the right of the page, then from the left up to the break again. Fig. 7 is an oscillograph record taken on the rectifier after operating a very short time, of the order of one and two seconds. These curves clearly show a building-up effect which almost completely cuts off current in one direction. To get a complete record of this process as well as the time element would require a record six to ten feet long, perhaps more, traveling at a speed of 600 feet per minute. This was not available. Lower frequencies were investigated as to the effect they might have on this action. A thirty-cycle also a fifteen-cycle current did not show any marked difference in contrast with the 60-cycle current in Fig. 12. Fig. 17 is a record of the current taken with the apparatus connected as in Fig. 3. This is complete rectification utilizing both halves of the a.c. wave.

## Conclusions.

The most popular explanation of contact rectification is that electrons are given up more easily by some solids than others, and that the rectification ratio is of the same order as the ratio of emission of electrons at the contact of dissimilar solids. If the "forming theory," given in this paper is correct, the theory of the passage of electrons is still intact. It seems from Fig. 12 that, if the frequency should be increased many times and a similar record taken, we might get a larger amount of current in the high-resisting direction, for the first few cycles. The writer intends to try this out at a later date.

Also the "forming action" will require not a little study in its details to understand more accurately what happens.

The writer wishes here to express his appreciation and thanks to Dr. F. E. Kester, of the University of Kansas, for his untiring help and inspiration to me in this work. To those in the department of physics who so kindly helped in many ways my sincere thanks are given.

Much of this investigation was made possible through the courtesy of Professor C. A. Johnson, of the school of electrical engineering of the University of Kansas, who gave of his time to furnish needed apparatus. The writer wishes to express his indebtedness to him.

Blake Physics Laboratory,
University of Kansas,
May 21, 1914.

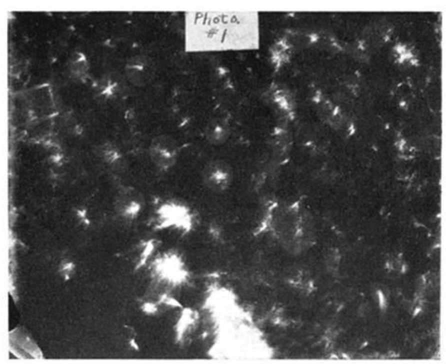



Fig. 1.

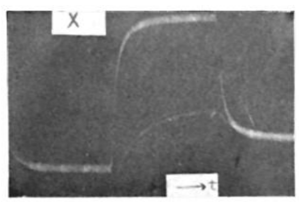



Fig. 10.

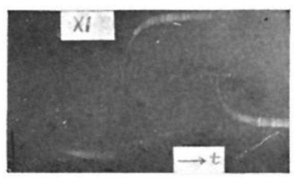



Fig. 11.

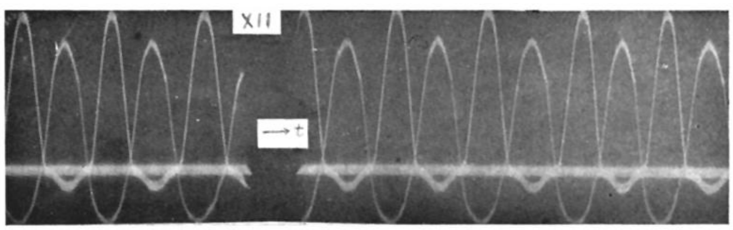



Fig. 12.

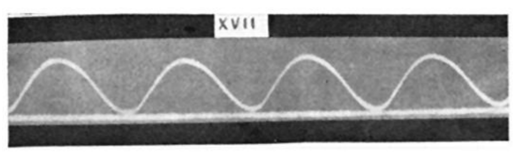
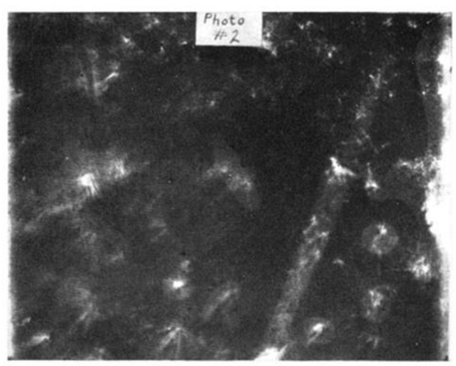



Fig. 17.

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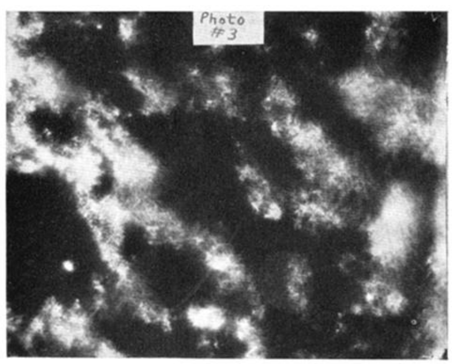


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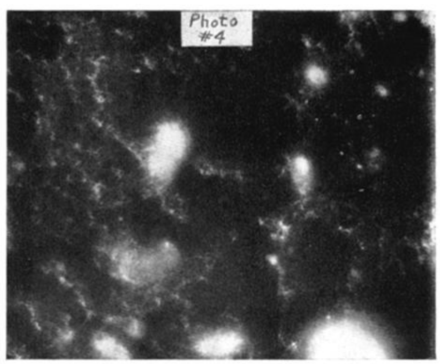


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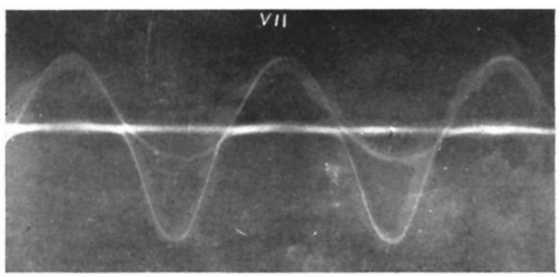


Fig. 7.

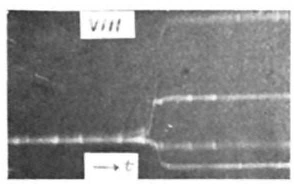


Fig. 8.

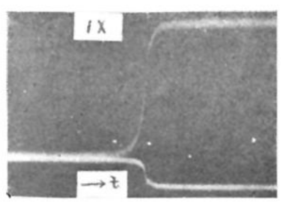


Fig. 9.