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THE INFLUENCE OF TEMPERATURE UPON THE  
PHOTO-ELECTRIC EFFECT.

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1. The discharge of negatively electrified bodies by the impinging of light waves upon them has been studied in various phases by a large number of observers. The results obtained by these have led to the hypothesis<sup>1</sup> that the discharge is due to an ionization produced at the surface of the body by the rapid absorption of certain of the waves of the impinging light. There is but little known, however, as to the relative parts played in the ionization by the material of the body and by the gas occluded in it or existing as a layer upon its surface.

The study of the effects of any cause, which produces variations in the rate of the discharge, is of interest inasmuch as it may aid in leading to a more exact knowledge of the fundamental conditions necessary for the discharge itself. The changes which have been observed in the rate of the discharge by altering either the electric force between the electrodes or the distance between them or the pressure of the gas, have recently been explained by Townsend<sup>2</sup> as due mainly to the secondary effect of the production of new ions in the gas by the rapid passage through it of the negative ions formed by the light at the metal surface. The influence of the temperature of a body upon the rate of the discharge from its surface has not been

<sup>1</sup>J. J. Thomson, *The Discharge of Electricity through Gases*; E. Rutherford, *Proc. Camb. Phil. Soc.*, Vol. IX., Pt. VIII., 1898.

<sup>2</sup>J. S. Townsend, *Phil. Mag.*, Feb., 1901, p. 220.

systematically studied, although the temperature of a body no doubt has a large effect upon the amount of the gas occluded and upon the surface layer of the gas as well as upon the molecular structure of the body itself. Hoor<sup>1</sup> found that by heating the zinc plate used in his experiments with a Bunsen burner to 55° C., the effect of the light was much diminished. He cites this as a proof that the discharge originates in the surface layer of gas, which he thinks had been driven off at the higher temperature. Stoletow<sup>2</sup> states that he obtained results the opposite to those of Hoor. He placed two platinum electrodes in an air bath and by gradually heating it to above 200° C. he found that the rate of the discharge produced by the light was rather increased, although not regularly.

2. The present paper gives the results of some preliminary experiments on the influence of the temperature of a body upon the rate at which electricity is discharged from its surface by ultra-violet light.

In the first experiment which was tried an open cylinder made of brass wire gauze was placed upon the plate of a gold-leaf electroscope. A coil of platinum wire was supported in the center of the cylinder and connected to earth. The temperature of the platinum wire could be altered by sending an electric current through it, and the light from an arc lamp could be concentrated upon the wire by means of a quartz lens. When the electroscope and the gauze cylinder were charged positively and hence the earthed platinum wire negatively, it was found that the discharge produced by the light was two to three times as rapid while the wire was heated to about redness as when it was at room temperature.

3. The following arrangement was then adopted for studying the effect more closely. The apparatus which was used is represented diagrammatically in Fig. 1, the parts, however, not being drawn to scale.

The surface from which the discharging effect of the light was observed was for the most part that of a platinum wire. Its temperature was varied by means of an electric current. A wire about 20 cms. long and having a diameter of .038 cms. was bent into the

<sup>1</sup> M. Hoor, *Beibl. z. d. Ann. d. Phys. u. Chem.*, p. 731, 1889.

<sup>2</sup> A. Stoletow, *Comptes Rendus*, 108, p. 1241, 1889.

form shown at *S* in the figure (the total diameter being about 2.5 cms.). Its actual position in the apparatus is represented at *P*. The ends of the wire were soldered to the ends of the brass rods *T* and *T'*. To the same solder junctions were fastened the two copper wires *U* and *U'* which were connected to the voltmeter *V* that was used for measuring the fall of potential between the ends

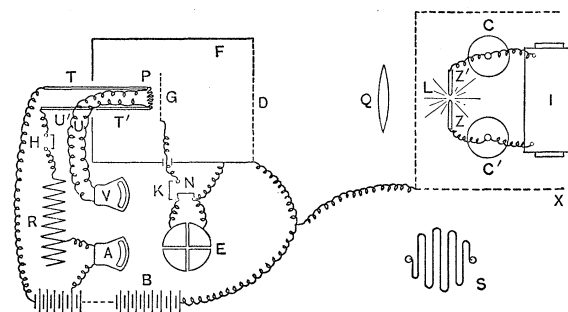


Fig. 1.

of the wire. The platinum wire *P* was maintained at a definite potential by means of the battery of large storage cells *B*, the negative end of which was connected to the rod *T* while the positive end was joined to earth.

By closing the key *H*, a current from the last few cells of the battery could be passed through the wire *P*, and its amount was measured by the ammeter *A* and regulated by means of the changeable resistance *R*.

The simultaneous readings of the voltmeter *V* and the ammeter, *A* determined the resistance of the wire *P*. From this resistance the average temperature of the wire could be obtained since the resistance of the wire had previously been determined at the melting point of ice and at the boiling points of water and of sulphur. The temperature coefficient of the wire was quite low, which indicates that the platinum was not pure. The average temperature of the wire is no doubt somewhat different from the temperature of the surface of the wire with which we are concerned in these experiments. This is due partly to the uneven distribution of the temperature throughout the cross-section of the wire and partly to the cooling of the wire at the points of attachment.

The source of light used was the electric spark  $L$  produced between the two zinc rods  $Z$  and  $Z'$  by the induction coil  $I$ . A six-inch Apps coil operated by the attached hammer was used. The Leyden jars  $C$  and  $C'$  served to increase the capacity. The source of light  $L$  was over 50 cms. from the wire  $P$ , and the light was concentrated upon the latter by the quartz lens  $Q$  which had a diameter of 9 cms. The visible light was brought to a focus at some distance beyond  $P$  so that the ultra-violet light would cover but the central portion of  $P$ .

An insulated circular brass wire gauze  $G$ , having a diameter of 6 cms., was placed 1.6 cms. in front of the wire  $P$ . By means of the key  $K$  the gauze could be connected to one pair of quadrants of the electrometer  $E$ , the other pair of which was joined to earth. The gauze  $G$  could be brought to zero potential by closing both of the keys  $K$  and  $N$ .

The negative potential of  $P$  created the electric field between  $P$  and  $G$  under the action of which negative ions produced at  $P$  were carried to  $G$ . The rate of discharge of  $P$  could therefore be measured on the electrometer  $E$ .

The parts  $P$  and  $G$  were surrounded by an earthed metallic cage  $F$ , 20 cms. long and 16 cms. in diameter. The front part was made of wire gauze for the admission of the light. The electrometer with the keys and connecting wires was also covered by metallic shields not shown in the figure, the keys being manipulated from the outside by means of levers. Lastly the induction coil with the Leyden jars and spark gap were completely enclosed in a wire gauze cage connected to earth.

4. The following was the procedure in taking readings with the apparatus. The proper current was allowed to flow through the platinum wire for about a minute to allow the wire to assume a stationary temperature. Then, for temperatures below those for which the wire showed any luminosity, the zero of the electrometer was read with the key  $K$  closed and  $N$  open. The induction coil was next started by closing a key not shown in the figure, and a stop watch was started at the same time. The readings on the ammeter and voltmeter were then taken. At the expiration of a minute the induction coil was stopped, and the electrometer reading was taken after it had assumed a stationary value.

When the wire *P* was hot enough to produce a discharge owing to its temperature, the zero of the electrometer was read with both of the keys *K* and *N* closed. The coil was started, and then simultaneously the key *N* was opened and the stop watch started. The readings of the ammeter and voltmeter were then taken as before. At the end of the minute the key *K* was opened, disconnecting *G* from the electrometer, the coil was stopped and the electrometer reading taken when stationary.

A similar procedure was followed for finding the discharge due to the heated wire alone, when unaided by the ultra-violet light.

5. It was found that, while for temperatures not far from that at which the wire begins to emit light the rate of discharge was greater than that at room temperature, for some intermediate temperatures, however, the rate of discharge was less.

This is shown by the following set of readings, taken after the wire had just been used for another set of readings.

TABLE I.  
PLATINUM WIRE.

Reference number.	Time of observation.	Resistance of wire.	Temperature.	Electrometer deflection.
1	4:10	No current.	20° C.	146
2	4:13	No current.	20	147
3	4:17	.342	80	132
4	4:20	.348	95	117
5	4:23	.390	170	91
6	4:27	.450	275	108
7	4:30	.588	520	235
8	4:33	.663	655	7*
9	4:35	.662	655	354

The platinum wire was maintained throughout at — 70.5 volts.

The reading number 8 was taken without any light on the wire and shows that at that temperature the wire was beginning to discharge negative electricity due to the heat alone. This discharge increases more rapidly with the temperature than does the discharge caused by the light, so that by increasing the temperature less than 100° above the highest used above the two become about equal. While the discharge due to the light alone can be obtained by sub-

tracting from the total effect that caused by the heat alone, it becomes difficult to attain any high accuracy after the discharge caused by the heat becomes large, since small changes in temperature which are liable to occur affect this latter discharge greatly. This gives a limit to the temperatures that can be employed in the experiments.

The results of the above table are shown graphically in Fig. 2, where the temperatures are plotted as abscissas and the electrometer deflections as ordinates.

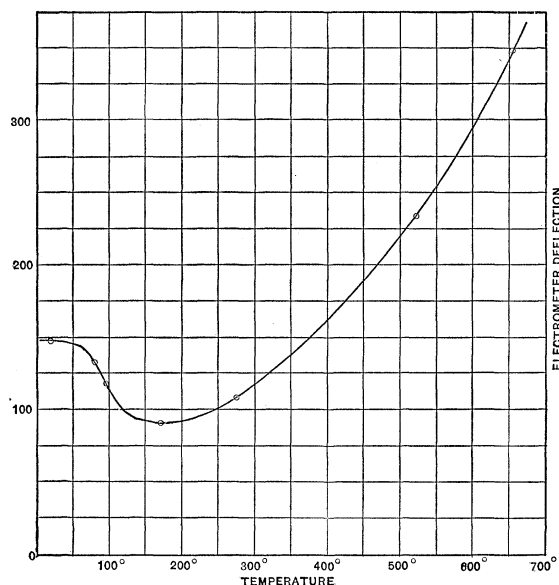


Fig. 2.

It is seen from the curve that the rate of discharge at first diminishes with increase of temperature and then finally increases. The amount of the diminution of the rate of the discharge at the minimum point of the curve, relative to the discharge at room temperature, was quite different in different sets of readings taken in the above manner. It is especially to be noted that when the wire had not been used for some time the first set of readings showed at the minimum point the smallest decrease from the readings at room temperature.

The rate of discharge at any temperature was thus found to vary for different conditions of taking the readings, depending considerably upon the immediate previous history of the wire.

The results indicate that the changes which are produced by an alteration of temperature and which affect the conductivity reach their state of equilibrium but slowly in some cases, and possibly do not attain the same stage for an increasing as for a decreasing temperature.

6. Some of these peculiarities are shown in the following set of readings where one series of observations was taken with the temperatures of the wire increasing step by step to the highest used and then diminishing similarly to room temperature; and a second series was taken like the above except that between the individual readings the wire was allowed to cool to room temperature and a reading always taken for that point.

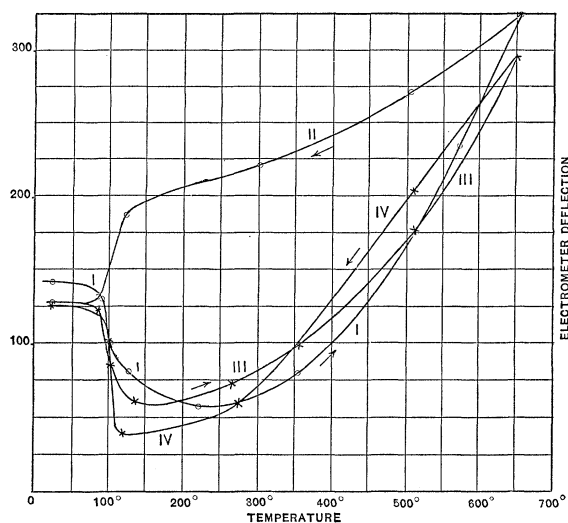


Fig. 3.

The results are shown graphically in Fig. 3.

Curve I. represents the readings for continuously increasing temperatures.

Curve II. represents the corresponding readings for decreasing temperatures.

TABLE II.  
PLATINUM WIRE.

Reference number.	Time of observation.	Resistance of wire.	Temperature.	Electrometer deflection.
1	8 : 40	No current	20°C	140
2	8 : 43		20	142
3	8 : 46		90	129
4	8 : 49	.345	100	99.5
5	8 : 52	.371	125	86
6	8 : 55	.420	220	57
7	8 : 58	.492	355	80.5
8	9 : 01	.617	570	234
9	9 : 05	.664	655	8.5*
10	9 : 06	.664	655	332.5
11	9 : 09	.578	505	270
12	9 : 12.5	.464	300	221
13	9 : 16	.368	120	187.5
14	9 : 19	.343	85	130
15	9 : 22	—	20	129.5
16	9 : 25	—	20	128
17	9 : 29	.344	85	123
18	9 : 31	—	20	125
19	9 : 35	.350	100	86
20	9 : 38	—	20	122
21	9 : 41	.376	135	66
22	9 : 44	—	20	132
23	9 : 47	.445	265	72.5
24	9 : 50	—	20	106
25	9 : 53	—	20	111.5
26	9 : 55.5	.493	355	97
27	9 : 58	—	20	89
28	10 : 01	—	20	95
29	10 : 05	—	510	177
30	10 : 08	.581	20	92
31	10 : 11	.663	655	13*
32	10 : 12.5	.663	655	308
33	10 : 16	—	20	112
34	10 : 19	.581	510	203.5
35	10 : 22	—	20	107
36	10 : 25	.453	275	59
37	10 : 27	—	20	104.5
38	10 : 30	.364	115	38
39	10 : 33	.364	115	42
40	10 : 35	—	20	123.5
41	10 : 38	.350	100	101.5
42	10 : 41	—	20	126.5

Readings number 9 and 31 which are marked by a \* were taken without the light, the observed discharge being produced by the heated wire alone. The potential of the platinum wire was—71 volts.



Curve III. represents the readings for increasing temperatures when the wire was cooled to room temperature after each reading.

Curve IV. represents the corresponding readings for decreasing temperatures.

The curves I., III. and IV. are practically alike except that IV. descends lower at the minimum point than the others, a peculiarity which appeared in repetitions of the observations.

Curve II. shows a larger conductivity than in the other cases, for all of the higher temperatures; as if on lowering the temperature some change produced at the higher temperature persisted through some of the lower ones.

It is noticed that at about  $100^{\circ}$  there is the most rapid change in the curves, the upper one (II.) and the lower ones approaching each other rapidly, indicating that at this temperature some more or less sudden change in the conditions takes place.

It is not possible to tell how much variation occurred in the intensity of the light during the progress of the readings, but there is reason to believe that it was not large and certainly not large enough to overshadow the peculiarities observed. The readings at room temperature at the beginning and at the end of the observations are not much different, while the two readings at the highest temperature used in the two series are also of nearly the same value. The ratio of the readings at the highest temperature to those at the temperature of the room is also the same in this series as in others which were taken at different times. Whatever disagreement exists among the readings at room temperature taken between the other readings is not necessarily all due to changes in the source of light, as there is an after effect here also which is more pronounced after a return from certain temperatures than after others.

7. The large difference between the readings at certain points for the same temperature, depending upon whether a lower or a higher temperature has been used immediately preceding is well shown by taking cycles of readings like the following :

The potential of the platinum wire was — 72 volts.

It is seen that number 4 which follows the high temperature is about three times as large as number 2, which was taken after the room temperature, although both points are for approximately the same temperature.

TABLE III.

Reference number.	Resistance of wire.	Temperature.	Electrometer deflection.
1	No current.	20° C.	92
2	.417	220	62
3	.623	590	203
4	.439	255	171
5	No current.	20	109

8. In order to find whether the effect was influenced by a change in the electric intensity between the platinum wire and the gauze, the distance between them was reduced to one third of its former value. The potential of the wire was kept the same as before, and the following set of readings was taken :

TABLE IV.

Reference number.	Resistance of wire.	Temperature.	Electrometer deflection.
1	No current.	20° C.	143
2	.419	220	64
3	.636	605	244
4	.428	240	207.5
5	No current.	20	126

Here again the large difference between numbers 2 and 4, taken after the low and high temperatures respectively, is apparent and is of about the same order as before.

9. A change in the intensity of the light was also tried, the spark being made much weaker. The following set of readings taken shows the same peculiarity with respect to numbers 2 and 4 as appears in the other cases :

TABLE V.

Reference number.	Resistance of wire.	Temperature.	Electrometer deflection.
1	No current.	20° C.	39
2	.430	240	17
3	.638	610	64
4	.426	235	43
5	No current.	20	27

10. In the above sets of readings the time interval between the successive observations was about three minutes. It was found that the conductivity observed at certain temperatures after the wire had just been cooled from some higher temperature was much larger than if the wire had not been heated. This increased conductivity is, however, in part, at least, but temporary. Some change is produced by the heating from which the wire recovers (at least partly), but in the time interval used above between the readings the recovery had not been completed, the conditions at the wire not having reached their steady state. This abnormal conductivity, therefore, gradually diminishes with time. The following set of readings illustrates this point:

TABLE VI.

Reference number.	Time of observation.	Resistance of wire.	Temperature.	Electrometer deflection.
1	9 : 22	No current,	20° C.	104
2	9 : 26.5	—	20	112
3	9 : 30	.436	250	65
4	9 : 33	.435	250	59
5	9 : 35.5	.435	250	58
6	9 : 39.5	.631	605	181
7	9 : 43	.633	605	181
8	9 : 46	.435	250	156
9	9 : 49	.434	250	138
10	9 : 53	.434	250	123
11	9 : 56	.433	245	120
12	10 : 01	.433	245	119
13	10 : 05.5	—	20	122
14	10 : 09	—	20	118.5
15	10 : 13	—	20	118.5
16	10 : 17	.434	250	62
17	10 : 20.5	.434	250	58.5
18	10 : 24	.434	250	52.5
19	10 : 27.5	.434	250	54.5
20	10 : 32	.626	590	5.5*
21	10 : 34	.626	590	167
22	10 : 36.5	.445	265	138.5
23	10 : 40	.445	265	120.5
24	10 : 43.5	.446	265	109.5
25	10 : 46.5	.446	265	102.5
26	10 : 50	—	20	106.5
27	10 : 54	.614	570	158.5
28	11 : 03	.445	265	102.5
29	11 : 06	—	20	103.5

Reading number 20 marked by a \* was taken without the light. The readings from number 8 to number 12 show that after the wire had been reduced from over  $600^{\circ}$  to about  $250^{\circ}$  the conductivity at first diminished quite rapidly with time, but after fifteen minutes the change was slow, its value being then about the same as at room temperature. The readings from number 22 to number 25 also illustrate this same point. In these sets of readings the wire was exposed to the light a number of times after the heating, which fact might have been the cause of the change which produced the diminution in the conductivity. That this was not the case is shown by readings 26 to 29. Here number 28 was taken, without intermediate readings, nine minutes after number 27, and it is seen that the value of the conductivity is diminished at once to approximately the same as at room temperature.

After changing the temperature of the wire from the room temperature to about  $250^{\circ}$  the readings 3 to 5 and the readings 16 to 19 show that here also there was some diminution of the conductivity with time.

11. The preceding results show that for the range of temperatures used the conductivity produced by the impinging of the ultra-violet light upon a negatively charged platinum wire, at first diminishes with the temperature, reaches a minimum value and then increases.

After reducing the temperature of the wire to certain intermediate temperatures, the conductivity is larger at first than if such temperatures had not been exceeded shortly before; the wire acquiring its steady state but slowly in such cases. Whether the steady state is the same for a descending as for an ascending temperature is not yet determined. Careful experiments will be made on this point, for if the final state is not the same in the two cases, this must be taken as good evidence that the result is due to a changed molecular arrangement of the wire.

The recovery of the steady state after a reduction of temperature is more rapid at certain temperatures than at others.

The temperature at which, upon descending to it, the recovery begins to be especially rapid is in the neighborhood of about  $100^{\circ}$  C., at which place also the conductivity diminishes quite rapidly in the

case where readings are taken when the temperatures are being increased.

12. Some experiments were performed in which the platinum wire used previously was replaced by an iron wire bent in the same form.

TABLE VII.

IRON WIRE.

Reference number.	Time of Observation.	Resistance of wire.	Electrometer deflection.
1	9 : 16	No current.	2.
2	9 : 21	.35	1.25
3	9 : 24	—	2.75
4	9 : 26.5	.35	1.75
5	9 : 30	—	2.75
6	9 : 33	.558	1.25
7	9 : 37	.558	1.
8	9 : 39	—	2.75
9	9 : 42	.714	1.25
10	9 : 46	—	1.75
11	9 : 49	.987	4.75
12	9 : 52	—	3.25
13	9 : 59	1.19	8.
14	10 : 01	—	1.5
15	10 : 04	1.30	6.
16	10 : 08	—	2.5
17	10 : 11	1.355	9.75
18	10 : 14	—	2.25
19	10 : 17	1.503	3. *
20	10 : 18	1.503	17.
21	10 : 21	—	2.
22	10 : 24	1.69	26. *
23	10 : 26	1.69	52.
24	10 : 29	—	1.75
25	10 : 33	1.875	162. *
26	10 : 36	1.875	220.
27	10 : 41	—	1.75
28	10 : 47	1.555	3.75*
29	10 : 49	1.555	13.
30	10 : 51	—	1.75
31	10 : 55	1.14	3.25
32	10 : 57	—	2.25
33	11 : 00	.403	1.
34	11 : 03	—	2.25

The conductivity obtained at the lower temperatures was very small and approached the lower limit of the electrometer.

The preceeding is a set of readings taken with the iron wire at  $-70$  volts, the current through it being broken after every reading and the conductivity at room temperature measured. The resistance calculated from the voltmeter and ammeter readings is given in each case as before. The corresponding temperatures cannot be given because the constants of the wire were not determined. The resistance of the wire at  $25^{\circ}$  C. was  $.31$  ohm, and when it was just beginning to glow on account of the current sent through it its resistance was about  $1.30$  ohms.

The readings marked by a \* were taken without the light, the observed conductivity being caused by the heated wire alone.

Before reading number 13 the wire was heated more than was desired, so it was cooled to and allowed to remain at room temperature for some time. In all the readings where the resistance is not given the wire was at room temperature.

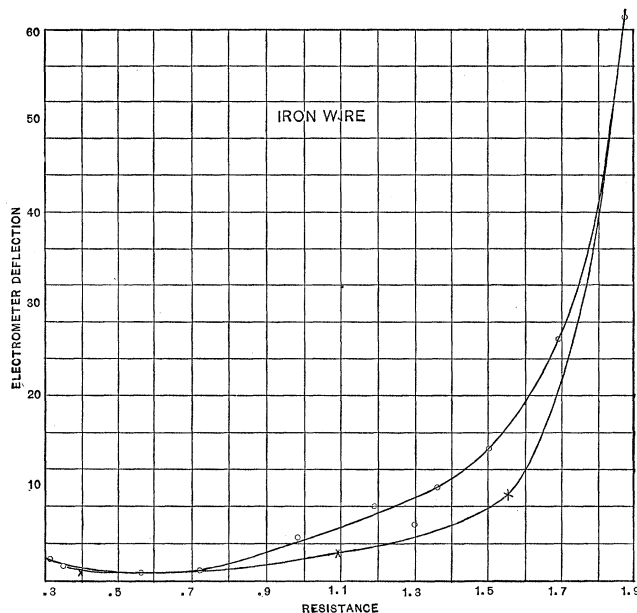


Fig. 4.

The results are shown graphically in Fig. 4, from which it is seen that as the temperature gets above what would correspond to about  $700^{\circ}$  C. the conductivity increases very rapidly. This in-

crease with the temperature is proportionally much larger than was the case with the platinum wire. It may be worthy of notice that the large change begins in the neighborhood of the point of recalcrescence of the iron.

As the temperature was increased above that of the room for a considerable range the observed conductivity was diminished as was the case with the platinum wire. The smallness of the readings at these temperatures may put some doubt upon the reality of this diminution ; but a number of other readings in this same region all gave a like result. It is possible that the difference between the ascending and the descending curves is all due to variations in the light.

A set of readings taken with continuously increasing and then decreasing temperatures, as was done in the case of the platinum, did not show the same tendency for the readings taken when the temperatures were decreasing, to exceed those taken for the same points when the temperatures were increasing.

13. The photo-electric effect presents the peculiarity that negative charges alone are dissipated by the light. It may be, from the very nature of the action, that only negative charges can be affected ; but it is possible that the existing forces simply hinder the removal of the positive charges more than of the negative and that in the former case the action of the ultra-violet light cannot overcome them.

Now when a body is heated it acquires at a certain temperature the power to discharge positive electricity from its surface, and at a somewhat higher temperature it discharges the negative also. It seemed possible therefore that, especially if the nature of the process of ionization due to the heat is at all analogous to that in the discharge by ultra-violet light, the resistance to the removal of the positive charge by the light might be sufficiently weakened at the higher temperatures to enable the light to overcome it.

Under such conditions if the wire were heated to a temperature where it was almost on the point of discharging positive electricity without any light, the addition of the influence of the latter ought to produce a discharge ; while on the other hand if the wire were sufficiently hot to produce a discharge of the positive, the addition of the light ought to increase this discharge.

The experiment was tried both with a platinum and an iron wire in the apparatus, charged in each case to +75 volts and maintained at a temperature not quite sufficient to discharge positive electricity. When the light was turned on, no certain leakage could be detected and if present at all it was certainly less than one division per minute.

When the platinum wire was heated to a dull red so that it discharged positive electricity slowly, the following readings were taken without the light and with the light, the action being allowed to continue for three minutes in each case.

TABLE VIII.  
PLATINUM WIRE. POSITIVE.

Time in minutes.	Electrometer deflection.	
	Without Light.	With Light.
1	14.	14.5
2	27.	26.5
3	39.5	39.5

An iron wire heated similarly gave the following readings per minute, the light being on and off alternately in this case.

TABLE IX.  
IRON WIRE. POSITIVE.

Light.	Electrometer deflection.
On.	102.5
Off.	101.
On.	101.5
Off.	101.
On.	101.

The results indicate that within the limits of the experiments the action of the light was without appreciable effect.

The process of the ionization in the discharge due to the heat must be quite different from what it is in the case of the light discharge. Such mechanical movements as may be produced by the absorption of the light do not appreciably affect the discharge of the positive electricity which is caused by the heat. Whether such



movements have any influence upon the discharge of the negative electricity by the heat is not certain from the experiments performed.

The following simple view may be taken of the cause of the unipolarity of the discharge produced by ultra-violet light.

The absorption of the light waves gives rise to intra-molecular forces which tend to separate a small negatively charged corpuscle<sup>1</sup> from the rest of the neutral molecule. The maximum impulse so given to the negative particle may give it a velocity away from the surface sufficient to carry it beyond what is called the range of molecular action, while the same outward impulse acting upon the much larger positive mass is not sufficient to get it beyond the influence of the attracting forces. We must consider the attraction tending to bring the departing particle back to the surface as not alone an electrical one or due altogether to the part of the molecule from which it has been separated, but as arising also from the attraction of all of the molecules within the range of molecular action. This latter force pulling the particle back to the surface is proportional to its mass and is therefore much the larger for the positive particles. Since the maximum outward impulses, in some way due to the light, are the same when given to a negative particle as when given to a positive one, it is possible to see how the light is effective in discharging the negatively electrified bodies alone.

When an unelectrified body is exposed to the light some of the negative ions being projected from the surface by the light action, diffuse away leaving the body charged positively. The electric field which is thus produced finally puts a stop to the increase of the charge by preventing further diffusion. By blowing past the surface the ions are carried away mechanically in opposition to the electrical forces and so the body may be charged to a higher potential.

To account for the lack of aid given by the light to the discharge of a positively electrified glowing wire we must consider any impulse given to the positive ion by the action of the light as too small to be noticed. This is quite plausible, since, according to the results of J. J. Thomson (*loc. cit.*), the mass of the negative par-

<sup>1</sup> The existence of such corpuscles is evidenced by the researches of J. J. Thomson. *Phil. Mag.*, December, 1899.

ticle which the light is just able to force away is only about one thousandth part of the mass of a hydrogen atom.

14. The experiments here described were interrupted nearly a year ago by derangements caused by the removal of our laboratory to temporary quarters. As there must still be some delay in resuming the work it was thought best to publish this account at this time.

As soon as possible, however, the work will be continued and it is intended to study carefully the effect of temperature changes upon the discharge from different metals when surrounded by different gases at different pressures. It is also desirable to carry the experiments to higher temperatures. At least two methods suggest themselves.

As stated before the difficulty lies in the presence of the larger conductivity caused by the glowing wire.

Now the results of Rutherford<sup>1</sup> and McClelland<sup>2</sup> show that the ions in the case of discharge by ultra-violet light travel with a greater velocity in the same electric field than those given off by the glowing wire. It would therefore be possible by blowing a properly regulated stream of gas across the path of the ions, to prevent the slower moving ions formed by the glowing wire from reaching the positive electrode, while some of those caused by the ultra-violet light would still get to it. The ions due to the heated wire being thus blown away, it would be possible to make measurements on the changing quantity of those caused by the light.

Probably a better method would be a modification of one devised by Rutherford (*loc. cit.*) for measuring the velocity of the ions. An alternating electromotive force is used between the two electrodes so that the direction of motion of the ions is periodically reversed. The electric intensity could be so regulated that the slower moving ions due to the heat in making their excursions from the glowing wire would not reach the other electrode, while the negative ions due to the ultra-violet light would reach it, before the reversal of the electromotive force occurred. Here again an electrometer joined to the latter electrode would show effects due alone to the ions produced by the action of the light.

<sup>1</sup> Rutherford, *Proc. Camb. Phil. Soc.*, Vol. IX., Pt. VIII., p. 401.

<sup>2</sup> J. A. McClelland, *Phil. Mag.*, July, 1898.

15. The results of the experiments described above show that temperature has a large influence upon the photo-electric effect. From a platinum wire the negative electricity is at first discharged more slowly as the temperature is increased; the rate of discharge reaches a minimum, however, and then increases as far as the highest temperature used (about  $700^{\circ}$  C.).

The rate of the discharge produced by the light also depends upon the immediate previous history of the wire. On coming to certain temperatures from a higher one the rate of discharge is much greater than if a lower temperature had been used just before. For small ranges at least this effect appears to be independent of the electric intensity and of the intensity of the light. After the reduction of temperature the rate of discharge gradually becomes smaller with time, showing that the large conductivity at first is due partly at least to the fact that the wire reaches its steady state but slowly. The recovery is much faster at temperatures below a certain point than for those above, the change being fairly abrupt.

From an iron wire the rate of discharge also appears to diminish at first with the temperature but after reaching a minimum it finally becomes a great many times its value at room temperature.

Heating the wire does not change the inactivity of the light for discharging positive electricity, even though the wire is raised to a temperature where, due to the heat alone, the positive electricity is being discharged.

The fact that after the platinum wire has had its temperature reduced the larger conductivity of the higher temperature persists for a time, there being a gradual recovery, shows that at least most of the variations which have been noticed in the experiments described are due to changes taking place at the metal surface and not in the gas between the electrodes. The comparatively abrupt change in this effect occurring at about  $100^{\circ}$  C. may indicate some molecular alteration of the metal. Any further discussion had best be delayed until the completion of further experiments.