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XII. The photoelectric properties of thin films of platinum.—Part II

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in (2), so that all the quantities required by (1) in order to give H in terms of the measured quantity Q are known. Q has of course to be corrected for radiation from the calorimeter, but this presents no difficulty. The constant B occurring in Regnault's correction formula is correctly determined by his method, and is not affected by the flow. It is quite easy to extend the above argument to the case where the connecting pipe really consists of two pipes of different materials, as in some of Regnault's experiments.

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Oct. 18, 1912.

XII. *The Photoelectric Properties of Thin Films of Platinum.*—Part II. *By* J. Robinson, *M.Sc., Ph.D.**

Introduction.

1. It was shown by Stuhlmann* that the photoelectric effect of thin films of different metals deposited on quartz depends on the thickness of the film, and on whether the film is on the side of the quartz facing the light (incident effect), or on the side away from the light (emergent effect). He measured the ionization currents in air, and found that when the films are thin enough the ratio $\frac{\text{emergent}}{\text{incident}}\left(\frac{E}{I}\right)$ currents is greater than unity, and for thicker films less than unity. For thin films the ratio is constant and equal to 1·14 for platinum.

In a former paper by the writer ‡ it was shown that this dissymmetry observed by Stuhlmann can be separated into two quite distinct effects, as regards (1) the velocities of the electrons emitted, and (2) the actual numbers of electrons emitted. The films were deposited at a low pressure, and then a liquid-air vacuum was established and measurements made as quickly as possible afterwards. In this way it was hoped that true values for the velocities would be obtained. For both the photo-currents and the maximum velocities of the electrons, similar curves to that of Stuhlmann for the ratios $\left(\frac{E}{I}\right)$ ionizations were obtained as the thickness of the

* Communicated by the Author. An account of part of this paper was read at the British Association Meeting at Dundee, September, 1912.

† Phil. Mag. Aug. 1910, p. 331.

‡ Phil. Mag. April 1912, p. 542.

film was altered, *i. e.* for thin films the emergent velocities and currents were larger than the incident velocities and currents, and *vice versa* for thick films. It was also found that the dissymmetry for the velocities was not so marked as for the currents.

2. The present investigation was undertaken to get more knowledge of these effects. The points investigated fall under the four heads:—

(*a*) There is a certain thickness of film for which the ratio $\frac{E}{I}$ currents=unity, and also a thickness for which $\frac{E}{I}$ velocities=unity. It was desired to find whether for the same source of light these two thicknesses of film are the same.

(*b*) The variation of the actual magnitude of the photo-current (incident and emergent) was investigated for different thicknesses of film.

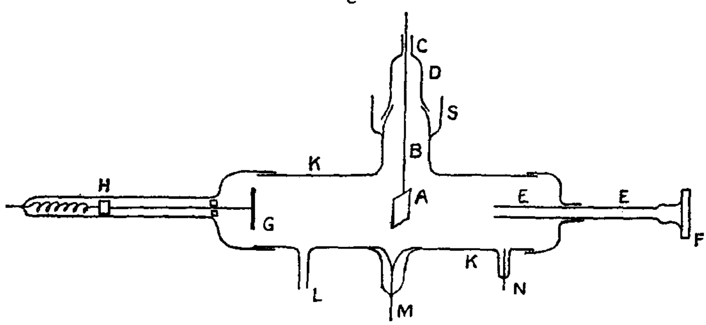
(*c*) Whether the dissymmetry is a function of the actual magnitude of the velocity of the emitted electrons.

(*d*) Whether the angle of incidence and the orientation of the plane of polarization of the light influences the dissymmetry.

3. *Apparatus.*

The apparatus used was similar to that described in the forementioned paper. Modifications were introduced to make still more sure that the effect of reflected light was reduced to a minimum, and that the film was uniform.

Fig. 1.



These improvements consisted in making the tube KK (fig. 1) wider (7 cm. diameter), the inlet for the light narrower, and the platinum electrode G larger. As before the walls of the vessel were coated with platinum before commencing the actual experiments, and the potential of the walls controlled by the wire M which was made to touch the platinized walls. The quartz plate A was 1·5 mm. thick, and 2·5 cm. long by 2 cm. wide. It was attached rigidly to the rod B, insulated by an amber plug C, and was capable of rotation about B as axis by the ground joint S. To deposit a film on the quartz plate A, the platinum electrode G was moved up to a fixed distance of 1 inch from it, and a discharge passed from an induction-coil, using G as cathode and an insulated wire at N as anode. This was done at a low pressure, and in most cases before depositing the discharge was passed for a few hours with G far removed from the quartz plate A which was placed with its plane parallel to the axis of the tube KK. This precaution was taken so as to get rid of any impurities on the surface of the platinum electrode, and to get it into the condition that it has stopped giving out gas *. The gas given out by the platinum was pumped away by a Gaede pump, and only when the amount given out per minute was small was a film deposited.

After depositing a film, a liquid air vacuum was obtained and measurements made. Then the film was thickened slightly and the measurements repeated, and so on till the film was so thick that the emergent effect was small.

Electrical contact with the film was made by first of all depositing a thick film of platinum on one end of the quartz plate. Tinfoil was laid over part of this, and the plate held firmly in a clamp which was soldered to the rod B. Platinum was deposited over this whole system. In some experiments the edge of the plate was silvered instead of being thickly coated with platinum.

The tube EE to admit the light was narrow so that light fell only on the centre of the film.

The rod B was connected in the ordinary way to one pair of quadrants of a Dolezalek electrometer. Measurements of the velocities of the electrons were made by earthing the walls of the vessel and finding the maximum potential acquired by the film. In some cases the velocities were also measured by finding the retarding potential that must be applied to the walls to prevent a photoelectric leak. The currents were measured by charging the walls to a potential of + 60 volts. The quadrants were joined through a high resistance of xylol and alcohol of 10^{10} ohms †,

* Hodgson, *Phys. Zeit.* 1912, p. 595.
† Campbell, Phil. Mag. Aug. 1911, p. 301.

and the steady deflexion read. On certain occasions this high resistance was dispensed with, and the leak measured directly.

As source of light a quartz mercury lamp was used. For some experiments a spark was also used.

4. *Corrections for Velocity Measurements.*

Some attention has recently been given to accurate measurements of the photoelectric velocities. Hughes * has shown that by distilling metals in vacuum, velocities can be measured accurately, and quite free from the errors introduced by surface films. For the purposes of the present investigation, the method for obtaining films, that of sputtering, is preferable to the distillation method, for it is easier to estimate the thickness of sputtered films, and possibly they may be of more uniform thickness over the whole of the quartz plate than if they had been distilled. An objection might be raised to the method of sputtering because the electric discharge may cause some kind of polarization of the film. Hughes † refers to such an influence of the discharge on thick electrodes, where it is possible to increase the maximum potential attained under exposure to light by using the electrode as a cathode in a discharge for a short time.

In the present experiments consistent values for the maximum potential were obtained for any one film. The velocities generally varied from film to film, but with very few exceptions they ranged from 2·3 to 2·9 volts. These do not differ much from the velocities given by Hughes for most of the metals that he distilled, and as he proved that the distillation method gave films free from gas layers, we are justified in concluding that the present method achieves the same result.

It is not in the scope of the present work to investigate the actual distribution of velocities, although the apparatus was designed in such a way as to make this possible if necessary. A disturbing factor in such investigations, and as was suggested by V. Baeyer ‡ also in velocity measurements, is the reflexion of electrons from the walls of the vessel. If this has to be taken into account, we must know how the emission of photoelectrons depends on the angle of emission. Hughes § came to the conclusion that the emission is the same for all angles, but this is not in harmony with some measurements made by the writer on

* Phil. Trans. A, vol. 212. p. 205 (1912).

† Proc. Camb. Phil. Soc. xvi. p. 167 (1911).

‡ *Verh. d. deutsch. Phys. Ges.* x. p. 96 (1908).

§ *Loc. cit.*

different metals *. It was shown that the greatest emission is normal to the electrode, and as the angle increases the emission diminishes. This point need not be considered further with regard to the velocity measurements, as it seems unlikely that reflected electrons can alter the maximum potential attained by the radiated films †.

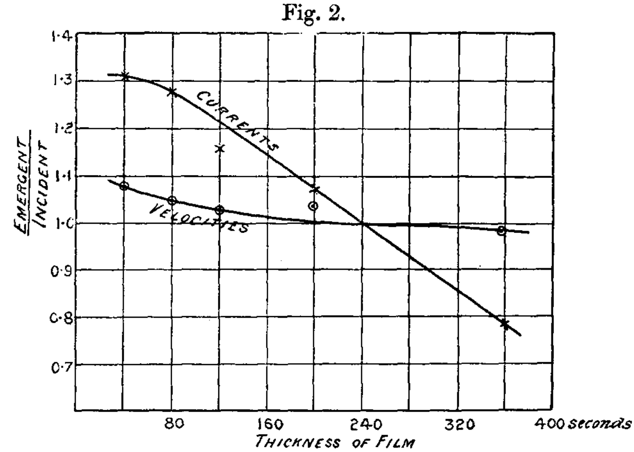
5. *Measurements of the Ratios* $\frac{E}{I}$.

The results for one series of experiments to find how the ratios $\frac{E}{I}$ currents and $\frac{E}{I}$ velocities vary with the thickness of the film are shown in Table I. The relative

TABLE I.

Thickness of Film.	$\frac{E}{I}$ currents.	$\frac{E}{I}$ velocities (in volts).
40 seconds	1·311	1·071
80 ,, ...	1·281	1·041
120 ,, ...	1·154	1·022
200 ,, ...	1·063	1·033
360 ,, ...	0·787	0·977

Fig. 2.



thicknesses of the films are given in terms of the time of deposit. The results of this table are shown graphically in fig. 2, where the ratios $\frac{E}{I}$ currents and $\frac{E}{I}$ velocities are

* *Ann. der Phys.* Bd. xxxi. p. 791 (1910).

† Ladenburg, *Phys. Zeit.* viii. p. 590 (1907); Hughes, *loc. cit.*

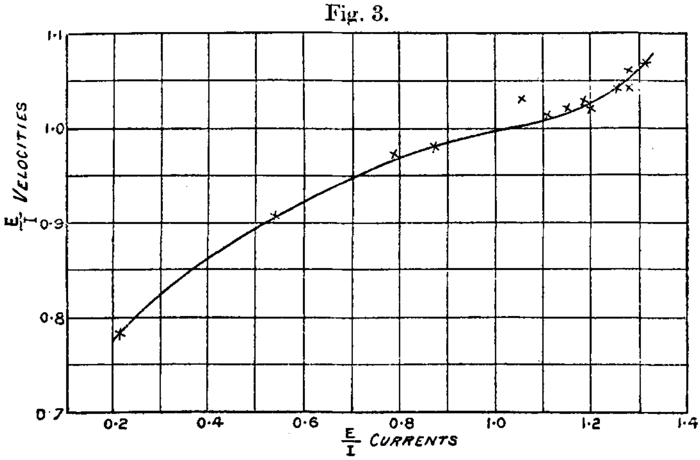
both plotted as ordinates against the thickness of the film. The two curves pass through the ratio unity together. The larger dissymmetry for currents than for velocities is well marked.

In order to determine more accurately whether the curves actually do pass through the value unity together, the results for a number of series of experiments are given together in Table II. The films are numbered in the order in which they

TABLE II.

Number of Film.	$\frac{E}{I}$ currents.	$\frac{E}{I}$ velocities (in volts).
11th	1·311	1·071
16th	1·281	1·062
12th	1·281	1·042
9th	1·259	1·049
7th	1·230	1·035
10th	1·200	1·020
1st.	1·185	1·030
13th	1·154	1·022
8th	1·116	1·014
14th	1·063	1·033
3rd	0·870	0·980
15th..........	0·787	0·977
2nd	0·570	0·915
4th	0·540	0·903
5th	0·206	0·784

Fig. 3.



were made. In fig. 3 the ratios $\frac{E}{I}$ currents are plotted as abscissæ and the corresponding ratios $\frac{E}{I}$ velocities as ordinates. A smooth curve drawn through the points is found to pass as nearly as possible through the point 1, 1 Hence we find that the ratios $\frac{E}{I}$ currents and $\frac{E}{I}$ velocities are unity for the same thickness of film.

6. *Actual Magnitudes of the Photo-Currents.*

No attempt was made in the experiments just described to compare the actual magnitudes of the photo-currents for different film thicknesses, but it was noticed that these currents were certainly not proportional to the thickness of the film. Attention was now directed to this point. It was found to be unnecessary to correct for any variations in the intensity of the mercury lamp used, as this formed a very constant source of ultra-violet light. From a large number of experiments the same general results were obtained. A typical set is given in Table III. The emergent and incident currents are both plotted against the thickness of the film in fig. 4 (p. 122).

TABLE III.

Thickness of Film.	Photo-Currents.		$\frac{E}{I}$.
	Emergent E.	Incident I.	
20 seconds	5·4	3·8	1·21
40 "	6·5	4·7	1·22
60 "	11·5	8·5	1·27
100 "	378	310	1·21
140 "	230	197	1·16
180 "	198	180	1·10

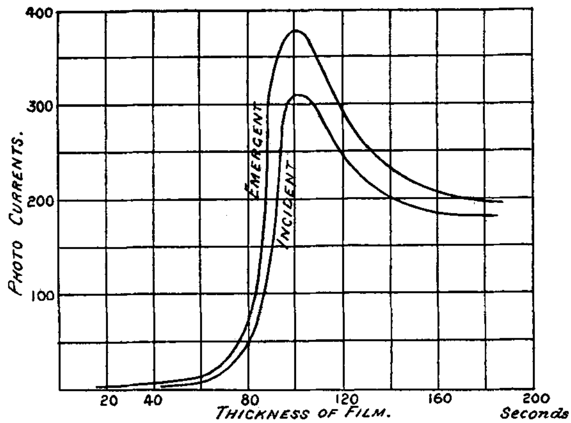
The most striking point about these results is the sudden increase in current at a certain thickness of film. An estimate of this thickness was obtained in the following way :—

After the photoelectric measurements were completed, the discharge was passed for a definite time to obtain a thicker film for which the specific resistance is known fairly accurately *. The resistance of this thick film was measured and its thickness calculated, making use of Paterson's values. From the relative times of deposit, the thickness of the film

* Paterson, Phil. Mag. iv. p. 652 (1902).

at which the sudden increase in current takes place was found to be 10^{-7} cm.

Fig. 4.



Another point of interest is the decrease in the magnitude of the currents for films thicker than 10^{-7} cm. It was at first thought that this diminution was spurious, and that it was due to the films beginning to absorb any traces of gas left in the apparatus. The consistency with which this effect was obtained in later experiments leads to the belief that it is not spurious, and that it is in some way connected with the sudden rise in current preceding it.

Still another point of interest is the fact that for films thinner than 10^{-7} cm. the ratio $\frac{E}{I}$ currents is practically constant, and that it only begins to diminish when the sudden rise in the actual magnitude of the currents takes place.

7. *Maximum Values of the Ratio* $\frac{E}{I}$.

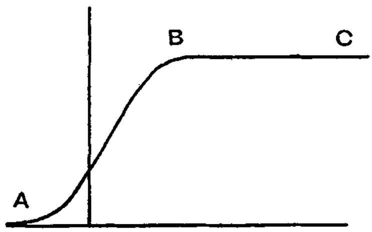
The constant value of the ratio $\frac{E}{I}$ currents for films thinner than the critical thickness 10^{-7} cm. was well marked in all the experiments performed. This ratio was found here to be at least 1·22, whilst Stuhlmann did not obtain experimental values greater than 1·14. This difference is so considerable that it was necessary to inquire whether there was some flaw in my apparatus. One of the films which gave a ratio 1·26 was taken, and the conditions of the experiment altered in various ways to find whether the ratio could be changed. Measurements of $\frac{E}{I}$ currents were made :—

1st. With the apparatus as already described, just after depositing a film.

2nd. At atmospheric pressure, and at various pressures down to a liquid-air vacuum.

3rd. By varying the potential of the walls, but so as to be always high enough for the current to be on the part BC of the distribution curve.

Fig. 5.



4th. After standing in air for a few days.

5th. After removing the platinum electrode G from the apparatus altogether to find whether light reflected from it had an influence.

6th. With the platinized walls covered with soot to be absolutely sure that reflected light from the walls had no influence.

None of these modifications produced any appreciable change in the ratio 1·26, so that the conclusion can be drawn that this maximum ratio $\frac{E}{I}$ can have larger values than 1·14 given by Stuhlmann.

8. *Influence of different sources of Light.*

It was at first intended to investigate the influence of the wave-length of the light used on the dissymmetry. It is very probable that this has some influence, for the velocity of the photoelectrons depends on the frequency. Millikan * has recently shown that there is a method for varying the velocities of the photoelectrons which gives much wider ranges than can be obtained by sifting out the different frequencies from a mercury lamp. Whilst the arc can only produce velocities up to about 3 volts, by using a spark as source of light, velocities can be obtained as high as 500 volts. If the velocities of the electrons affect the dissymmetry, this will be

* *Verh. d. deutsch. Phys. Ges.* No. 14, p. 712 (1912).

detected most quickly by comparing the effects due to the light from a spark and from a mercury arc *.

A spark was obtained between brass terminals, and was excited by an induction-coil through the primary of which an alternating current was sent. The capacity in parallel with the spark-gap was varied, and Millikan's results verified that in this way the photo velocities could be altered considerably. The spark-gap was arranged between the mercury lamp and the photoelectric cell so that the photo-current from each could be measured at will. The intensity of light from the spark was also very constant so that no corrections for variation in intensity were necessary. A liquid-air vacuum was not obtained, but the pressure was kept as low as possible by a Gaede pump. The orders of the velocities obtained were 1–2 volts from the arc, and 50 volts from the spark.

A whole series of films was investigated as in the preceding sections, and the photo-currents (incident and emergent) measured for each source of light. In Table IV. the actual

TABLE IV.

Thickness of Film.	Arc.			Spark.		
	Currents. E.	Currents. I.	$\frac{E}{I}$.	Currents. E.	Currents. I.	$\frac{E}{I}$.
20 seconds ...	3	2	1·16	2	1·5	1·27
40 „ ...	4	...	...	2		
60 „ ...	37	32	1·16	32	27	1·20
80 „ ...	560	480	1·17	185	148	1·23
110 „ ...	440	430	1·024	128	119	1·075
140 „ ...	250	310	0·79	84	99	0·85
	Velocities. E.	Velocities. I.	$\frac{E}{I}$.	Velocities. E.	Velocities. I.	$\frac{E}{I}$.
140 seconds ...	1·5 Volt.	1·8	0·83	51 Volts.	54	0·94

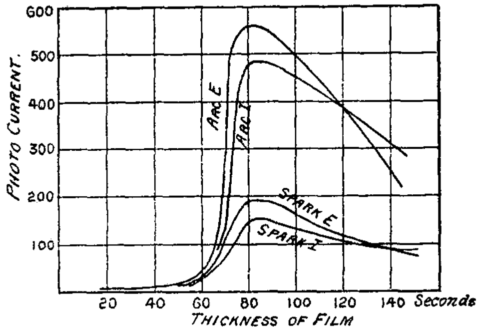
magnitudes of the currents are given in scale-divisions of the electrometer, as well as the ratios $\frac{E}{I}$ currents. The results

* In making measurements on this point, I was assisted by Mr. J. W. Buckley, of Sheffield University, to whom I express my best thanks.

are plotted to show the influence of the thickness of the film on

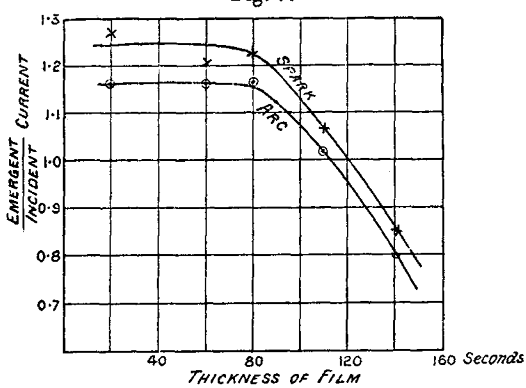
(*a*) The actual magnitude of the currents (fig. 6);
(*b*) The dissymmetry (fig. 7).

Fig. 6.



From fig. 6 it is seen that for both sources of light there is a certain thickness of film for which the photo-current begins to increase rapidly, and that this thickness is the same

Fig. 7.



for both sources. The relative increase in current is larger for the arc than for the spark. As before, a diminution of the photo-currents sets in after the sudden increase. Fig. 7 shows that the dissymmetry is obviously a function of the velocity of the electrons emitted, and that the larger the velocity, the larger is the dissymmetry. Other inferences that can be drawn from these results are :—

(*a*) The thickness of film which makes the emergent current equal to the incident is greater the greater the maximum velocity of emission.

(*b*) Although the velocities are only given for one film, the dissymmetry is not so marked as for the currents.

(*c*) The maximum value of the ratio $\frac{E}{I}$ currents for the arc is now smaller than in the preceding experiments, and now they agree more nearly with the value given by Stuhlmann. As the apparatus was not altered at all, we must conclude that the films are modified by allowing the spark radiations to fall on them, and in such a way as to diminish the ratio $\frac{E}{I}$ as measured with the arc as source of light.

9. *Influence of the angle of incidence and the orientation of the plane of polarization of the light on the dissymmetry.*

In the experiments described up to the present only normal incidence of light was used. If the apparatus described is used for oblique incidence, then more attention ought to be directed to the influence of reflected light. Because of this, only measurements of the photo-currents were made, and no attention paid to the velocities. The walls of the vessel were blackened and kept at a potential of +60 volts. To polarize the ultra-violet light, Prof. W. M. Hicks kindly placed a calcite polarizer at my disposal.

The actual magnitudes of the currents were found to increase slightly as the angle of incidence was increased up to 45°, whether total light or light polarized parallel to or perpendicular to the plane of incidence was used. On the other hand, it was not found possible to establish an influence of the plane of polarization on the dissymmetry, as Table V. shows. The variations are small and irregular, so that they are most probably due to experimental errors.

TABLE V.

Thickness of Film.	Angle of Incidence.	$\frac{\text{Emergent}}{\text{Incident}}$ Currents.	
		E ∥	E ⊥
$<10^{-7}$ cm. ...	0°	1·14	1·15
	32°	1·12	1·145
$>10^{-7}$ cm. ...	0°	0·85	0·83
	32°	0·84	0·85

Discussion.

10. If we wish to explain the variation of the magnitude of the photo-current with the thickness of film, we must also take into account some results recently given by Dyke * on the variation of the photo velocities with the film thickness. His results are given only for the incident effect. Velocity measurements involve so many difficulties that no regular curves were obtained, but a general statement of Dyke's results is that for films thinner than 10^{-7} cm. the velocities are high, and for thicker films much lower. This thickness 10^{-7} cm. is also a critical thickness for the velocities, which undergo a sudden decrease here.

We will consider the merits of certain possible explanations of these photoelectric phenomena at the thickness of film 10^{-7} cm.

(*a*) It was shown by Paterson † that the specific resistance of thin films of platinum depends on the thickness. As the thickness diminishes from 10^{-6} cm. the specific resistance remains fairly constant till the thickness 10^{-7} cm. is reached, when it begins to increase rapidly. As this sudden change in specific resistance occurs for the same thickness as the change in the photoelectric effects, it might be suggested that the high resistance of films thinner than 10^{-7} cm. accounts for the small values of the photo-currents observed. This is, however, improbable, for when measurements of the current were made by the leakage method no lag of the electrometer needle was observed, and such would certainly have been observed if the films had an enormously high resistance. The readings of the currents were always steady and very consistent for the thinnest films.

(*b*) Again, no satisfactory explanation can be found by considering the films to be discontinuous. Such discontinuities obviously will exist for very thin films, but as long as there is some metal on the quartz plate, the film will conduct if there is no break right across it of more than about ·001 inch in width. Wood ‡ has recently shown that conduction can take place between two metals kept at this distance apart. Discontinuities might exist so that the film appears something like a draughts-board. As more metal is deposited the empty spaces left get gradually filled up. Hence the area of metal exposed to the light might alter with the time of deposit. It is, however, difficult to see how an explanation can be reached along this direction.

* Phys. Rev. xxxiv. p. 459 (1912).
† *Loc. cit.*
‡ Phil. Mag. Aug. 1912, p. 316.

(*c*) The effects do not seem to be due to gas layers at the surface of the films. In most of the experiments when the greatest precautions were taken, there were most probably no such gas films. Had there been any they would most probably have influenced thin films and thick films alike.

(*d*) Possibly platinum films can only absorb gas when their thickness is greater than 10^{-7} cm. If we make this assumption, and assume besides that the photoelectric effect is due to absorbed gas as well as to the metal, then the sudden increase in current can be explained. There would also be many more molecules about in proportion to the thickness at 10^{-7} cm. than for thinner films, so that the photoelectrons would have their energy reduced by collision. Hence we might account for a decrease in velocity also. But although the photoelectric effects may be in harmony with this view, it is difficult to see why the specific resistance should diminish so much when gas is absorbed.

(*e*) There may be some alteration in the power of films to absorb light at 10^{-7} cm. We might suppose that there is a sudden increase in the absorption of light and so account for the sudden rise in current, but such an assumption would not be in harmony with the diminution of velocity, for it is generally supposed that the photo velocities are independent of the intensity of light, and of the amount of light absorbed.

(*f*) An explanation which is in harmony with all the facts known at present is the following:—

Let us suppose that the photoelectrons have the power of ionizing molecules of platinum by colliding with them. Then there will be two kinds of electrons in the photoelectric effect of thick metals: "primary," which are produced by light falling on molecules, and "secondary," which are produced by the collision of the primary electrons and molecules. To have both kinds of electrons in a film the thickness must be greater than a certain quantity λ, which we may call the mean free path of the electrons. For films thinner than λ we have only primary electrons, and for those thicker than λ, both primary and secondary. This accounts for the sudden increase in photo-current if the thickness at which it takes place is equal to the mean free path of electrons in platinum. An estimate of this quantity was given by Paterson * from measurements of the Hall effect, and he found λ of the order of 10^{-7} cm., which is the critical film thickness for the photoelectric phenomena.

* *Loc. cit.*

If primary electrons can produce secondaries by collision, then we ought to expect a diminution in the velocity of the electrons at 10^{-7} cm., which is what Dyke found.

The fact that the critical thickness is the same for the slow electrons produced by the arc and the quicker electrons due to the spark, is also in harmony with this view, for the mean free path of the electrons does not vary much with their velocity.

Again, for films thinner than the mean free path, the photo-currents will not be influenced by the absorption of electrons, which can only take place when the electrons come near to the molecules. This explains why the ratio $\frac{E}{I}$ currents is constant for thicknesses up to 10^{-7} cm. For thicker films, absorption will take place so that the ratio $\frac{E}{I}$ begins to diminish.

11. *Minimum Energy for Ionization.*

It is necessary to consider whether slow photoelectrons have sufficient energy to ionize molecules of platinum. Estimates of the minimum amount of energy required to ionize a molecule have been given by different writers. Hughes * estimates this quantity to be that of an electron of 8 volts velocity for oxygen.

The similarity of the curves for the arc and the spark in fig. 6 suggests that their characteristics have the same origin. There is no doubt that the 50 volt electrons produced by the light of the spark can ionize, and as all the other facts agree with this ionization theory, we conclude that it is possible that the slow photoelectrons due to the arc also have sufficient energy to ionize.

The method employed by Hughes to calculate the minimum amount of energy required to ionize a molecule of oxygen is interesting, and it can readily be applied to the present problem. He found that to ionize oxygen by light, the wave-length must not be longer than λ 1350. He showed how to represent the velocity of photoelectrons as a function of the frequency of the light. If V is the velocity in volts, and n is the frequency of the light,

$$V = kn - V_0,$$

where k and V_0 are constants for each substance. As λ 1350 is the wave-length limit for oxygen, an electron emitted by light of this wave-length would just emerge from

* *Loc. cit.*

the molecule, and thus $V=0$. V_0 is the energy that an electron must acquire in order just to emerge from a molecule. Hence, for oxygen, $V_0=kn$, where n is the frequency corresponding to λ 1350.

He did not investigate the law for platinum, but he showed that it holds rigorously for a large number of metals and also that k does not vary much from metal to metal. We will take k for platinum to be the mean for the different metals investigated, i. e. $k = 3{\cdot}62 \times 10^{-15}$, and assume that the longest wave-length which is capable of producing a photoelectric effect in platinum is $\lambda=3400$, which was near the wave-length limit for cadmium.

This gives $V_0=3{\cdot}25$ volts, which gives the minimum energy to produce a photoelectron in platinum. If there are electrons in the metal with velocities larger than this, then it will be possible to produce secondary electrons by collision. By the application of the law $V=kn-V_0$ we can easily find whether there are electrons present with velocities greater than 3·25 volts. By assuming a high enough value for n, and this is only limited by the temperature of the lamp and the absorption of quartz, electrons can be found with velocities greater than 3·25 volts. This limitation of quartz on the frequency may prove a drawback. For instance, if λ 1849 is the shortest wave-length which falls on the film, we find V to be 2·65 volts, which is less than the minimum to produce ionization. [This theoretical value for the maximum velocity agrees fairly well with the actual values observed, see § 4.]

The discovery of Dyke enables us to get over this difficulty. For thin films the maximum velocity is much larger than for thick films, and Hughes's results only apply to thick films. If we take a moderate estimate of the ratio of the velocities for thin films to those for thick films as 3, from Dyke's results, there will be electrons in ordinary thick metals with velocities of $2{\cdot}65\times 3$ volts, which is well outside the limit of 3·25 volts required for ionization to be possible.

12. The decrease in magnitude of the photo-currents following after the sudden increase can possibly be explained by an absorption of the electrons. The incident current does not decrease as much as the emergent, for the ratio $\frac{E}{I}$ diminishes. If the experiments had been extended to much thicker films, possibly the incident current would have been found to increase again; for Ladenburg showed

that as the thickness of nickel increases up to about 8 wave-lengths, the incident photo-current increases. It attains its maximum value when all the light is absorbed.

Another estimate of the maximum depth for platinum at which light can produce a photoelectric effect can be obtained from measurements of the emergent current. We find by extrapolation in fig. 2 that the emergent current would be zero at about 5×10^{-6} cm. This means that the light can produce electrons only to a depth less than 5×10^{-6} cm. This estimate of the maximum depth to which light can produce electrons is much smaller than that of Ladenburg, who found it to be 8 wave-lengths, or of the order of 10^{-4} cm. This discrepancy may be due to the fact that the estimates are given for different metals.

13. As to the causes of the dissymmetrical effect it is very difficult to suggest a satisfactory explanation. As more electrons emerge in the direction of the light, and as they have a larger velocity in this direction, there must be some influence at work in the actual process of causing electrons to leave the molecules, which tends to make them emerge more readily in the direction of the light. If this were not the case, and if electrons emerge from molecules equally in all directions, then we should be left with the task of explaining the dissymmetry by the pressure of light on the electrons after they have emerged from the molecules. Such a consideration does not appear to account for the magnitude of the dissymmetry.

It may be asked why the emergent velocity diminishes as the thickness of the film increases. All the films used were semitransparent. Hence some light gets right through the films, and as these films absorb all wave-lengths uniformly * some ultra-violet light also gets right through. If the general view is correct that the velocity of photoelectrons is independent of the intensity of the light used, then we ought not to expect the emergent velocity to diminish so long as some light goes right through the films. As the emergent velocity does diminish we may account for it by some assumption as :—

(*a*) Perhaps light must have a certain minimum intensity to produce electrons ;

(*b*) Possibly the velocity of the electrons is a function of the intensity of the light ;

* Robinson, Phil. Mag. April 1912, p. 549.

(c) Possibly some part of the photoelectric effect is due to some other radiation accompanying ultra-violet light, which radiation is more easily absorbed by platinum than light. Millikan's * work seems to show that this is not very probable.

Prof. C. H. Lees suggested another possibility to me, that the form of the light-waves may have an influence on the dissymmetry. It is supposed that light-waves are modified in going through matter. Some experiments were performed by Stuhlmann † which seem to support this view. He showed that the dissymmetry was much less marked when the light had to pass through a greater thickness of quartz, and explained this by the absorption of light by quartz. As quartz does not absorb ultra-violet light appreciably, it seems probable that the view here suggested might have some bearing on the dissymmetry.

14. *Summary of Results.*

1. $\frac{E}{I}$ currents and $\frac{E}{I}$ velocities are both unity for the same thickness of film.

2. The dissymmetry for velocities is not so strongly marked as for currents.

3. As the thickness of film increases through 10^{-7} cm., the photo-current increases suddenly.

4. The ratio $\frac{E}{I}$ currents is constant for films thinner than 10^{-7} cm. and begins to diminish after the sudden increase in current has set in.

5. Radiations from the spark produce much quicker electrons than those from the arc.

6. The dissymmetry is more strongly marked the quicker the electrons produced.

7. It has been shown that it is possible that photoelectrons possess sufficient energy to ionize molecules of platinum, and that it is this which leads to the best explanation of the sudden rise of photo-current at 10^{-7} cm.

8. The thickness of film which gives the sudden rise in current is the same for slow and quick moving electrons.

9. The orientation of the plane of polarization of the light has no influence on the dissymmetry.

East London College,
Oct. 24th, 1912.

* *Loc. cit.* † *Loc. cit.*