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FATIGUE AND RECOVERY OF THE PHOTO-ELECTRIC CURRENT.[1]

By W. F. Holman.

THE experiments of H. A. Wilson[2] showing that the escape of negative electricity from incandescent platinum disappears when the metal is freed from absorbed hydrogen; and those of Skinner,[3] that in the glow current through rarefied gases hydrogen atoms serve as carriers of negative electricity from metallic cathodes to the gas, suggest the possibility of the absorbed gas playing a part in the escape of negative electricity from a metal subjected to ultra-violet radiation. In fact, the experiments of Wulf[4] indicate that the presence of absorbed hydrogen increases the photo-electric current from platium, in that after the plantinum has been allowed to stand in an atmosphere of hydrogen for some time there is a marked increase of the current over that obtained in air and again a decrease as the metal supposedly loses its charge of hydrogen.

This photo-electric current depends on two principal factors, first that arising from the escape of negative carriers from the metal, and secondly, that from the ionization of the gas by these carriers. Thus the experiments of Stoletow,[5] Lenard,[6] and Varley[7] show that as

[1] Read in part before the joint meeting of the American Physical Society and Section B of the American Association for the Advancement of Science, Ithaca, June, 1906.

[2] Phil. Trans., 202, p. 243, 1903.

[3] Phys. Rev., XXI., p. 1, 1905; Phil. Mag., Nov., 1906.

[4] Ann. d. Physik, 9, p. 946, 1902.

[5] Jour. de Phys., 9, p. 468, 1890.

[6] Ann. d. Physik, 2, p. 359, 1900.

[7] Phil. Trans., 202, 1903.

the gas pressure is reduced indefinitely the photo-electric current drops to a definite minimum value which thereafter remains practically constant for all values of the electric field. This is considered as that arising solely from the carriers escaping from the metal. On the other hand when the discharge takes place in an atmosphere of appreciable density the current may be produced largely by the second factor, the ionization of the gas by the motion of these escaping carriers. For instance, Kreussler [1] found that in air at atmospheric pressure the current increases very rapidly with the electric intensity, if the latter approaches that required to produce a spark discharge.

The present investigation was undertaken therefore with the intention of studying the current arising from the escaping carriers alone, as it is affected by changing the store of hydrogen in the surface of the metal. The results were such as to include a study of certain phases of the so-called *fatigue* and *recovery* of the metal under the conditions of operation.

The plan which suggested itself as most likely to yield conclusive results was based on the discovery of Skinner that as cathode in a glow current, the metal gives off hydrogen, while as anode it absorbs it. In case therefore these conditions can be brought about without otherwise affecting the surface of the metal, this plan furnishes a simple scheme for making a test of the effect of changing the quantity of hydrogen in the metal. As will be seen, however, this condition was attained without question only in one series of experiments.

EXPERIMENTAL ARRANGEMENT.

Fig. 1 presents a diagram of the system used. An electric arc A operated, in parallel with a capacity K, by an induction coil fed by a fifty-volt alternating current served as source of light. This arc was focused by a quartz lens L through a window Q of same material on the cathode E charged from a battery B. The current of negative electricity from E to the anode H, placed opposite, was determined by measuring the rate with which a definite capacity C, connected to the latter, was charged. For this purpose a Thomson quadrant electrometer was employed in the customary manner.

[1] Ann. d. Physik, 6, p. 398, 1901.

The positive pole of the battery and the other terminal of the condenser C were connected to earth. Both the electrometer and the arc system were enclosed in grounded metal cases. Spurious effects were corrected for in all cases by taking observations with the electrode simply screened from the light, other conditions remaining the same.

The electrode chamber is shown in vertical section and plan in Fig. 2. It was designed for testing several metals successively. These were in form of disks E mounted on the face of a circular glass plate which could be rotated at will about a supporting axis of brass by means of the ground joint D and key K. The electrical connections were made through J, the supporting axis, and

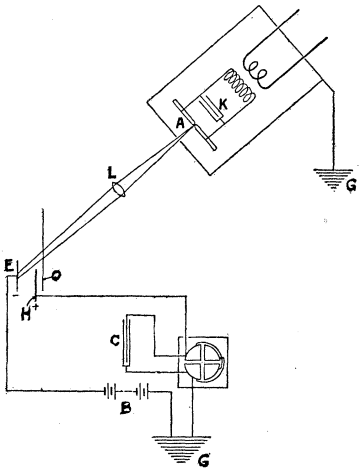

Fig. 1.

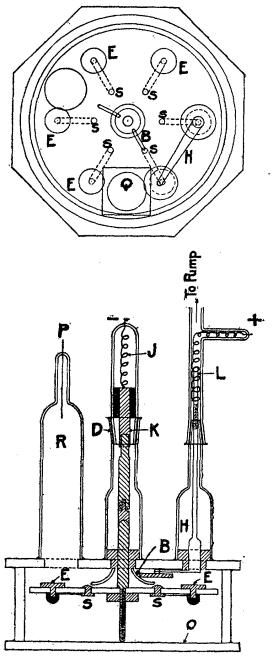

Fig. 2.

the spring brush B to the contact S connected, by tin foil strips placed under the plate, to the cathode E. The connection with the fixed aluminum anode was made through its supporting arm H and the wire L. In order to use the metals E as electrodes with a glow

discharge, a tube R with an additional electrode P was attached to the chamber as indicated. For this purpose a second spring brush similar to B served as connection. The arrangement was such as to insulate all electrodes except the one in action. All fixed joints which could not be fused were sealed with de Khotinsky's laboratory cement. The chamber proved to perfectly air-tight. The electrodes could be renewed by removing the base plate O, which permitted the plate carrying them to be taken out.

In the vacuum system all stop-cocks and ground joints were lubricated with a mixture, recommended by Travers, free of hydrocarbons. Evacuation was produced by a Rapps automatic pump. A McLeod gauge multiplying the pressure about ten thousand times served as pressure indicator. P_2O_5 was used as dryer. A battery of small accumulators served as source of potential.

For an electric arc that found by Varley to be most satisfactory, namely steel electrodes in a slow stream of hydrogen, was used. It proved to be much more constant than other sources tried.

The capacity C (Fig. 1) consisted of an air condenser of tin foil mounted on plane glass plates insulated with quartz.

EXPERIMENTS.

Zinc, carefully polished and cleaned, was tested first. This was mounted in the electrode chamber which was immediately evacuated and left at an indefinitely low pressure in connection with the drying chamber for several hours.

With a gas pressure of .001 mm., a P.D. of about 500 volts[1] and a capacity C (Fig. 1) of about 1,400 cm., the photo-electric current produced in ten seconds the following series of deflections of the electrometer (8.5 scale divisions = one volt). The arc was stopped after each reading and started anew for the next.

TABLE I.

33.4	32.5	32.6
34.4	32.7	31.5
32.9	33.4	30.0
27.0	33.5	30.5
	Mean,	32.0

[1] At the pressures used the photo-electric current proved in all cases wholly independent of the magnitude of the P.D. between the electrodes.

This value is equivalent to 6×10^{-10} amperes. After admitting hydrogen at a pressure of 1.5 mm. a glow current was then sent from the zinc as cathode for about fifteen minutes, and the chamber again evacuated to a pressure less than .001 mm. The photo-electric current observed at this point gave the following successive values:

TABLE II.

20.2	20.2		20.4
20.5	16.1		19.8
20.2	19.5		20.6
20.2	20.6		21.1
		Mean,	20.0

representing a current of 3.8×10^{-10} amperes, which is a marked decrease compared with the fresh metal.

After standing then twelve hours, the following series of observations were taken under the same conditions as before:

TABLE III.

21.3	20.9		21.7
21.5	21.8		22.7
21.3	21.9		22.5
17.7	22.7		22.3
		Mean,	21.5

representing 4.1×10^{-10} amperes. This shows only a comparatively slight increase over the values obtained twelve hours before. Following this, hydrogen was again admitted and the metal used in this case as *anode* during a period of about seven minutes, after which the chamber was evacuated to less than .001 mm. and the following series of values obtained for the photo-electric current.

TABLE IV.

27.5	31.4		32.0
28.0	33.0		32.5
30.1	32.7		32.2
31.5	32.2		
		Mean,	31.2

or a current of about 5.9×10^{-10} amperes which is strikingly close to the first values as given in Table I.

The above results are readily explained in the light of Skinner's experiments if we assume that hydrogen may also serve as carrier of negative electricity in the photo-electric current. With the unused

metal the photo-electric current was 6×10^{-10} amperes. By use as cathode with a glow current the quantity of hydrogen present was undoubtedly considerably reduced. The photo-electric current in this condition was also reduced to about two thirds its original value, 3.8×10^{-10} amperes. Left at rest for several hours the metal indicated practically no change from this last value, but after use as anode in hydrogen — which charges the metal with this gas — the photo-electric current returned to its original magnitude. The same explanation, however, may be given by assuming a migration of electrons with the negative current, if we assume the possibility of appreciably changing their available number in the metal in the same way as the quantity of hydrogen is changed.

A repetition of the above experiments with several different metals brought to light an entirely different set of influences. With electrodes freshly polished the electrode chamber was left at extreme vacuum in connection with the dryer for several hours, after which the photo-electric current was tested as before in an atmosphere of less than .001 mm. pressure. The mean results of a number of tests, in which the individual observations revealed about the same fluctuation in value as those in the previous experiments, are given in Table V. In this series the capacity C was about 2,800 cm., other conditions as before.

TABLE V.

	Photo-electric Current (10^{-10} Amperes).				
	Zinc.	Copper.	Silver.	Aluminium.	Iron.
After using as cathode with glow current in hydrogen.	16	11.6	6.4 0.6	0.6	0.6
After standing 12 hours in hydrogen.	8.8	1.8	14	0	0
After again using as cathode.	41	16		5	4.5
After using as anode in hydrogen.	7	15	6	1.3	1.4
After using as cathode again.	36	16.5	25	2.7	5
After standing in hydrogen several hours.	28	9.3	16	2.5	3.2

A striking feature in these results is the exceptionally large value of the photo-electric current of zinc as compared with the previous tests — the magnitude in one case being as much as seven times as great as the largest values before, and in no case dropping as low as the maximum value previously obtained. In these experiments

it is to be noted that after use as cathode the current is greatest, and after standing in hydrogen or used as anode, it is generally considerably smaller — the different metals being affected in different degrees. The probable explanation is that use as anode or even contact with the gas (possibly not entirely pure) tarnished the surface of the metal and this reduced, as is known, the photo-electric action. In action as cathode with the glow discharge the metal surface in these tests was probably cleaned of tarnish but not sufficiently depleted of its negative carriers to reduce the photo-electric current.

It was thought possible to obtain less complicated results by operating with the glow discharge in argon instead of hydrogen, since according to Skinner use as cathode in this gas serves to deplete the store of hydrogen while use as anode has no appreciable effect. The results obtained are recorded in Table VI. For these experiments, the capacity C was again reduced to 1,400 cm.

TABLE VI.

	Photo-electric Current (10^{-10} Amperes).				
	Zinc.	Copper.	Silver.	Aluminium.	Iron.
After standing *in vacuo*.	1.2	0.5	0.9	1.2	0.2
After use as anode with glow current in argon.	1.2	13	5	0.4	0.7
After use as cathode in argon.	19	11.6	6.3	1.4	0.7
After standing in hydrogen for several hours.	2.4	9	1	0.5	1.2

The effects here are very similar to those recorded in Table V. with the exception that the use of copper and silver as anode with a glow current in argon appears to clean the metal of its tarnish in that it increases its photo-electric current. It should be remarked that in no case did a *visible* tarnish appear when argon was used.

Although the results given in Tables I., II., III., and IV. could not be duplicated, they are so definite that it seems probable that the desired state of depletion of the metal by use as cathode was not reached in the later experiments. Unfortunately further prosecution of the investigation was impossible.

I wish here to express my thanks to Dr. C. A. Skinner of the University of Nebraska for his help and inspiration to me in this work. I am also grateful to Dr. J. E. Almy for much aid and many helpful suggestions.