POSITIVE RAYS PRODUCED BY ULTRA-VIOLET LIGHT

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ABSTRACT

Experimental test for positive photo-electric emission from Au, Cu and Al.—Following the announcement by Dember in 1909 that positive emission had been observed, an attempt was made to verify its existence under improved conditions. His experiment was repeated using light from a quartz mercury arc and curves similar to his obtained. It was found, however, that when proper precautions against scattered light effects were taken, no true positive current could be detected from Au, Cu or Al surfaces, and it is shown that the Dember effect may be accounted for on the basis of spurious currents due to scattered light. Outgassing of the surface failed to cause the appearance of any positive current.

IN 1909 Dember[1] found that if a metal plate were exposed in vacuum to radiation from a quartz mercury arc and a proper accelerating field applied, a receiving cylinder placed a few millimeters from the plate slowly acquired a positive charge. He attributed the effect to the emission by the metal plate of a small number of positive ions produced by the action of the ultra-violet light, thereby pointing to the possible existence of a positive as well as a negative photo-electric current. No attempt to study this effect further seems to have been made since 1909.[2] It seemed worth while, therefore, to repeat Dember's experiment using a somewhat different method, and to study the nature and behavior of these positive carriers should their existence be verified.

DEMBER'S EXPERIMENT

Dember's apparatus is indicated in Fig. 1. The perforated plate P of the metal under test (gold, zinc, copper, aluminum and magnesium plates being used) is placed in front of a quartz window in a vacuum tube. The metal grid N is connected to a set of small batteries and given a positive potential so that positive carriers emitted from the plate will be driven through to the receiving plate C, which is connected to an electrometer. When light was admitted through the quartz window the electrometer indicated a small positive current, which, when plotted as a function of the voltage on N, gave a curve of the type shown in Fig. 2. The currents were exceedingly small, being of the order of 1.4×10^{-13} amp., which was only 1/1000th as great as the ordinary negative photo-current,

[1] Dember, Ann. der Phys. **30**, 137 (1909)

[2] Cf. A. L. Hughes, Bull. Nat. Res. Coun., Apr. 1921, p. 125.

which could be measured simultaneously by the galvanometer connected between the plate and the grid.

It is evident that such a positive current might be due to any one of three possible effects. (1) The photo-electrons from P might produce

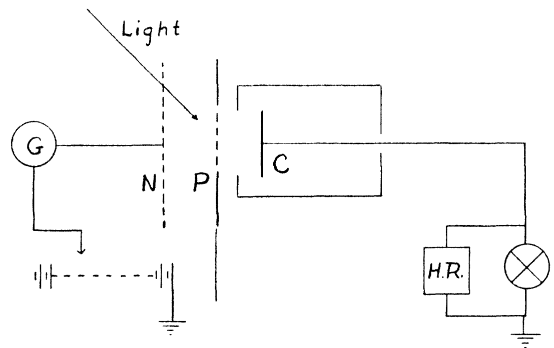

Fig. 1. Diagram of apparatus used by Dember.
P, metal plate; *N*, grid; *C*, receiving plate; *G*, galvanometer; *HR*, high resistance.

ions by collision with the residual gas between N and P. (2) Light scattered from the surface of the plate P might strike C producing a small ordinary photo-electronic emission from it. (3) There might be an emission of positively charged ions from P.

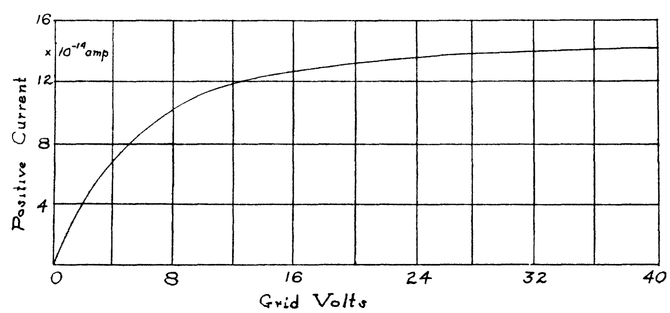

Fig. 2. Relation between positive current to receiving plate and grid voltage, as obtained by Dember.

The first of these effects Dember obtained independently by working at pressures as high as .001 mm Hg with the plate and grid several millimeters apart. Under these conditions ionization of the residual gas set in suddenly at a grid voltage of about 20 volts, positive, causing the curve shown in Fig. 2 to rise sharply at this point. This effect, however, was independent of the one he was studying which persisted even at the lowest obtainable pressures (8×10^{-6} mm Hg) and with the grid and plate only 2 mm apart. He therefore excluded (1) as a complete explanation of the effect.

Dember dismisses the second possible explanation of the effect on the ground that a photo-electronic emission from the plate C should be independent of the voltage on N, while his curves show that the effect depends directly upon this voltage. He therefore concludes that (3) is the true explanation and that a positive photo-electric effect does in fact exist.

In order to further study this effect, D. M. Bennett in 1921 designed and constructed a tube in this laboratory which, it was thought, would more definitely eliminate the possibility of spurious scattered light effects and make it possible to study only the true positive current. He was forced to give up the work, however, before conclusive results could be obtained, and so the plan of his tube was taken over and used by the author for the earlier part of this work.

Apparatus

A diagram of the tube used is shown in Fig. 3. Light from a quartz mercury arc is focussed through a quartz lens on to the plate P of the

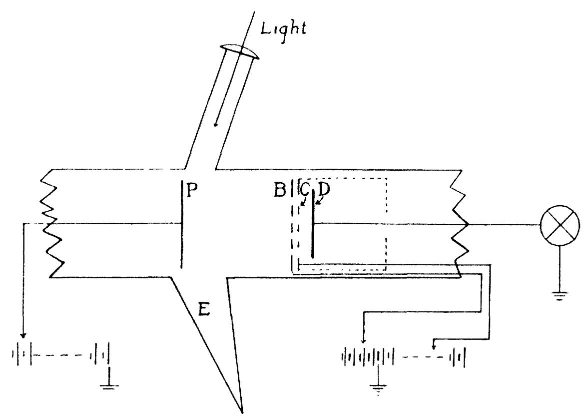

Fig. 3. Diagram of tube used.
P, metal plate; B-C, grids; D, receiving plate; E, absorbing cone for reflected light.

metal under test. The two perforated metal grids B and C are insulated from each other. The receiving plate D is connected to an electrometer. An accelerating potential for the positive carriers may be applied between P and B thus driving them through the grids to D. In order to prevent the emission of electrons from D under the action of scattered light, the grid C could be given a small negative potential. This potential could be sufficient to prevent electrons from leaving D but yet not large enough to establish a field between C and D great enough to stop the positive carriers from P, if they had been given a sufficiently high velocity between P and B.

The two grids B and C were necessary in order that C might be completely shielded from scattered light, and they proved useful in giving greater flexibility in altering the fields between P and B. The shielding of C was accomplished by making the perforations in C slightly larger than those in B and concentric with them, and then placing the two plates very close together. Shielding C in this manner eliminated the possibility of stray light causing an emission of electrons from this plate which would find their way to D and thus mask any true positive current from P. In order to reduce further the possibility of scattered light effects the plates B, C and D as well as all other metal parts within the tube except P were made of nickel whose photo-electric sensitivity is fairly low in the range of the quartz mercury arc.

The plate P used for the first runs consisted of a very thin (barely opaque) film of gold cathodically sputtered onto a plate of French plate glass. This gave a very smooth and very excellent reflecting surface so that light incident upon it would be reflected directly into the absorbing cone E with a minimum of scattering. For later runs solid plates of gold, copper and aluminum were used, the incident face in every case being carefully cleaned and polished in order to give as good a reflecting surface as possible.

The tube was connected to an evacuating system consisting of a mercury diffusion pump backed by a Cenco Hyvac pump. All runs were made at pressures very near to 10^{-7} mm Hg as measured by a McLeod gauge. The usual liquid air trap was employed to condense out mercury and other vapors and precautions were taken to keep the tube free from wax vapors.

In order to make the tests as sensitive as possible an electrometer of great sensit vity was required. The one used was of the Compton tilted needle type.[3] A quartz fibre sputtered with gold was used as a conducting suspension. With the fibre used the maximum sensitivity at which the system was stable was 40,000 mm per volt at a scale distance of 1.3 m, using a potential of 60 volts on the needle. For much of the work lower sensitivities were used but for the final measurements the maximum was employed. The capacity of the electrometer system as determined by the method of mixtures was 50 e.s.u. giving a current sensitivity of 1.4×10^{-15} coul./mm.

[3] K. T. Compton, Phys. Rev. **14**, 85 (1919)

Results

With the tube in this form a positive current similar to the one described by Dember was obtained. With an accelerating field for the positive carriers between P and B of 80 volts and with the grid C at a negative potential of 5 volts, the electrometer showed D to be acquiring a positive charge at the rate of about 10^{-13} coul./sec. This was of the same order of magnitude as the effect obtained by Dember and was about 1/1000th of the negative current obtained when P was given a negative potential. Moreover when this current was plotted as a function of the voltage on P (corresponding to the voltage on the grid N in Dember's arrangement, Fig. 1) a curve very similar to the Dember curve shown in Fig. 2 was obtained.

Further observations, however, showed that *this current could not possibly be due to positively charged ions arriving from P*, for the effect still persisted when B was given a positive potential greater than that of P. In this case positive carriers would be retarded and prevented from leaving P, while the negative carriers now accelerated between P and B could not reach D because of the larger retarding field between B and D. In other words, no current could now reach the receiving plate D from P. Since the effect still persisted under these conditions, the only explanation for it was that the receiving plate itself was losing electrons under the action of scattered light, in spite of the precautions which had been taken against this effect. It will be seen that the negative potential of C would cause any electrons leaving from the central portions of D to return, but that electrons leaving from near the edge of D might be driven to the side of the tube or to an earthed shield behind D. Electrons leaving the receiving plate in this manner would cause the electrometer to indicate a small positive current.

In order to prevent this effect the plate D was surrounded by a nickel cylinder which was given the same potential as the grid C. The position of the cylinder is shown by the dotted line in Fig. 3. By applying a negative potential to this cylinder, electrons could be prevented from leaving D in any direction while the high velocity positive carriers from P would not be affected. Since it was impossible to be certain that the entire cylinder would be shielded from scattered light as the grid C had been, it was necessary to determine whether there were any scattered light currents between the cylinder and the receiving plate. This was accomplished by cutting off all currents from P by giving B a high positive potential as before. When the cylinder was given a negative potential a small negative current to the plate was in fact observed and carefully measured as a function of the cylinder potential. A positive current of somewhat greater magnitude due to electrons leaving D was observed when the cylinder was given a positive potential. Plotting these *scattered light currents* as a function of the voltage on the cylinder the curve shown in Fig. 4 was obtained. At no point were these currents large enough to mask a positive current from P, even though the current were only 1 per cent as great as the one observed by Dember. The Dember effect then, were it present, should appear as an upward shift of the entire curve when B was earthed and P given a high positive potential.

On applying a positive potential of from 20 to 200 volts between P and B however, *no shift of the curve could be detected at any point.* With the cylinder voltage in the neighborhood of two volts negative, for which the net scattered light currents were practically zero, no positive current could be observed which would produce an electrometer deflection as

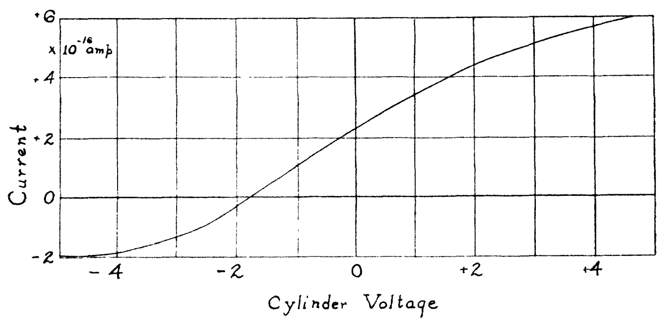

Fig. 4. Scattered light currents to the receiving plate as a function of the potential on the cylinder.

great as 1 mm per minute. This meant that there was no positive current reaching D as great as 2×10^{-17} coul./sec. The currents obtained by Dember were around 1.4×10^{-13} or about 7000 times the above value, therefore his currents must be entirely accounted for on the basis of scattered light effects. These results were repeated with each of the metals used, Au, Cu and Al.

Inasmuch as it is known that the ordinary photo-electric current is decidedly a function of the gas content of the surface under test, it was thought worth while to determine whether a positive current might appear as outgassing of the tube progressed. The entire tube was baked for eight hours at a temperature of 400° C with the pumps going continuously so that the pressure while the tube was at this temperature was reduced to less than 5×10^{-6} mm Hg. After cooling the tube the mercury would stick to the top of the capillary of the McLeod gauge, indicating a pressure of less than 5×10^{-8} mm Hg. After this first baking the scattered light currents (negative photo-currents) increased enormously but no positive current appeared, and none appeared after several such periods of baking, during which time the scattered light currents again gradually decreased. Heating the plate to a bright red or yellow heat by high frequency induction also failed to cause the appearance of a positive current. Under no circumstances could a true positive emission from *P* be detected.

Discussion

It will be remembered that an explanation for his results on the basis of a scattered light effect from the receiving plate was dismissed by Dember in his paper solely on the ground that such an effect ought to be independent of the voltage on the grid. It was found by the author however that scattered light effects from the receiving plate were not independent of the plate potential, and that on plotting these effects as a function of the plate potential, curves very similar to those obtained by Dember were obtained. There was every indication of an appreciable penetration of the field between *P* and *B* into the space between *C* and *D*, (Fig. 3) especially when the former fields were large or when *P* and *B* were close together as they were in Dember's arrangement. Assuming the Dember effect to be due to an electronic emission from his receiving plate, such a penetration of the field between *N* and *P* (Fig. 1) into the space between *P* and *C* might very well account for the slow rise in his current-voltage curves between 7 and 40 volts (Fig. 2). The rapid fall of the curves to zero below seven volts may be due not only to a decrease in the negative current from the receiving plate because of the smaller fields, but also to an increase in the number of electrons emitted from the perforated plate *P* (or perhaps from the grid *N*) which could find their way to *C* against the reduced retarding fields. Such an increase would reduce the net "positive" current, causing it ultimately to vanish.

It seems evident from the above results that the Dember effect may be entirely accounted for on the basis of an electronic emission from the receiving plate due to scattered light, against which no precautions had been taken, and that when proper precautions against scattered light effects are taken the Dember effect disappears. We may conclude then that there is no measurable photo-electric production of either gaseous or metallic positive ions by the range of wave-lengths emitted by the quartz mercury arc.

In conclusion I wish to express my appreciation to Prof. C. E. Mendenhall who suggested the problem and under whose direction the above work was carried on.

Physics Laboratory,
University of Wisconsin,
September 30, 1924.