THE PHOTOELECTRIC THRESHOLD OF A DOUBLY EVAPORATED FILM

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Abstract

A method is described whereby a platinum, a nickel, and a "double" platinum-nickel film were obtained by evaporation, simultaneously and under the same conditions. The threshold wave-lengths were first found from saturation photoelectric currents obtained with monochromatic light of different wave-lengths. These values, which were confirmed and determined more precisely by retarding-potential, photocurrent curves, are for Ni 3333A, for Pt 2804A and for the double Ni-Pt 3318A. A similar investigation with tungsten and platinum gave the thresholds of the Pt and the double Pt-W film at 2831A and 2804A respectively, almost 500A above the threshold of W which was 2338A. The threshold of each double film is, therefore, practically the threshold of the constituent which, when pure, has the longer wave-length threshold.

Introduction

IN GENERAL, when light of a frequency ν is incident upon a metallic surface electrons are emitted with velocities ranging from zero up to a definite maximum velocity v. In the equation usually given,

$$(V-K)e=h\nu-h\nu_0, \tag{1}$$

where K is the contact difference in potential between the film and the opposing electrode, h, the Planck constant, $h\nu_0$ is the energy lost in passing from a system where the photoelectron starts to a point just outside the surface.

It is not known what fraction of this energy is spent in separating the electron from the original atom and what work is done to take the electron through the outer surface. It was thought that some light might be thrown on this question by finding the photoelectric thresholds of three metal films formed under the same conditions by evaporation, two of these being made of two different metals and a third of a mixture of the two. This has been done in the experiments to be described and the interesting result found that the photoelectric threshold of the mixture of two metals(in the two different sets of metals used) is the same as that of the constituent having the threshold of lower frequency.

Experimental Arrangement

Figure 1 gives a diagrammatic representation of the apparatus used in the present experiment. The apparatus was made of Pyrex glass. Q is a quartz

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plate to admit the ultra-violet light. D is a cylinder to collect the photo-electrons. It was constructed of oxidized copper, the threshold wave-length of which is below that part of the spectral region in which the work was to be done. B are two filaments of different metals for the purpose of depositing films by evaporation. Evaporation was the method selected to be used because of the greater homogeneity and freedom from gas in the case of films prepared in this way as compared with those obtained by sputtering.[1] In this case where the nature of the surface was to enter into the problem so intimately it was deemed advisable to do away with the presence of gases as much as possible. The three thin glass plates H, upon which the films were laid, were held vertically by three iron containers, which were in turn supported by the vertical aluminum shaft E. This vertical support was slotted to run through a keyed passage in the aluminum throat piece F and, since this latter was secured by device in the glass, the plates throughout all the vertical motion faced on the same direction, rotation being prevented. This was necessary to maintain the plates perpendicular to the beam of light entering Q in order that the reflected light should not strike the cylinder, for in spite of the fact that the cylinder is insensitive, it is naturally desirable to avoid all possibility of a spurious source of photoelectrons. The aluminum rod was secured at the top to a hollow iron cylinder. The vertical motion of this latter was produced by means of a solenoid on the outside of the glass. (Not shown.) A cam gave the suspended solenoid a uniform up and down motion. By means of this vertical oscillation it was secured that the uppermost plate was subjected only to the influence of the upper filament, the lowest plate was subjected only to the influence of the lower filament, while the middle plate was subjected to both filaments. It will thus be seen that one of the films deposited by evaporation was of one pure metal, a second was of a second pure metal and that the third film was a mixture of these two metals. The temperatures of the two filaments were so regulated as to give approximately equal rates of deposition and the speed of the up and down motion of the plates was such as to give intimate mixing of the metals on the middle glass disk. Judging from a comparison of opacity with films of known thickness, the films were about twenty molecules deep, which means, if the total number of exposures is taken into account, that each layer of molecules was formed by exposure alternately to the one evaporation and then to the other, seventy-five times before each layer was complete. This insured the presence of an equal number of molecules of both kinds in

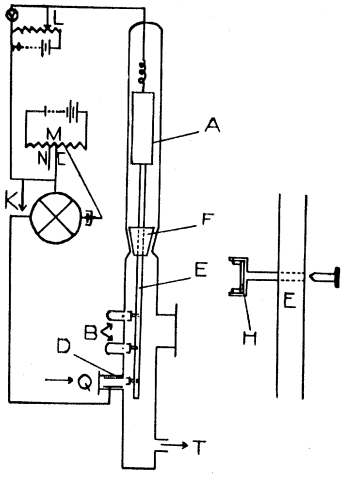


Fig. 1. Diagram of apparatus.

[1] C. Cha, Phil. Mag. **49**, 262 (1925).

the surface layer and each layer underneath. After the deposition of the films larger displacements of the solenoid placed any one of the films behind the Faraday cylinder and in the path of the light.

In order to secure proper electrical connections to very thin films, it is desirable that the external mechanical connections be made to a thick boundary of the film of the same material, which tapers off at its edges into the main thin film, whose properties are being investigated in the experiment. Stuhlmann and Compton[2] found that they secured results for films on glass or quartz, practically as good as their best, by using a sputtered contact and this method was adopted here. The sputtering was done before the formation of the films was begun. Iron spring rings served both to retain the glass plates in their holders and to form the electrical connection between the sputtered edge and the iron holder. The connection to the source of the retarding potential is shown in the diagram at L.

A two stage mercury diffusion pump, backed by a Cenco oil pump maintained a vacuum of 10^{-5} mm of mercury while the films were being made and studied. Pressures were measured with a McLeod gauge and a liquid air trap was used to keep mercury vapor from the rest of the apparatus. The quadrant electrometer used in this experiment had a sensitivity of 3700 mm/volt.

The quadrant electrometer was provided with a subsidiary condenser whose central member was attached to its insulated quadrant. The outer member of this condenser was connected to the point C on a megohm resistance. The midpoint of this megohm was connected to the case of the electrometer, and a point N on the other side of the megohm was connected to the needle of the electrometer. The ends of the megohm were connected to a battery, and the capacity of the condenser was adjusted so that on throwing on the battery, no deflection was obtained in the needle when the quadrant was disconnected from the case. By this method, the influence of fluctuations of the potential of the needle during the measurements was avoided. The source of light was an iron arc used in conjunction with a Gaertner monochromatic illuminator.

Photoelectric Thresholds

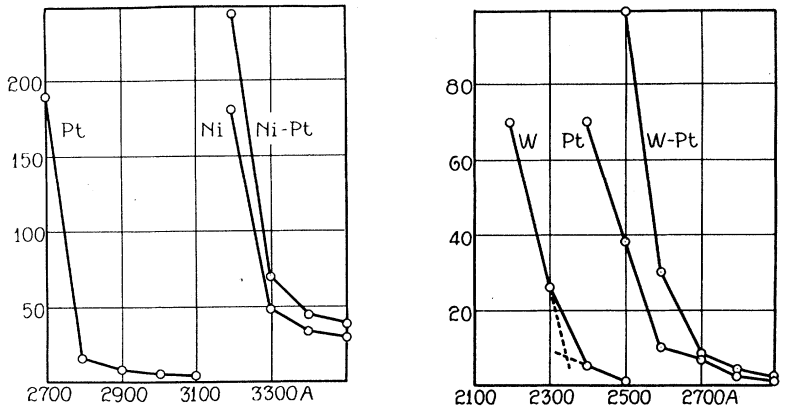
The photoelectric currents, with varied wave-length of exciting light, were taken for all films, the voltage being sufficient to obtain saturation current. Proper alignments were necessary to prevent disturbing reflections.

The pure platinum photocurrent vs. wave-length curve, Fig. 2, shows the usually accepted platinum threshold with reasonable certainty at 2800A. The pure nickel gives 3320A for the threshold wave-length. This latter value was further confirmed when the retarding potential vs. photocurrent curves were taken, since it was found impossible to get any photocurrents at any voltage with wave-lengths above 3300A. The point of interest is the fact that the threshold for the double nickel-platinum film is approximately the

[2] O. Stuhlmann, Jr. and K. T. Compton, Phys. Rev. **2**, 209 (1913).

same as for the pure nickel, which is the one of the two pure films which has the longer wave-length threshold.

Another pair of metals used was tungsten and platinum. The curves for these are shown in Fig. 3. They are not as easy to interpret as those in Fig. 2. The "foot" attributable to scattered light in the monochromator in the case of W joins the main curve more gradually than does that for Pt in Fig. 2. A reasonable extrapolation of the main curve gives for the threshold a wave-length of about 2340A which is somewhat above 2300A, the value obtained by Hagenow.[3] These curves are consistent with Fig. 2 in that the threshold of the double film is again equal, or nearly equal, to that of the constituent whose threshold wave-length is the longer. The Pt threshold obtained from



Figs. 2 and 3. Saturation photoelectric current vs. wave-length.

Fig. 3 does not agree with that obtained from Fig. 2, probably owing to some variation in one of those unknown factors which seem to govern so largely the position of photoelectric thresholds. This method not being entirely satisfactory in this regard, it appeared best to try a retarding potential method.

Retarding Potential vs. Wave-length

To find the maximum velocity of photoelectron emission for any wave-length the routine was not to try to find the exact retarding potential experimentally which would just stop the departure of the photoelectrons, "a very uncertain procedure at best"[4] but rather to plot the photocurrent, retarding-potential curve. Should the least amount of radiation of frequencies somewhat greater than that being considered enter the apparatus, as was unavoidable, the voltage requisite completely to hinder a negative discharge would not be the value sought. In all the retarding potential curves obtained there were evidences of the presence of light coming from the monochromator of a frequency greater than the indicated frequency. The current curve,

[3] Hagenow, Phys. Rev. **13**, 422 (1919).
[4] Millikan, Phys. Rev. **7**, 18 (1916).

for any indicated frequency of light being used, approached the potential axis at a constant slope until just before it reached that axis when it would approach the axis asymtotically.

In studying the films by the retarding potential method it was found that the slope of the curves giving the variation of photo effect with retarding

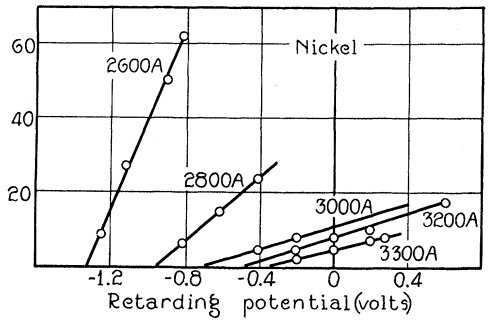
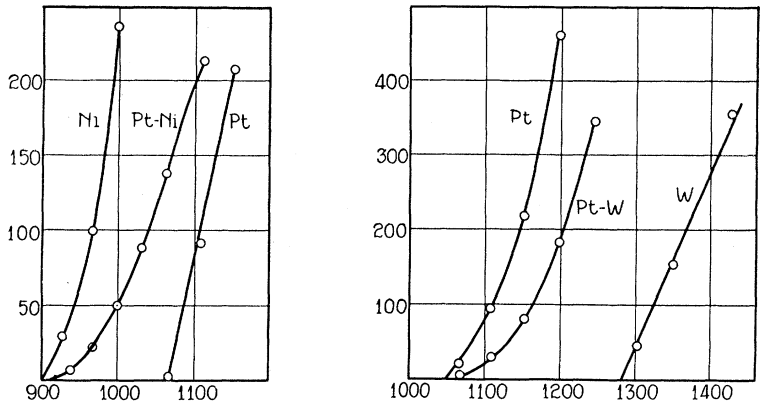


Fig. 4. Photo-electric current vs. retarding potential.

potential for light of different given frequencies decreased rapidly as the threshold frequency was approached. Naturally with light of threshold frequency there would be no current no matter what the value of the retarding potential, i.e., the slope would be zero.

An example of one set of curves as obtained for a nickel film is given in Fig. 4, the individual wave-length curves of which are as yet uncorrected for changes of light intensity and of slit width used in the monochromator.



Figs. 5 and 6. Arctan (photocurrent retarding potential) vs. frequency $\times 10^{-12}$.

The intensity of the lines used in the Fe spectrum was measured with a photoelectric cell under the conditions of the research, corrected with the cell's sensitivity factor. The data so taken, when properly corrected for the two variations just mentioned, formed the basis for the curves of the various films which are represented in Figs. 5 and 6. Each point on these curves has for

its ordinate the angle of slope of one of the curves examples of which are given in Fig. 4. As stated above, these angles are expressed as variations of photo current with change of retarding potential. The object of plotting the results in this way is to find the frequency for which there would be no photo-current with any potential, without actually attempting experimentally to realize this limiting condition.

An examination of the curves in Figs. 5 and 6 shows, as was found in the first part of the work, that for both sets of films the threshold frequency of the double film is approximately that of the component having the lower frequency threshold. The actual values of the wave-length thresholds obtained from these curves are for Ni 3333A, for Pt 2864A, for W 2338A, for the double Ni-Pt 3318A and for the Pt-W 2804A.

CONCLUSIONS

The threshold of the double film agrees with that of the component having the upper wave-length threshold in each case to within a small percentage although the threshold difference between the pure metals in each of the pairs studied is about 500A.

It will be noted that in the platinum and tungsten case, platinum, having a higher threshold than tungsten, was the deciding factor in the new threshold; but in the case of nickel and platinum it was not the platinum but the nickel which was effective.

The investigation described in this paper was carried out under the direction of Professor W. F. G. Swann of the laboratory and the writer desires to convey his thanks to Professor Swann for the very kind advice and encouragement which he extended through the course of the work. For his continued interest in the problem appreciation is expressed to Professor John Zeleny, Chairman of the Physics Department.