

## VARIATION OF THE PHOTOELECTRIC EFFECT WITH TEMPERATURE AND DETERMINATION OF THE LONG WAVE-LENGTH LIMIT FOR TUNGSTEN

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## ABSTRACT

The photoelectric characteristics of a tungsten surface have been studied from room temperature to 1140°K. It has been found necessary to use a tube of glass and quartz, and to seal it off the pumps after a thorough outgassing. The surface is rendered insensitive at room temperature by traces of gas, but regains its sensitivity between 800 and 900°K. The long wave-limit was found to be  $2570 \pm 50\text{Å}$ , and was independent of temperature.

## VARIATION OF THE PHOTOELECTRIC EFFECT WITH TEMPERATURE

IN VIEW of the recent important theoretical work on the problem of electrons in metals, and their passage through the surface, it was thought well to publish the following data on the photoelectric behavior of carefully outgassed tungsten. The problem was suggested to the writer by Dr. Millikan as a check on the conclusions drawn from the invariance of the "field currents" with temperature.<sup>1</sup> Millikan and Eyring had found that the currents pulled from metals by high fields are independent of the temperature below 1050°K but increase slightly above, and then merge into the thermionic emission. From this they drew the conclusion that the conduction electrons do not participate in the thermal agitation of the metal, as we should expect from classical kinetic theory.

The photoelectric effect should exhibit the same characteristics shown by the field currents, since it is concerned with the same mechanism within the metal. The photo-current should be independent of the temperature until it is influenced by the thermionic emission, and the long wave-limit should also be constant.

A great deal of time was devoted to an unsuccessful attempt to use a large piece of the metal, which would provide large area and consequently large photo-currents. It was found impossible to outgas thoroughly, and very inconvenient for the study of the temperature effect, as it was heated by means of an induction furnace, which had to be stopped in order to make photomeasurements. The cooling was so rapid that it was impossible to study the upper temperatures, though Nielsen had used this apparatus for the study of aluminum and nickel in the region from 500°K down to room temperature.

In the next type of tube the tungsten specimen was a loose conical spiral of commercial ten mil wire, spot-welded to heavy tungsten leads. A platinum

<sup>1</sup> Millikan and Eyring, *Phys. Rev.* **27**, 51 (1926).

Faraday cage surrounded this and was connected to a Dolazalek electrometer having a sensitivity of 1300 mm per volt at 150 cm scale distance. All glass parts of the apparatus were of Pyrex, through which electrical connections were made by means of tungsten seals. Light was admitted through a fused quartz window which was joined to the Pyrex by means of a graded seal.

Two liquid-air traps in series were used between the tube and the diffusion pumps. The McLeod gauge was sealed in between the traps and the pumps, and was entirely of glass. There were no stopcocks or wax seals on the low pressure side of the pumps for the entire system was of glass from the point where the fore-vacuum was connected.

Even when this tube was given the most rigorous outgassing, and left on the pumps, it was impossible to get consistent results. Consequently two side tubes, one containing cocoanut charcoal and the other a thin walled magnesium cylinder, were attached to the photoelectric tube, and the entire group arranged so that they could be sealed off the pumps as a unit.

In outgassing the glass was initially brought up to a temperature of 500°C for fifteen minutes, and then allowed to cool to 350°C where it was maintained for three hours. In this interval the glass between the tube and the liquid air traps was heated several times almost to the softening point by means of a hand torch. This entire procedure was repeated after an interval in which the metal parts of the apparatus were heated. The Faraday cage had been given a preliminary outgassing at white heat in a special tube before being mounted in the photoelectric tube, and then was heated to a bright yellow for a total of ten minutes. The magnesium cylinder was given a preliminary heating before the tube was sealed off. The platinum and magnesium were both heated by means of an induction furnace. The tungsten filament was given a total of twenty-four hours heating at 2400°K. The charcoal was maintained at 500°C during the entire time the tube was on the pumps. It was immersed in liquid air as soon as the tube had been sealed off, and kept so during the entire period of the measurements, which covered about three and a half months. After sealing off, the magnesium was vaporized as a getter.

By means of a Leeds and Northrup optical pyrometer the temperature of the center of the filament was measured, and corrected for the emissivity of tungsten and the transmission of the quartz. The temperature was a maximum in the central turns, so that in all determinations of the thermionic work function, which was used as a criterion of the cleanliness of the surface, the effect of end cooling was taken into account by the method of Forsythe and Worthing. Since the temperature of the filament was never kept high enough to vaporize the metal except for occasional flashing periods of a minute at a time, the temperature of the filament always was the same for any given value of the heating current. The curve for a straight ten mil wire, drawn from data published by Langmuir and Jones<sup>2</sup> agrees excellently with the pyrometer curve above 1400°K, but falls below it for temperatures lower than this. The pyrometer values were checked repeatedly, and a set of points was determined for me by Dr. Prescott of the Gates Chemical Laboratory of the

<sup>2</sup> Langmuir and Jones, *Gen. Elect. Review* **30**, 310 (1927).

Institute, using a more accurate pyrometer, with the same result. All data have been plotted using the Langmuir curve, as the experimental one could not be used in the range from  $1400^{\circ}\text{K}$  to room temperature without some very arbitrary assumptions.

The light source was a Cooper-Hewitt quartz mercury arc, operating at 93 volts, 2 amperes, and  $200^{\circ}\text{C}$ . The energy distribution of such an arc has been determined by Kazda in this Laboratory, and has been checked by other workers here. The light was directed upon the spiral by means of a Hilger quartz monochromatic illuminator, using slits 0.04 inches wide.

The photo-current was measured by observing the charging rate of the electrometer. With the current through the filament fixed, the temperature was known. The electrometer rate was measured with the target dark. The

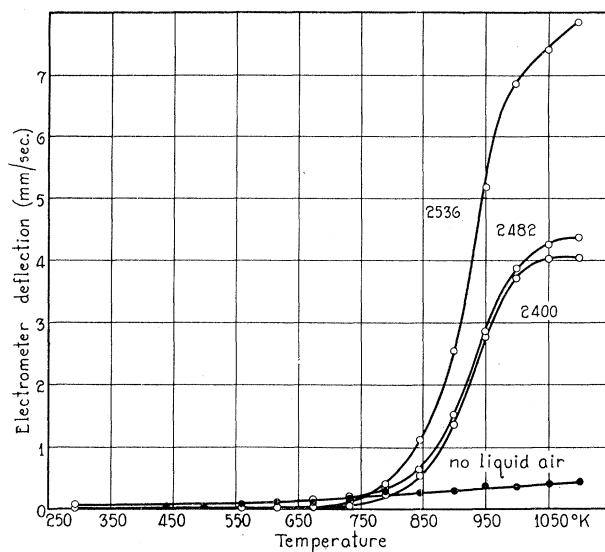


Fig. 1. Photo-current as a function of temperature.

rates were then determined with illuminations of three different wavelengths, 2399.6, 2482 and 2536. This procedure was repeated from room temperature up to  $1100^{\circ}\text{K}$  where the thermionic emission masked the photoelectric. The results of such a run are shown in Fig. 1 in which the photo-current is plotted against temperature, for each of the wavelengths used.

The remarkable increase in sensitivity found between  $800^{\circ}$  and  $1000^{\circ}$  may be due to (1) a true temperature effect, caused by the change in the kinetic energy of the conduction electrons or a variation in the crystal lattice, or (2) a contamination of the surface at the lower temperatures. The magnitude of the effect is much greater than we should expect from indications given by the experiments on pulling electrons out by high fields, or on any of the theories of the temperature effect. A plot of the long wave-limit for each temperature, determined by plotting current per unit intensity against wave-

length, shows that the long wave-limit did not change appreciably, so that the electrons escaped against the same work function for all temperatures. (Fig. 2.)

The results can be explained if we assume that there was a contamination present in spite of the precautions taken which increased the work function of the surface to so great a value that the illumination used was not able to release electrons from the portion of the surface affected. As the temperature increased the proportion of the surface contaminated grew less, and the emission increased, without any change in the long wave-limit, which is determined by the clean part of the surface. If these assumptions are correct, the elimination of the contaminations should make the surface more sensi-

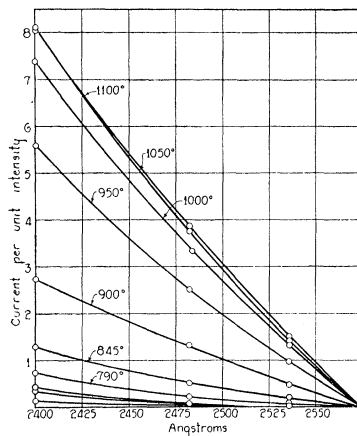


Fig. 2. Gas causes change in sensitivity but not in long wave-limit.

tive at the lower temperatures. At the conclusion of the measurements the liquid air was removed from around the charcoal, with the result that the sensitivity of the surface was reduced to a very low value for all temperatures. This is shown by the black dotted curve in Fig. 1. Further work is in progress.

The author wishes to express his appreciation to Dr. Millikan for his constant interest and advice and for placing the facilities of the Norman Bridge Laboratory at his disposal. The help of the technical staff is also very much appreciated, particularly the ingenuity and skill of the glassblower, Mr. William Clancy.

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