does not enter as importantly. This circumstance arises from the fact that the hfs separation for deuterium is so small that the moment in the B field is practically independent of the field. The ratio of the proton moment to the deuteron moment is 3.35. This value should be somewhat more accurate than that of those for the individual moments since systematic errors should effect both values in the same direction. It is to be noted that this value differs considerably from the value 4 obtained by Farkas and Farkas[11] from the rates of the para-ortho conversion for hydrogen and deuterium.

The value of the proton moment which we previously obtained by the use of atomic beams, 3.25 ± 10 percent is considerably higher than our present results. The cause of this discrepancy is rather obscure but may lie in our previous assumption that the temperature of the beam was the same as the temperature of the source slit.

With the sign of the moments established one can deduce an approximate value of the neutron moment on the naive assumption that the deuteron moment is the algebraic sum of the proton and neutron moments with the additional assumption that the spin of the neutron is $\frac{1}{2}$. The neutron moment is thus -2 nuclear magnetons.

In conclusion we wish to express our appreciation of the aid of a grant from the Carnegie Institution of Washington. Also, we wish to thank Professor H. C. Urey for the generous gift of the heavy water used in these experiments.

[11] Farkas and Farkas, Proc. Roy. Soc. **A152**, 152 (1935).

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The Photoelectric Properties of Zinc

CHARLES F. DEVOE, *University of Wisconsin*

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The work function of a vacuum distilled surface of zinc was found to be 4.24 volts at 1.5×10^{-8} mm pressure; as the pressure of air was increased the work function decreased to a minimum at about 10^{-6} mm pressure and then increased. Helium had no effect to a pressure of 3 mm. Nitrogen had no effect to a pressure of 10^{-3} mm.

EXPERIMENTS on the photoelectric properties of high melting point metals have shown that the metals must be heated at high temperatures for hundreds of hours before reproducible values for the long wave limits are obtained. Since this technique cannot be applied to zinc, several methods have been used to produce a gas-free surface rather than attempt to outgas a contaminated one.[1–9] The values for the long wave limit of zinc obtained in these experiments ranged between 2940A and 4000A.

Hughes[7] measured the long wave limit of a vacuum distilled surface of zinc but the vacuum he used was low compared to that available now. The purpose of this experiment was to study zinc surfaces prepared by Hughes' method under the best possible vacuum conditions.

Apparatus

The experimental tube is shown in Fig. 1. The thin molybdenum strip A, spotwelded to a tungsten wire yoke and shaft, could be moved into the molybdenum collecting cylinder G, or in front of a tungsten filament E from which the strip could be heated by electron bombardment, or could be placed horizontally over either of the two quartz crucibles Z containing the zinc by means of an electromagnet acting on the soft iron bar C. The collecting cylinder G was sup-

[1] Richardson and Compton, Phil. Mag. **24**, 575 (1912).
[2] Hennings, Phys. Rev. **4**, 228 (1914).
[3] Küstner, Ann. d. Physik **46**, 893 (1915).
[4] Hennings and Kadesch, Phys. Rev. **8**, 209 (1916).
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[6] Werner, Zeits. f. Physik **67**, 207 (1928).
[7] Hughes, Phil. Trans. Roy. Soc. London **212**, 205 (1912).
[8] Dillon, Phys. Rev. **38**, 408 (1931).
[9] Rentschler, Henry and Smith, Rev. Sci. Inst. **3**, 794 (1932).

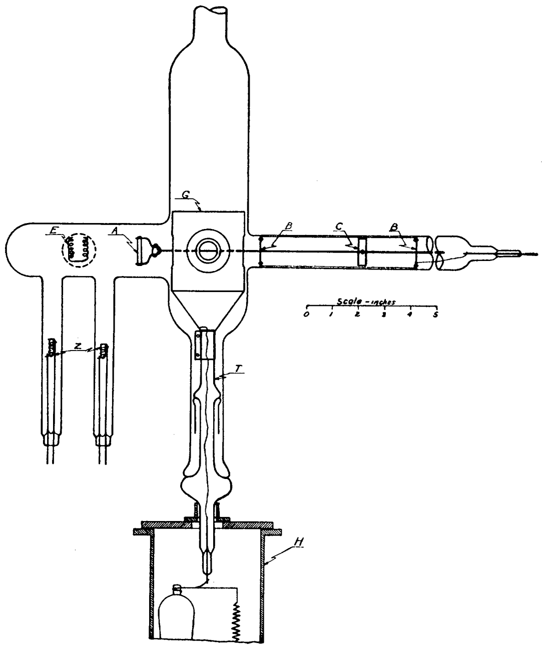

FIG. 1. Diagram of experimental tube.

ported by the skirted tube T. This mounting provided a glass path of more than one foot between the cylinder and any other electrode, thus leakage currents were eliminated.

The source of light was a high intensity water cooled quartz capillary mercury arc[10] used with a Leiss double prism quartz monochromator. The monochromator, arc, and auxiliary lenses were mounted on a heavy cast iron base provided with two lateral crossed motions and a rotation around a vertical axis so that the system could be rotated against adjustable stops to send the light either into the photoelectric tube or into a vacuum thermopile. The quartz window on the thermopile was identical with the quartz window on the photoelectric tube, thus the optical paths in the two cases were identical. Thermopile readings were made with a Kipp and Son type ZC galvanometer. The sensitivity of the thermopile was 2.95×10^{-3} erg/sec./mm^2/mm deflection of the galvanometer with the scale at three meters. From the current sensitivity of the galvanometer and the resistance of the circuit the absolute sensitivity of the thermopile was 10.91 microvolts/erg/sec./mm^2. The thermopile was calibrated after each set of observations by radiation from a pyrometer lamp which was calibrated by comparison with a standard lamp. Because of the high intensity of the capillary arcs narrow slit widths of the monochromator ranging from 0.2 mm for 2260A to 0.04 mm for 2805A were used.

The photo-currents were measured by a modification of the Barth[11] circuit using a Western Electric D 96475 tube. The tube and high resistances were mounted in the brass vacuum chamber H (Fig. 1) which also enclosed the seal connection to the collecting cylinder, thus the entire photo-current lead was in a vacuum. Three high resistances (6.7×10^8, 4.1×10^9, 2.2×10^{10} ohms) and a ground lead were mounted on a clear Bakelite block inside the vacuum chamber in such a way that an externally controlled contact arm could shunt the amplifier tube with any one of the resistances or the ground connection. The voltage sensitivity of the amplifier was measured after each set of photo-current readings. The highest sensitivity used was 140,000 mm/volt. Although the high resistances were not calibrated in absolute units (the values given above were the manufacturer's values) the ratios of the resistances were measured several times during the experiment by comparing the deflections produced with the tube shunted by the various resistances and the surface illuminated by light of the same intensity and wave-length. These ratios were found to remain constant during the experiment which indicated that the resistances remained constant.

PROCEDURE

The 99.99 percent pure zinc obtained through Professor Kahlenberg from Evanwall Zinc Company was fractionally distilled four times in a vacuum less than 10^{-7} mm in a series of bulbs. It was then transferred in air to the quartz crucibles which had been outgassed on an auxiliary vacuum system. The gas absorbed during this transfer was removed in the final distillation onto the strip.

The collecting cylinder and the strip mounting were heated to bright red by electron bombardment in separate vacuum systems until pressures less than 5×10^{-7} mm were obtained with the parts heated. The ionization gauge, the filament

[10] Daniels and Heidt, J. Am. Chem. Soc. **54**, 2381 (1932).

[11] Barth, Zeits. f. Physik **87**, 399 (1934).

E, and the crucibles were also outgassed on auxiliary systems. The photoelectric tube, except the side tubes containing the zinc, was baked at 400°C for four weeks while the remainder of the system was heated with a hand torch. During this period the pressure decreased from 8×10^{-8} to 1.5×10^{-8} mm as measured with the ionization gauge. The strip was heated at 1000°C for three weeks after which the tube was again baked for four days.

A small amount of zinc was evaporated to remove the surface layer of gas, then the strip was placed over the crucible and an opaque layer was condensed in about thirty minutes. The pressure during the distillation was less than 3×10^{-8} mm. The strip was then drawn into the collecting cylinder for observations. The long wave limit at absolute zero was obtained by the method of Fowler.[12]

Results

The long wave limits for twenty sets of observations on eight surfaces ranged between 2900 and 2930A; this corresponded to a work function of 4.24 volts. That the surfaces were well outgassed was shown by the facts that (1) the long wave limit did not change during a period of two weeks after the surface was prepared; (2) heating the surface at 100° to 150°C did not change the long wave limit; (3) illumination of the surface by the total radiation from a mercury arc produced no change in the long wave limit.

Although the long wave limits determined by the twenty sets of observations were within one percent of 2915A, the photo-currents per unit incident light intensity for one set of observations were as much as twice the photo-currents at corresponding wave-lengths for another set of observations. Thus the abscissa shifts necessary to put the observed curves into coincidence with the Fowler curve were nearly equal but the ordinate shifts were different. Fig. 2 shows the agreement of the twenty curves plotted with no abscissa shifts but with the ordinate shifts given in Table I. Since these ordinate shifts were not due to changes in the sensitivity of either the thermopile or the amplifier they indicated that the reflecting powers of the surfaces differed by a factor which was constant over the entire spectral range studied, or that there were differences in the electron transmission of the surfaces.

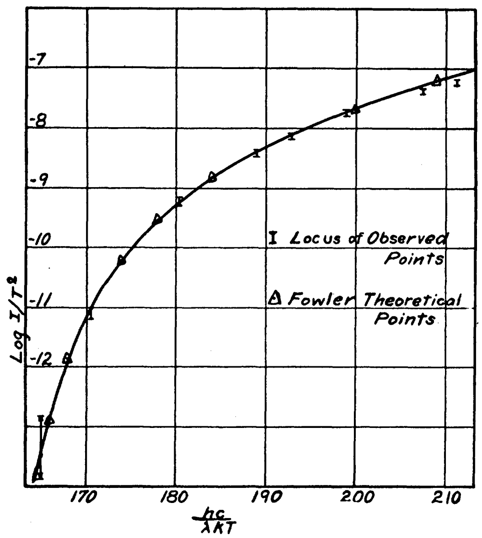

FIG. 2. Plot of the 20 experimental curves. There have been no abscissa shifts but the ordinates have been shifted as given in Table I.

Gas Effects

The fair agreement of the value 2915A with that obtained by Hughes[7] (3016A) for evaporated surfaces in a vacuum less than 5×10^{-4} mm and the discrepancy with Dillon's value[8] (3730A) for a surface in a good vacuum suggested a possible correlation between long wave limit and pressure.

TABLE I. *Values of ordinate shifts used in Fig. 2.*

Curve	Ordinate Shift	Factor	Treatment of the Surface Prior to the Curve
1	Standard curve		New surface
2	0	1	Full arc for 24 hr.
3	+0.3	1.35	Heated quartz window 3 days
4	− .59	0.555	New surface
5	− .165	.85	New surface
6	− .13	.88	New surface
7	− .15	.86	Stood 24 hr. in 1.5×10^{-8} mm
8	− .15	.86	Heating by radiation 6 hr.
9	− .19	.83	Heating by radiation 8 days
10	− .25	.78	Stood 6 days in vacuum
11	− .25	.78	Stood 24 hr. in vacuum
12	− .54	.585	New surface
13	− .39	.675	Stood in vacuum 24 hr.
14	− .26	.77	Stood in vacuum 10 days
15	+ .09	1.095	Heated quartz window 8 hr.
16	+ .07	1.07	Full arc 3 days
17	− .43	0.65	New surface
18	− .43	.65	Stood in vacuum 48 hr.
19	− .43	.65	Full arc 24 hr.
20	− .35	.71	New surface

[12] Fowler, Phys. Rev. **38**, 45 (1931).

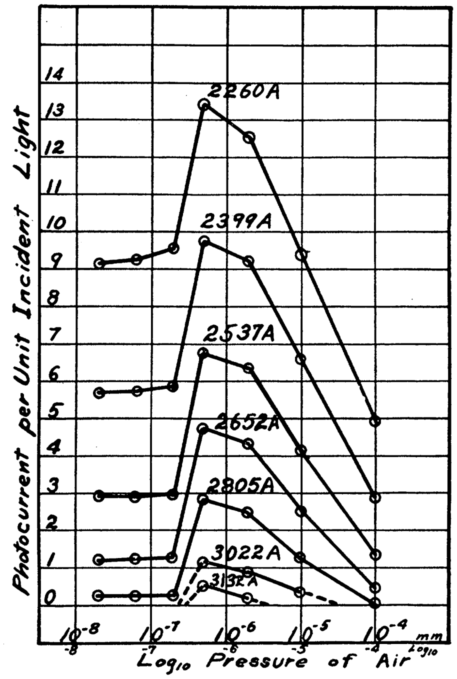

FIG. 3. Photo-currents per unit light intensity as a function of the log of the pressure of air in the tube.

The pressure in the photoelectric tube was therefore varied either by adjusting the temperature of the mercury pump boiler or by introducing small amounts of gas into the vacuum system. The second method was designed especially for introduction of pure gases. Three oblique bore stopcocks were sealed very close together in the form of a T; the volume between the stopcocks was about 1 cc. The other side of one stopcock was connected to a reservoir containing the gas; another was connected to the forepump; and the third was connected through a liquid-air trap containing glass beads to the main system between the liquid-air traps and the mercury cutoff. Thus stopcock grease and water vapor could not enter the vacuum system. The 1 cc volume between the stopcocks was evacuated and filled with the gas to be introduced into the system, it was pumped to 10^{-4} mm by the forepump, and then connected with the main system. The gas contained in the 1 cc at 10^{-4} mm doubled the pressure at 10^{-8} mm.

In Fig. 3 the photo-currents per unit light intensity are plotted against the log of the pressure of air in the tube. Each curve is for one wave-length. The ordinate unit for Figs. 3, 6, and 7 is 3.9×10^{-13} ampere/erg/sec. The photo-currents are plotted in Fowler coordinates in Fig. 4. The curves are theoretical while the points are the experimental values. The agreement between the

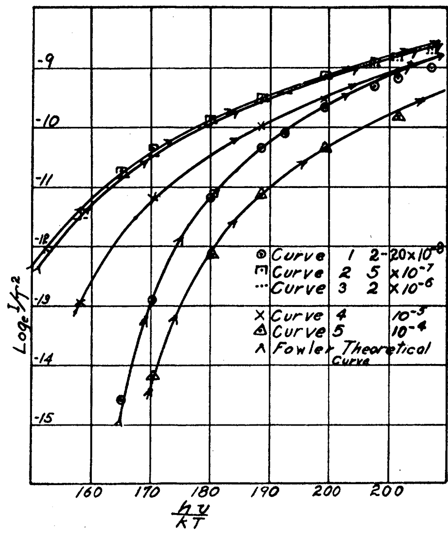

FIG. 4. Photo-currents plotted in Fowler coordinates.

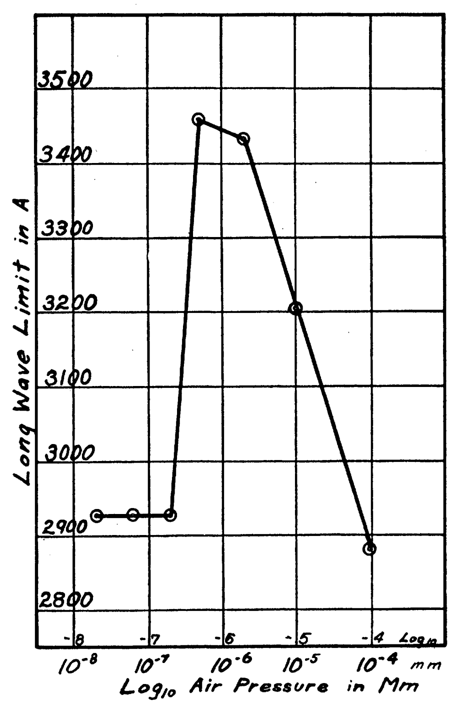

FIG. 5. Long wave-length limits plotted against the log of the pressure of air.

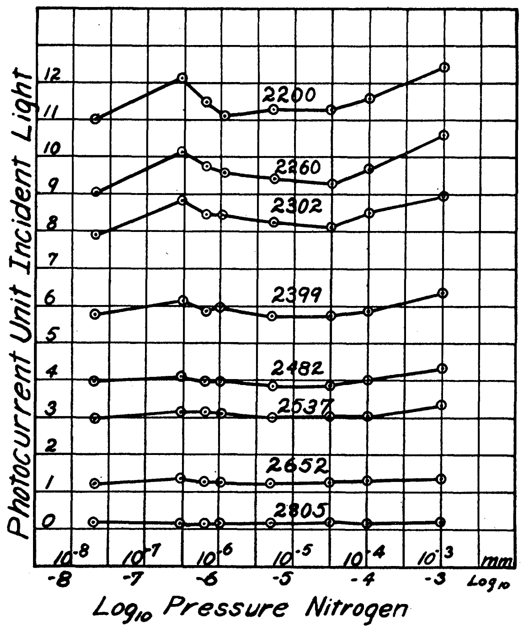

FIG. 6. Effect of pure nitrogen on the photo-currents.

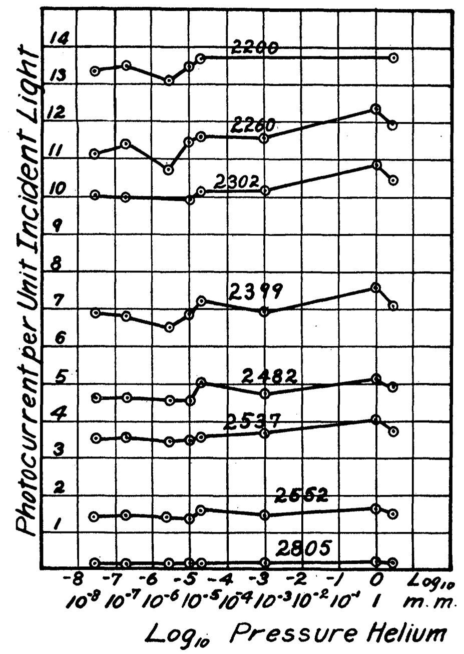

FIG. 7. Effect of helium on photo-currents.

experimental and theoretical curves is very good for all the pressures studied. The long wave limits are plotted against the log of the pressure of air in Fig. 5. This curve shows that the long wave limit was a maximum between 2×10^{-7} and 2×10^{-6} mm. According to this curve Hughes' value is for a surface in equilibrium with a pressure of 5×10^{-5} mm, which probably was the case. Dillon's value is probably for a surface in equilibrium with a pressure of about 10^{-6} mm. The discrepancy between 10^{-6} and the pressure he actually used is probably due to the difficulty of removing the gas absorbed during the transfer of the zinc from the mold to the vacuum system.

The effect of pure nitrogen on the photo-currents is shown in Fig. 6. The nitrogen was purified by passing through hot copper, hot copper oxide, and a liquid-air trap. Although the short wave-length curves show maxima similar to those in Fig. 3, the long wave-length curves do not increase to the high maxima. In fact, the percentage changes in the photo-currents were constant for all wave-lengths at a given pressure, thus there was no shift in the long wave limit.

The effect of helium is shown in Fig. 7. The helium was purified by passing twice through charcoal at liquid air temperature. These curves show that except for small variations in the photo-currents (for which no explanation has been found) the photoelectric properties were not changed by increasing the pressure of helium from 3×10^{-8} to 3 mm. This result explains the agreement of 2915A with that obtained by Rentschler, Henry, and Smith[9] for a surface sputtered in an inert gas atmosphere if the effect of helium is characteristic of the inert gas they used.

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