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The Effect of Intense Electrostatic Fields on the Reflectivity of Tungsten

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The results of a study of the effects of intense electrostatic fields on the reflectivity of tungsten show no detectable change with surface voltage gradients up to about 6×10^6 volts/cm. The indications are that, in order to produce observable effects on the reflectivity of tungsten, it will probably be necessary to use much higher surface voltage gradients and a more sensitive detecting means.

I. INTRODUCTION

IN a survey prior to the present investigation, no reference to the effect of intense electric fields on the reflectivity of metals was found. However, references were found dealing with the effects of such fields on the vaporization and resistance of metals.

Worthing,[1] working with tungsten at incandescence, observed a decrease in the vaporization rate and resistance with surface voltage gradients of about 10^6 volts/cm. In similar studies with molybdenum, Estabrook[2] observed a decrease in vaporization rate and an increase in resistance. In the case of metals, in accord with theories of surface potential barriers, and as suggested by Hutchisson,[3] one might expect not only modifications of vaporization rates and resistivity, but also a modification of the reflectivity. The purpose of the present research was to investigate whether or not any such changes of reflectivity for tungsten are obtainable.

II. APPARATUS

The apparatus consisted of a high voltage d.c. power supply, a vacuum test chamber, a mount for the test sample, a high vacuum pumping system, and pyrometer measuring devices. Except for the pyrometer equipment, all was enclosed in wire screen cages.

In the high voltage d.c. power supply the 60,000-volt secondary of a 3-kva transformer was connected through a Kenotron rectifier and safety devices to a filter circuit, consisting of a parallel arrangement of condenser and resistance, designed to reduce the a.c. ripple to less than 0.5 percent. Part of the resistance of the filter circuit was that of a high voltage voltmeter, to whose terminals the d.c. power supply line was connected.

The voltmeter consisted of a high quality 1582-megohm resistor[4] connected in series with a shunted mirror galvanometer. Except for a small opening at the front, the galvanometer was enclosed in a grounded metal case.

The vacuum test chamber is shown in Fig. 1. It was a vertical glass tube about 20 in. long by $2\frac{7}{8}$-in. O.D., having four sealed electrical terminals and an annular indentation near the bottom for supporting the mount for the test sample. The bottom of the tube was connected to the pump. The top edge was ground smooth for sealing.

The test sample was a fine filament of tungsten wire,[5] which was mounted vertically along the axis of a spaced turn, single layer, helical coil of Kovar wire called the "potential coil." This arrangement makes possible pyrometer studies of the test sample while its surface is subjected to intense electrostatic fields. The voltage gradient at the surface of the test filament is given by

$$G=\frac{E_{AB}}{R_B \ln \dfrac{R_A}{R_B}},$$

where R_B = radius of tungsten filament; R_A = radius of helical or "potential coil"; E_{AB} = potential difference between "potential coil" and filament.

[1] A. G. Worthing, Phys. Rev. **17**, 418–420 (1921).
[2] G. B. Estabrook, Ph.D. Thesis, University of Pittsburgh (1932); and Phys. Rev. **63**, 352–358 (1943).
[3] E. Hutchisson, Phys. Rev. **47**, 328 (1935).
[4] International Resistance Company, Type MVO 1500-megohm resistor.
[5] Supplied by the General Electric Company, Lamp Development Division.

Very high gradients are obtainable with moderate applied voltages when the test filament has a very small diameter. The radius of the "potential coil" is relatively unimportant. This radius was made rather large, however, in order to minimize the sidewise electrostatic forces resulting from lack of centering.

The diameter of the tungsten filament was about 0.000875 cm. Its length was 13.5 cm. The "potential coil" was a 16-turn coil of 0.153-cm diameter wire, having an over-all length of 7.7 cm and a mean diameter of 4 cm.

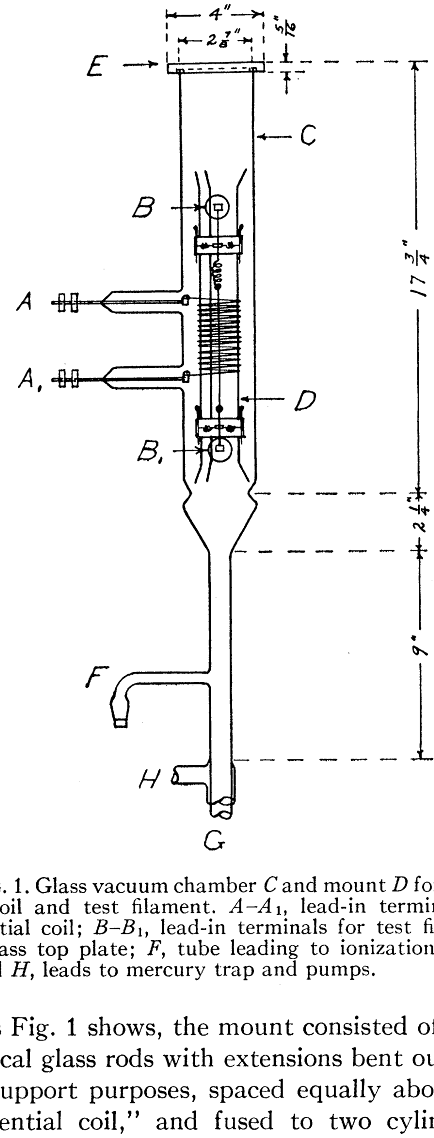

FIG. 1. Glass vacuum chamber C and mount D for potential coil and test filament. A–A_1, lead-in terminals for potential coil; B–B_1, lead-in terminals for test filament; E, brass top plate; F, tube leading to ionization gauge; G and H, leads to mercury trap and pumps.

As Fig. 1 shows, the mount consisted of three vertical glass rods with extensions bent outward for support purposes, spaced equally about the "potential coil," and fused to two cylindrical glass collars. Each collar supported a small brass centering disk in a horizontal position by means of four radial springs. The outer end of each spring was looped through a hole in the wall of the glass collar. By means of tapered glass pins through these loops, the brass disks were centered. The test filament was attached to the centering disks and was held taut by means of a strong Kovar spring. The terminals of the "potential coil" and filament were connected to the four sealed-in terminals A, A_1, B, and B_1.

The high vacuum pumping system was of the usual type with provision for flushing the system with dry air.

Three different optical arrangements were used for the pyrometer measurements.

In the first arrangement, a 100-watt light source, focused on a small celluloid diffusing screen attached to the outside wall of the vacuum chamber, served to illuminate the test filament. Reflected light from the tungsten test filament passed between the center turns of the "potential coil" and an achromatic lens to a standard optical pyrometer. The orientation was such that no light reflected from the glass walls could enter.

The pyrometer, of the disappearing filament type, was equipped with a red glass filter and extra lenses. The image of the tungsten test filament in the focal plane was of about the same size as the pyrometer filament. The pyrometer was calibrated in the usual manner.

The second arrangement was similar to the first, except that two 100-watt light sources were used, one to illuminate each side of the test filament.

In the third arrangement, shown in Fig. 2, the double light source as described was used with an alternate type of pyrometer. The tungsten test filament itself was used as a pyrometer filament. A ribbon filament lamp, introduced back of the test chamber, served as the background source. The light from both the background, kept at a constant brightness, and the tungsten test filament were viewed through a Ramsden eyepiece and red filter glass. A pyrometer balance was obtained by varying the voltage applied to the light sources illuminating the test filament. One of the two lamps of the double light source was calibrated against a standard lamp on a photometer bench, with the eyepiece and filter used in the tests.

III. METHODS AND DATA

With a tungsten test filament in position, in a high vacuum, better than 10^{-6} mm Hg in all cases, various d.c. voltages up to 36 kilovolts were applied between the filament and the concentric "potential coil," and corresponding test filament brightness measurements were made. The filament was made a positive grounded electrode in order to eliminate electronic discharge.

Six pyrometer tests were made under various conditions. In all tests, the d.c. potential difference between the "potential coil" and filament was varied from zero to the highest value possible without filament vibration, in approximately equal voltage steps. At each step, five or six pyrometer balances were made. Some tests were made with increasing pyrometer filament brightness, others with decreasing filament brightness.

In the first test, the first optical arrangement described under apparatus was used with the light source connected to a 115-volt a.c. power supply. A 750-megohm damping resistor was connected in the high voltage d.c. supply line, to limit vibration of the test filament.

In the second test, the first optical arrangement was used, but the light source was connected to a constant voltage d.c. supply and no damping resistor was used.

Because of the uncertainty of the d.c. voltage drop across a damping resistor in the high voltage d.c. supply line, the high probability of filament breakage when no damping resistance was used, and the non-uniform illumination of the filament by a single light source, the arrangements for the remaining tests were modified.

In the third test, the second optical arrangement was used with the double light source supplied by a constant d.c. voltage. A 360-megohm damping resistor was so connected in the high voltage filter circuit as to permit direct measurement of the potential difference between the test filament and potential coil and also limit the vibration of the test filament.

In the fourth, fifth, and sixth tests, the third optical arrangement as shown in Fig. 2 was used with the double light source supplied with a constant d.c. voltage. Preliminary tests were made with the optical system to determine conditions of high sensitivity and accuracy as described by Worthing and Forsythe.[6] The 360-megohm damping resistor was connected as in the third test.

During the sixth test, the vacuum chamber was irradiated by radium in an attempt to eliminate charges on the glass surfaces. There was no observable effect on the results obtained.

Certain data and computed values obtained for these tests are tabulated in Tables I and II. Table I shows a sample set of data for an individual test. Table II shows a summary of pertinent data for all six tests.

IV. DISCUSSION

The summary of Table I shows that, in all tests, any change in the average brightness or

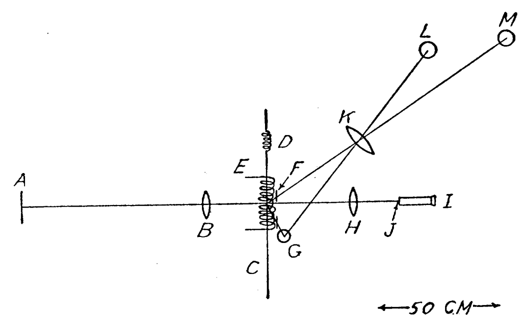

FIG. 2. Optical arrangement using test filament as pyrometer filament. A, ribbon filament background lamp; B, camera lens; C, tungsten test filament, kept taut by spring D; E, potential coil; F, diffusing screens on vacuum chamber wall; G, mirror; H and I, parts comprising the eyepiece of a disappearing filament optical pyrometer with an adjustable aperture at J; K, lens for concentrating light from sources L and M on the test filament at the axis.

reflectivity of the filament due to a change in voltage gradient was much less than the range of measured brightness or reflectivity in obtaining a set of pyrometer measurements. With the most sensitive arrangement tried, there was no certain change in brightness or reflectivity of the tungsten filament, within the range of surface voltage gradients used.

A comparison of the results for the six tests seems to indicate that the results of the third and sixth tests are most reliable and that we may use them to indicate the maximum change

[6] A. G. Worthing and W. E. Forsythe, Phys. Rev. **4**, 163–176 (1914).

in reflectivity which might have occurred and still have been undetected. Thus, the results of Table I indicate that the average brightness or relative reflectivity of the tungsten filament could not have changed by more than about 3 percent when the surface gradient was varied from 0 to 6.48×10^6 volts/cm.

In order to proceed further with this study, it seems that it would be necessary either to obtain a more sensitive means of measuring reflectivity or to obtain higher surface voltage gradients.

In the present work the sensitivities of the two pyrometer arrangements were limited by the smallness of the test filament, and the surface voltage gradient was limited by filament vibration, which was apparently initiated by mechanical shock or electrical disturbances in the system.

There are various theories of metallic reflection which indicate that an electric field should affect the reflectivity. Schiff and Thomas[7] present a quantum theory of metallic reflection in which the interaction of light with a metal is expressed by scattering by the conduction electrons. Frenkel[8] treats the interaction of light with a metal as the probability of photons penetrating or being reflected by a surface potential barrier.

In two recent studies,[9,10] surface gas layers were used to explain the observed variations of vaporization rate and resistivity of tungsten. However, if such gas layers were present in this reflectivity study, they had no observable effect.

It seems possible that the electrostatic fields

TABLE I. Tests for a variation of reflectivity of tungsten filament with surface voltage gradient. Test No. 6. Measurements with special optical pyrometer; vacuum chamber irradiated with radium source; background lamp current constant at 3.8 amp. d.c.; high voltage voltmeter directly across test chamber terminals (360-megohm damping resistance).

Applied potential difference kilovolts	Gradient at filament 10^6 volts/cm	Lamp voltage for 6 pyrometer balances Max.	Min.	Av.	Average brightness of filament[a]	Average deviation of brightness measurement, percent	Range of measured brightness or reflectivity, percent
		Without Ra irradiation					
0	0	91.8	89.5	90.6	1.003	2.5	8.4
		With Ra irradiation					
0	0	91.8	89.5	90.5	1.000	2.4	8.4
3.96	1.07	92.5	90.0	91.2	1.026	2.7	9.0
7.91	2.15	92.0	89.8	91.0	1.018	2.5	8.1
11.87	3.22	91.8	89.5	90.8	1.011	2.5	8.3
15.82	4.28	92.2	89.8	90.9	1.015	2.7	9.0
19.78	5.36	92.0	89.5	90.7	1.008	2.9	9.1
23.90	6.48	91.0	90.5	90.8[b]	1.011	0.9	1.9
0	0	91.0	89.8	90.2	0.992	1.1	4.3
23.90	6.48	Test stopped due to filament vibration.					

Range of average brightness or relative reflectivity for entire test =3.4 percent.
[a] Arbitrary units—based on initial zero gradient value with Ra irradiation as unity. Reflectivity is proportional to the average brightness.
[b] Two balances instead of six.

TABLE II. Summary of results of reflectivity *vs.* surface voltage gradient tests on tungsten filament.

Test No.	Gradient at filament 10^6 volts/cm	Average brightness of filament[a]	Average deviation of brightness measurement, percent	Range of measured brightness or reflectivity, percent
		Ordinary pyrometer		
1	0	1.00	5.6	23
	4.28	0.98	9.4	23
	8.65	0.98	9.4	23
	9.78	1.08[b]	—	—
2	0	1.00	8.0	13
	2.15	0.98	5.5	13
	4.28	1.01	9.2	20
3	0	1.00	3.5	6.2
	2.15	1.00	3.5	6.2
	5.36	0.98	1.8	6.2
		Special pyrometer		
4	0	1.00	1.3	5.0
	3.22	1.00	3.5	12.
	5.36	1.00	4.4	12.
	6.00	0.98[c]	3.6	10.
5	0	1.00	1.3	5.9
	2.15	1.00	1.7	12.
	3.22	1.04	3.3	5.8
	4.28	1.03[c]	0.8	2.4
6	0	1.00	2.4	8.4
	2.15	1.02	2.5	8.1
	5.36	1.01	2.9	9.1
	6.48	1.01[d]	0.9	1.9

[a] Arbitrary units based on average value at zero gradient as unity. Reflectivity is proportional to the average brightness.
[b] One pyrometer balance instead of five.
[c] Four pyrometer balances instead of six.
[d] Two pyrometer balances instead of six.

[7] L. I. Schiff and L. H. Thomas, Phys. Rev. **47**, 860–869 (1935).

[8] J. Frenkel, *Wave Mechanics* (Oxford University Press, New York, 1932).

[9] P. L. Vissat, Ph.D. Thesis, University of Pittsburgh (1941).

[10] W. P. Reid, Ph.D. Thesis, University of Pittsburgh (1942); and Phys. Rev. **63**, 359–366 (1943).

used in the vaporization and reflectivity studies have not been able to modify with certainty the surface structure of the metal. The indications are that in extremely high vacuums certain changes in the vaporization rate and in the reflectivity of a metal should be produced by the application of sufficiently high electrostatic fields to the metal surface. In the case of reflectivity, in order to observe such effects, an improved form of apparatus would probably be required.

ACKNOWLEDGMENT

The author wishes to express his gratitude to Dr. Elmer Hutchisson, who suggested this problem and under whose guidance the research was started; to Dr. A. G. Worthing, who acted as advisor during the absence of Dr. Hutchisson in the present emergency, and made helpful suggestions in the preparation of the manuscript; and to Dr. A. J. Allen and other members of the Physics Department who offered suggestions.

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Letters to the Editor

PROMPT publication of brief reports of important discoveries in physics may be secured by addressing them to this department. The closing date for this department is the third of the month. Because of the late closing date for the section no proof can be shown to authors. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents. Communications should not in general exceed 600 words in length.

Note on Events Distributed According to Chance

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April 17, 1944

IN a recent paper[1] I have shown how to calculate the chance W_n that n events will occur in a domain of several dimensions described by variables x, y, etc. W_n can always be found if we are given the chance $f(x, y)dxdy$ that an event will occur in $dxdy$. In this note, I wish to record a development which arose in a problem dealing with surface flaws and volume flaws in glass and other brittle materials. It turns out that the method can easily be extended to give us the chance W_n that n flaws will be found in the volume V and on the surface S of a specimen. Let f be the volume density of interior flaws and f' the surface density of flaws on the boundary (which may be of the same kind, or of a different kind). Then, if f and f' are *constant*, we find, putting $fV+f'S=b$, that $W_n=b^n e^{-b}/n!$ This Poisson formula will be obvious to those who happen to be familiar with the result of superimposing random distributions, dependent on a single variable, but perhaps not so obvious to the majority of physicists interested in the faults of brittle materials. For more general cases, where f and f' are not constant, differential equations analogous to those in the above-mentioned paper have been set up. The methods of integrating them are in general the same as in the previous paper.

I take this opportunity to correct an error in the above-mentioned paper; a minus sign is needed in the second line below Eq. (10).

[1] A. E. Ruark, Phys. Rev. 65, 88 (1944).

The Decomposition of Water by the So-Called Permanent Magnet and the Measurement of the Intensity of the Magnetic Current

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April 28, 1944

THE magnetic current manifests itself in many phenomena. The polar movement[1] of bodies in an homogeneous magnetic field, reversing their direction of movement with the reversal of the field, showing that they bear an excess of north or south magnetic charge, constitutes a magnetic current. Thus the Peregrinus experiment becomes positive when performed with sensitive means. The well-known breaking experiment quoted by Maxwell[2] that a magnet when broken *ad infinitum* invariably gives always two separate magnets with equal poles cannot be found in the scientific literature, and it cannot be performed. This idealistic experiment does not prove that there is no true magnetism, north or south, because each breaking creates constriction, and from each constriction there is produced magnetism.

The decomposition of water into oxygen and hydrogen by the electromagnet[3] and the circulation of positively or negatively charged bodies and bubbles in the same plane, and at the same time, in directions opposite to one another, in the constant homogeneous vertical magnetic field, reversing their direction of circulation with the reversal of the field,[4] proves the existence of the magnetic current by the same criteria from which the existence of the electric current was deduced.