CERTAIN PHOTOELECTRIC PROPERTIES OF GOLD

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Abstract

Variations in the photoelectric behavior of a gold filament were studied both during an extended outgassing, and later upon reaching a stable condition.

Changes in photoelectric properties as outgassing proceeded.—Full arc sensitivity rose quickly in the initial period, then decreased slowly to a stable value. Fatigue curves showed a systematic change from a negative fatigue (i.e. a decrease in sensitivity with time of standing) at the beginning to a gradually increasing positive fatigue which slowly decreased to zero. A shift in long wave limit consistant with the change in full arc sensitivity was observed.

Changes in photoelectric properties produced by increasing temperature.—Full arc sensitivity decreased slightly. Individual line sensitivity was studied by use of a quartz double monochromator. Lines close to the long wave limit increased enormously in sensitivity with temperature, for those more removed this was less marked, while below 2350A there was a slight decrease. A shift in long wave limit toward the red was observed during the outgassing period and the final fatigueless state. During this latter period photo-current per unit light intensity curves established a shift in long wave limit from 2560A to 2610A between temperatures of 20°C and 740°C.

SEVERAL studies have been made in this laboratory of the photoelectric behavior of thoroughly outgassed metals. This report covers an investigation of the photoelectric properties of gold with particular reference to:

1. Variation of full arc sensitivity of the gold filament together with the associated change in long wave limit as outgassing proceeds.
2. A systematic change in fatigue curves with continued outgassing.
3. Variation of full arc and line sensitivity together with long wave-length limit as a function of temperature when the filament is in a "fatigueless" condition.

Apparatus

The gold samples in the form of U-shaped filaments some 0.03 mm thick by 4 mm wide were hung within a molybdenum cylinder which served as the collecting electrode. Potential and current leads passed out through a pressed seal at the top of the tube. The cylinder was supported from the bottom of the Pyrex tube by a double re-entrant seal through which the collector lead passed. This insured the longest possible glass path between filament and cylinder. As an additional precaution, grounded interior and exterior guard rings were placed at the top of the tube between the filament and collector. Photo-currents were read upon a Compton quadrant electrometer by using

either the rate of charge method or by maintaining a steady deflection by means of cupric oxide and glass high resistances.

The exciting light entered through a quartz window attached to the tube by a graded quartz to Pyrex seal. A hole in the side of the cylinder crossed by molybdenum wires allowed the light to fall upon the filament. The source of light was a vertical type Cooper-Hewitt quartz mercury arc operated at 80 volts. This was used either directly in front of the window or in connection with a Leiss quartz double-monochromator with lens by which the slit image was thrown upon the filament.

In the latter portion of the work this monochromator and arc were mounted upon a heavy cast iron base provided with levelling screws, two horizontal motions, and one of rotation about a vertical axis. Adjustable stops were provided on this latter motion so the monochromator slit image could be thrown quickly from the filament to a linear thermopile deep within an evacuated brass chamber, the double walls of which were filled with water. The beam entered through a quartz window of the same thickness as that on the photoelectric tube, thus giving the same optical path in the two cases. The dimensions of the slit and pile were such that it was unnecessary to refocus the image when changing from one wave-length to another, further assuring exact equivalence throughout a run of the light incident on filament and pile. Thermopile readings were taken by means of a Kipp type ZC galvanometer with a scale distance of 6 meters.

Pressures were measured by either a McLeod gauge or an ionization manometer of the Dushman-Found[1] type which read to 1×10^{-8} mm of mercury. Usual precautions were taken to avoid waxed joints and the only stopcocks were on the low pressure side of the system separated by two liquid air traps from the tube. The second trap, nearest the tube, was immersed in liquid air, only after the major portion of the outgassing process was complete.

The gold from which the filaments were rolled was obtained from the Bureau of Standards. Although no analysis was given it was stated to be the purest obtainable at any of the government mints.

Procedure

The ionization gauge was outgassed and the rest of the vacuum system thoroughly torched for a week before the tube was sealed on. During this time the molybdenum cylinder was bombarded at a cherry red for 40 hours in a separate system. The filament was carefully cleaned with absolute alcohol and the tube was then assembled and sealed on to the system with the cylinder at atmospheric pressure for only a short time.

After initial photoelectric readings were taken the filament was heated by gradually increasing currents, with frequent stops to check variations in sensitivity and associated long wave-length limit. Then the tube was baked for 100 hours at 470°C, the filament being maintained at a slightly higher tem-

[1] Dushman and Found, Phys. Rev. **23**, 734 (1924).

perature by a small heating current. During this period the vacuum system and mercury columns received frequent and vigorous torchings. The filament was then glowed at 600°C to 700°C for many hundreds of hours. Temperatures were based on the measured variation of resistance of the gold filament in combination with data given by Northrup[2] on the temperature variation of the resistivity of gold. With the placing of liquid air on the second trap pressures of 1×10^{-8} were reached and maintained throughout the experiment.

Long wave-length limits were measured in the initial stages by glass filters and various organic solutions indicated by Dahm,[3] their transmission being checked on a quartz spectrograph. Later the monochromator was used, while for the last run the monochromator and thermopile arrangement described above was employed. In these determinations the electrometer was used with rate of charge at from 20,000 to 40,000 mm per volt.

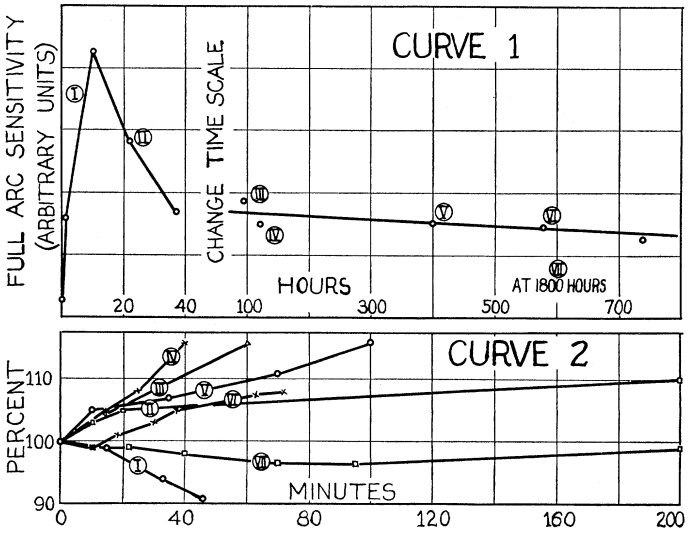

Fig. 1. Curve 1. Variation of full-arc sensitivity in arbitrary units as a function of outgassing time.
Curve 2. Variation of photo-sensitivity with time of standing after heating current is stopped expressed in percent of initial sensitivity.

Results

The results obtained during the outgassing process are summarized in Fig. 1. Curve 1 portrays the change in photoelectric full-arc sensitivity with increasing time of outgassing. The initial period is pictured on an enlarged scale to show better the rapid variation which takes place at first heating. The term "outgassing" is used to cover both glowing of the filament at 650°C and also baking. In the early stages low filament currents were used and the

[2] Northrup, Jour. Frank. Inst. **177,** 287 (1914).
[3] Dahm, Jour. Opt. Soc. **15,** 266 (1927).

time scale is adjusted to equalize roughly their unequal heating effects. That is, 5 hours with 2 amperes heating current is plotted as one hour for the first reading, 20 hours at 3 amperes as 9 hours, etc.

In the initial stages of outgassing the sensitivity changes gradually after the heating current is stopped. This phenomenon, frequently called fatigue, is believed to be due to the gas layer being reformed on the surface of the metal. Curve 2 shows the behavior of these fatigue curves during outgassing. There is a rapid change in sensitivity when the heating current is stopped due to the filament cooling. At the end of five minutes this change is negligible, however, and the curves shown here are plotted as percent of the deflection five minutes after the heating ceases. The Roman numerals on the fatigue curves correspond to the time as shown by corresponding numerals on curve 1.

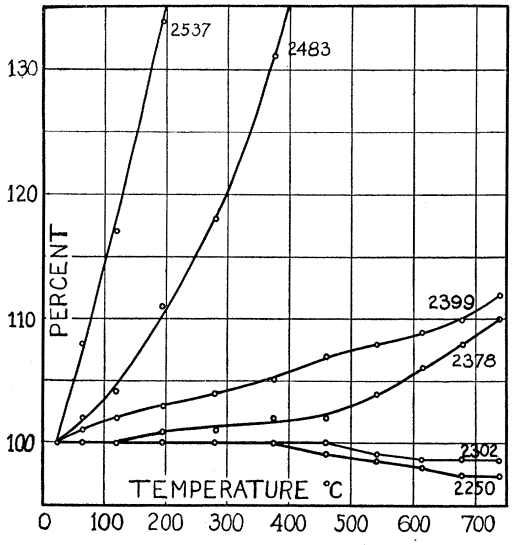

Fig. 2. Variation of line sensitivity with temperature expressed in percent of sensitivity at room temperature.

Two things are of interest here. Fatigue curve I which was taken on the upward slope of curve 1 shows negative fatigue as would be reasonable to expect. The others show a systematic change, rising to a maximum positive fatigue in IV and returning to practically zero fatigue in VII. Fatigue curves taken with monochromator on individual lines at same time as VII also show small fatigue. The pressure at this time was 1×10^{-8} mm and the ionization gauge showed no difference in pressure with the filament hot or cold, although in the earlier stages large changes resulted upon starting the heating currents.

The change in long wave-length limit observed during the run was consistent with the variation in the full-arc sensitivity. The long wave limit rose rapidly upon outgassing from a value in the neighborhood of 2000A at the start to 3200A at the point of greatest sensitivity. From then on it moved towards shorter wave-lengths as the full-arc sensitivity decreased.

Tests made throughout the outgassing process demonstrated a shift in long wave limit towards longer wave-lengths with increasing temperature. During intermediate stages determinations made with both absorption cells and monochromator were in good agreement and showed a shift of 200A approximately linear with temperature between 20°C and 640°C.

The full-arc deflections were at all times temperature sensitive and showed a marked decrease between 550°C and 740°C to a value well below that at room temperature. This, of course, represented the integrated result of the change in wave-length sensitivity throughout the effective spectrum. The results of a study of the variation of the individual line sensitivity with temperature are given in Fig. 2.

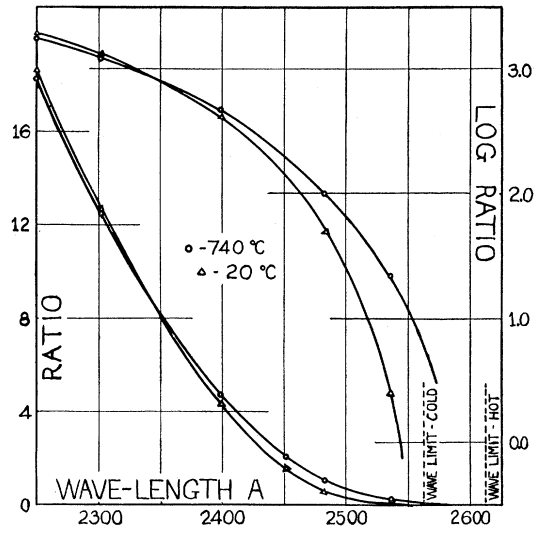

Fig. 3. Ratio of photo-current to incident light intensity and its logarithm as a function of the wave-length of incident light.

The double monochromator was used at slit widths of 0.6 mm, comparison tests made with a spectrograph showing the purity obtained to be equivalent to that of a single monochromator using slit widths of 0.2 mm or less. Coincident measurement of the line intensities by means of the thermopile arrangement mentioned earlier, in connection with the curves in Fig. 2, form the basis for the long wave-length determinations shown in Fig. 3. Due to difficulty of plotting the points for intermediate temperatures only the curves for room temperature and 740° are shown. The omitted points fall in order between these extremes and would have yielded a family of curves lying within those shown. More recent research in these laboratories on tantalum and silver by Cardwell[4] and Winch,[5] respectively, have yielded curves of

[4] Not yet published.

[5] Winch, Phys. Rev. **37**, 1269 (1931). Next paper in this issue.

the same general character. In fact, this type of behavior was presaged by earlier work of Ives[6] and Hornbeck[7] on potassium.

The marked increase in sensitivity for the longer wave-length lines (eightfold for 2537 between room temperature and 740°) is to be expected from their proximity to the long wave limit which changes with increase in temperature. That this increase is not due to a change in reflecting power appears probable from the results obtained by Winch, mentioned above. He observed similar curves for silver and found no change in reflecting power with temperature for any of the wave-lengths used. It is planned to investigate this for gold in future work.

As for Fig. 3, the observed shift in the long wave-length limit and the extended toe of the high temperature curve may be the direct result of the increased kinetic energy of the conduction electrons. The shape of the curve renders an exact determination of the long wave limit difficult. The log-curves would yield 2560A cold and 2610A at 740° as probable values. Present experiments with an arc of extremely high intensity promise to allow the use of much smaller slit-widths that may more accurately define these threshold values.

In conclusion, the author wishes to express his indebtedness to Dr. C. E. Mendenhall under whose direction the work was done.

[6] Ives, J.O.S.A. and R.S.I. **11,** 565 (1925).
[7] Hornbeck, Phys. Rev. **24,** 631 (1924).