THE DISPERSION OF THE OPTICAL CONSTANTS OF MERCURY

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Abstract

Measurements were made on clean mercury surfaces prepared by the method of Roentgen as used by Wheeler. The optical constants were determined *for the range* 4358 *to* 3022*A* using the method of Jamin. Light from a mercury arc was dispersed by a quartz spectroscope of the Littrow type with a fused silicon mirror to reduce scattered visible light, and a phosphorescent screen or fluorescent solution was used in making the readings. The results for *refractive index n, absorption coefficient nk* and computed percentage *reflectivity R* at normal incidence, are as follows:

	4358	4047	3650	3130	3022
n	0.88	0.79	0.64	0.44	0.55
nk	3.47	3.40	2.97	2.53	2.25
R	77	78	78	79	70

The beginning of a region of transparency is apparently indicated at 3022A.

Introduction

THE effects of slight surface films on values obtained for the optical constants of metals by katoptric methods was pointed out by Voigt.[1] To eliminate such films Drude[2] attempted to specify a so-called "normal" surface, but large inconsistencies still remained in his results even among successive measurements on the same reflecting surface. Minor,[3] Meier,[4] Tool,[5] Ingersoll,[6] and Tate[7] have measured the optical constants of several of the metals from wave-length 2500A (Minor) to wave-length 2.25μ (Ingersoll). The values obtained have been collected by Wheeler.[8] He has pointed out that while different observers are in good agreement as to the amount and trend of the dispersion of the refractive index and absorption coefficient of a particular metal over a given region, they are not in good agreement on the absolute magnitude of these constants.

Wheeler[9] has measured the refractive index of several transparent liquids in contact with mercury by the reflection method, using Roent-

[1] Voigt, Wied. Ann. **24,** Wied. Ann. **25,** (1885).
[2] Drude, Wied. Ann. **36,** 885; Wied. Ann. **39,** 481 (1899-1900).
[3] Minor, Ann. d. Physik **10,** 591 (1903).
[4] Meier, Ann. d. Physik **31,** 1017 (1910).
[5] Tool, Phys. Rev. **31,** 1 (1910).
[6] Ingersoll, Astrophys. J. **32,** 265 (1910).
[7] Tate, Phys. Rev. **33,** 321 (1912).
[8] Wheeler, Am. J. Sci. **35,** 491 (1913).
[9] Wheeler, Phil. Mag, **22,** 229 (1911); Am. J. Sci. **32,** 85 (1911).

gen's[10] modification of the method suggested by Rayleigh[11] to clean the surface of contact between the mercury and the transparent liquid. Differing from those of previous observers, his results are very consistent, and agree in the third place with values of the refractive index of the same liquids determined by the usual methods. It would appear therefore, that all contaminating films at the metal-liquid surface were eliminated. He has also measured the optical constants of mercury in air over a portion of the visible spectrum.[12]

The present investigation was undertaken to determine the optical constants of a mercury surface, cleaned in this manner, from the violet as far into the ultraviolet as feasible.

Method and Apparatus

The optical constants were determined by the usual method of measuring the ellipticity introduced into plane polarized light by reflection from the metal surface. The theory of the method has been given in detail by Drude.[2] If the incident light is plane polarized at an angle of 45° with the plane of incidence, if $\varphi \equiv$ the angle of incidence, $\Delta \equiv$ the phase difference after reflection between the components parallel and perpendicular to the plane of incidence, and $\psi \equiv$ the azimuth of the restored plane of polarization, then if we write

$$\tan Q \equiv \sin \Delta \tan 2\psi \; ; \qquad \cos P \equiv \cos \Delta \sin 2\psi \; ;$$

$$S \equiv \tan \tfrac{1}{2} P \sin \varphi \tan \varphi \; ;$$

we get to a second approximation

$$n = S \cos Q(1 + \sin^2\varphi / 2 S^2)$$

$$nk = S \sin Q(1 - \sin^2\varphi / 2 S^2)$$

$$k = \tan Q(1 - \sin^2\varphi / S^2)$$

where n is the refractive index and nk the absorption coefficient.

A spectrometer by the Société Genevôise, arranged so that the table could be swung to a vertical position to accommodate a horizontal mirror, was used as Jamin circle. The divided circle could be read to 20″ of arc. The polarizer and analyzer prisms were of the uncemented straight end type (Foucault-Glan), and their positions could be read to 0.1°. The compensator was of the Babinet-Soleil type, giving a uniform field instead of bands as in the original Babinet form. The movement of its

[10] Roentgen, Wied. Ann. **46,** 152 (1892).
[11] Rayleigh, Phil. Mag. (5) **30,** 392 (1890).
[12] O'Brien and Wheeler, Phys. Rev. (2) **21,** 376, Abs. 26 (1923).

wedge could be read to 0.0025 mm, which corresponded to an increment in Δ of 0.19° at the longest and 0.30° at the shortest wave-length used.

The source of light was a mercury arc in quartz, and a small quartz spectroscope of the Littrow type, which was built in this laboratory, was used as monochromatic illuminator. The reflector of the spectroscope was of fused silicon in place of the usual tin amalgam, the high ultraviolet and low visible reflectivity of the silicon reducing the effect of scattered visible light in the field.

The optical system is shown in Fig. 1. The mercury arc I was placed very close to the slit S_1 to eliminate a condensing lens. After passing through the analyzer the light was brought to a focus by the quartz lens L_3 on a fluorescent target F which was viewed from the side through an eyepiece E.

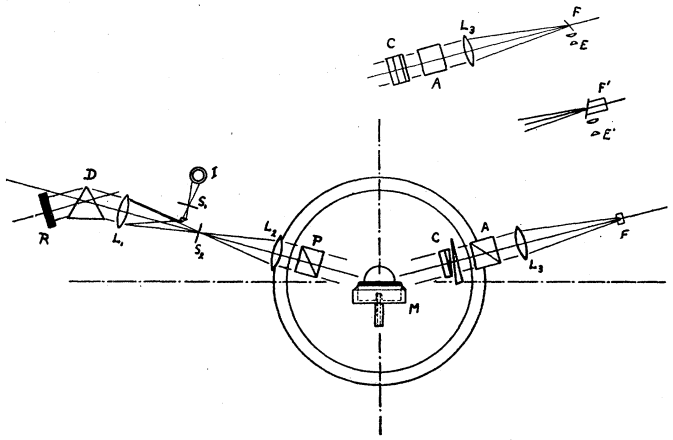

Fig. 1. The optical system.

A phosphorescent screen of very short period, and also a cell filled with a fluorescent solution were used. The screen consisted of varnished mica on which was dusted finely powdered potassium uranyl sulphate while the varnish was still "tacky." The cell was cylindrical, of glass, with a quartz end, and was filled with a very dilute aqueous solution of uranin, the sodium salt of fluorescein. The end of the cell on which was mounted the quartz window was cut obliquely so that the plane of the window made an angle of about 60° with the axis of the cell. The screen, when used, was placed as shown at F in Fig. 1. The cell, when used, was placed as shown at F' in Fig. 1, with its axis coincident with the optic axis of the lens L_3 and with the quartz window turned obliquely away from the eyepiece E' so that the solution immediately behind the window was viewed through the glass side-wall. The screen gave the more brilliant

image, but the cell was preferable at certain settings where there was appreciable scattered visible light in the field. The maximum intensity of emitted light from both potassium uranyl sulphate and uranin lies at about the same wave-length as the maximum of visual sensitivity for faint illumination. This, together with their intense fluorescence, makes these materials particularly suitable for fluorescent eye pieces.

The whole system was enclosed in a light tight housing, and care was taken to exclude all light from the room. The eyes were rested in total darkness before each set of readings, and it was found possible to set the compensator and analyzer quite sharply to the position of quenching.

The surface cleaning apparatus was the one used by Wheeler,[8] with a few minor refinements. This has been described in detail by him. The mercury used had been electrolytically purified and distilled, and was the purest available. Precautions were taken to avoid contamination, the mercury coming in contact only with glass, "pure gum" rubber tubing, and iron, all of which were carefully cleaned. The mercury pool is shown diagrammatically at *M*, Fig. 1, the surrounding cup, upper and lower mercury reservoirs, etc., being omitted. Simply allowing mercury to run in through the nozzle in the center of the pool and overflow the rim, which was ground to a knife edge, produced an exceedingly clean surface, as shown by the consistency with which readings could be repeated on successive surfaces.

Measurements

The lines of the mercury arc which were used were identified by taking the interval between them from a plate made with a spectrograph of similar dispersing system. The plane of polarization of the polarizing prisms was determined by reflecting light from a distilled water surface at the polarizing angle, the water surface having been cleaned by the method described above for mercury. The divided circles of the prisms were investigated for uniformity of scale. The compensator was calibrated over the full range of motion of its wedge at each wave-length used. The angle of incidence was made 74° 50′, which is close to the principal angles of incidence for mercury at the wave-lengths used, and was checked by two methods. Readings were taken with the polarizer both right and left of the plane of incidence in each series, and at both 0° and 180° quenching points along the full travel of the compensator wedge.

Observations were made in still air quite free from dust, and the mercury surface was cleaned every five minutes, although no change in constants could be detected in a surface standing as long as fifteen minutes. Measurements were repeated to within the probable error of

observation over a period of several months, and it is believed that surfaces were obtained free from all contaminating films, the figures representing absolute values for the metal itself. The temperature of the room and of the mercury remained between 20.0° and 22.0°C throughout the period of observation.

The results obtained, together with the probable errors, are given in Table I and are shown graphically in Fig. 2. The values of n and nk were computed from the formulas given above, and the reflectivity at normal incidence, R, from the formula

$$R=\frac{n^2(1+k^2)+1-2n}{n^2(1+k^2)+1+2n}.$$

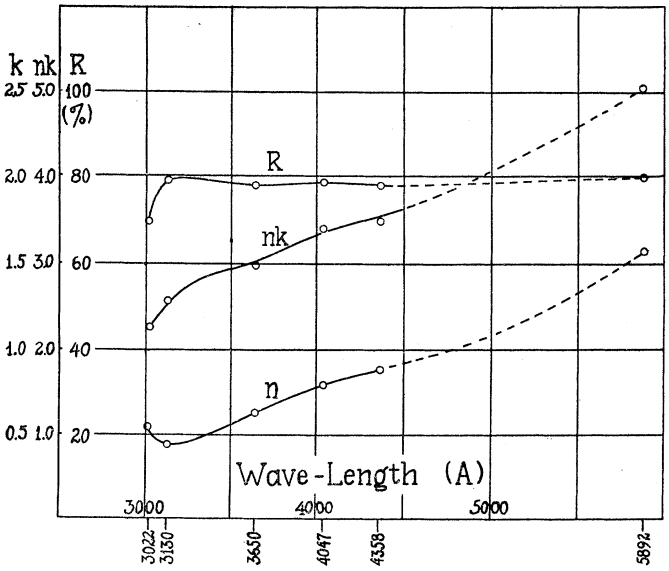

Fig. 2. The optical constants of mercury as a function of wave-length.

The figures in parentheses were computed from values of Q, P, and S, at wave-length 5892A, and for $\varphi=60°$, given by Wheeler.[8] He has also

TABLE I

Optical constants of mercury in air

λ	φ^0	Δ^0	ψ^0	n	nk	R(calc)
(5892A)*	(60.00)	(149.73±0.07)	(40.67±0.09)	(1.57)	(5.05)	(79.6)%
4358	74.83	92.2 ±0.18	38.3±0.09	0.88±0.01	3.47±0.01	77.1±0.4
4047	74.83	90.7 ±0.18	38.9±0.16	0.79±0.03	3.40±0.02	78.5±0.8
3650	74.83	83.3 ±0.15	39.5±0.10	0.64±0.01	2.97±0.01	77.7±0.7
3130	74.83	74.7 ±0.23	40.8±0.12	0.44±0.01	2.53±0.02	78.9±0.9
3022	74.83	69.4 ±0.48	39.4±0.16	0.55±0.01	2.25±0.03	69.7±1.4

* Results for this wave-length are from measurements by Wheeler.[8]

measured[12] the constants of mercury at wave-lengths 5770, 5461, and 4358A. The present result for 4358A is in good agreement with his. Settings were made at wave-length 4047A both by the direct visual method and with the phosphorescent screen, and agree within the probable error.

It is of interest to note from the trend of the curves at the shortest wave-length investigated, that we are apparently approaching a region of transparency similar to that found for silver at slightly longer wave-length.

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