# NATIONAL BUREAU OF STANDARDS REPORT

8014

# A New Standard of Spectral Irradiance

by
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NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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## ABSTRACT

The National Bureau of Standards has made available a new standard of spectral irradiance in the form of a 200-watt quartz-iodine lamp with a coiled-coil tungsten filament operating at about 3000°K and calibrated over the spectral range of 0.25 to 2.6 microns. The calibration of this standard is based upon the radiance of a blackbody as defined by the Planck law of radiation since it was done by comparisons with the NBS standards of spectral radiance, of luminous intensity, and of total irradiance, each of which was established through the use of blackbodies. This standard is used without auxiliary optics. Because of its small physical size and high operating temperature, relatively high spectral irradiances may be obtained through its use.

## 1. INTRODUCTION

The precise measurement of irradiance from a source requires the use of a calibrated detector or a calibrated source which may be employed in a transfer calibration. The need for a calibrated source was originally met by Coblentz [1] in 1914 with the development of a carbon filament standard of total irradiance. Calibration and use of this type of standard has been subsequently reported by Coblentz and other personnel of the NBS Radiometry Laboratory [2-4]. Accurate calibration with this type of standard requires a detector with a non-selective spectral response. A thermopile heavily coated with dull lampblack or carbon black meets this requirement reasonably well from the near ultraviolet through the visible and near infrared portions of the spectrum. However, the relatively low sensitivity of thermopiles and other thermal detectors together with the fact that they are not entirely non-selective spectrally makes their use difficult for the evaluation of the spectral distribution of radiant flux.

Considerable work has been done on the emissivity of tungsten ribbon and filament wire [5], and, coupled with measurements of temperature, an approximate standard of spectral radiance or of spectral irradiance can be set up. A number of laboratories including the NBS have followed this procedure [12-17]. In 1960 the National Bureau of Standards developed a standard of spectral radiance [18] in the form of a tungsten ribbon-filament lamp calibrated by direct comparison with a blackbody, the spectral radiance of which is computed from Planck's radiation equation. These lamp standards have found wide use in the calibration of spectroradiometric and other equipment in which a small area, like a slit, is to be irradiated. However, the use of this standard is limited by the small area which can be irradiated, by the low irradiance which the standard provides in the ultraviolet, and by the auxiliary optics required. For many types of spectroradiometric calibration, a standard of spectral radiance has been found to be very useful and will no doubt continue to be useful. However, in many cases, a standard of spectral irradiance is needed. To fulfill this need and to provide a source of higher irradiance in the ultraviolet, a new standard of spectral irradiance has been developed.

## 2. Apparatus and Method.

Before proceeding with the establishment of a standard of spectral irradiance for the region of 0.25 to 2.6 microns based upon the radiance of a blackbody at a known temperature, a study was made of possible lamp designs. First thought was given to the specially constructed tungsten-in-quartz lamp previously employed in this laboratory [12-13] as a standard of spectral irradiance based upon color temperature and the published spectral emissivity data for tungsten. It was recognized that this lamp had three principal deficiencies; namely, its low operating temperature, poor optical quality and bulkiness of the quartz envelope, and relatively large filament area. Only very low ultraviolet irradiances could be realized at a spectrometer slit. Also, since each tungsten filament differs somewhat in emissivity as a function of its specific shape and surface condition the computed values of spectral irradiance were uncertain by an indefinite amount.

Attention was given next to lamps being made commercially. The General Electric (GE) Model 6.6A/T4Q/1CL-200-watt quartz-iodine lamp (See figure 1) was examined and found to have acceptable characteristics for use as a standard. It is of robust construction, in a small quartz envelope of relatively good optical quality so that the intensity usually varies but little over a considerable solid angle centered normal to the axis of the lamp. The filament is a compact coiled coil with overall dimensions approximating 1/8 by 1/2 inch. The small size of the lamp envelope (about 1/2 x 2 inches) together with the small area of the filament permits placing the lamp within a few inches of the slit of a spectrometer. Since this lamp is being set up as a standard of spectral irradiance to be employed without auxiliary optics, relatively high irradiance at a slit can be realized simply by placing the source close to it.

Because of its high operating temperature, the quartz-iodine lamp emits a relatively large percentage of ultraviolet radiation. The high temperature is made possible through the unique chemical action of the iodine vapor [19,20] which results in the return of evaporated tungsten from the bulb to the lamp filament, thereby keeping the envelope clean and prolonging the useful life of the lamp. The design life of this lamp when operated at 6.6 amperes is 500 hours. For calibration as a standard the current is set at 6.50 amperes which usually gives a color temperature between 3000° and 3100°K, corresponding to a filament temperature around 3000°K.

The establishment of the new standard of spectral irradiance was accomplished by comparing a group of quartz-iodine lamps with three other types of NBS standards, each of which is based upon the spectral radiance of a blackbody computed from Planck's radiation equation wherein radiation constants, $C_1 = 1.19088 \times 10^{-12}$ watt - cm$^2$/ster and $C_2 = 14380$ cm - °K.

The group of quartz-iodine lamps was first compared spectroradiometrically with the NBS standards of spectral radiance [18/] The optical arrangement is shown in figure 2. Additional details may be found in the reference cited. To cover the complete spectrum from 0.25 to 2.6 microns, three detectors were employed. An RCA type 1P-28 multiplier phototube was used to cover the range from 0.25 to 0.75 micron. For the range of 0.35 to 1.2 microns an RCA type 7102 multiplier phototube was employed, while an Eastman PbS cell was used through the range of 0.5 to 2.6 microns. To eliminate the effect of spectral reflectance of the two aluminized mirrors employed with the ribbon-filament standards of spectral radiance, two plane mirrors having identically prepared surfaces were used with the quartz-iodine lamps. Actually, plane mirror $M_1$ was common to both optical systems (See figure 2). By this procedure all instrumental characteristics were identical or closely similar for the two types of lamps. Hence, the optical and electronic factors should cancel out in the procedure. However, it was found that the light beam from the quartz-iodine lamp passed through the spectroradiometer somewhat differently and irradiated a slightly different area of the detector from that irradiated by the ribbon-filament standard. The beam of flux from the ribbon filament converged on entering the spectrometer, then diverged filling an appreciable part of the instrumental aperture, and finally at the exit slit emerged as a divergent beam. The flux from the quartz-iodine lamp passed through the spectrometer and emerged as an essentially narrow "pencil" of flux thereby being confined to a small part of the instrumental aperture and falling upon a small area of the detector. As a result, differential transmission within the spectrometer and variations in the sensitivity of the detector over its surface area* resulted in small errors of unknown magnitude. Hence, the resulting spectral energy curves for the quartz-iodine lamps, obtained by this method, require adjustment.

Three methods for determining the correction for the observed data were pursued. They are:

(a) Direct comparison, without the use of a spectrometer, of the quartz-iodine lamps with the ribbon-filament lamps by a thermopile and filter method, wherein selected spectral regions were compared radiometrically. This comparison was accomplished by focusing an image of the ribbon filament on the receiver of the thermopile by means of the two aluminum mirrors usually employed with the standard of spectral radiance. The quartz-iodine lamp directly irradiated the thermopile receiver. Correction was made for the spectral reflectance of the two aluminum mirrors. The ratio between the two radiometric readings gave a measure of the relative spectral intensities of

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*Much of the variation of the detector sensitivity was eliminated by placing in front of it a quartz plate finely ground on both faces.

the two sources for the different spectral regions defined by the filters employed.

(b). Measurement of luminous intensity as compared to calculated luminous intensity based upon the spectroradiometrically determined curve and the spectral luminous efficacy of the CIE standard observer. This method gave an independent evaluation of the spectral irradiance of the quartz-iodine lamps in the visible spectrum based upon NBS standards of luminous intensity, which had been assigned values by measurements relative to a blackbody at the freezing point of platinum 21/.

(c) Measurement of irradiances over selected spectral regions by employing optical filters and a thermopile found by comparison with a cavity detector to have a relatively flat spectral response and calibrated through the use of the NBS carbon-filament standard of total radiation. This method afforded an independent evaluation of the spectral irradiance from the quartz-iodine lamps based upon the NBS standard of total irradiance and the blackbodies used in its establishment 1,2/. Corrections ranging from 4.2 to 5.3 percent and non-selective with wavelength were indicated by the three methods. The original spectroradiometric data were accordingly corrected by 5.0 percent.

## 3. Results.

Spectral irradiance data obtained on three quartz-iodine lamps are given in table 1 in microwatts per square centimeter at a distance of 43 centimeters (measured from the axis of the lamp filament and normal to the plane of the lamp press) for a wavelength interval of 1 nanometer. It is estimated that the maximum uncertainty in the results ranges from about 8 percent at the shortest wavelengths in the ultraviolet to about 3 percent in the visible and infrared. The data have been corrected for the water-vapor absorption occurring at or near 1.1, 1.4, 1.9, and 2.6 microns. No significant radiant-energy absorption occurs at other wavelengths because of other gases normally present in the usual laboratory environment.

The quartz-iodine lamps may be employed at any convenient distance by computing or otherwise determining the irradiance at the new distance. The inverse square law should not be applied to these lamps for distances shorter than about 40 centimeters. In most laboratory atmospheres the correction for water-vapor absorption will be small for distances of less than 50 centimeters. However, for greater distances and under conditions of high humidity a correction may be required 22-26/. The relationship between the apparent absorption of water vapor (as indicated in a prism spectrum) and the amount of vapor is not a simple one since each absorption band really consists of many lines of unequal intensity and irregularly spaced. Furthermore, the attenuation at any wavelength due to water vapor is a complicated function of the pressure, temperature, and concentration of the vapor per unit volume.

Aging tests conducted on three quartz-iodine lamps indicate after 100 hours of operation an increase at 6.50 amperes of less than one percent in total irradiance, luminous intensity, and ultraviolet irradiance around 360 nanometers.

## 4. Use of the Standard of Spectral Irradiance.

Each quartz-iodine standard is marked with an identifying number at one end of the lamp. The lamp is mounted in a metal support and is calibrated with this marked end down and with the plane of the front surface of the lower press seal set to contain the horizontal perpendicular to the line connecting the lamp filament axis and detector or spectrometer slit. The lamp tip seal is positioned away from the detector or slit. Precise setting of the lamp as regards to verticality and to rotation about the filament as an axis are important since a few degrees displacement may result in an error of one percent or more.

The current is set at 6.50 amperes a.c. and the lamp is allowed to operate for at least 5 minutes before data are recorded. Any convenient method may be employed to control the current; however, the circuit illustrated in figure 3 has been found very useful in this laboratory. It consists of two variable autotransformers (10 ampere and 5 ampere capacities) and a radio filament transformer. (One half of a center-tapped 5- or 6.3-volt secondary has been found to be satisfactory for smooth current control). If a 30-volt step-down transformer is available it may profitably be used between the variable autotransformer, T-1, and the lamp.

## 5. Conclusions.

The quartz-iodine lamp is a useful working standard for use in spectral irradiance measurements within the region of 0.25 to 2.6 microns. The methods of calibration are based upon indirect comparisons with the radiances of blackbodies and thus do not involve evaluation of filament temperature or tungsten emissivity. The principal uncertainties in the results are due to difficulties involved in accurate blackbody high-temperature evaluation and precise current settings for the various lamps. The maximum uncertainty in the results is estimated to range from about 8 percent at the shortest wavelengths in the ultraviolet to about 3 percent in the visible and infrared.

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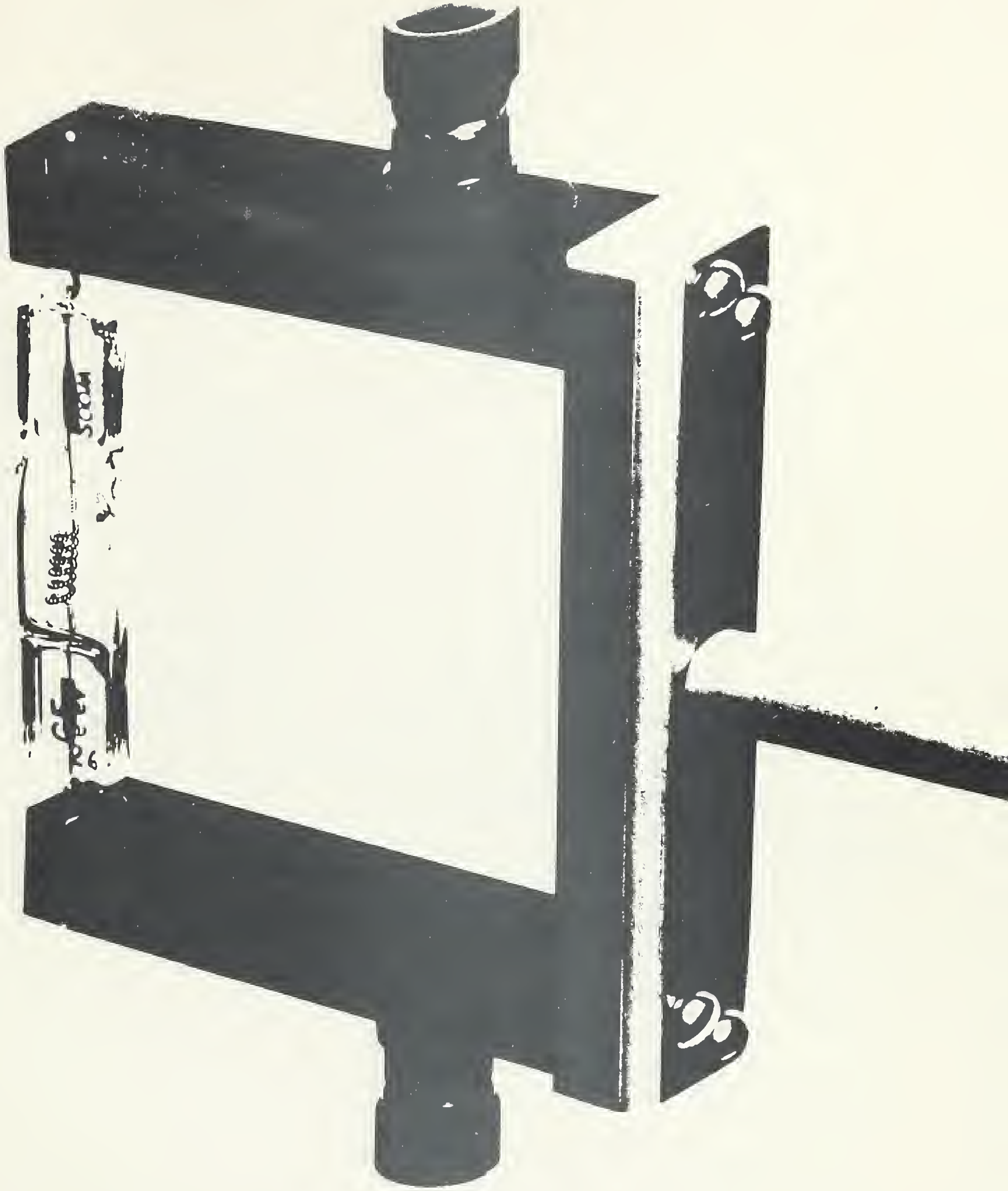

Figure 1. Quartz-iodine lamp standard of spectral irradiance.

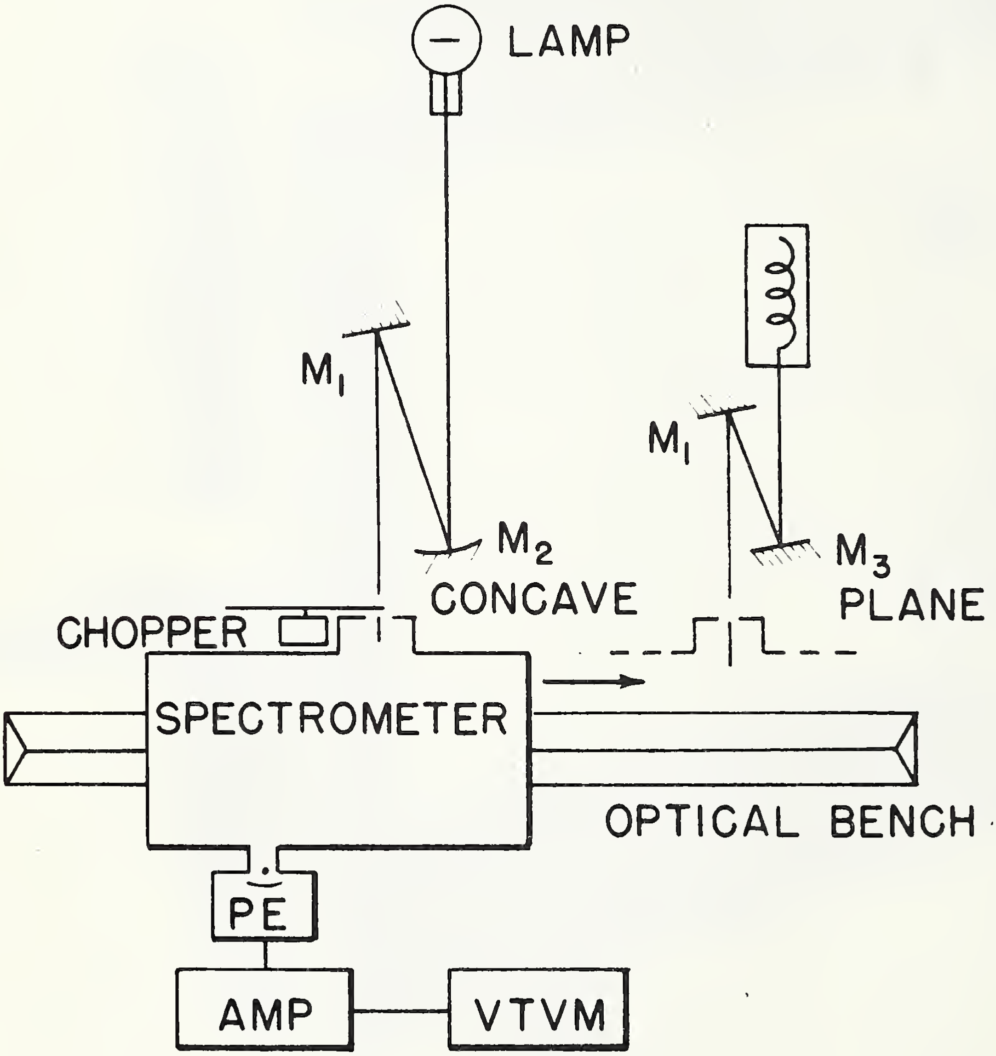

Figure 2. Optical arrangement of spectrometer, lamp, mirrors and associated equipment for comparing the quartz-iodine lamp standards of spectral irradiance with the ribbon-filament standards of spectral radiance.

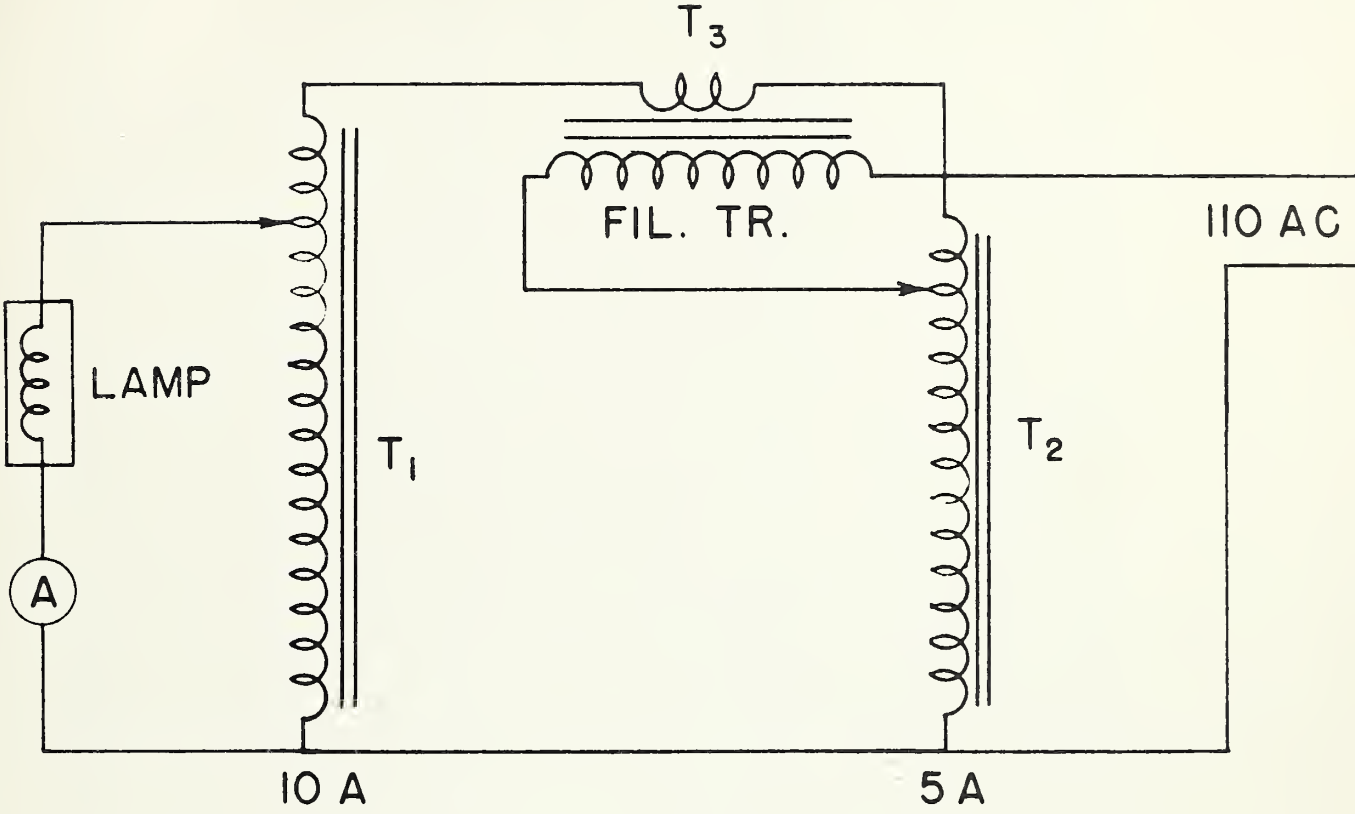

Figure 3. Electrical circuit for lamp operation to provide smooth current control.

Table 1. Spectral irradiance of three 200-watt quartz-iodine tungsten-filament lamps in microwatts per ($cm^2$-nanometer) at a distance of 43 cm (measured from the axis of the lamp filament and normal to the plane of the lamp press) when operated at 6.50 amperes.

| Wavelength nm | Lamp QL-2 | Lamp QL-5 | Lamp QL-10 |
|---|---|---|---|
| 250 | 0.0051 | 0.0052 | 0.0051 |
| 260 | .0093 | .0093 | .0090 |
| 270 | .0158 | .0159 | .0155 |
| 280 | .0253 | .0252 | .0244 |
| 290 | .0380 | .0380 | .0369 |
| 300 | .0545 | .0548 | .0532 |
| 320 | .104 | .105 | .102 |
| 350 | .237 | .242 | .234 |
| 370 | .366 | .374 | .363 |
| 400 | .643 | .647 | .630 |
| 450 | 1.26 | 1.26 | 1.23 |
| 500 | 2.04 | 2.04 | 2.02 |
| 550 | 2.93 | 2.96 | 2.91 |
| 600 | 3.88 | 3.94 | 3.88 |
| 650 | 4.79 | 4.91 | 4.80 |
| 700 | 5.54 | 5.72 | 5.58 |
| 750 | 6.11 | 6.32 | 6.14 |
| 800 | 6.51 | 6.69 | 6.49 |
| 900 | 6.72 | 6.94 | 6.71 |
| 1000 | 6.51 | 6.73 | 6.53 |
| 1100 | 6.07 | 6.25 | 6.11 |
| 1200 | 5.53 | 5.67 | 5.55 |
| 1300 | 4.97 | 5.09 | 4.98 |
| 1400 | 4.44 | 4.52 | 4.44 |
| 1500 | 3.93 | 4.00 | 3.93 |
| 1600 | 3.46 | 3.51 | 3.45 |
| 1700 | 3.03 | 3.06 | 3.01 |
| 1800 | 2.63 | 2.65 | 2.61 |
| 1900 | 2.29 | 2.28 | 2.26 |
| 2000 | 1.98 | 1.97 | 1.95 |
| 2100 | 1.73 | 1.71 | 1.70 |
| 2200 | 1.52 | 1.51 | 1.50 |
| 2300 | 1.36 | 1.34 | 1.33 |
| 2400 | 1.22 | 1.21 | 1.21 |
| 2500 | 1.12 | 1.10 | 1.11 |
| 2600 | 1.04 | 1.03 | 1.04 |

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**Metrology.** Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Volume.

**Heat.** Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

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**Office of Weights and Measures.**

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