NATIONAL BUREAU OF STANDARDS REPORT

6979

on
Lamps for International Intercomparisons
to be Carried Out at
Bureau International Des Poids et Mesures

by
Ray P. Teele
Harry K. Hammond III
Warren L. Holford

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. Research projects are also performed for other government agencies when the work relates to and supplements the basic program of the Bureau or when the Bureau’s unique competence is required. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

Publications

The results of the Bureau’s work take the form of either actual equipment and devices or published papers. These papers appear either in the Bureau’s own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three periodicals available from the Government Printing Office: The Journal of Research, published in four separate sections, presents complete scientific and technical papers; the Technical News Bulletin presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: Monographs, Applied Mathematics Series, Handbooks, Miscellaneous Publications, and Technical Notes.

Information on the Bureau’s publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($1.50), available from the Superintendent of Documents, Government Printing Office, Washington 25, D.C.
Lamps for International Intercomparisons to be Carried Out at Bureau International Des Poids et Mesures

by
Ray P. Teele
Harry K. Hammond III
Warren L. Holford
Photometry and Colorimetry Section
Metrology Division

IMPORTANT NOTICE

Approved for public release by the director of the National Institute of Standards and Technology (NIST) on October 9, 2015

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
THE LUMINOUS INTENSITY OF 18 LAMPS
AND
THE LUMINOUS FLUX OF 8 LAMPS
FOR
INTERCOMPARISONS TO BE CARRIED OUT
AT
BUREAU INTERNATIONAL DES POIDS ET MESURES

by
Ray P. Teele
Harry K. Hammond III
Warren L. Holford

1. PURPOSE

This report describes the standards and comparison methods and gives the results of the 1960 calibration on groups of lamps transmitted to BIPM. These groups of lamps embody the United States photometric units maintained at the National Bureau of Standards for: (1) The candela at 2042°K, (2) the candela at 2353°K, (3) the candela at 2854°K, (4) the lumen at 2353°K, and (5) the lumen at 2788°K.

2. LAMPS

The lamps are all of special construction. The lamps designated by the prefix letters TS were manufactured in Japan where their manufacture was in accord with the specifications of the Electrotechnical Laboratory. The lamps calibrated for luminous intensity at 2042°K and 2353°K, except for the TS lamps, and the lamps calibrated for luminous flux at 2353°K and 2788°K were made in France where their manufacture was supervised by the Bureau International Des Poids et Mesures. The lamps calibrated for luminous intensity at 2854°K were made in the United States.

3. STANDARDS

Each group of lamps was calibrated in terms of the NBS group of reference standards for the respective photometric unit maintained at the National Bureau of Standards. These NBS groups of reference standards are as follows:

(1) Candela at 2042°K. This group consists of lamps BS 2395, BS 2398, BS 2399, BS 2400, BS 2401, BS 2402, BS 2407, and BS 2270. These lamps were calibrated in 1937 against a blackbody radiator at the freezing point of platinum. The mean of the eight lamps is 16.817 candelas.
(2) Candela at 2353°K. This group consists of lamps BS 2987, BS 2988, BS 2989, BS 2990, BS 2991, BS 2992, BS 2993, BS 2994, and BS 2995. This group of standards is the current reference group and its mean value is on the same basis as the mean of the group of 5 lamps (BS 2987, BS 2990, BS 2991, BS 2992, and BS 2993) used as a base for results previously reported to the BIPM for the Second (1952) and Third (1957) Comparisons. The mean of the nine lamps is 33.408 candelas.

(3) Candela at 2854°K. This group consists of lamps NBS 922, NBS 923, NBS 924, NBS 925, NBS 926, and NBS 927. The mean of the six lamps is 536.2 candelas.

(4) Lumen at 2353°K. This group consists of lamps BS 5470, BS 5472, BS 5473, BS 5477, BS 5478, and BS 5485. The mean of the six lamps is 444.0 lumens.

(5) Lumen at 2788°K. In assigning values of luminous flux to the 2788°K group (lamps 3772, 3773, 3775, and 3776) we have followed an unusual procedure after study of the BIPM Reports on the First 1/Second 2/and Third 3/Comparisons of National Photometric Standards of Intensity and Flux. In the First (1948) Comparison, it will be noted (reference 1, p. 71) that the relative values for the size of the unit of flux at 2788°K were not listed. One of the reasons was the discrepancy of minus one percent in the measured flux of the three NBS lamps (group 2011) after their measurement at BIPM and subsequent return to NBS. Because of this discrepancy, another group of four NBS lamps (group 2288-2291) which had been measured by BIPM in June 1950 were sent by BIPM to NBS where they were measured and then returned to BIPM; their average NBS value was 2377 lumens (reference 1, p. 72 and reference 5). These same lamps with the same assigned values of luminous flux (reference 2, p. 95) were used in the Second (1952) Comparison. For the Third (1957) Comparison a new group of four lamps of French manufacture (group 3772-76) was submitted (reference 3, p. 84).

In the BIPM Note on the Unification of the Photometric Units (Reference 4, p. 105) use is made of the data recorded in the 1952 and 1957 Comparisons. In Table A of the Note NBS is shown as having a unit at 2788°K which is in accord (to within 0.1%) with the mean of the five laboratories listed in Table A. However, as indicated in NBS Report 3484, copy enclosed, the value of 2377 lumens (average) reported for the lamps in the 1952 Comparison was apparently high by 1.5 to 2.0%. In view of the adjustments made by three of the national laboratories (P.T.B., C.N.A.M., and E.T.L.) to bring their units into accord with the 1952 - 1957(x) mean listed at the bottom of Table X, reference 3, it is not deemed appropriate to request that the discrepancy in the 1952 average value (2377 lumens) be taken into account now. Instead, tentatively, and in anticipation of an early complete re-evaluation of our
photometric standards based upon measurements now in process, we are assigning values of luminous flux at 2788°K to the lamps in the Fourth Comparison and also to our own standards such that the unit of luminous flux at 2788°K equals the unit embodied in the 1952-1957(x) mean listed at the bottom of Table X, reference 3. To accomplish this we have increased the values assigned to our standards by the factor 1.013.

4. METHODS

To provide an index of reproducibility of results, the test lamps and the reference standards were compared at least three times by each of two staff groups using different electrical and photometric equipment.

Except for a series of measurements of the luminous intensity standards at 2854°K which were made with a thermoelectric photometer as discussed below, all measurements were made photo-electrically by using barrier-layer photocells equipped with filters to correct the spectral response to approximate that of the CIE photopic spectral luminous efficiency function. A modified form of the photometer described in NBS J. Research 25, 703 (December 1940), RP 1348, was used for all types of lamps. Measurements of luminous intensity at 2042°K and at 2353°K were also made with a "balance" circuit in which the currents of two photocells, one illuminated by the test lamp and one by a comparison lamp, are balanced by adjusting the distance between the comparison lamp and photocell; the relative lamp intensities were computed from the squares of the distances. Measurements of luminous intensity at 2854°K were also made by a modified form of the thermoelectric photometer, consisting of a thermopile and CIE photopic spectral luminous efficiency curve filter, described in NBS J. Research 27, 217 (September 1941), RP 1415.

Corrections were made for lack of linearity of all of the barrier-layer photocells used in this work.

(1) Luminous intensity. The luminous intensity measurements were made by a substitution method on a horizontal bar photometer with all lamps operating in a base down position. Each clear-bulb lamp was oriented by projecting the shadow of the filament by means of an auxiliary projector so that the plane of the filament was perpendicular to the photometer axis; the glass supporting structure was turned away from the photometer in those lamps having such a structure; the lamps with numbers preceded by TS were oriented with the arrow on the base toward the photometric receiver. The four inside-frosted lamp standards of intensity at 2854°K were aligned by use of a jig and bipost socket sent with the lamps to the BIPM. This jig was placed in the socket with the three pins on the top, a pair of pins on one side and a single pin diametrically opposed. The socket was
adjusted so that the shadow of the single pin fell midway between the shadow of the pair of pins. The projector producing the shadow was on a line at right angles to the photometric axis on the side of the single pin. After the socket was aligned both horizontally and vertically it was fastened in place. The bipost lamps were inserted for measurement in turn without further adjustment of the socket; each lamp was oriented with the base marking "AA-850" away from the photometer.

The photometric distance was 1.65 meters. For the clear-bulb lamps the distance was measured to the plane of the filament; for the frosted-bulb lamps the distance was measured to the plane which bisects the biposts of the base. The height of the socket was adjusted for each clear-bulb lamp so as to position the center of the filament on the photometric axis. For frosted-bulb lamps the height of the socket was adjusted by means of the jig so that the tops of the rods containing the pins were at the height of the photometric axis and the socket position then remained the same for each lamp.

(2) Luminous flux. The luminous flux measurements were made by a substitution method in a 60-inch and in an 85-inch integrating sphere. The lamps were operated in a base-up position.

A blue glass filter was used to compensate for the effect of spectral selectivity of the photometric spheres used for the measurement of flux. The required filter thickness (2.03mm) was determined by spectroradiometric measurement of the light from the sphere. A check of the compensating filter was made by visually evaluating the color temperature alteration of the light emitted by the sphere window, blue filter included. This check revealed that the temperature was altered by less than 100K.

5. RESULTS

The results are given in Tables A, B, C, D, and E. The uncertainty of the luminous value (intensity or flux) for each individual lamp was calculated at the 0.1 percent confidence level from the variations in the results in the several sets of measurements. The uncertainty of the average was also computed in this way. In addition, the uncertainty of the average was calculated from the square-root of the sum of the squares of the uncertainties of the values for the individual lamps divided by the number of lamps in the group. This second value of uncertainty for the group is given in parentheses in each table under the first value.
Table A. Luminous Intensity at 2042°K (BIPM 1951 Scale)
(2039°K NBS Scale). Distance 1.65 Meters. Base Down Position

<table>
<thead>
<tr>
<th>Lamp No.</th>
<th>Heat Up Time</th>
<th>Volts (set)</th>
<th>Amperes</th>
<th>Candelas</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBS3757</td>
<td>10</td>
<td>97.200</td>
<td>0.5541</td>
<td>11.85</td>
<td>±.04</td>
</tr>
<tr>
<td>NBS3759</td>
<td>10</td>
<td>97.900</td>
<td>0.5595</td>
<td>11.90</td>
<td>±.03</td>
</tr>
<tr>
<td>NBS3761</td>
<td>10</td>
<td>98.200</td>
<td>0.5380</td>
<td>11.64</td>
<td>±.03</td>
</tr>
<tr>
<td>NBS3762</td>
<td>10</td>
<td>98.200</td>
<td>0.5586</td>
<td>12.08</td>
<td>±.06</td>
</tr>
<tr>
<td>TS1522</td>
<td>15</td>
<td>9.956</td>
<td>5.2814</td>
<td>13.74</td>
<td>±.03</td>
</tr>
<tr>
<td>TS1525</td>
<td>15</td>
<td>9.991</td>
<td>5.2900</td>
<td>13.68</td>
<td>±.06</td>
</tr>
<tr>
<td>TS1539</td>
<td>15</td>
<td>9.954</td>
<td>5.2532</td>
<td>13.32</td>
<td>±.05</td>
</tr>
</tbody>
</table>

12.60±.02 (±.01)

Table B. Luminous Intensity at 2353°K (BIPM 1951 Scale)
(2352°K NBS Scale). Distance 1.65 Meters. Base Down Position

<table>
<thead>
<tr>
<th>Lamp No.</th>
<th>Heat Up Time</th>
<th>Volts (set)</th>
<th>Amperes</th>
<th>Candelas</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBS3764</td>
<td>10</td>
<td>92.300</td>
<td>0.3399</td>
<td>22.68</td>
<td>±.06</td>
</tr>
<tr>
<td>NBS3767</td>
<td>10</td>
<td>90.900</td>
<td>0.3434</td>
<td>21.95</td>
<td>±.07</td>
</tr>
<tr>
<td>NBS3769</td>
<td>10</td>
<td>91.800</td>
<td>0.3403</td>
<td>22.34</td>
<td>±.08</td>
</tr>
<tr>
<td>NBS3771</td>
<td>10</td>
<td>90.900</td>
<td>0.3463</td>
<td>22.22</td>
<td>±.05</td>
</tr>
<tr>
<td>TS3019</td>
<td>10</td>
<td>13.065</td>
<td>3.1552</td>
<td>29.34</td>
<td>±.09</td>
</tr>
<tr>
<td>TS3020</td>
<td>10</td>
<td>12.800</td>
<td>3.2554</td>
<td>29.63</td>
<td>±.06</td>
</tr>
<tr>
<td>TS3032</td>
<td>10</td>
<td>12.882</td>
<td>3.2652</td>
<td>29.40</td>
<td>±.12</td>
</tr>
</tbody>
</table>

25.36±.05 (±.03)
Table C. Luminous Intensity at 2854°K (NBS Scale). Distance 1.65 Meters. Measured After 5 Minutes of Burning. Base Down Position.

<table>
<thead>
<tr>
<th>Lamp No.</th>
<th>Volts (set)</th>
<th>Amperes</th>
<th>Candelas</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBS5612</td>
<td>107.700</td>
<td>3.822</td>
<td>643.6</td>
<td>± 2.1</td>
</tr>
<tr>
<td>NBS5613</td>
<td>107.400</td>
<td>3.807</td>
<td>638.7</td>
<td>± 2.4</td>
</tr>
<tr>
<td>NBS5617</td>
<td>107.600</td>
<td>3.799</td>
<td>633.2</td>
<td>± 2.3</td>
</tr>
<tr>
<td>NBS5619</td>
<td>106.800</td>
<td>3.818</td>
<td>629.4</td>
<td>± 5.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>636.2</td>
<td>± 2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(± 1.6)</td>
</tr>
</tbody>
</table>

Table D. Luminous Flux at 2353°K (BIPM 1951 Scale) (2356°K NBS Scale). Measured After 5 Minutes of Burning. Base Up Position.

<table>
<thead>
<tr>
<th>Lamp No.</th>
<th>Volts (set)</th>
<th>Amperes</th>
<th>Lumens</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBS3780</td>
<td>99.000</td>
<td>0.3206</td>
<td>232.2</td>
<td>± 0.6</td>
</tr>
<tr>
<td>NBS3782</td>
<td>98.500</td>
<td>0.3206</td>
<td>231.2</td>
<td>± 0.5</td>
</tr>
<tr>
<td>NBS3783</td>
<td>98.200</td>
<td>0.3195</td>
<td>226.1</td>
<td>± 0.7</td>
</tr>
<tr>
<td>NBS3784</td>
<td>99.100</td>
<td>0.3218</td>
<td>233.5</td>
<td>± 0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>230.8</td>
<td>± 0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(±0.3)</td>
</tr>
</tbody>
</table>

Table E. Luminous Flux at 2788°K (BIPM 1951 Scale) (2811°K NBS Scale). Measured After 5 Minutes of Burning. Base Up Position.

<table>
<thead>
<tr>
<th>Lamp No.</th>
<th>Volts (set)</th>
<th>Amperes</th>
<th>Lumens</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBS3772</td>
<td>108.90</td>
<td>1.7377</td>
<td>2738</td>
<td>± 14</td>
</tr>
<tr>
<td>NBS3773</td>
<td>110.00</td>
<td>1.7582</td>
<td>2795</td>
<td>± 8</td>
</tr>
<tr>
<td>NBS3775</td>
<td>109.00</td>
<td>1.7337</td>
<td>2750</td>
<td>± 18</td>
</tr>
<tr>
<td>NBS3776</td>
<td>108.90</td>
<td>1.7427</td>
<td>2745</td>
<td>± 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2757</td>
<td>± 6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(±6.4)</td>
</tr>
</tbody>
</table>
6. REFERENCES

1/ Comité Consultatif de Photométrie, Session de 1952, Proces-Verbaux des Seances, Annexe P3, 46-75.

2/ Same Annexe P4, 76-100.

3/ Comité Consultatif de Photométrie, 4e Session (1957), Proces-Verbaux des Seances, Annexe P8, 74-103.

4/ Same Annexe P9, 104-110.

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colo., is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.


Office of Weights and Measures.

BOULDER, COLO.


