NATIONAL BUREAU OF STANDARDS REPORT

10 005

LAMPS FOR INTERNATIONAL INTERCOMPARISONS TO BE CARRIED OUT AT BUREAU INTERNATIONAL DES POIDS ET MESURES

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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THE LUMINOUS INTENSITY OF 16 LAMPS AND THE LUMINOUS FLUX OF 8 LAMPS FOR INTERCOMPARISONS TO BE CARRIED OUT AT BUREAU INTERNATIONAL DES POIDS ET MESURES

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I. PURPOSE AND SCOPE

Since 1948 the National Bureau of Standards has participated in the First[1], Second[2], Third[3], and Fourth[4] Comparisons of National Photometric Standards of Intensity and Flux. The present report covers the preparation of standards of luminous intensity at 2042 K and 2854 K and standards of luminous flux at 2788 K for the Fifth Comparison of National Photometric Standards. A description of the present reference standards maintained at NBS and the recent program to recheck their values will also be given.

II. INTRODUCTION

As part of the national measurement system the National Bureau of Standards maintains reference groups of lamp standards of luminous intensity at 2042 K, 2360 K and 2854 K and also reference groups of lamp standards of luminous flux at 2360 K and 2788 K. Periodically these derived groups of reference standards are referred to a blackbody at the freezing point of platinum. The last time such a comparison was made was in 1958. In order to firmly establish a unified photometric system and also to prepare for NBS participation in the Fifth Comparison of National Photometric Standards, a program was begun two years ago to rederive the NBS units of luminous intensity at 2360 K and 2854 K, and also the NBS unit of luminous flux at 2788 K. Since this work will be reported in detail elsewhere, only a summary will be presented here. Since the NBS international standard of luminous intensity, a blackbody at the freezing point of platinum, was not operative at the time this work was begun, the NBS reference lamp groups (BS 2395 and NBS 839) at 2042 K, which had been calibrated in terms of the international standard in 1937 and 1958 respectively, were assumed to accurately embody the defined unit of luminous intensity. Direct comparison showed these two groups to be in disagreement by 0.27 %. Accordingly the grand mean of the 16 lamps in these two groups was held constant and the mean values of each group adjusted by 0.135 %. Hence it is considered that no change has been made in the NBS candela at 2042 K.

The reference lamp standards of luminous intensity at 2360 K and 2854 K were derived from the 2042 K reference groups by means of: 1) a blue filter, 2) a yellow filter, 3) a physical photometer[5] and 4) a spectroradiometer. The results obtained by these various methods initially showed systematic disagreements. The major cause of these observed disagreements was the filter transmittances, which had been determined by means of a spectrophotometer. The particular blue and yellow filters used were several millimeters thick, and it is believed that the optical differences between the spectrophotometric and photometric procedures invalidate the transmittances so determined. Hence, these transmittances were not used. Instead, the filter transmittances were determined on the physical photometer. Then the observed range of data for the four methods used was 0.7 % for the 2042 K-2360 K transfer and also for the 2360 K-2854 K transfer. The results of this work indicate a decrease of 0.4 % in the size of the NBS unit of luminous intensity at 2360 K and no change in the size of the unit at 2854 K.

The NBS reference standards of luminous flux at 2788 K are based on a group of 300-watt opal-bulb transfer standards (NBS 526). Extensive distribution photometry had been performed on these lamps in 1938 and again in 1958. The results of these two extensive sets of measurements were in agreement, and so no further distribution work was done at this time. The luminous intensity in a specified direction was redetermined for this group of opal-bulb lamps. From these values of luminous intensity and the previous distribution work, values of total luminous flux were computed for this group of lamps. The results indicate a decrease of 0.25 % in the size of the unit of luminous flux at 2788 K, from the values reported in the Fourth Comparison of National Photometric Standards of Intensity and Flux.

In the report covering the work done at NBS for the Fourth Comparison of National Photometric Standards of Intensity and Flux (NBS Report #6979), NBS announced the intention to adjust the size of the United States unit of luminous flux at 2788 K to bring it into accord with the units as realized in other national standardizing laboratories. Implementation of this decision was delayed pending the completion of the recheck work described above. Now the intention is to adjust, on the basis of this recheck work, the United States photometric units at the close of the present international intercomparison.

In all cases, both for values of luminous intensity and for values of luminous flux, lamp values given in this report incorporate the results of the most recent recheck work.

III. MATERIAL

In preparation for the Fifth Comparison of National Photometric Standards of Intensity and Flux, the Consultative Committee on Photometry decided that the Bureau International des Poids et Mesures should make arrangements for the manufacture, selection, seasoning, and procurement of lamps to be used in the intercomparison[6]. After such arrangements had been made, each national laboratory participating in the intercomparison procured the required number of lamps directly from the selected lamp companies. In

addition to the lamps, each lamp manufacturer supplied the electrical operating characteristics and alignment procedures to be used in assigning the lamps. Accordingly NBS purchased ten each of the following types of lamps:

1. 10-volt, 5.5-ampere, 15-candela lamps manufactured by the Tokyo Shibaura Electric Company, Ltd., of Tokyo, Japan, to be calibrated for luminous intensity at 2042 K.

2. 30-volt, 6-ampere, lamps, type Wi 41/G manufactured by the Osram Lamp Company, of Berlin, Germany, to be calibrated for luminous intensity at 2854 K.

3. 100-volt, 200-watt flux standards manufactured by Osram, GEC, Ltd. of Wembley, Middlesex, England, to be calibrated for total luminous flux at 2788 K.

After calibration, eight lamps from each of these three groups were sent to the Bureau International des Poids et Mesures; the remaining two lamps of each group were retained at NBS.

IV. STANDARDS

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

1. Candela at 2042 K. This group consists of lamps NBS 839, NBS 840, NBS 841, NBS 842, NBS 843, NBS 844, NBS 845 and NBS 846. These lamps were calibrated in 1958 against a blackbody radiator at the freezing point of platinum. The group relative values were adjusted in 1968 as explained in section II. The mean intensity of the eight lamps of the NBS 839 group is 15.79_0 candelas.

2. Candela at 2854 K. This group consists of lamps NBS 5612, NBS 5613, NBS 5614, NBS 5615, NBS 5616, NBS 5617, NBS 5618, NBS 5619, NBS 5620 and NBS 5621. These lamps were calibrated in 1968 by the methods discussed in section II of this report. The mean intensity of the ten lamps is 633.5 candelas.

3. Lumen at 2788 K. Two groups of standards were used for this comparison. One group of lamps, the opal-bulb lamps, consists of lamps NBS 526, NBS 527, NBS 528, NBS 529, NBS 530 and NBS 531. The mean luminous flux of these six lamps was found to be $2760._8$ lumens in 1968 by the methods described above. The second group consists of lamps NBS 6807, NBS 6808, NBS 6810, NBS 6812, NBS 6814 and NBS 6815. The mean luminous flux of these lamps was determined in 1968 in terms of the NBS 526 group and is 3242.5 lumens. Values determined with these two groups differed by 0.12 % on the average. Since the NBS 6807 group is assigned in terms of the NBS 526 group, data taken with the NBS 6807 group was given a weight of 1/2 (a statistically valid number which takes into account the length of the unit chain) in assigning values to the lamps submitted to the Bureau International des Poids et Mesures.

V. EQUIPMENT AND PROCEDURES

To provide an index of the reproducibility and stability of the results, the test lamps and the reference standards were compared at least five times in a series of measurements extending over a period of at least two months.

All measurements were made photoelectrically by using barrier-layer photocells equipped with filters to correct the spectral response to approximate that of the CIE photopic spectral luminous efficiency function. Measurements of luminous intensity at 2042 K and 2854 K were made with a "balance" circuit photometer 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 flux were made with a zero-resistance photometer.[7]

All measurements of luminous intensity were made by a substitution method on a horizontal bar photometer with all lamps operating vertically in a base-down position. The measurements of luminous flux were made by a substitution method in an 80-inch integrating sphere. The lamps were operated in a base-up position. The sphere was coated with Burch sphere paint and a blue glass filter was used to compensate for the effect of spectral selectivity of the sphere coating.

1. Luminous Intensity at 2042 K. The clear, spherical-bulb test lamps were received from the manufacturer with markings on the base to indicate the polarity of the applied potential and also arrows which were to face the receiver. The lamps were scribed on the metal base with the numbers listed in Table 1. In addition a circle was scribed on the base on the side opposite the arrow. In operation the circle was away from the receiver, and hence the arrow was toward the receiver as specified by the manufacturer. These lamps were oriented by projecting the shadow of the filament by means of an auxiliary projector so that the plane of the filament was perpendicular to and centered on the photometer axis. The voltage applied to the terminals of the lamps was fixed at the values listed in Table 1. and readings were taken of the current and luminous intensity of the lamps. The polarity was fixed in the manner specified by the manufacturer. The photometric distance was 1.50 meters.

2. Luminous Intensity at 2854 K. The conical-bulb test lamps have one half their surface blackened, except for a small clear window to permit viewing of the filament. The numbers listed in Table 2 were etched on the necks of the bulbs. The lamps were oriented with the blackened half of the bulb and window toward the receiver. The lamps were aligned by projecting the shadow of the filament by means of an auxiliary projector so that the plane of the filament was perpendicular to and centered on the photometer axis. The voltage applied to the base of the lamps was set at the values listed in Table 2 and readings taken of the current and luminous intensity. The photometric distance was 1.50 meters. Note is made of the fact that these lamps should have been set by current rather than by voltage. It is

understood that they will be set at the values of current listed in Table 2 when they are measured at BIPM and they will also be so set when they are returned for measurement at NBS.

3. Luminous Flux at 2788 K. All of the clear spherical-bulb test lamps were operated in a base-up position. The numbers listed in Table 3 were etched on the necks of the bulbs. The voltage applied to the base of the lamps was set at the values listed in Table 3 and readings taken of the current and luminous flux of the lamps. An unlighted standard was in place in the sphere when readings were made on the test lamps to compensate for the effects of self absorption of the lamps. Similarly an unlighted test lamp was in place in the sphere when readings of the standards were taken.

VI. RESULTS

The results are given in Tables 1, 2 and 3. In Tables 1 and 2 the values reported for current and luminous intensity are the averages of five measurements taken over a period of two months. The values of luminous flux reported in Table 3 are the weighted average of six measurements taken over a period of three months.

VII. UNCERTAINTY

Indices of the precision of the values reported in the above tables were computed on the basis of pooling the data on the individual lamps in each group (including the lamps retained at NBS).

1. Luminous Intensity at 2042 K. A pooled estimate of the standard deviation of a single measurement was computed on the basis of 40 degrees of freedom to be 0.42 %. Accordingly a 3-sigma limit for the mean intensity of the eight lamps submitted to the Bureau International des Poids et Mesures is 0.21 % (or 0.033 candela) based on five measurements on each of the eight lamps submitted.

2. Luminous Intensity at 2854 K. A pooled estimate of the standard deviation of a single measurement was computed on the basis of 40 degrees of freedom to be 0.50 %. Accordingly a 3-sigma limit for the mean intensity of the eight lamps submitted to the Bureau International des Poids et Mesures is 0.24 % (or 0.63 candela) based on 5 measurements of each of the eight lamps submitted.

3. Luminous Flux at 2788 K. Pooled estimates of the standard deviation of a single measurement were computed on the basis of 18 degrees of freedom each for the measurements against the NBS 526 group and for the measurements against the NBS 6807 group. These were 0.21 % and 0.30 % respectively. Applying the factors appropriate to the weighting described above, a 3-sigma limit for the mean flux of the eight lamps submitted to the Bureau International des Poids et Mesures is 0.11 % (or 2.7 lumens).

In all cases these values of the uncertainties apply only to the precision of the transfer of the NBS unit to the various lamps submitted to the Bureau International des Poids et Mesures. No allowance has been made for possible systematic errors in the NBS standards.

Table 1

Luminous Intensity at 2042 K; measurements taken after 15 minutes warm-up time

Lamp Number	Potential (Volts) (Set)	Current (Amperes)	Luminous Intensity (Candelas)
NBS 8460	10.375	5.357	15.13
NBS 8461	10.385	5.353	15.14
NBS 8462	10.380	5.371	14.98
NBS 8463	10.425	5.345	15.18
NBS 8464	10.460	5.383	15.16
NBS 8465	10.385	5.344	15.07
NBS 8466	10.385	5.376	15.17
NBS 8467	10.430	5.358	14.95
			15.098

Table 2

Luminous Intensity at 2854 K; measurements taken after 10 minutes warm-up time

Lamp Number	Potential (Volts) (Set)	Current (Amperes)	Luminous Intensity (Candelas)
NBS 8358	31.65	5.8870	260.1
NBS 8360	31.97	5.8570	270.7
NBS 8361	31.86	5.8720	267.2
NBS 8362	32.14	5.9140	262.8
NBS 8363	31.79	5.8570	264.0
NBS 8364	31.52	5.9970	264.2
NBS 8365	31.23	5.8780	256.6
NBS 8366	31.65	5.7960	258.6
			262.46

Table 3

Luminous Flux at 2788 K; measurements taken after 10 minutes warm-up time

Lamp Number	Potential (Volts) (Set)	Current (Amperes)	Luminous Flux (Lumens)
NBS 8380	95.70	2.050	2538
NBS 8381	95.30	2.034	2505
NBS 8382	96.40	2.054	2627
NBS 8383	96.90	2.036	2621
NBS 8384	97.80	2.025	2600
NBS 8385	96.00	2.037	2538
NBS 8386	97.80	2.069	2671
NBS 8387	94.90	2.042	2506
			2575.8

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2. Same Annexe P4, 76-100

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