NATIONAL BUREAU OF STANDARDS REPORT

6979

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

by

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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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

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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 16.81_7 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 33.40_8 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 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. 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 88-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 10°K.

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

Lamp No.	Heat Up Time Minutes	Volts (set)	Amperes	Candelas	Uncertainty
NBS3757	10	97.200	0.5541	11.85	±.04
NBS3759	10	97.900	.5595	11.90	±.03
NBS3761	10	98.200	.5380	11.64	±.03
NBS3762	10	98.200	.5586	12.08	±.06
TS1522	15	9.956	5.2814	13.74	±.03
TS1525	15	9.991	5.2900	13.68	±.06
TS1539	15	9.954	5.2532	13.32	±.05
				12.60_3	$\pm.02_3$ ($\pm.01_7$)

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

Lamp No.	Heat Up Time Minutes	Volts (set)	Amperes	Candelas	Uncertainty
NBS3764	10	92.300	0.3399	22.68	±.06
NBS3767	10	90.900	.3434	21.95	±.07
NBS3769	10	91.800	.3403	22.34	±.08
NBS3771	10	90.900	.3463	22.22	±.05
TS3019	10	13.065	3.1552	29.34	±.09
TS3020	10	12.800	3.2554	29.63	±.06
TS3032	10	12.882	3.2652	29.40	±.12
				25.36_5	$\pm.05_7$ ($\pm.03_5$)

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

Lamp No.	Volts (set)	Amperes	Candelas	Uncertainty
NBS5612	107.700	3.822_7	$643._6$	$\pm 2._1$
NBS5613	107.400	3.807_1	$638._7$	$\pm 2._4$
NBS5617	107.600	3.799_6	$633._2$	$\pm 2._3$
NBS5619	106.800	3.818_6	$629._4$	$\pm 5._0$
			$636._2$	$\pm 2._0$
				$(\pm 1._6)$

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

Lamp No.	Volts (set)	Amperes	Lumens	Uncertainty
NBS3780	99.000	0.3206	232.2	± 0.6
NBS3782	98.500	.3206	231.2	± 0.5
NBS3783	98.200	.3195	226.1	± 0.7
NBS3784	99.100	.3218	233.5	± 0.3
			230.8	± 0.4
				(±0.3)

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

Lamp No.	Volts (set)	Amperes	Lumens	Uncertainty
NBS3772	108.90	1.7377	2738	± 14
NBS3773	110.00	1.7582	2795	± 8
NBS3775	109.00	1.7337	2750	± 18
NBS3776	108.90	1.7427	2745	± 8
			2757	$\pm 6._0$
				$(\pm 6._4)$

6. REFERENCES

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

2/ Same Annexe P4, 76-100.

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

4/ Same Annexe P9, 104-110.

5/ NBS Report 2.1/127556 dated February 8, 1951.

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

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ELECTRICITY. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics.

METROLOGY. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

HEAT. Temperature Physics. Heat Measurements. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research. Equation of State. Statistical Physics. Molecular Spectroscopy.

RADIATION PHYSICS. X-Ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

CHEMISTRY. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

MECHANICS. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Combustion Controls.

ORGANIC AND FIBROUS MATERIALS. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

METALLURGY. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

MINERAL PRODUCTS. Engineering Ceramics. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

BUILDING RESEARCH. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

APPLIED MATHEMATICS. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

DATA PROCESSING SYSTEMS. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

ATOMIC PHYSICS. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics.

INSTRUMENTATION. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Office of Weights and Measures.

BOULDER, COLO.

CRYOGENIC ENGINEERING. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

IONOSPHERE RESEARCH AND PROPAGATION. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

RADIO PROPAGATION ENGINEERING. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

RADIO STANDARDS. High frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

RADIO SYSTEMS. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Space Telecommunications.

UPPER ATMOSPHERE AND SPACE PHYSICS. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

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