Designation: E1341 − 16 (Reapproved 2020)

Standard Practice for Obtaining Spectroradiometric Data from Radiant Sources for Colorimetry[1]

This standard is issued under the fixed designation E1341; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

The fundamental procedure for characterizing the color and absolute luminance of radiant sources is to obtain the spectroradiometric data under specified measurement conditions, and from these data to compute CIE chromaticity coordinates and luminance values based on the CIE 1931 Standard Observer. The considerations involved and the procedures to be used to obtain precision spectroradiometric data for this purpose are contained in this practice. The values and procedures for computing CIE chromaticity coordinates are contained in Practice E308. This practice includes minor modifications to the procedures given in Practice E308 that are necessary for computing the absolute luminance of radiant sources.

1. Scope

1.1 This practice prescribes the instrumental measurement requirements, calibration procedures, and physical standards needed for precise spectroradiometric data for characterizing the color and luminance of radiant sources.

1.2 This practice lists the parameters that must be specified when spectroradiometric measurements are required in specific methods, practices, or specifications.

1.3 This practice describes the unique calculation procedures required to determine basic colorimetric data of luminous sources.

1.4 This practice is general in scope rather than specific as to instrument, object, or material.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E275 Practice for Describing and Measuring Performance of Ultraviolet and Visible Spectrophotometers

E284 Terminology of Appearance

E308 Practice for Computing the Colors of Objects by Using the CIE System

E387 Test Method for Estimating Stray Radiant Power Ratio of Dispersive Spectrophotometers by the Opaque Filter Method

E925 Practice for Monitoring the Calibration of Ultraviolet-Visible Spectrophotometers whose Spectral Bandwidth does not Exceed 2 nm

E958 Practice for Estimation of the Spectral Bandwidth of Ultraviolet-Visible Spectrophotometers

2.2 *NIST Publications:*

NIST Technical Note 594-1 Fundamental Principles of Absolute Radiometry and the Philosophy of the NBS Program (1968–1971)[3]

[1] This practice is under the jurisdiction of ASTM Committee E12 on Color and Appearance and is the direct responsibility of Subcommittee E12.06 on Display, Imaging and Imaging Colorimetry.

Current edition approved Oct. 1, 2020. Published October 2020. Originally approved in 1991. Last previous edition approved in 2016 as E1341 – 16. DOI: 10.1520/E1341-16R20.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

NIST Technical Note 594-3 Photometric Calibration Procedures[3]

2.3 *CIE Publications:*

CIE Publication 015:2004 Colorimetry, 3rd ed.[4]

CIE Publication No. 38 Radiometric and Photometric Characteristics of Materials and their Measurement, 1977[4]

CIE Publication No. 63 Spectroradiometric Measurement of Light Sources, 1984[4]

2.4 *IES Standard:*

IES Guide to Spectroradiometric Measurements, 1983[5]

2.5 *ANSI Standard:*

ANSI/IES RP-16-1980 Nomenclature and Definitions for Illuminating Engineering[5]

3. Terminology

3.1 *Definitions:*

3.1.1 The definitions of appearance terms in Terminology E284 are applicable to this practice.

4. Summary of Practice

4.1 Procedures are given for selecting the types and operating parameters of spectroradiometers used to produce data for the calculation of CIE tristimulus values and other color coordinates to describe the colors of radiant sources. The important steps of the calibration of such instruments, and the standards required for these steps, are described. Parameters are identified that must be specified when spectroradiometric measurements are required in specific methods or other documents. Modifications to Practice E308 are described in order to account for the differences between objects and radiant sources.

5. Significance and Use

5.1 The fundamental method for obtaining CIE tristimulus values or other color coordinates for describing the colors of radiant sources is by the use of spectroradiometric measurements. These measurements are used by summation together with numerical values representing the CIE 1931 Standard Observer (CIE Publication 015:2004) and normalized to K_m, the maximum spectral luminous efficacy function, with a value of 683 lm/W.

5.2 This practice provides a procedure for selecting the operating parameters of spectroradiometers used for providing the desired precision spectroradiometric data, for their calibration, and for the physical standards required for calibration.

5.3 Special requirements for characterizing sources of light possessing narrow or discontinuous spectra are presented and discussed. Modifications to the procedures of Practice E308 are given to correct for the unusual nature of narrow or discontinuous sources.

6. Requirements When Using Spectroradiometry

6.1 When describing the measurement of radiant sources by spectroradiometry, the following must be specified.

6.1.1 The radiometric quantity determined, such as the irradiance (W/m^2) or radiance (W/m^2-sr), or the photometric quantity determined, such as illuminance (lm/m^2) or luminance (lm/m^2-sr or cd/m^2). The use of older, less descriptive names or units such as phot, nit, stilb (see ANSI/IES RP-16-1980) is not recommended.

6.1.2 The geometry of the measurement conditions, including whether a diffuser was used and its material of construction, the distances from the source of irradiation to the entrance to the spectroradiometer, and the presence of any special intermediate optical devices such as integrating spheres.

6.1.3 The spectral parameters, including the spectral region, wavelength measurement interval, and spectral bandwidth.

6.1.4 The type of standard used to calibrate the system, a standard lamp, a calibrated source, or a calibrated detector, and the source of the calibration.

7. Apparatus

7.1 The basic instrument requirement is a spectroradiometric system designed for the measurement of spectral radiance or irradiance of light sources. The basic elements of a spectroradiometric system are calibration sources with their regulated power supplies, a light detector, electronics for measuring the photocurrents, a monochromator with control equipment for computer interfacing, receiving optics, and a computer as described in CIE Publication No. 63 and IES Guide to Spectroradiometric Measurements. The computer is listed as an integral part of the system since the required precision is unobtainable without automated control. The characteristics of each element are discussed in the following sections.

7.2 *Calibration Sources*—The standard calibration lamp for spectroradiometry is a tungsten-filament lamp operated at a specified current. Such lamps are available from many standardizing laboratories. Typical of such standards is the tungsten filament, 1000 W, halogen cycle, quartz-envelope FEL-type lamp recommended by the National Institute of Standards and Technology (NIST). (See NIST Technical Note 594-1, and 594-3.) Uncertainties in the transfer of the scale of spectral radiance or irradiance are about 1 %. It is preferable to have more than one standard source to permit cross-checks and to allow calibration at a range of illuminance levels. Such sources can be constructed from lamps operating at any color temperature and spectral nature that have been characterized against a standard lamp. Monochromatic emission sources, such as a low-pressure mercury arc lamp or tunable laser, should also be available for use in calibrating the wavelength scale in accordance with Practice E925. Multiline lasers, such as continuous wave (cw) argon-ion and helium-neon, are preferred since they can be tuned to a small number of lines of well known wavelengths.

7.2.1 *Calibration Source Power Supplies*—The electrical supplies for the calibration sources should be of the constant current type. The supply should be linear and not a switching supply. Current regulation should be maintained to better than

[4] Available from U.S. National Committee of the CIE (International Commission on Illumination), C/o Alan Laird Lewis, 282 E. Riding, Carlisle, MA 01741, http://www.cie-usnc.org.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

0.1 %. This level of regulation is required to maintain a constant flux across the entrance to the spectroradiometer.

7.2.2 A standard for the measurement of length (such as a high-quality metric rule) should also be available since absolute irradiance calibrations must be performed at exact distances from the filament of the standard lamp.

7.3 *Detectors:*

7.3.1 *Photomultiplier Tubes*—Photomultiplier tubes are the traditional detectors in spectroradiometers. This is due to their superior performance in low-light-level conditions such as are encountered at the exit slit of a low-efficiency monochromator. The photocathodes of photomultipliers are sensitive to temperature, polarization, and magnetic fields. Light levels on the photocathode should never be allowed to generate photocurrents in excess of 10^{-6} A. The high-voltage supply should be stabilized to better than 0.01 % since the gain of the multiplier tube is controlled by the voltage across the dynodes.

7.3.2 *Silicon Photodiodes*—Recently, silicon photodiodes have superseded photomultiplier tubes in radiometric instruments. Photodiodes are less sensitive to temperature, polarization, and magnetic fields than photomultipliers, but care should still be taken to control these variables. Two silicon photodiode based detectors used in instrumentation are Charge Coupled Devises (CCD) and Complimentary Metal Oxide Silicon (CMOS).

7.4 *Monochromators*—The monochromator is the wavelength dispersive element in the system. The region of the monochromator should be 360 to 830 nm for highest accuracy, but a region of 380 to 780 nm should suffice for most characterizations. The bandwidth should be kept constant across the region of measurement at between 85 and 100 % of the measurement interval, but no greater than 5.0 nm. The CIE recommends a 1.0 nm bandwidth and measurement interval for highest accuracy, and suggests 2.0 nm as a compromise for characterizing radiation sources with spectra that contain both continuous and line emissions (CIE Publication No. 63). The precision of the wavelength setting should be 0.1 nm with an absolute accuracy of better than 0.5 nm. The size and shape of the entrance and exit slits of the monochromator should be chosen to provide a symmetric bandshape, preferably triangular. The entrance slit should be completely and uniformly filled with light. Specialized versions of the general spectroradiometer may be constructed and used for specific applications where the instrument can depart from the above guidelines. For example, a source with little or no radiant energy in the far red end of the visible spectrum may be correctly characterized by measurements to 700 or 710 nm rather than 780 nm.

7.4.1 *Scanning Monochromators*—The newer technology of holographically reproduced gratings has made possible the production of single- and double-grating monochromators with very high throughputs and very low stray-light levels. Second-order spectra need to be eliminated through the use of either a predisperser or a long-pass filter. A drive mechanism and position encoder should be attached to the scanning monochromator drive to allow the monochromator to scan the wavelength region under control of a computer. Prism-based scanning monochromators can also be used though the drive mechanism is more complex and the slit width must be changed as a function of the wavelength to maintain constant bandwidth.

7.4.2 *Polychromators*—Photodiode arrays are used in flat-field spectrographic radiometers. The bandwidth and sampling interval are determined by the pitch of the array and the reciprocal linear dispersion of the spectrograph. The guidelines given above should be followed for the diode array instrument as well.

7.5 *Receiving Optics*—To maximize the light throughput, the number of optical surfaces between the source of light (either a calibration or test source) and the monochromator entrance slit should be kept to a minimum. In extended diffuse sources, only a set of limiting apertures may be needed. For small sources a diffusing element may be required, such as a PTFE-fluorocarbon cap or integrating sphere. In some instances, it may be desirable to image the source with an intermediate focusing lens or mirror assembly. Care should be taken to use a magnification that will adequately fill the entrance slit when viewing both the calibration and test source. The CIE recommends the use of a rotatable integrating sphere as the input optics (CIE Publication No. 63). The entrance port of the sphere is rotated to view first the calibration source and then to view the test source. Since the efficiency of integrating spheres tend to be rather low, this method is only useful for bright sources.

7.6 *Computer System:*

7.6.1 There are no special requirements for the computer. Any minicomputer or microcomputer should suffice. The program should control or monitor as many of the instrument parameters as possible. Included in the computer system is the analog to digital conversion process, which changes the photocurrents to voltages, amplifies the voltages, and digitizes the voltages into computer-readable signals. A 3½ digit autoranging digital ammeter with a computer interface is suitable for this purpose. Alternatively, an autoranging electrometer with a computer interface can be used, but shielding and guarding of the low level signals becomes more critical. This is equivalent to a twelve bit ADC (analog to digital converter) with variable gains on the input signal. The use of a detector housing with a built-in current to voltage amplifier is recommended since the photocurrents are very small and can be affected by stray electromagnetic fields and capacitances. Amplification and conversion to voltage at the detector package minimizes these effects and will provide the voltage signal necessary for common ADC converters that are available for mini and microcomputers.

7.6.2 The data that is acquired by the computer should be converted and displayed as real number values. The raw readings should be corrected for dark current by subtraction of the measured signal with no light impinging on the entrance to the monochromator, and then scaled to the absolute values of the calibration source measurements. The results can be displayed on any appropriate device, though a printed copy is a desirable option. The corrected values should be stored on the computer's storage media for later processing. The generation of a plot of normalized radiance (irradiance) versus wavelength is also desirable, since a skilled operator will be able to obtain much useful information for both diagnostic and analytic purposes from the graph.

8. Calibration and Verification

8.1 Calibration and its verification are essential steps in ensuring that precise and accurate results are obtained by spectroradiometric measurements in accordance with Practice E275. They require the use of physical standards, some of which may not be normally supplied by commercial instrument manufacturers. It remains the user's responsibility to obtain and use the physical standards necessary to keep his instrument in optimum working condition.

8.2 *Radiometric Scale:*

8.2.1 *Zero Calibration or Its Verification*—All photometric devices have some inherent photocurrent, even in the absence of light. This so called "dark current" must be measured and subtracted from all subsequent readings either electrically or computationally. The easiest way to measure the dark current is to block the incoming light, preferably at the entrance to the receiving optics. Some commercial systems provide a shutter between the detector and the exit aperture of the monochromator. While this provides a means to determine the electrical noise of the detector, it does not determine the instrument signal due to other sources of stray optical radiation. This method is only appropriate if all optical components in the instrument system are absolutely light tight.

8.2.2 *Radiometric Scale Calibration*—The output of the detector is an electric current. Some means of relating that electric current in amperes to the incident optical power in watts is required. A physical standard of spectral irradiance (for example NIST 39040C, see NIST Technical Note 594-1) is normally used. After the dark current has been determined, the calibration source is positioned in front of the receiving optics at the specified distance and operated at the specified electric current. This provides a good approximation to a Planckian radiator across the visible spectrum. The calibration source is measured and the values of the dark-currentcorrected photocurrent are recorded. These photocurrents are then related to the calibration values of spectral irradiance that were provided by the standardizing laboratory. The ratio of spectral irradiance to photocurrent becomes the instrument calibration factor. All subsequent measurements are multiplied by this ratio.

8.2.3 *Linearity Verification*—Periodically after the radiometric and zero-scale readings are established, the linearity of the scale should be verified. The use of the double-aperture method or the superposition of two sources is recommended. In the former, the light from the calibration source is reduced by using an aperture plate with two smaller areas. The spectral character is unchanged while the light output is measured for each of the two apertures individually and then simultaneously, in combination. In the latter, each source is measured independently and then simultaneously. The simultaneous measurement should be equal to the sum of the two independent measurements.

8.3 *Wavelength Scale:*

8.3.1 *Scale Calibration and Verification*—Since the output of some sources contain spectral line structure, the wavelength scale must be precise and accurate enough to characterize this line structure. The best method of wavelength calibration utilizes a low-pressure mercury or neon arc lamp. In grating monochromators, where the blocking filters can be removed, the second-order spectrum of the arc lamp may be used. Generally, the best method of either calibration or verification of the wavelength scale is to determine the difference between the measured peaks, or more preferably, the wavelength centroids and the tabulated positions of the emissions lines of the arc lamp. The mercury lamp has five useful lines for calibration: 404.7, 435.8, 546.1, 577.0, and 579.1 nm. A neon arc will provide six additional lines in the longer wavelength region at 614.3, 633.4, 638.3, 640.2, 650.6, and 703.2 nm. Most monochromators exhibit significant nonlinear wavelength errors in addition to random linear errors. Generally, the best method of either calibration or verification of the wavelength scale is to determine the differences between the measured peaks and the tabulated positions of the emission lines of the arc lamps. The differences should be averaged and reported. A sign test on the differences will reveal systematic offsets in wavelength reading and will require mechanical correction. Random errors larger than 1 nm should be cause for concern. Fitting the differences to a quadratic or cubic polynomial can correct for significant nonlinear wavelength errors.

8.3.2 *Spectral Bandwidth Verification*—The low pressure arc lamps used for wavelength calibration may also be used to verify the spectral bandwidth if data can be collected with a sufficiently small measurement interval in accordance with Practice E958. The interval should be at least one tenth of the nominal bandwidth. Only singlet lines should be chosen to be used in the analysis. The line should be measured using the smallest measurement intervals available. When plotted, the data should show a symmetric, monomodal peak with the maximum at or near the wavelength of the spectral line and the width of the peak at one half of the peak value will be approximately equal to the bandwidth.

8.4 *Stray Light*—The level of stray light can be estimated by using the same low-pressure arc lamp used in wavelength calibration. The arc lamp's lines are essentially infinitely narrow since there is very little line broadening in the low pressure conditions. Thus, at wavelengths more than two bandwidths away from the center wavelength of a spectral line there should be no light passing through the system in accordance with Test Method E387. Any detectable signal above the noise level of the measuring system is stray light.

8.5 *System Verification*—The precision and bias of the entire measurement system, including the calculation of CIE tristimulus values, radiance (irradiance), luminance (illuminance), and correlated color temperature should be verified by periodic measurement of the calibrated source modified by placing a color temperature correction filter between the lamp and the detector. The transmittance of the filter can be determined independently and the modified spectral radiance values calculated by multiplying the tabulated calibration values by the transmittance values on a wavelength by wavelength basis. The calculated distribution should be checked against the measured distribution.