INTERNATIONAL

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Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres[1]

This standard is issued under the fixed designation E903; 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.

1. Scope

1.1 This test method covers the measurement of spectral absorptance, reflectance, and transmittance of materials using spectrophotometers equipped with integrating spheres.

1.2 Methods of computing solar weighted properties from the measured spectral values are specified.

1.3 This test method is applicable to materials having both specular and diffuse optical properties.

1.4 This test method is applicable to material with applied optical coatings with special consideration for the impact on the textures of the material under test.

1.5 Transmitting sheet materials that are inhomogeneous, textured, patterned, or corrugated require special considerations with respect to the applicability of this test method. Test Method E1084 may be more appropriate to determine the bulk optical properties of textured or inhomogeneous materials.

1.6 For homogeneous materials this test method is preferred over Test Method E1084.

1.7 This test method refers to applications using standard reference solar spectral distributions but may be applied using alternative selected spectra as long as the source and details of the solar spectral distribution and weighting are reported.

1.8 *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.*

1.9 *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

E424 Test Methods for Solar Energy Transmittance and Reflectance (Terrestrial) of Sheet Materials

E490 Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables

E772 Terminology of Solar Energy Conversion

E971 Practice for Calculation of Photometric Transmittance and Reflectance of Materials to Solar Radiation

E1084 Test Method for Solar Transmittance (Terrestrial) of Sheet Materials Using Sunlight

E1175 Test Method for Determining Solar or Photopic Reflectance, Transmittance, and Absorptance of Materials Using a Large Diameter Integrating Sphere

E2554 Practice for Estimating and Monitoring the Uncertainty of Test Results of a Test Method Using Control Chart Techniques

G173 Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface

G197 Table for Reference Solar Spectral Distributions: Direct and Diffuse on 20° Tilted and Vertical Surfaces

2.2 *Other Documents:*

Federal Test Method Standard No. 141, Method 6101[3]

ASHRAE Standard 74-1988[4]

CIE 38 Radiometric and Photometric Characteristics of Materials and their Measurement[5]

CIE 44 Absolute Methods for Reflection Measurement[5]

NIST SP 250-48 Spectral Reflectance[6]

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[1] This test method is under the jurisdiction of ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.20 on Optical Materials for Solar Applications.

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[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 Standardization Documents, Order Desk, Building 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5049, Attn: NPODS.

[4] Available from American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc., 191 Tullie Circle, NE. Atlanta GA 30329.

[5] Available from U.S. National Committee of the CIE (International Commission on Illumination), C/o Thomas M. Lemons, TLA-Lighting Consultants, Inc., 7 Pond St., Salem, MA 01970, http://www.cie-usnc.org.

[6] Online, Available: https://www.nist.gov/publications/spectral-reflectance

NIST SP 250-69 Regular Spectral Transmittance[7]

3. Terminology

3.1 For definitions of terms used in this test method, refer to Terminology E772.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *integrating sphere, n*—an optical device used to either collect flux reflected or transmitted from a sample into a hemisphere or to provide isotropic irradiation of a sample from a complete hemisphere. It consists of a cavity that is approximately spherical in shape with apertures for admitting and detecting flux and usually having additional apertures over which sample and reference specimens are placed.

3.2.2 *near normal-hemispherical, adj*—indicates irradiance to be directional near normal to the specimen surface and the flux leaving the surface or medium is collected over an entire hemisphere for detection.

3.2.3 *photovoltaic solar, adj*—referring to an optical property; indicates a weighted average of the spectral property using the number of photons per second per unit area per unit wavelength derived from a standard solar irradiance distribution as the weighting function.

3.2.4 *smooth, adj*—having an even and level surface, having no roughness or projections. Free from inequalities or unevenness of surface.

3.2.5 *specular, adj*—indicates the flux leaves a surface or medium at an angle that is numerically equal to the angle of incidence, lies in the same plane as the incident ray and the perpendicular, but is on the opposite side of the perpendicular to the surface.

3.2.5.1 *Discussion*—Diffuse has been used in the past to refer to hemispherical collection (including the specular component). This use is deprecated in favor of the more precise term *hemispherical*.

3.2.6 *textured, adj*—the nature of a surface other than smooth. Having some degree of unevenness, roughness or projections.

4. Summary of Test Method

4.1 Measurements of spectral near normal-hemispherical transmittance (or reflectance) are made over the spectral range from 300 to 2500 nm with an integrating sphere spectrophotometer.

4.2 The solar transmittance, reflectance, or absorptance is obtained by calculating a weighted average with a standard or selected solar spectral irradiance as the weighting function by either direct calculation of suitable convolution integrals, or the weighted (see 8.3.3) or selected (see 8.3.4) ordinate method.

5. Significance and Use

5.1 Solar-energy absorptance, reflectance, and transmittance are important in the performance of all solar energy systems ranging from passive building systems to central receiver power systems. This test method provides a means for determining these values under fixed conditions that represent an average that would be encountered during use of a system in the temperate zone.

5.2 Solar-energy absorptance, reflectance, and transmittance are important for thermal control of spacecraft and the solar power of extraterrestrial systems. This test method also provides a means for determining these values for extraterrestrial conditions.

5.3 This test method is designed to provide reproducible data appropriate for comparison of results among laboratories or at different times by the same laboratory and for comparison of data obtained on different materials.

5.4 This test method has been found practical for smooth materials having both specular and diffuse optical properties. Materials that are textured, inhomogeneous, patterned, or corrugated require special consideration.

5.4.1 Surface roughness may be introduced by physical or chemical processes, such as pressing, rolling, etching, or deposition of films or chemical layers on materials, resulting in textured surfaces.

5.4.2 The magnitude of surface roughness with respect to the components of the spectrophotometer and attachments (light beam sizes, sphere apertures, sample holder configuration) can significantly affect the accuracy of measurements using this test method.

5.4.3 Even if the repeatability, or precision of the measurement of textured materials is good, including repeated measurements at various locations within or orientations of the sample, the different characteristics of different spectrophotometers in different laboratories may result in significant differences in measurement results.

5.4.4 In the context of 5.4.3, the term 'significant' means differences exceeding the calibration or measurement uncertainty, or both, established for the spectrophotometers involved, through measurement of or calibration with standard reference materials.

5.4.5 The caveats of 5.4.3 and 5.4.4 apply as well to measurement of smooth inhomogeneous or diffusing materials, where incident light may propogate to the edge of the test material and be 'lost' with respect to the measurement.

5.5 This test method describes measurements accomplished over wider spectral ranges than the Photopic response of the human eye. Measurements are typically made indoors using light sources other than natural sunlight, though it is possible to configure systems using natural sunlight as the illumination source, as in Practice E424. Practice E971 describes outdoor methods using natural sunlight over the spectral response range of the human eye.

5.6 Light diffracted by gratings is typically significantly polarized. For polarizing samples, measurement data will be a function of the orientation of the sample. Polarization effects may be detected by measuring the sample with rotation at various angles about the normal to the samples.

6. Apparatus

6.1 *Instrumentation:*

[7] Online, Available: https://www.nist.gov/publications/nist-measurement-services-regular-spectral-transmittance

6.1.1 *Integrating Sphere Spectrophotometer*—A spectrophotometer with an integrating sphere attachment capable of measuring the spectral characteristics of the test specimen or material over the solar spectral region from 300 to 2500 nm is required. Double beam, ratio recording instruments are recommended because of their low sensitivity to drift in source brightness or amplifier gain. Recording spectrophotometers with integrating spheres that have been found satisfactory for this purpose are commercially available.

NOTE 1—For determining extraterrestrial solar optical properties using Standard E490, the spectral region should extend down to 250 nm.

NOTE 2—This test method is used primarily for solar thermal and some photovoltaic applications that require the full spectral range be covered. There are other applications for which a narrower range is sufficient and that could otherwise use the procedures of this test method. For example, some applications involving photovoltaic cells utilize a narrower spectral responsive range and some others pertain only to visible light properties that have an even narrower spectral range. In such cases, the user of the test method is permitted to use a narrower range. Similarly, a user with an application requiring a broader spectral range is permitted to use a broader range. Any deviations from the spectral range of this test method should be noted in the report.

6.1.1.1 The integrating sphere shall be either a wall-mounted type such that the specimen may be placed in direct contact with the rim of an aperture in the sphere wall for transmittance and reflectance measurements or center-mount type (Edwards type) such that the specimen is mounted in the center of the sphere for reflectance and absorptance measurements.

6.1.1.2 The interior of the integrating sphere shall be finished with a stable highly reflecting and diffusing coating. Sphere coatings having the required properties can be prepared using pressed tetrafluoroethylene polymer powder, or other highly reflective, stable material.

NOTE 3—For high accuracy (better than ±0.01 reflectance units) measurements with absolute sphere configuration, the ratio of the port area to the sphere wall plus port area should be less than 0.001 (**1**).[8] In general, large spheres (> 200 mm) meet these requirements and are preferred while small spheres (< 100 mm) can give rise to large errors.

6.1.1.3 For the evaluation of near normal-hemispherical or hemispherical-near-normal reflectance, the direction of the incident radiation or the direction of viewing respectively shall be between 6 and 12° from the normal to the plane of the specimen so that the specular component of the reflected energy is not lost through an aperture. Ambient light must be prevented from entering the sphere by placing a ring of black or white material around the external rim of the specimen ports or by covering the entire sphere attachment with a light tight housing. Black backing or border material may result in significant light absorption or loss, while white backing material should be more representative of the sphere interior and affect measurement results to a lesser extent. Several acceptable system configurations are illustrated in Appendix X1.

NOTE 4—The hemispherical near-normal irradiation-viewing mode is also allowed under this test method since the Helmholtz reciprocity relationship which holds in the absence of polarization and magnetic fields guarantees equivalent results are obtainable.

6.1.1.4 Some commercial instruments have sample ports equipped with quartz windows. There is a possibility for multiple reflections to occur between sample and window surfaces and miss or inadvertently enter the sample port. In transmission measurement mode ensure that any light reflected from the sample is collected at the sample port. Best practice is to ensure that the sample does not interact with the optical system of the spectrophotometer.

6.1.1.5 In spectrophotometer systems with multiple gratings and multiple detectors, discontinuities in the spectral data due to changes in bandwidth, grating efficiency, or detector sensitivity may occur at grating and detector switch over points. If observed, the magnitude and cause of the discontinuity should be investigated. Careful calibration over the entire spectral band of interest should account for such discrepancies.

6.2 *Standards:*

6.2.1 In general, both reference and working (comparison) standards are required.

NOTE 5—Reference standards are the primary standard for the calibration of instruments and working standards. Reference standards that have high specular reflectance, high diffuse reflectance, and low diffuse reflectance were formerly available from the National Institute of Standards and Technology as Standard Reference Materials (SRM).[9] See NIST Special Publications 250-48 and 250-69. However, the low demand and high cost of these materials has been replaced by offers of measurement services from National Metrology Institutions (NMI) such as NIST. These laboratories offer to measure customers samples and report spectral optical properties. These become NIST (or NMI) traceable reference standards for customers. The customers often include commercial firms which then produce SRMs and reference standards based on their NMI traceable standards and provide them to their customers along with traceability and uncertainty information. These SRMs and reference standards are permitted within the context of this standard. Example NMIs include the National Physical Laboratory (NPL) of the United Kingdom, the National Research Council (NRC) of Canada, the Physical Technical Bureau (PTB) of Germany, The National Laboratory of Metrology and Test (LNE-INM) of France, etc.

6.2.1.1 Working standards are used in the daily operation of the instrument to provide comparison curves for data reduction. In general, ceramic and vitrified enamel surfaces are highly durable and desirable. A working standard shall be calibrated by measuring its optical properties relative to the properties of the appropriate reference standard using procedures given in 8.2.

NOTE 6—Even the best standards tend to degrade with continued handling. They should be handled with care and stored in a clean, safe manner. Working standards should be recalibrated periodically and cleaned, renewed, or replaced if degradation is noticeable. Avoid touching the optical surfaces. Only clean soft cloth gloves should be worn for handling the standards. Only lens tissue or sterile cotton is recommended for cleaning. This is especially important for reference standards carrying NIST calibration.

[8] The boldface numbers in parentheses refer to the list of references at the end of this standard.

[9] National Institute of Standards and Technology, Office of Standard Reference Materials, Room B311, Chemistry Bldg., Washington, DC 20234. Additional details covering the appropriate SRMs (2019–2022) are available on request.