Transmittance or Blocking of Erythemally Weighted Ultraviolet Radiation through Fabrics

Developed in 1998 by AATCC Committee RA106; reaffirmed 1999, 2000; revised 2004.

1. Purpose and Scope

1.1 This standard test method is used to determine the ultraviolet radiation blocked or transmitted by textile fabrics intended to be used for UV protection.

1.2 This method provides procedures for measuring this fabric property with specimens in either the dry or wet states.

2. Principle

2.1 The transmission of ultraviolet radiation (UV-R) through a specimen is measured on a spectrophotometer or spectroradiometer at known wavelength intervals.

2.1.1 The ultraviolet protection factor (UPF) is computed as the ratio of the erythemally weighted ultraviolet radiation (UV-R) irradiance at the detector with no specimen to the erythemally weighted UV-R irradiance at the detector with a specimen present.

2.1.2 The erythemally weighted UV-R irradiance at the detector with no specimen present is equal to the summation between wavelength intervals of the measured spectral irradiance times the relative spectral effectiveness for the relevant erythemal action spectra times the UV-R weighting function of the appropriate solar radiation spectrum times the appropriate wavelength interval.

2.1.3 The erythemally weighted UV-R irradiance at the detector with a specimen present is equal to the summation between wavelength intervals of the measured spectral irradiance times the relative spectral effectiveness for the relevant erythemal action spectrum times the spectral transmittance for the specimen times the wavelength interval.

2.1.4 The percent blocking of UVA and UVB radiation is also calculated.

3. Terminology

3.1 erythema, n.—abnormal redness of the skin (sunburn) due to capillary congestion (as in inflammation).

3.2 percent UV blocking, n.—100 minus the UV transmission.

3.3 ultraviolet protection factor (UPF), n.—the ratio of the average effective ultraviolet radiation (UV-R) irradiance transmitted and calculated through air to the average effective UV-R irradiance transmitted and calculated through fabric.

3.4 ultraviolet radiation, n.—radiant energy for which the wavelengths of the monochromatic components are smaller than those for visible radiation and more than about 100 nm.

NOTE: The limits of the spectral range of ultraviolet radiation are not well defined and may vary according to the user. Committee E-2.1.2 of the International Commission on Illumination (CIE) (see 15.4) distinguishes in the spectral range between 400 and 100 nm:

UV-A	315-400 nm
UV-B	280-315 nm
UV-R	280-400 nm

4. Safety Precautions

NOTE: These safety precautions are for information purposes only. The precautions are ancillary to the testing procedures and are not intended to be all inclusive. It is the user's responsibility to use safe and proper techniques in handling materials in this test method. Manufacturers MUST be consulted on specific details such as material safety data sheets and other manufacturer's recommendations. All OSHA standards and rules must also be consulted and followed.

4.1 Under any circumstances, do not look directly at the equipment and materials that may increase the light source intensity, such as mirrors.

4.2 Good laboratory practices should be followed. Wear prescribed safety glasses in all laboratory areas.

5. Uses and Limitations

5.1 This method can also be used to determine the UPF of fabrics in a stretched state. However, the techniques for stretching the specimens are not part of this method and are addressed in a separate test procedure. It must be noted that stretching the specimens could change the UPF properties.

6. Apparatus and Materials

6.1 A spectrophotometer or spectroradiometer equipped with an integrating sphere (see 15.1 and, for a more complete description of an instrument, Appendix A).

6.2 As indexed in catalogues: Filter, Schott Glass UG11 (see 15.2).

6.3 Clear plastic food wrap for use with wet samples (polyvinylidene chloride or polyvinylchloride film).

6.4 AATCC Blotting paper (see 15.5).

7. Instrument Verification and Calibration

7.1 Calibration. Calibrate the spectrophotometer or spectroradiometer according to manufacturer instructions. The use of physical standards are recommended for validating the measurement of spectral transmittance.

7.1.1 When running a wet sample place the plastic wrap over the port and repeat calibration.

7.2 Wavelength scale. Calibrate the wavelength scale of the spectrophotometer or spectroradiometer using the spectral emission lines of an electrical discharge in mercury vapor. The wavelength calibration of a spectrophotometer can be performed using the absorption spectra of a holmium oxide glass filter. Reference wavelengths for both mercury arc emission and holmium oxide absorption are provided in ASTM Practice E 275, Standard Practice for Describing and Measuring Performance of Ultraviolet, Visible and Near-Infrared Spectrophotometers.

7.2.1 Transmittance scale. Set the transmittance scale to a 100% value by operating the instrument without a sample in the optical path; therefore, referenced to air. The 0% value can be subsequently verified by fully obstructing the sample beam path with an opaque material. Validate the linearity of the transmittance scale by means of either calibrated neutral density filters or calibrated perforated screens supplied by the instrument manufacturer or standardizing laboratories.

8. Specimens

8.1 Test a minimum of two (2) specimens from each sample for the wet and the dry testing. Cut each specimen at least 50 × 50 mm (2.0 × 2.0 in.) or 50 mm (2.0 in.) in diameter. Avoid distorting the specimen during preparation and handling.

8.1.1 Should the fabric have areas of different colors or structure, test each color or structure if its size is sufficient to cover the measuring port.

8.2 See Appendix A5 for specimens exhibiting fluorescence.

9. Conditioning

9.1 For dry specimens.

9.1.1 Prior to testing, precondition and condition the test specimens as directed in ASTM D 1776, Standard Practice for Conditioning and Testing Textiles. Condition each specimen for at least 4 h in an atmosphere of 21 ± 1°C (70 ± 2°F) and 65 ± 2% RH by laying each test specimen separately on a perforated shelf or conditioning rack.

10. Procedure

10.1 Dry Evaluation.

10.1.1 Place the specimen flush against the sample transmission port opening in the sphere.

10.1.2 Make one UV transmission measurement with the specimen oriented in one direction, a second measurement at 0.79 rad (45°) to the first and a third at 0.79 rad (45°) to the second. Record the individual measurements.

10.1.3 On multicolored specimens, determine the area of highest UV transmission and make the three measurements in that area.

10.2 Wet Evaluation

10.2.1 Weigh the test specimen. Thoroughly wet out the specimen in distilled water by placing it flat in the bottom of a beaker and then pour distilled water into the beaker until the specimen is covered. Allow the specimen to remain submerged for 30 minutes. Press and move the specimen from time to time to ensure a good and uniform penetration. Prepare only one specimen at a time.

10.2.2 Bring the wet pick-up to 150 ± 5% by squeezing the wet specimen between blotting paper (see 6.4) through a hand wringer or similar convenient means (such as squeeze between two glass rods). If the fabric has low moisture absorption, repeat the soaking and wringing steps. Note, some samples may not be capable of achieving the specified wet pick-up such as tightly woven synthetic fabrics.

10.2.3 Use plastic wrap over viewing port to protect instrument from water.

10.2.4 Continue as directed in 10.1. Avoid evaporative reduction of the moisture content below the specified level before the actual UV transmission measurements are made.

11. Calculations

11.1 Calculate the average spectral transmittance for the three measurements on each specimen.

11.2 Calculate the Ultraviolet Protection Factor (UPF) of each specimen using Equation 1:

Table I—Relative Erythemal Effectiveness Function (E_λ)[a]

nm	response	nm	response	nm	response
280	1.00e+00	320	8.55e-03	360	4.84e-04
282	1.00e+00	322	5.55e-03	362	4.52e-04
284	1.00e+00	324	3.60e-03	364	4.22e-04
286	1.00e+00	326	2.33e-03	366	3.94e-04
288	1.00e+00	328	1.51e-03	368	3.67e-04
290	1.00e+00	330	1.36e-03	370	3.43e-04
292	1.00e+00	332	1.27e-03	372	3.20e-04
294	1.00e+00	334	1.19e-03	374	2.99e-04
296	1.00e+00	336	1.11e-03	376	2.79e-04
298	1.00e+00	338	1.04e-03	378	2.60e-04
300	6.49e-01	340	9.66e-04	380	2.43e-04
302	4.21e-01	342	9.02e-04	382	2.26e-04
304	2.73e-01	344	8.41e-04	384	2.11e-04
306	1.77e-01	346	7.85e-04	386	1.97e-04
308	1.15e-01	348	7.33e-04	388	1.84e-04
310	7.45e-02	350	6.84e-04	390	1.72e-04
312	4.83e-02	352	6.38e-04	392	1.60e-04
314	3.13e-02	354	5.96e-04	394	1.50e-04
316	2.03e-02	356	5.56e-04	396	1.40e-04
318	1.32e-02	358	5.19e-04	398	1.30e-04
				400	1.22e-04

Note: The intervals in Table I are in 2 nm. For 5 nm UV transmission data use the interpolated data between those ending in a "4" and a "6."

[a] CIE Publication 106/4 available from CIE National Committee of USA, c/o TLA-Lighting Consultants Inc., 7 Pond St., Salem, MA 01970.

Table II—Solar Spectral Irradiance of Noonday, July 3, Sunlight, Albuquerque, NM (S_λ)[a]

nm	W/cm²/nm	nm	W/cm²/nm	nm	W/cm²/nm
280	4.12e-11	320	3.14e-05	360	5.64e-05
282	2.37e-11	322	3.32e-05	362	6.00e-05
284	3.14e-11	324	3.61e-05	364	6.48e-05
286	4.06e-11	326	4.45e-05	366	7.18e-05
288	6.47e-11	328	5.01e-05	368	7.62e-05
290	3.09e-10	330	5.32e-05	370	7.66e-05
292	2.85e-09	332	5.33e-05	372	7.50e-05
294	2.92e-08	334	5.23e-05	374	6.61e-05
296	1.28e-07	336	5.04e-05	376	6.66e-05
298	3.37e-07	338	4.99e-05	378	7.46e-05
300	8.64e-07	340	5.39e-05	380	7.54e-05
302	2.36e-06	342	5.59e-05	382	6.42e-05
304	4.35e-06	344	5.35e-05	384	5.85e-05
306	7.19e-06	346	5.34e-05	386	6.26e-05
308	9.68e-06	348	5.37e-05	388	6.72e-05
310	1.34e-05	350	5.59e-05	390	7.57e-05
312	1.75e-05	352	5.89e-05	392	7.16e-05
314	2.13e-05	354	6.13e-05	394	6.55e-05
316	2.43e-05	356	6.06e-05	396	6.81e-05
318	2.79e-05	358	5.38e-05	398	8.01e-05
				400	1.01e-04

Note: The intervals in Table II are in 2 nm. For 5 nm UV transmission data use the interpolated data between those ending in a "4" and a "6."

[a] Sayre, R. M., et al., "Spectral Comparison of Solar Simulators and Sunlight," *Photodermatol Photoimmunol. Photomed.*, 7, 159-165 (1990).

$$\mathrm{UPF} = \frac{\sum_{280\,nm}^{400\,nm} E_\lambda \times S_\lambda \times \Delta\lambda}{\sum_{280\,nm}^{400\,nm} E_\lambda \times S_\lambda \times T_\lambda \times \Delta\lambda} \qquad (1)$$

where:

E_λ = relative erythemal spectral effectiveness (see Table I)

S_λ = solar spectral irradiance (see Table II)

T_λ = average spectral transmittance of the specimen (measured)

$\Delta\lambda$ = measured wavelength interval (nm)

NOTE: Although integration is indicated from 280 nm to the stated wavelengths, little or no contribution will occur in the 280-290 nm region.

11.3 Calculate the average A-range ultraviolet (UV-A) transmittance using Equation 2:

$$T(\mathrm{UV\text{-}A})_{AV} = \frac{\sum_{315\,nm}^{400\,nm} T_\lambda \times \Delta\lambda}{\sum_{315\,nm}^{400\,nm} \Delta\lambda} \qquad (2)$$

11.4 Calculate the average B-range ultraviolet (UV–B) transmittance using Equation 3:

$$T(\mathrm{UV\text{-}B})_{AV} = \frac{\sum_{280\,nm}^{315\,nm} T_\lambda \times \Delta\lambda}{\sum_{280\,nm}^{315\,nm} \Delta\lambda} \qquad (3)$$

11.5 Calculate the percent blocking for UV-A and for UV-B using Equation 4 and Equation 5:

$$= 100\%\text{-}T(\mathrm{UV\text{-}A}) \qquad (4)$$

$$= 100\%\text{-}T(\mathrm{UV\text{-}B}) \qquad (5)$$

where:

T(UV-A) or *T*(UV-B) is expressed as a percentage.

12. Report

12.1 Report the following by sample identification:

12.1.1 The ultraviolet protection factor, UPF

12.1.2 The UV-A transmittance, *T*(UV-A)

12.1.3 The UV-B transmittance, *T*(UV-B)

12.1.4 The percent blocking (UV-A)

12.1.5 The percent blocking (UV-B)

12.1.6 The actual percent wet pick-up if other than 150%.

13. Precision and Bias

13.1 *Precision*. In March 1998, an ultraviolet transmittance scan was performed on the same specimen of 100% polyester woven fabric fifteen (15) times and the UPF calculated according to this procedure. The average UPF was 19.41 and the standard deviation was 0.18. *Between-laboratory* precision has not been established for this test method. Until such precision information is available, users of the method should use standard statistical techniques in making any comparison of test results for *between-laboratory* averages.

13.2 *Bias*. Transmittance or blocking of erythemally weighted ultraviolet radiation through fabrics can be defined only in terms of a test method. There is no independent method for determining the true value. As a means of estimating this property, the method has no known bias.

14. References

14.1 ASTM D 1776, Standard Practice for Conditioning and Testing Textiles (see 15.3).

14.2 ASTM E 179, Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials (see 15.3).

14.3 ASTM E 275, Practice for Describing and Measuring Performance of Ultraviolet, Visible and Near-Infrared Spectrophotometers (see 15.3)

14.4 ASTM G 159, Standard Tables for References Solar Spectral Irradiance at Air Mass 1.5: Direct Normal and Hemispherical for a 37° Tilted Surface (see 15.3).

14.5 ASTM E 1247, Test Method for Identifying Fluorescence in Object-Color Specimens by Spectrophotometry (see 15.3).

14.6 ASTM E 1348, Test Method for Transmittance and Color by Spectrophotometry using Hemispherical Geometry (see 15.3).

15. Notes

15.1 Spectrophotometers or spectroradiometers that meet the requirements of this test method are available from a large number of manufacturers.

15.2 Available from Schott Inc., 400 York Ave., Duryea PA 18642; tel: 717/457-4485.

15.3 Available from ASTM, 100 Barr Harbor Dr., West Conshohocken PA 19428-2959; tel: 610/832-9500; fax: 610/832-9555.

15.4 Commission International de L'Éclairage (CIE), Bureau Central de la CIE, Paris, France.

15.5 Available from AATCC, P.O. Box 12215, Research Triangle Park NC 27709; tel: 919/549-8141; fax: 919/549-8933; e-mail: orders@aatcc.org.

Appendix A

Spectrophotometer or Spectroradiometer Specifications

A1. The integrating sphere surface is internally coated or constructed using a material that is both diffuse and highly reflecting in the ultraviolet region. The total surface area consumed by all port openings required shall not exceed 3% of the total surface area of the integrating sphere.

A2. Illumination and viewing geometries.

A2.1 Directional illumination/hemispherical collection (0/T). In this geometry the specimen is illuminated with an unidirectional beam whose axis is not greater than 0.14 rad (8°) from the surface normal of the sample. Any ray of this beam shall not exceed 0.09 rad (5°) from the beam axis. The cross-sectional area of the illuminating beam shall be at least 10 times the dimension of the largest hole in the test material. The total flux transmitted by the specimen is collected by the integrating sphere.

A2.2 Hemispherical illumination/directional viewing (T/0). In this geometry the specimen is illuminated by an internally illuminated integrating sphere. The specimen is viewed unidirectionally with an axis not greater than 0.14 rad (8°) from the surface normal of the sample. Any ray of this beam shall not exceed 0.09 rad (5°) from the beam axis.

The cross-sectional area of the viewing beam shall be at least 10 times the dimension of the largest hole in the test material.

A2.3 Sample substitution errors. Integrating spheres can experience "sample substitution" error due to contributions of the reflectance of the specimen on the internal Illumination of the sphere. The error can be eliminated in either geometry by use of a separate reference beam that traverses its own port opening in the sphere. The reference beam impinges on either a portion of the sphere wall or a reference material mounted at a diametrically opposed port opening.

A3. Spectral requirements. The spectrophotometer or spectroradiometer shall have a spectral bandpass of 5 nm or less over the spectral range of 280 nm (or less) to 400 nm (or more). The measured wavelength interval over this spectral range should not be greater than 5 nm.

A4. Stray radiation. The contribution of stray radiation within the instrument, including that due to sample fluorescence, shall produce an error of less than 0.005 in the value of spectral transmittance being measured.

A5. Sample fluorescence. The contribution of sample fluorescence on spectral transmittance measurements on certain dyes and whitening agents present in fabrics that may fluoresce could result in artificially high values of spectral transmittance.

A5.1 Monochromatic illumination. In spectrophotometers where the monochromator precedes the specimen within the optical path, the artificially high values of transmittance appear at the excitation wavelengths of the fluorescing agent. This includes nearly all wavelengths in the UVR spectral region. The error due to the fluorescence can be removed by placing a UV transmitting, visible blocking filter after the sample. A Schott Glass UG11 filter has been found to be satisfactory. However, the decrease in transmission of the filter with increasing wavelength may reduce the usefulness of the long wavelength UVA measurement.

A5.2 Polychromatic illumination. In spectrophotometers and spectroradiometers where the illumination is polychromatic and the monochromator follows the specimen in the optical path, the artificially high values of transmittance appear at the emission wavelengths of the fluorescing agent. The effects of fluorescence are, therefore, eliminated at most UVR wavelengths. The use of an illuminating light source that conforms to the spectral distribution requirements for solar simulators will most accurately include the contribution of sample fluorescence to the long wavelength UVA measurement. However, because the fluorescent component does not contribute to the UPF, the spectral distribution of the source is irrelevant, so long as it provides sufficient energy to cover the spectral range of interest to acceptable signal to noise ratios in the spectral data.