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Standard Test Methods for Evaluating the Relative Lightfastness and Weatherability of Printed Matter[1]

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1. Scope

1.1 These test methods cover the determination of the relative lightfastness and weatherability of printed matter under the following seven conditions, of which two involve exposure to natural daylight and five involve accelerated procedures in the laboratory:

1.1.1 *Test Method 1*—Daylight behind window glass,

1.1.2 *Test Method 2*—Outdoor weathering,

1.1.3 *Test Method 3*—Xenon-arc apparatus with window glass filters to simulate daylight behind window glass,

1.1.4 *Test Method 4*—Xenon-arc apparatus with water spray and daylight filters to simulate outdoor weathering,

1.1.5 *Test Method 5*—Enclosed carbon-arc apparatus without water spray,

1.1.6 *Test Method 6*—Enclosed carbon-arc apparatus with water spray, and

1.1.7 *Test Method 7*—Fluorescent lamp apparatus to simulate indoor fluorescent lighting in combination with window-filtered daylight.

1.2 These test methods require that a suitable print or other control (reference standard) be run along with the test sample. Color changes due to conditions of exposure may be evaluated by visual examination or instrumental measurement.

1.3 These test methods are applicable to prints on any flat substrate including paper, paperboard, metallic foil, metal plate, and plastic film, and are produced by any printing process including letterpress, offset lithography, flexography, gravure, and silk screen.

1.4 *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 and health practices and determine the applicability of regulatory limitations prior to use.* For specific hazard statements, see Section 8.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1729 Practice for Visual Appraisal of Colors and Color Differences of Diffusely-Illuminated Opaque Materials[2]

D 2244 Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates[2]

D 2616 Test Method for Evaluation of Visual Color Differences with a Gray Scale[2]

D 4302 Specification for Artists' Oils, Resin Oil, and Alkyd Paints[3]

D 4674 Test Method for Accelerated Testing for Color Stability of Plastics Exposed to Indoor Fluorescent Lighting and Window-Filtered Daylight[4]

D 5067 Specification for Artists' Watercolor Paints[3]

D 5098 Specification for Artists' Acrylic Emulsion Paints[3]

E 284 Terminology of Appearance[2]

E 991 Practice for Color Measurement of Fluorescent Specimens[2]

E 1331 Test Method for Reflectance Factor and Color by Spectrophotometry Using Hemispherical Geometry[2]

E 1347 Test Method for Color and Color Difference Measurements by Tristimulus (Filter) Colorimetry[2]

E 1349 Test Method for Reflectance Factor and Color by Spectrophotometry Using Bidirectional Geometry[2]

G 7 Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials[5]

G 23 Practice for Operating Light-Exposure Apparatus (Carbon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials[5]

G 24 Practice for Conducting Exposures to Daylight Filtered Through Glass[5]

G 26 Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials[5]

G 113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials[5]

G 151 Practice for Exposing Nonmetallic Materials in Accelerated Test Devices That Use Laboratory Light Sources[5]

G 153 Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials[5]

G 155 Practice for Operating Xenon Arc Light Apparatus for Exposure of Nonmetallic Materials[5]

[1] These test methods are under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and are the direct responsibility of Subcommittee D01.56 on Printing Inks.

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[2] *Annual Book of ASTM Standards*, Vol 06.01.

[3] *Annual Book of ASTM Standards*, Vol 06.02.

[4] *Annual Book of ASTM Standards*, Vol 08.03.

[5] *Annual Book of ASTM Standards*, Vol 14.04.

2.2 *ANSI Standard:*

PH 2.30 for Graphic Arts and Photography—Color Prints, Transparencies and Photomechanical Reproductions, Viewing Conditions[6]

3. Terminology

3.1 Definitions relating to weathering tests are covered in Terminology G 113. Definitions relating to color attributes and color differences are covered in Practice D 1729 and Test Method D 2244. Other appearance terms used in these test methods are defined in Terminology E 284.

3.2 *Definitions:*

3.2.1 *radiant exposure, H, n*—time integral of the irradiance at a given point over a specified time interval.

3.2.2 *Discussion*—Radiant exposure is usually a spectral quantity, with units of joules per square metre per unit wavelength [$J/m^2 \cdot nm$]. The wavelength region to be covered should be specified.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *ultraviolet radiant exposure*—an integration with respect to time of the ultraviolet irradiance on the exposed face of the specimen. UV irradiance (wavelengths below 400 nm) is believed largely responsible for degradation of organic materials. Units are J/m^2.

4. Summary of Test Methods

4.1 Printed specimens of the test and control are simultaneously exposed under conditions appropriate to the end-use application, or as agreed upon between the producer and the user.

4.2 The color changes of the exposed prints are periodically evaluated visually or instrumentally versus either an exposed control or an unexposed file specimen.

4.3 The endpoint is reached when it is established that the test print is equal to, better than, or worse than the control.

5. Significance and Use

5.1 Lightfastness or weatherability for specified periods of time is pertinent for certain types of printed matter such as magazine and book covers, posters and billboards, greeting cards and packages. Since the ability of printed matter to withstand color changes is a function of the spectral-power distribution of the light source to which it is exposed, it is important that lightfastness be assessed under conditions appropriate to the end-use application.

5.2 The accelerated procedures covered in these test methods provide means for the rapid evaluation of lightfastness or weatherability under laboratory conditions. Test results are useful for specification acceptance between producer and user and for quality control.

5.2.1 The xenon-arc lamp with an appropriate filter system exhibits a spectral-power distribution that corresponds more closely to that of daylight than the carbon-arc. In turn, accelerated tests using xenon-arc apparatus may be expected to correlate better with exposure to natural daylight than do those using carbon-arc apparatus.

5.2.2 Exploratory studies demonstrated that the fluorescent-lamp apparatus ranked a series of 16 printed specimens in nearly the same order as did fluorescent lighting prevailing in cooperating laboratories.

5.3 To accommodate variations in light intensity among days, seasons, locations, or instruments, duration of exposure is preferably expressed as the cumulative ultraviolet radiant exposure rather than time. In either case, the inclusion of an appropriate control serves to minimize effects of variations in test conditions.

5.4 Color changes are not a linear function of duration of exposure. The preferred method of determining lightfastness or weatherability is to expose the prints for a number of intervals and to assess the radiant exposure required to obtain a specified color difference.

5.5 For a given printing ink, lightfastness and weatherability or both depend on the type of substrate, the film thickness on the print, and the area printed (solid versus screen). Therefore, it is important that the nature of the test and control specimens correspond to that expected under actual use conditions.

NOTE 1—Specifications D 4302, D 5067, and D 5098 provide useful guides to the lightfastness of pigments in several types of artists' paints after 1260 MJ/m^2 total radiant exposure (equivalent to about 2 or 3 months' exposure to daylight behind glass). However, because of major differences between printing inks and artists' colors, especially in applied film thickness, it cannot be assumed that the lightfastness categories of printed ink films containing these pigments will be comparable to those indicated in the three specifications.

6. Apparatus

6.1 *Exposure Apparatus*:

6.1.1 *Test Method 1 Daylight Behind Window Glass*—Outdoor exposure cabinet conforming to Method A of Practice G 24. The cabinet is covered with window glass that transmits typically less than 3.5 % at wavelengths shorter than 310 nm. Accessories include a mutually agreeable radiometer[7] (for example, 295 to 385 nm), and humidity and temperature recorders.

6.1.2 *Test Method 2 Outdoor Weathering*—Outdoor exposure rack conforming to Practice G 7. Accessories are the same as in 6.1.1 with the addition of a wetness meter and rain gage.

NOTE 2—All equipment must be calibrated in accordance with the manufacturer's instructions.

6.1.3 *Test Method 3 Xenon-Arc with Window Glass Filters*—Xenon-arc apparatus equipped with a window glass filter system to simulate natural daylight filtered through window glass as specified in the Apparatus sections of Practices G 151 and G 155.

6.1.4 *Test Method 4 Xenon-arc with Daylight Filters and Water Spray*—Xenon-arc apparatus equipped with a daylight filter system and water spray to simulate outdoor weathering as specified in the Apparatus sections of Practices G 151 and G 155.

6.1.5 *Test Methods 5 and 6 Enclosed Carbon-Arc*—

[6] Available from American National Standards Institute, 25 West 43rd St., 4th Floor, New York, NY 10036.

[7] The most popular radiometer in the United States monitors in the wavelength range 295 to 385 nm, which accounts for about 80 % of the solar UV irradiance between 300 and 400 nm. A radiometer that measures a narrow spectral band may also be used.

Enclosed carbon-arc apparatus conforming to the Apparatus sections of Practices G 151 and G 153.

NOTE 3—Previous versions of these test methods referenced Practice G 23 for enclosed carbon-arc devices and Practice G 26 for xenon-arc devices; both practices describe very specific equipment designs. In the current version of these test methods, these practices have been replaced by Practice G 151, which gives performance criteria for all exposure devices that use laboratory light sources, and by Practices G 153 and G 155, which give requirements for exposure in enclosed carbon-arc and xenon-arc devices, respectively.

6.1.6 *Test Method 7 Fluorescent-Lamp Apparatus*—Exposure cabinet conforming to Test Method D 4674. The cabinet is constructed of UV reflective aluminum with a clear chromatic conversion coating, and the light source is a combination of very high-output cool white fluorescent lamps and soda lime glass-filtered fluorescent UV sunlamps. Accessories include a broad-band detector (250 to 400 nm) and a temperature sensing device.

6.2 *Apparatus for Print Evaluation*:

6.2.1 *Standard Daylight*, (for visual evaluation), preferably a D50 light source conforming to ANSI Standard PH 2.30.

6.2.2 *Gray Scale Chart and Masks*, (optional, for visual evaluation) conforming to Test Method D 2616.

6.2.3 *Color Measuring Instrument*, (for instrumental evaluation), such as a spectrophotometer conforming to Test Method E 1331 or E 1349, or a tristimulus colorimeter conforming to Test Method E 1347, or, if the specimens are fluorescent, to Practice E 991.

7. Materials

7.1 *Control (Reference Standard)*, preferably a printed specimen of known lightfastness or weatherability; alternatively, AATCC Blue Wool Lightfastness Standards in accordance with Practice G 151.

7.2 *Mounting Material*, such as light-weight card stock, on which to mount non-rigid specimens (paper, plastic, or foil) during exposure tests.

7.3 *Masking Material*, (optional), such as white card stock, aluminum foil, or other opaque material with a non-UV-reflecting surface.

7.4 *Unprinted Stock*, (optional), identical to that used for the printed specimens.

7.5 *Backing Material*, (for use during instrument measurements on nonopaque specimens), such as several sheets of the unprinted stock, a standard white (card) stock, or a spare calibration standard.

8. Hazards

8.1 **Precaution:** Never look directly at sunlight or the operating light source of an accelerated apparatus unless wearing UV protective eyewear.

8.2 Newer accelerated apparatus are equipped with safety switches that turn the lamps off prior to gaining access. Users of very old carbon-arc apparatus must be certain to turn the switch off before opening the test chamber door.

8.3 Users of carbon-arc apparatus are cautioned that burning carbon rods become very hot. After the device is turned off, wait at least 15 min for the arcs to cool, and wear canvas or other protective work gloves when changing the rods. Avoid inhaling ash dust.

9. Test Specimens

9.1 These test methods do not cover preparation of printed specimens. The test print should match the control print in color, substrate, print area, and ink film thickness.

9.2 It may be useful to include the unprinted substrate and a vehicle print in exposure tests so as to determine the contribution of paper or vehicle yellowing to color changes.

9.3 Unless otherwise agreed upon, at least two specimens are to be exposed at each set of test conditions. The test specimens shall be of uniform color, gloss, and texture; clean and free of fingerprints.

9.3.1 **Warning:** When handling test specimens, be careful not to contaminate the surface by touching with fingers.

9.4 For visual evaluation, the specimen size indicated in Practice D 1729 is a minimum of 90 by 165 mm. For instrumental evaluation, the specimen must be large enough to cover the specimen port; a minimum size of 35 mm^2 is satisfactory for many instruments. In the case of samples intended for xenon-lamp or carbon-arc exposure, the specimens should be of sufficient dimensions to be accommodated in the specimen holders.

9.5 Prepare file specimens (unexposed controls) in the following manner:

(*1*) For visually evaluated tests, set aside a replicate print or cut off a segment of suitable size; store in a dark dry place.

(*2*) For instrumentally evaluated tests, make color measurements on the relevant specimen area(s) prior to exposure; see 11.3.1 and 11.3.2.

NOTE 4—The file specimen should not be a masked specimen. Even though shielded from radiation, some materials may undergo color changes due to the heat or moisture present during the test.

9.6 Mount nonrigid specimens onto cardstock. If masking is specified in order to obtain multiple exposures on a single specimen, make certain that the size of each exposed area conforms to 9.4. Place specimens intended for xenon-arc or carbon-arc exposure in specimen holders; provide a sufficient number of blanks so as to fill the specimen rack.

10. Procedures for Light and Weather Exposure

10.1 Expose the test specimens simultaneously with the control in the apparatus and under the conditions agreed upon between the producer and the user. When conditions have not been specified, use the following guidelines:

TEST METHOD 1 DAYLIGHT BEHIND WINDOW GLASS

10.1.1 Common commercial exposure sites are southern Florida (a high humidity area) and Arizona (a low humidity area).

NOTE 5—Either site averages about 0.5 MJ/m^2 of total ultraviolet radiation under glass per day.

10.1.2 Mount the test and control specimens under glass on open racks at an angle of 45° facing the equator.

10.1.3 Monitor cumulative ultraviolet radiant exposure of the glass-filtered daylight (for example, 295 to 385 nm, little of

which will be below 310 nm), relative humidity, and air temperature, in accordance with Practice G 24.

TEST METHOD 2 OUTDOOR WEATHERING

10.1.4 Commercial sites are the same as in 10.1.1.

NOTE 6—Either site averages about 1 MJ/m^2 of total ultraviolet radiation per day.

10.1.5 Mount the test and control specimens on a rack faced with unpainted plywood at an angle of 45° facing the equator.

10.1.6 Monitor ultraviolet radiation exposure (for example, 295 to 385 nm), relative humidity, air temperature, hours of wetness, and total rain fall in accordance with Practice G 7.

TEST METHOD 3 XENON-ARC APPARATUS WITH WINDOW GLASS FILTERS TO SIMULATE DAYLIGHT BEHIND WINDOW GLASS

10.1.7 Set up the xenon-arc apparatus with the Window glass filter system and operate in accordance with the Apparatus section of Practices G 151 and G 155.

10.1.8 Unless otherwise specified, use the following exposure cycle:

10.1.8.1 Expose the specimens to 100 % light.

10.1.8.2 Set the irradiance level to 0.35 watts or higher per square metre per unit wavelength ($W/m^2 \cdot nm$) at 340 nm, and maintain at ± 0.02 $W/m^2 \cdot nm$. Consult the manufacturer for the equivalent 300 to 400 nm or 300 to 800 nm broad band irradiance setting and tolerance applicable to the specific equipment for which it is needed.

10.1.8.3 Set the uninsulated black-panel temperature to 63 ± 3°C (145 ± 5°F), and, in apparatus capable of controlling humidity, the relative humidity to 40 ± 5 %.

10.1.9 Fill the rack with mounted test and control specimens making sure that the specimens face the lamp. Fill empty spaces, if any, with blanks.

10.1.10 Monitor the cumulative radiant exposure in either the narrow or broad band regions.

10.1.11 Reposition the specimens after specified intervals in accordance with the Procedure sections of Practices G 151 and G 155.

TEST METHOD 4 XENON-ARC APPARATUS WITH WATER SPRAY AND DAYLIGHT FILTERS TO SIMULATE OUTDOOR WEATHERING

10.1.12 Install the xenon-arc with the Daylight filter system in accordance with the Apparatus sections of Practices G 151 and G 155.

10.1.13 Unless otherwise specified, use the following exposure cycle:

10.1.13.1 Use a cycle of 102 min of light followed by 18 min of light and water spray.

10.1.13.2 Set the irradiance level to a minimum of 0.40 $W/m^2 \cdot nm$ at 340 nm and maintain at ± 0.02 $W/m^2 \cdot nm$. Consult the manufacturer for the equivalent 300 to 400 nm or 300 to 800 nm broad band irradiance setting and tolerance applicable to the specific equipment for which it is needed.

10.1.13.3 Set the uninsulated black-panel temperature to 63 ± 3°C (145 ± 5°F). In apparatus with humidity control, set the relative humidity to 40 ± 5 %.

10.1.14 Same as in 10.1.9-10.1.11.

TEST METHOD 5 ENCLOSED CARBON-ARC WITHOUT WATER SPRAY

10.1.15 Set up the carbon-arc apparatus to operate in accordance with the Apparatus sections of Practices G 151 and G 153.

10.1.16 Unless otherwise specified, use the following exposure cycle:

10.1.16.1 Expose samples to 100 % light.

10.1.16.2 Set the uninsulated black-panel temperature to 63 ± 3°C (145 ± 5°F), and in apparatus with humidity control, set the relative humidity to 40 ± 5 %.

10.1.17 Fill the rack with mounted test and control specimens making sure that the specimens face the lamp. Fill empty spaces, if any, with blanks.

10.1.18 Insert new carbons and clean the globe after each 20 to 22 h of operation. See specific hazards in 8.2 and 8.3. Reposition the specimens daily in accordance with the Procedure sections of Practices G 151 and G 153.

TEST METHOD 6 ENCLOSED CARBON-ARC WITH WATER SPRAY

10.1.19 Set up the carbon-arc apparatus to operate in accordance with the Apparatus sections of Practices G 151 and G 153.

10.1.20 Unless otherwise specified, use the following exposure cycle:

10.1.20.1 Expose specimens to a cycle of 102 min of light alternating with 18 min of light and water spray.

10.1.20.2 Set the uninsulated black-panel temperature to 63 ± 3°C (145 ± 5°F). In apparatus with humidity control, set the relative humidity to 40 ± 5 %.

10.1.21 Same as 10.1.17 and 10.1.18.

TEST METHOD 7 FLUORESCENT LAMP APPARATUS

10.1.22 Load the specimen trays and perform other steps in accordance with the Procedure Section in Test Method D 4674. Select the ultraviolet actinic exposure (UVAE) value equal to 1000 Wh/m^2 for specimens of poor lightfastness and 2000 for specimens of reasonably good lightfastness.

10.1.23 Reposition the specimen in accordance with Test Method D 4674 at time intervals equal to 25 ± 5 % of the total test time.

11. Evaluations

11.1 *Exposed Samples Evaluation*:

11.1.1 After one or more mutually agreeable intervals, remove the test specimens from the exposure apparatus, make visual (see 11.2) or instrumental evaluations (see 11.3), and, if further exposure is required, return the specimen to the apparatus in a rotated order, when specified. The exposure intervals may be as follows:

11.1.1.1 Specific duration(s) of time,

11.1.1.2 Specific duration(s) of ultraviolet radiant exposure (if measured), or

11.1.1.3 A number of intervals (time or ultraviolet radiant exposure) spanning that required to determine whether the test

sample is equal to, better than, or worse than the control after equal exposure periods or based on duration of exposures required to produce a predetermined color change in each.

11.2 *Visual Evaluation*:

11.2.1 In order to facilitate direct comparisons, it may be necessary to trim off the unprinted paper border and the unexposed part of the print, if any, on the longer side of the exposed specimens.

11.2.2 Using standard daylight, preferably the D50 light source specified in ANSI pH 2.30, examine the specimens in accordance with Practice D 1729. Compare the exposed specimens with the exposed control and (if specified) the unexposed file specimen. If the gray scale is used, follow the procedure in Test Method D 2616.

11.2.3 Where there is a perceptible color difference, note the nature of the changes in accordance with Practice D 1729, for example, turns lighter, darker, greener, redder, bluer, or yellower.

11.3 *Instrumental Evaluation*:

11.3.1 Set the spectrophotometer or colorimeter for the largest area of view or illumination that can accommodate the respective specimens, and standardize according to Test Methods E 1331, E 1347, or E 1349. If the test substrate is not completely opaque, provide a background as suggested in 7.5.

11.3.2 Make measurements as prescribed in Test Methods E 1331, E 1347, or E 1349 using either the CIE 1964 (10°) Supplementary Standard Observer and Standard Illuminant D_{65} or the CIE 1931 (2°) Standard Observed and Standard Illuminant C, as long as the same basis is consistently used. If hemispherical geometry is used, the specular component may be either included or excluded as long as the same condition is consistently used. Make the measurements on each test and control specimen prior to exposure (see 9.5), and after each exposure. Make a minimum of three measurements per specimen, moving or rotating the specimen between measurements.

11.3.3 Using the CIE 1976 L* a* b* equation described in Test Method D 2244, calculate ΔL^*, Δa^*, Δb^*, and ΔE^*_{ab} between each exposed specimen and its file specimen (unexposed counterpart).

11.3.4 (Optional) Plot ΔE^*_{ab} or other specified color difference parameter versus time or cumulative ultraviolet radiant exposure. Determine by interpolation the duration required to obtain a specified level of color difference. This approach permits the rate of color changes to be determined and lightfastness or weatherability to be more thoroughly analyzed than with tests based on a single duration.

12. Report

12.1 The report shall contain the following information for both the test material and the control:

12.1.1 Specimen identification, including the method of printing, print area (solid or halftone), and substrate,

12.1.2 Exposure apparatus and conditions as indicated in the appropriate referenced document. If a radiometer is used, include the wavelengths of light that were monitored,

12.1.3 Procedure for evaluating color changes (either visual or instrumental), and

12.1.4 Whether the test sample was equal to, better than, or worse than the control.

NOTE 7—In the case of instrumental measurements, a single ΔE^*_{ab} cannot be used to specify acceptable color differences irrespective of color. While many colors are visibly different at a ΔE^*_{ab} of 1.0 or less, oranges may require a ΔE^*_{ab} of at least 4.0 and yellows 5.0.

13. Precision and Bias

13.1 *Precision*—An interlaboratory test of Test Method 5 (enclosed carbon-arc lamp without water spray) was conducted in which eight laboratories tested the relative lightfastness of two pairs of colors (Yellow 12 versus Yellow 13, and Red 53 versus Red 57:1). Each color was printed by the sheet-fed offset process as a solid and a 40 % halftone onto a coated paper and an uncoated paper. The Yellow 13 prints were more lightfast than the corresponding Yellow 12 prints, and the Red 57:1 prints, which darkened, were more lightfast than the Red 53 prints. Furthermore, the uncoated paper prints were more stable than the corresponding coated paper prints, and the solids more stable than the halftones.

13.2 *Bias*—It is not possible to compute precision and bias because the test is non-quantitative.

14. Keywords

14.1 accelerated exposure; carbon-arc apparatus; color difference measurements; daylight behind window glass; fluorescent lamp apparatus; gray scale; lightfastness; outdoor exposure; printed matter; printing inks; weatherfastness; xenon-arc apparatus