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T 425

DRAFT NO. 02 SARG

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WORKING GROUP
CHAIRMAN To be determined

SUBJECT
CATEGORY Optical Properties

RELATED
METHODS See "Additional Information"

CAUTION:
This Test Method may include safety precautions which are believed to be appropriate at the time of publication of the method. The intent of these is to alert the user of the method to safety issues related to such use. The user is responsible for determining that the safety precautions are complete and are appropriate to their use of the method, and for ensuring that suitable safety practices have not changed since publication of the method. This method may require the use, disposal, or both, of chemicals which may present serious health hazards to humans. Procedures for the handling of such substances are set forth on Material Safety Data Sheets which must be developed by all manufacturers and importers of potentially hazardous chemicals and maintained by all distributors of potentially hazardous chemicals. Prior to the use of this method, the user must determine whether any of the chemicals to be used or disposed of are potentially hazardous and, if so, must follow strictly the procedures specified by both the manufacturer, as well as local, state, and federal authorities for safe use and disposal of these chemicals.

Opacity of paper (15/*d* geometry, illuminant *A*/2°, 89% reflectance backing and paper backing)

(Five-year review of Official Method T 425 om-16)

(No changes from previous draft. Standard Reaffirmed)

1. Scope and significance

1.1 Opacity is a fundamental optical property of paper as a whole, yet the measurement of opacity is determined by a ratio of reflectance measurements. The opacity of the sheet is influenced by thickness, the amount and kind of filler, degree of bleaching of the fibers, coating, and the like. The utility of bond, writing and book papers is enhanced by a high opacity.

1.2 The essential principle of this method for determining the opacity of paper is as follows: The reflectance of paper when combined with a white backing is higher than that of paper when combined with a black backing because, in the former case, light transmitted through the imperfectly opaque sheet is largely reflected by the white backing, and a portion of the light is transmitted through the paper a second time thus increasing the total reflection. Two types of "white" backing are used, leading to two measures of opacity:

1.2.1 *Opacity (89% reflectance backing)*, sometimes called *contrast ratio*, $C_{0.89}$ is defined as 100 times the ratio of the diffuse reflectance, R_0, of a specimen backed by a black body of 0.5% reflectance or less to the diffuse reflectance, $R_{0.89}$, of the same specimen backed with a white body having an absolute reflectance of 89%; thus, $C_{0.89} = 100\ (R_0/R_{0.89})$. Accordingly, the contrast ratio is 100% for perfectly opaque paper and is only a few percent for perfectly transparent sheets.

1.2.2 *Opacity (paper backing)*, sometimes called *printing opacity*, is defined as 100 times the ratio of the light reflected by a paper specimen when the specimen is backed by a black body of 0.5% reflectance or less, R_0, to that when the specimen is backed by a thick stack of the same kind of paper, R_∞; thus opacity (paper backing) = $100\ (R_0/R_\infty)$.

1.3 The determination of opacity is of vital importance to both the manufacturer and the consumer. When white pigment is added to a sheet, it scatters more light and thus increases opacity; however, it is also possible to increase opacity of a sheet by adding dark pigment or dye which absorbs light. This being so, it is of value to the manufacturer, in meeting an opacity specification, to be able to predict whether a sheet which does not have desired opacity can be brought up to specification by raising or, alternatively, lowering the reflectivity within permissible limits. To the consumer, opacity measurements are used to evaluate some of the characteristics of appearance. The user is interested in the comparison of samples under identical conditions. When comparisons are made, one sample with another, very small differences can be identified visually. For this reason, small measured differences between similar samples represent actual differences in appearance.

1.4 This method employs 15/*d* geometry, illuminant A/2° and 89% reflectance backing or paper backing. For the measurement of opacity with *d*/0 geometry, illuminant C/2° and paper backing, see TAPPI T 519.

2. Apparatus

2.1 *Opacity meter*[1], equipped with an accurate linear or a corrected photometric system. The reflectance involved in the determination of contrast ratio should be for 15 degree direct illumination and diffuse viewing.

NOTE 1: The direction of illumination should be 15 ± 1° from the normal. The instrument may be designed to measure directly the ratio of reflectance of paper backed by black and white, or, alternatively, the instrument may be adjusted to indicate a cardinal value such as 100.0 with the white backing in place, and then the ratio of reflectance is obtained by replacing the white body with the black body. The photometric system must be sufficiently stable that the instrument will not fluctuate by more than approximately 0.1% of its full-scale deflection while the contrast ratio is being measured.

2.2 The more important requirements of the apparatus are as follows:

2.2.1 *Standard black backing*, consisting of a cavity lined with black velvet or other material which will

[1] Names of suppliers of testing equipment and materials for this method may be found on the Test Equipment Suppliers list, available as part of the CD or printed set of Standards, or on the TAPPI website general Standards page.

cause the reflectance of the cavity to be 0.5% or less.

2.2.2 *Standard white backing*, having an effective absolute reflectance equal to 89% when illuminated under the conditions of actual testing with a sheet of paper (*1*). This backing consists either of a permanent diffusing surface of the appropriate reflectance in contact with the sample, or of a device which allows adjustment of the spacing between a diffuse white sample and a cover glass.

2.2.3 *Incandescent light source*, operated at a color temperature of 2854 ± 200°K and sufficiently stable to provide opacity readings within 0.1 opacity units. An infrared absorbing filter must be located between the lamp and specimen to eliminate sample heating.

2.2.4 *Photocell*, in combination with optical filters and lamp to produce an overall spectral response of the instrument equivalent to Commission Internationale de l'Eclairage (CIE) function W_y for illuminant A, 1931 Observer as given in ASTM Standard E308-95, Table 6.1. This function has an effective wavelength of 572 nm and closely approximates the response of the human eye *(2)*.

2.2.5 *Integrating cavity* with inside surfaces coated with barium sulfate or halon. Total area of non-white surfaces (including all openings) shall not exceed 6% of the total white area. The specimen opening shall be round with a diameter of 14.8 ± 0.25 mm (0.584 ± 0.010 in.). The illuminated area shall be circular with a diameter of 9.53 ± 0.38 mm (0.375 ± 0.015 in.) and centered in the specimen opening. A light trap should be fitted inside the integrating cavity to limit stray light to no more than 0.5%.

3. Calibration

Check the calibration utilizing evaluated opal glass or paper standards[1] and readjust as necessary in accordance with the manufacturer's instructions and Appendix A. After calibration, the instrument must read the opal glass or paper standards within ± 0.3 of assigned values.

4. Sampling and test specimens

4.1 Obtain a sample in accordance with TAPPI T 400 “Sampling and Accepting a Single Lot of Paper, Paperboard, Containerboard, or Related Product,” free from watermarks or blemishes.

4.2 Cut at least five specimens of sufficient size to fit the specimen holder and completely cover the standard backings. Do not touch the test area with the fingers, and keep these areas perfectly clean and free from folds and wrinkles.

5. Conditioning

Testing atmosphere shall be as follows:

Relative humidity: not to exceed 60% RH

Temperature: 23.0 ± 4.0°C

6. Procedures

6.1 *Opacity (89% reflectance backing).*

6.1.1 Check the calibration using an opal glass or paper standard which is as close in value as possible to the specimen to be measured. If agreement is not within ± 0.3 recalibrate as instructed in Appendix A.

6.1.2 With the specimen backed by the standard white backing, set the instrument to read 100.0.

6.1.3 Replace the white backing with the black backing, and read the meter to obtain the contrast ratio. Record the individual results to three significant figures. Measure a minimum of 5 specimens.

NOTE 2: Usually neither the side nor direction of the grain of the paper makes any significant difference. If either effect exceeds 0.2, report each side and/or direction separately.

6.2 *Opacity (paper backing).*

6.2.1 Check the calibration using an opal glass or paper standard which is as close in value as possible to the specimen to be measured. If agreement is not within ± 0.3 recalibrate as instructed in Appendix A.

6.2.2 Place the specimen over the opening backed by a stack of the same paper. The thickness of the pile should be such that doubling the thickness has no detectable effect on the reading. Set the instrument to read 100.0.

6.2.3 Place the specimen over the opening backed by the black body. The meter reading gives opacity with a paper backing (100 R_0/R_∞). Record to three significant figures.

6.3 *Scattering power (sW).* The ability to predict the effect upon opacity due to a change of grammage or reflectance of a sheet has been found particularly useful to paper, pigment, and dyestuff manufacturers. The determination of scattering power is the first essential step in making these predictions. To determine scattering power:

6.3.1 Obtain a white reflectance standard with known absolute reflectance at an effective wavelength of 572 nm.

6.3.2 Carefully place the reference white surface over the specimen opening of the instrument. Adjust the instrument to read the absolute reflectance value for the reference material (at 572 nm).

6.3.3 With the instrument adjusted to read correctly on the absolute scale, place a single sheet of the specimen over the specimen opening backed by the black backing and read R_0.

6.3.4 Leave the single specimen sheet (used in 6.3.3) in place over the specimen opening and back with a stack of the same paper. The thickness of the stack should be such that doubling the thickness has no detectable effect

on the reading. Read R_∞.

6.3.5 Using R_0, R_∞ and W (grammage) in g/m^2, calculate scattering and absorption powers and coefficients as follows:

$$a = 0.5\,[(1/R_\infty) + R_\infty]$$
$$b = 0.5\,[(1/R_\infty) - R_\infty)]$$
$$X = [1 - aR_0]/[bR_0]$$

Scattering power	$sW = (0.5/b)\ln[(X + 1)/(X - 1)]$
Scattering coefficient	$s = 1000\ sW/W$
Absorption power	$kW = (asW) - sW$
Absorption coefficient	$k = 1000\ kW/W$

Scattering power and absorption power are unitless values. Scattering coefficient and absorption coefficient have inverse grammage units: m^2/kg.

6.3.6 If the scattering power (sW) and reflectivity (R_∞) are known for a paper specimen of given grammage, the opacity of the same specimen at a different grammage (known as Normalized TAPPI Opacity, C_n) may be calculated as follows *(3)*:

Where sW_n is normalized scattering power, BSW_d is desired grammage and BSW_k is known grammage:

$$sW_n = sW(BSW_d/BSW_k)$$

Where R_∞ is expressed as a decimal.

$$a = e^{sWn[(1/R_\infty) - R_\infty]}$$

$$C_n = \frac{(a - 1)[0.89 - R_\infty - a[0.89 - (1/R_\infty)]]}{[(a/R_\infty) - R_\infty]\,[(0.89/R_\infty) - aR_\infty\,[0.89 - (1/R_\infty)] - 1]}$$

For further information concerning the calculation and use of scattering and absorption coefficients see TAPPI Technical Information Paper 0804-03.

7. Report

State the type of opacity measured, (i.e. 89% backing or paper backing). State the average, and the standard deviation values for the 5 or more specimens measured to the nearest 0.1 opacity units. State scattering and absorption power to the nearest 0.01 and scattering and absorption coefficient to the nearest 0.1.

8. Precision

8.1 The precision of these methods for test results consisting of averages for five specimens is:

8.1.1 Repeatability (within a laboratory): *89% backing*, 0.62% (0.28 – 1.06); *paper backing*, 0.64% (0.44 – 1.06).

8.1.2 Reproducibility (between laboratories): *89% backing*, 1.22% (0.70 – 2.05); *paper backing*, 0.77% (0.46 – 1.08).

8.2.1 The above precision data are in conformance with TAPPI T 1200 "Interlaboratory Evaluation of Test Methods to Determine TAPPI Repeatability and Reproducibility," and were obtained in the TAPPI Collaborative Reference Program for paper in which the range of test results was 88-96%. The numbers in parentheses are minimum and maximum values, and those before the parentheses are averages of all the papers involved. The data have been derived from Reports 12 through 22 for 89% backing (22 papers and an average of 57 laboratories) and Reports 19 through 22 for paper backing (8 papers and an average of 13 laboratories).

8.2.2 The user of these precision data is advised that it is based on actual mill testing, laboratory testing or both. There is no knowledge of the exact degree to which personnel skills or equipment were optimized during its generation. The precision quoted provides an estimate of typical variation in test results which may be encountered when this method is routinely used by two or more parties.

9. Keywords

Opacity, Paper, Diffuse reflection, Reflectance, Contrast ratio, Scattering, Absorption.

10. Additional Information

10.1 Effective date of issue: To be assigned.

10.2 This method was first published in 1926 as a Tentative Standard, became an Official Method in 1928 and was revised in 1975. The 2001 revision eliminated the obsolete "zero resistance" linearity check, included changes to take into account state-of-the-art instrumentation and included a method for determining scattering power. In 2011, wording was modified for the purpose of clarifying the verbiage.

10.3 Related methods: ASTM D 589 “Opacity of Paper,” American Society for Testing and Materials, Philadelphia, PA; PAPTAC E.2 “Opacity of Paper,” Pulp and Paper Technical Association of Canada, Montreal, Canada; TAPPI T 519 “Diffuse Opacity of Paper (*d*/0° Paper Backing),” and TAPPI T 220 “Physical Testing of Pulp Handsheets,” Technical Association of the Pulp and Paper Industry, Atlanta, GA; ISO 2471 “Determination of Opacity (Paper Backing) - Diffuse Reflectance Method,” International Organization for Standardization, Geneva, Switzerland; SCAN P-8, “Opacity for Paper,” Scandinavian Pulp, Paper and Board Testing Committee, Stockholm, Sweden.

Literature cited

1. Report No. 22, Part II, to the American Paper Association, “Instrumentation Studies XL VIII, Part II, Calibration of the Bausch and Lomb Opacimeter,” *Paper Trade J.* **119** (17): 27 (1944).
2. ASTM Standard E-308-95, American Society for Testing and Materials, Philadelphia, PA.
3. Robinson, James V., “A Summary of Reflectance Equations for Application of the Kubelka-Munk Theory to Optical Properties of Paper,” *Tappi* **58**: 152 (10): (1975).
4. Hofert, H. J., and Loof, H., Z. *für Instrumentenkunde* **72:** 72 (1964).

References

Judd, D. B., “Opacity Standards,” *J. Research Nat. Bur. Standards* **13:** 381 (1934); Research Paper 709.

Judd, D. B., “Optical Specification of Light-Scattering Materials,” *Paper Trade J.* **106** (1): 39, T. S. 5 (1938).

Van den Akker, J. A., “The Meaning and Measurement of Opacity,” *Tappi* **50** (5): 41A (1967).

Dixon, W. J., and Massey, F. J., Jr., “Introduction to Statistical Analysis”, Table VIII, McGraw-Hill, New York, 1951, p. 316.

Van den Akker, J. A., “Scattering and Absorption of Light in Paper and Other Diffusing Media,” *Tappi* **32** (11): 498 (1949).

Kubelka, P., and Munk, F., “Ein Beitrag zur Optik der Farbanstriche,” *Z. tech. Physik* **12:** 593 (1931).

Steele, F. A., “The Optical Characteristics of Paper: I. The Mathematical Relationships Between Basis Weight, Reflectance, Contrast Ratio, and Other Optical Properties,” *Paper Trade J.* **100** (12): 37 (1935); *Tech. Assoc. Papers* **18:** 299 (1934).

Kubelka, P., “New Contributions to the Optics of Intensely Light-Scattering Materials,” *J. Opt. Soc. Amer.* **38:** (5): 448 (1948) and (12): 1067 (1948).

Report No. 22, Part I, to the American Paper and Pulp Association, “Instrumentation Studies XXX, Part I,” *Paper Trade J.* **109** (4): 29 (1949).

Dearth, R. A., Shillcox, W. M., Wink, W. A., and Van den Akker, J. A., “A Study of Instruments for the Measurement of Opacity of Paper. V. Comparison of Printing Opacity Determined with Several Selected Instruments,” *Tappi* **53** (3): 436-41 (1970).

Report No. 22, Part IV, to the American Paper Institute, "Comparison of TAPPI and Printing Opacity Determined with Five Instruments," (May 8, 1971).

Appendix A

A.1 *Calibration of the opacity meter (4).*

A.1.1 *Optical adjustment.* Arrange the instrument to permit the beam of light exiting the specimen aperture to illuminate a wall perpendicularly 0.6 to 1.2 m (2 to 4 ft) away from the instrument. The filament image observed should be in a good state of focus and centered in the beam. If not, the lamp or optics should be repositioned in accordance with the manufacturer's instructions.

A.1.1.1 When a sheet of paper is laid over the specimen aperture to inspect the distribution of light in the aperture, the circular light spot should be (a) centered in the aperture, (b) nearly fill the aperture but should not be in contact with the edge of the aperture (there should be a clearance of about 2.5 mm between the edge and the boundary of the light spot), and (c) the boundary of the light spot should be as sharp and as free of color as possible. After the optics have been adjusted, usually it is necessary to adjust the lamp only for subsequent checks of the optical system. The alignment and state of focus of the lamp should be checked before each calibration of the instrument. The lenses should be cleaned to minimize the light scattered into the integrating cube. Cleanliness of the optical system may be tested by comparing the zero reading obtained with the lamp on and the black body placed over the specimen aperture to the reading with the lamp off. There should be very little difference.

A.1.2 *Photometric linearity.* The instrument shall incorporate a photometric measurement system which measures reflectance in direct proportion to the light energy incident upon the sample within 0.2% of full scale throughout the entire range of measurement. Photometric linearity errors are normally associated with the photocell and/or electronics. A means of measuring photometric linearity is described in TAPPI Technical Information Paper 0804-06 "Photometric Linearity of Optical Properties Instruments."

A.2 *Adjustment of the white backing*. The adjustment of the white backing to conform to the requirement that it have an absolute reflectance of 0.89 (under the conditions of actual test with a known test specimen or standard in place) may be carried out by means of opal glass or paper standards evaluated for opacity.

A.2.1 *Adjustment by means of opal glass or paper standards.*

A.2.1.1 Clean the opal glass standard by washing it with a mild soap solution. Rinse with water before drying with a lint-free non-abrasive towel. Do not rub back of standard when drying. Gently dab until dry.

A.2.1.2 Read the opacity of the calibrated area of the opal glass or paper standard. If this opacity reading conforms to the value of opacity certified for the standard within ± 0.3%, the white backing may be regarded as correctly adjusted.

A.2.1.3 If the reading departs from the certified value of opacity by more than ± 0.3%, adjust the distance between the white surface and the standard. Too high an opacity reading means that the distance must be decreased;

too low a reading means that it must be increased.

A.2.1.4 Check the adjustment by means of standards of different opacities. Adjust the white backing so that the opacimeter will read within ± 0.3% of the assigned standard values throughout the range of interest.

NOTE 3: If it is impossible to set the instrument at 100.0 for the normal range of white papers, when backed by the white body, the integrating cavity should be recoated, or the photocell and/or the lamp should be replaced. If, because of low reflectance of the paper, the adjustment to 100.0 with the specimen backed with the white body is impossible, set the instrument at 90.0, 80.0, or other value. The contrast ratio is then obtained from the ratio of the readings with the black to white bodies. A note must be recorded indicating that the measurement was made using non-standard conditions any time a value other that 100 is used to calculate contrast ratio.

A.2.1.5 The zero of the instrument should be checked and readjusted if necessary. With the apparatus turned on and the specimen aperture covered with the black body, the reading should not exceed 0.3 divisions with 100 divisions equal to full scale.

Your comments and suggestions on this procedure are earnestly requested and should be sent to the TAPPI Standards Department. ■