Standard Test Method for
Opacity of Paper (15° Diffuse Illuminant *A*, 89 % Reflectance Backing and Paper Backing) [1]

1. Scope

1.1 This test method covers the determination of the opacity of paper.

1.2 Two different types of "white" backing are specified, leading to two different opacity values, in accordance with Section 3.

1.3 This test method employs 15° diffuse 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).

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.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 585 Practice for Sampling and Accepting a Single Lot of Paper, Paperboard, Fiberboard, and Related Product[2]

D 646 Test Method for Grammage of Paper and Paperboard (Mass Per Unit Area)[2]

D 685 Practice for Conditioning Paper and Paper Products for Testing[2]

D 1968 Terminology Relating to Paper and Paper Products[2]

E 122 Practice for Calculating Sample Size to Estimate, with a Specified Tolerable Error, the Average for Characteristic of a Lot or Process[3]

E 308 Practice for Computing the Colors of Objects by Using the CIE System[4]

2.2 *TAPPI Standards:*

TAPPI Technical Information Sheet 0804-03—Interrelation of reflectance, R_0; reflectivity, R_∞; TAPPI opacity, $C_{0.89}$ scattering, s; and absorption, k[5]

TAPPI Technical Information Sheet 0804-06—Photometric linearity of optical properties instruments[5]

T 519 Diffuse opacity of paper (d/0° paper backing)[5]

T 1206 Precision statement for test methods[5]

3. Terminology

3.1 *Definitions:* Definitions:

3.1.1 Definitions shall be in accordance with Terminology D 1968 and the *Dictionary of Paper.*[5]

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *opacity (89 % reflectance backing), $C_{0.89}$*—one hundred 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 0.89; 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. (Sometimes called contrast ratio.)

4. Summary of Test Method

4.1 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 thus reflected is transmitted through the paper a second time. Two types of "white" backing are used, leading to the two measurements of opacity defined in Section 3.

5. Significance and Use

5.1 Opacity is a fundamental optical property of paper as a whole, yet the measurement of opacity is empirical. The opacity of the sheet is influenced by the amount and kind of filler, degree of bleaching of the fibers, coating, and the like. The utility of bond, writing, and book papers may be enhanced by a high opacity.

5.2 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.

6. Apparatus

6.1 *Opacity Meter*, equipped with an accurate linear or a corrected photometric system. The reflectance involved in the determination of contrast ratio should be for either normal illumination and diffuse viewing, or the equivalent converse, that is, diffuse illumination and normal viewing.

NOTE 1—The direction of illumination or, alternatively, the direction of viewing, should be $15 \pm 2°$ 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 reflectances 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 the full-scale deflection while the contrast ratio is being measured.

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

6.2.1 *Standard Black Backing*, consisting of a cavity lined with black or velvet or other material which will cause the reflectance of the cavity to be 0.5 % or less.

6.2.2 *Standard White Backing*, having an effective absolute reflectance equal to 0.89 when illuminated under the conditions of actual testing with a sheet of paper in place (**1**).[6] This backing consists either of a permanent diffusing surface of the apparent reflectance in contact with the sample, or of an equivalent cavity such as that provided by a diffusing surface separated from the sample by a cover glass.

6.2.3 *Incandescent Light Source*, with the color temperature adjusted to yield an overall instrumental response equivalent to the Commission Internationale de l'Eclariage (CIE) function $E_a y$ which has an effective wavelength of 572 nm. In a single-photocell instrument, stability requires that the voltage must not change by more than approximately 0.1 %.

6.2.4 *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 $E_a y$ (given in Table 1) which has an effective wavelength of 572 nm and closely approximates the response of the human eye.

6.2.5 *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 %.

7. Sampling and Test Specimens

7.1 The material shall be sampled in accordance with Practice D 585.

7.2 When sampling for other than acceptance purposes, Practice E 122 may be used as an alternative.

7.3 At least five representative specimens shall be selected for each test unit. They shall be free of watermarks or blemishes and of sufficient size to fit the specimen holder, and completely cover the standard backings. The test areas shall not be touched with the fingers, and these areas shall be kept perfectly clean and free of folds and wrinkles.

8. Calibration

8.1 Check the calibration utilizing evaluated opal glass or paper standards and readjust as necessary in accordance with the manufacturer's instructions and Annex A1. After calibration, the instrument shall read the opal glass or paper standards within ±0.3 of their assigned values.

9. Conditioning

9.1 Condition the test specimens in accordance with Practice D 685.

10. Procedure

10.1 *Opacity (89 % Reflectance Backing)*:

TABLE 1 CIE E_a Y Weighting Functions, 10-nm Intervals (see Practice E 308)

nm	CIE $E_a Y$ Weighting Functions	nm	CIE $E_a Y$ Weighting Functions
400	0.000	600	7.547
410	0.002	610	6.360
420	0.008	620	5.061
430	0.027	630	3.716
440	0.061	640	2.559
450	0.117	650	1.639
460	0.209	660	0.971
470	0.362	670	0.533
480	0.618	680	0.289
490	1.039	690	0.147
500	1.802	700	0.075
510	3.091	710	0.039
520	4.756	720	0.020
530	6.320	730	0.010
540	7.599	740	0.005
550	8.571	750	0.003
560	9.219	760	0.001
570	9.456	770	0.001
580	9.224	780	0.000
590	8.543		

---

[6] The boldface numbers in parentheses refer to the list of references at the end of this test method.

10.1.1 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 Annex A.

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

10.1.3 Replace the white backing with the black body, and read the meter to obtain the contrast ratio. Record the individual results to three significant figures. Measure a minimum of five 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, place the specimen with the selected side toward the instrument and in the selected orientation, and state the conditions used in the report.

10.2 *Opacity (Paper Backing)*:

10.2.1 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 Annex A1.

10.2.2 Place the specimen over the opening backed by a pile 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.

10.2.3 Place the specimen over the opening backed by the black body. The meter reading gives opacity with a paper backing ($100\, R_0/R_\infty$). Record up to three significant figures.

10.3 *Scattering Power (sW)*—The ability to predict the effect upon opacity due to a change of basis weight 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. Determine scattering power as follows:

10.3.1 Obtain a white reflectance standard with known absolute reflectance at 572 nm.

10.3.2 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).

10.3.3 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 body and read R_0.

10.3.4 Leave the single specimen sheet (used in 10.3.3) in place over the specimen opening and back with a pile of the same paper. The thickness of the pile should be such that doubling the thickness has no detectable effect on the reading. Read R_∞.

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

$$a = 0.5\,[(1/R_\infty) + R_\infty] \qquad (1)$$

$$b = 0.5\,[(1/R_\infty) - R_\infty)] \qquad (2)$$

$$X = [1 - aR_0]\,/\,[bR_0] \qquad (3)$$

Scattering power $sW = (0.5/\,b)\,\mathrm{1n}\,[(X + 1)/(X - 1)]$

$$\text{Scattering coefficient:} \qquad s = 1000\,sW/W \qquad (4)$$

$$\text{Absorption power:} \qquad kW = (asW) - sW \qquad (5)$$

$$\text{Absorption coefficient:} \qquad k - 1000\,kW/W \qquad (6)$$

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

10.3.6 If the scattering power (sW) and reflectivity (R_∞) are known for a paper specimen of given basis weight, the opacity of the same specimen at a different basis weight (known as Normalized TAPPI Opacity, C_n) may be calculated as follows (**2**):

$$C_n = \frac{(a - 1)[0.89 - R_\infty - a[0.89 - (1/R_\infty)]]}{[(a/R_\infty) - R_\infty][(0.89/R_\infty) - aR_\infty[0.89 - (1/R_\infty)] - 1]} \qquad (7)$$

where:
sW_n = normalized scattering power,
BSW_d = desired basis weight, and
BSW_k = known basis weight: $sW_n = sW\,(BSW_d/BSW_k)$
  where R_∞ is expressed as a decimal.

$$a = e^{\,sWn}\,[(1/R_\infty) - R_\infty] \qquad (8)$$

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

11. Calculation

11.1 Average the opacity values determined for each of the five or more representative specimens tested from each test unit.

11.2 Calculate the averages for opacity (89 % reflectance backing) and opacity (paper backing) separately.

12. Report

12.1 Report the mean value and range for either or both opacity values specified in this test method, as agreed upon between the buyer and the seller.

13. Precision and Bias

13.1 The precision of this test method for test results consisting of averages for five specimens is:

13.1.1 *Repeatability*:

13.1.1.1 *89 % Backing*—0.62 %.

13.1.1.2 *Paper Backing*— 0.64 %.

13.1.2 *Reproducibility*:

13.1.2.1 *89 % Backing*—1.22 %

13.1.2.2 *Paper Backing*— 0.77 %.

13.2 The above precision data are in conformance with TAPPI T 1206, and were obtained in the TAPPI Collaborative Reference Program for paper having opacities in the range from 88 to 96 %. 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).

13.3 The user of these precision data is advised that it is based on actual mill testing or 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 the test method is routinely used by two or more parties.

13.4 *Bias*—This test method has no bias, as the values for opacity are defined in terms of the specific procedures described.

14. Keywords

14.1 absorption coefficient; absorption power; contrast ratio; opacity (89 % reflectance backing); opacity meter; opacity (paper backing); paper; printing opacity; scattering power

---

ANNEX

(Mandatory Information)

A1. Instrument Calibration and Adjustment Procedures

A1.1 Calibration of the Opacity Meter Ref (3)

A1.1.1 *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, reposition the lamp or optics in accordance with the manufacturer's instructions.

A1.1.1.1 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 standardization 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.

A1.1.2 *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 or electronics, or both. A means of measuring photometric linearity is described in Technical Information Sheet 0804-06 (old number 018-5).

A1.2 Adjustment of the White Backing

A1.2.1 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 test specimen or standard in place) may be carried out by means of opal glass or paper standards evaluated for opacity.

A1.2.2 *Adjustment by Means of Opal Glass or Paper Standards*:

A1.2.2.1 Clean the opal glass standard by washing it with a mild soap solution, rinsing it with water, and drying it with a lent-free non-abrasive towel.

A1.2.2.2 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.

A1.2.2.3 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.

A1.2.2.4 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 interest.

NOTE A1.1—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 and white bodies, respectively, backing the specimen.

A1.2.2.5 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.

REFERENCES

(**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 Journal*, Vol 119, No. 17, p. 27 1944.

(**2**) Robinson, James V., "A Summary of Reflectance Equations for Application of the Kubelka-Munk Theory to Optical Properties of Paper." *Tappi* Vol 58, No. 152, p.10: 1975.

(**3**) Hofert, H. J., and Loof, H., Z. *für Instrumentenkunde* Vol 72, No. 72 1964.