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Paper — Determination of transmittance by diffuse reflectance measurement

Papier — Détermination de la transmittance par le mesurage de la réflectance diffuse

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 22891 was prepared by Technical Committee ISO/TC 6, *Paper, board and pulps*.

This second edition cancels and replaces the first edition (ISO 22891:2007), of which it constitutes a minor revision.

Introduction

This International Standard presents a method of determining the transmittance indirectly from reflectance factor data obtained by measurement under specified conditions. The equation used to calculate the transmittance is based on the Kubelka-Munk theory of light scattering and light absorption, and the equation can therefore only be strictly applied if measurements are made on materials which scatter light sufficiently to justify the application of this theory.

The reflectance factor depends on the conditions of measurement, and particularly on the spectral and geometric characteristics of the instrument used for its determination. This International Standard should therefore be read in conjunction with ISO 2469 and ISO 2471.

The transmittance value obtained by this method is a single value compatible with the opacity value determined according to ISO 2471, since all measurements are related to the luminance factor calculated with respect to the CIE illuminant C.

The method described in this International Standard gives only the total transmittance and does not distinguish between regular transmittance and diffuse transmittance. It does not provide a direct measure of the ability to distinguish, for example, written text through a transparent medium. This can be assessed only if the ratio of the regular to the diffuse transmittance is known.

It is emphasized that this method is for the determination not of the transmittance by direct measurement but of the transmittance obtained indirectly from reflectance factor measurements. Under ideal conditions, they are the same, but in practice, it can be necessary to emphasize the difference.

Paper — Determination of transmittance by diffuse reflectance measurement

1 Scope

This International Standard specifies a method for the calculation of transmittance based upon diffuse reflectance measurements.

The use of the method is restricted to white and near-white translucent papers (see 3.9). If it is necessary to determine the transmittance of papers which contain fluorescent whitening agents, the fluorescence emission is eliminated using the prescribed UV cut-off filter.

NOTE This means that, although this International Standard refers to ISO 2469, which permits the use of both filter colourimeters and abridged spectrophotometers, a filter colourimeter with no means of eliminating the emission of fluorescence is not suitable for this type of measurement if fluorescent whitening agents are present.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 186, *Paper and board — Sampling to determine average quality*

ISO 2469, *Paper, board and pulps — Measurement of diffuse radiance factor (diffuse reflectance factor)*

ASTM E308-06, *Standard Practice for Computing the Colors of Objects by Using the CIE System*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
reflectance factor
R
ratio of the radiation reflected by a body to that reflected by the perfect reflecting diffuser under the same conditions of illumination and detection

Note 1 to entry: This ratio is often expressed as a percentage.

3.2
luminance factor (C)
R_y
reflectance factor weighted with reference to the colour matching function $\bar{y}(\lambda)$ of the CIE 1931(2°) Standard Observer and the CIE illuminant C

Note 1 to entry: This property corresponds to the attribute of visual perception of the luminance of the reflecting surface. The strict definition refers to the luminous efficiency function (for photopic vision) $V(\lambda)$. Since this function is identical with the $\bar{y}(\lambda)$ function, the latter is preferred here, since it is more familiar in a paper technology context and it is this function which is indicated in connection with the ASTM E308 tables necessary for the computations.

Note 2 to entry: Since the concept of "luminance" in this International Standard is strictly for small fields of view, it only embodies the $\bar{y}(\lambda)$ function of the CIE 1931(2°) Standard Observer. Thus, it is sufficient to only add the qualification (C) to indicate the CIE illuminant C, and not the full designation (C/2°).

3.3
single-sheet luminance factor (C)
R_0
luminance factor (C) of a single sheet of paper over a black cavity

3.4
white backing luminance factor (C)
R_w
luminance factor (C) of a white backing

3.5
intrinsic luminance factor (C)
R_∞
luminance factor (C) of a layer or pad of material thick enough to be opaque, i.e. such that increasing the thickness of the pad by doubling the number of sheets results in no change in the measured luminance factor

3.6
transmittance
τ
ratio of the transmitted radiant or luminous flux to the incident flux under given conditions

[CIE Publication 17.4:1987, 845-04-59]

3.7
regular transmittance
τ_r
ratio of the regularly transmitted part of the (whole) transmitted flux to the incident flux

[CIE Publication 17.4:1987, 845-04-61]

3.8
diffuse transmittance
τ_d
ratio of the diffusely transmitted part of the (whole) transmitted flux to the incident flux

[CIE Publication 17.4:1987, 845-04-63]

Note 1 to entry: $\tau = \tau_r + \tau_d$.

3.9
transparent medium
medium in which the transmission is mainly regular and which usually has a high regular transmittance in the spectral range of interest

[CIE Publication 17.4:1987, 845-04-108]

Note 1 to entry: Objects may be seen distinctly through a medium, which is transparent in the visible region, if the geometric form of the medium is suitable.

3.10
translucent medium
medium which transmits visible radiation largely by diffuse transmission

[CIE Publication 17.4:1987, 845-04-109]

Note 1 to entry: Objects are not seen distinctly through a translucent medium.

3.11
transmittance from reflectance factor measurements
T
transmittance obtained by direct measurement of luminance factor (C) (filter reflectometer) or determination of luminance factor (C) from measured reflectance factors (abridged spectrophotometer) and subsequent calculation as defined in this method

4 Principle

The luminance factors of a single sheet of paper over a black cavity and over a white backing are determined by measurement according to standard procedures. The transmittance is calculated from the luminance factors.

5 Apparatus

5.1 Reflectometer, having the geometric, spectral and photometric characteristics described in ISO 2469, equipped for the measurement of the luminance factor, and calibrated in accordance with the provisions of ISO 2469.

5.2 Filter-function: in the case of a filter reflectometer, a filter that, in conjunction with the optical characteristics of the basic instrument, gives an overall response equivalent to the CIE tristimulus value Y of the CIE 1931 standard colourimetric system of the test piece evaluated for the CIE illuminant C.

In the case of an abridged spectrophotometer, a function that permits calculation of the CIE tristimulus value Y of the CIE 1931 standard colourimetric system of the test piece evaluated for the CIE illuminant C using the weighting functions given in Annex A. The spectrophotometer should be fitted with a 420 nm UV cut-off filter for fluorescence elimination, as described in ISO 2469.

5.3 Reference standards, issued by an ISO/TC 6 authorized laboratory in accordance with the provisions of ISO 2469 for calibration of the instrument and the working standards. For maximum accuracy, reference standards having assigned values within the maximum range expected for the particular product to be tested should be selected.

If there is reason to suspect that the instrument has poor linearity or that the deviations from the true colour matching and observer functions are greater than can be tolerated, the use of product-specific reference standards should be considered.

Use new reference standards sufficiently frequently to ensure that the reflectometer is maintained in agreement with the reference instrument.

5.4 Two working standards, calibrated in the apparatus concerned against ISO reference standards of level 3 supplied by an authorized laboratory (see ISO 2469). Calibrate the working standards sufficiently frequently to ensure that satisfactory calibration is maintained.

5.5 Black cavity, for calibration or validation of the low end of the photometric scale, and also for use as a black backing for some of the measurements. This black cavity shall have a radiance factor which does not differ from its nominal value by more than 0,2 percentage points at all wavelengths. The black cavity should be stored upside-down in a dust-free environment or with a protective cover. During calibration, the instrument shall be adjusted to the nominal value of the black cavity.

It is not yet possible to institute a system of reference standards to enable testing laboratories to check the reflectance factor of the black cavity. At the time of delivery, the level should be guaranteed by the instrument maker. Questions concerning the use and condition of the black cavity should be resolved by contacting the instrument maker.

5.6 White backing, consisting of an opaque non-fluorescent white material with a flat, matt surface.

NOTE A pad of paper or a ceramic tile is suitable.

6 Sampling

If the tests are being carried out to evaluate a lot, the sample should be selected in accordance with ISO 186. If the tests are carried out on another type of sample, make sure that the test pieces taken are representative of the sample received.

7 Preparation of test pieces

Avoiding watermarks, dirt, and obvious defects, cut at least five rectangular test pieces approximately 75 mm × 150 mm. Place the test pieces between the protecting sheets.

Mark the test pieces in one corner to identify the sample and its top side.

If the top side can be distinguished from the wire side, it shall be uppermost; if not, as may be the case for papers manufactured on double-wire machines, ensure that the same side of the sheet is uppermost.

8 Procedure

8.1 If the test material contains or is suspected to contain a fluorescent whitening agent, make sure that the fluorescence emission is eliminated by inserting the 420 nm UV cut-off filter (see 5.2) into the light beam, as indicated in ISO 2469.

8.2 Using the procedure appropriate for the instrument in accordance with the manufacturer's instructions, determine the luminance factor (C) of the white backing, R_w. Read and record the value to the nearest 0,01 % luminance factor (C).

8.3 Without touching the test area, place the first test piece over the white backing and determine the luminance factor (C) of the top side of the test piece, R. Read and record the value to the nearest 0,01 % luminance factor (C).

8.4 Place the first test piece over the black cavity, so that the same region is in the measurement port, and determine the single-sheet luminance factor (C), R_0. Read and record the value to the nearest 0,01 % luminance factor (C).

8.5 Repeat 8.3 and 8.4 until five pairs of measurements have been made.

NOTE By definition, transmittance is independent of illumination direction and it should therefore not be necessary to make measurements on both sides of the sheet.

9 Calculation

For each pair of readings, calculate the transmittance, T, according to Formula (1):

$$T = [(R - R_0)\ (1/R_w - R_0)]^{1/2} \qquad (1)$$

where the luminance factor (C) values are expressed as decimal fractions and not as percentages, and where

R is the luminance factor (C) of the test piece over a white backing (8.3);

R_w is the luminance factor (C) of the white backing (8.2);

R_0 is the luminance factor (C) of the test piece over the black cavity (8.4).

Calculate the mean and standard deviation, and express the results as percentages with one decimal.

NOTE 1 Formula (1) is equivalent to Formula (2):

$$T = [(R_\infty - R_0)\ (1/R_\infty - R_0)]^{1/2} \qquad (2)$$

but, since the determination of R_∞ can be difficult with a translucent material because of, for example, edge-losses, Formula (1) is preferred in this International Standard, and the use of Formula (2) is not in accordance with this International Standard

NOTE 2 For greater accuracy, the Kubelka-Munk analysis can be applied to the spectral data as in Formula (3):

$$T(\lambda) = \{[R\ (\lambda) - R_0\ (\lambda)]\ [1/R_w(\lambda) - R_0\ (\lambda)]\}^{1/2} \qquad (3)$$

but this is outside the scope of this International Standard.

10 Test report

The test report shall include the following details:

a) the date and place of testing;

b) a precise identification of the sample;

c) a reference to this International Standard, i.e. ISO 22891;

d) the mean transmittance and the standard deviation;

e) the type of instrument used;

f) whether or not a 420 nm cut-off filter was used to eliminate fluorescence;

g) any departure from this International Standard or any circumstances or influences that might have affected the results.

Annex A
(normative)

Spectral characteristics of reflectometers for measuring luminous reflectance factors

A.1 For filter colourimeters

The required spectral characteristics of the reflectometer are arrived at by a combination of lamps, integrating spheres, glass optics, filters, and photoelectric cells. The filters should be such that they, together with the optical characteristics of the instrument, give a response equivalent to the CIE tristimulus Y-value for the CIE 1931 standard observer of the test piece established for the CIE standard illuminant C.

A.2 For abridged spectrophotometers

The desired reflectance factors are obtained by summing the products of the spectral reflectance factors and the weighting functions (Table A.1) given in ASTM E308-06 for the CIE 1931 (2°) observer and the CIE illuminant C.

ASTM E308-06[1)] presents two sets of tables. The values given in the table in this annex are taken from the tables which should normally be used. They have been prepared to apply a correction for spectral bandpass dependence built into the calculation of the tristimulus values, using data for which the bandpass is approximately equal to the measurement interval.

The figure labelled "Check sum" at the bottom of each column of the tables given in this annex is the algebraic sum of the entries. It provides, as a convenience, a check value to ensure that the tables have been copied correctly, should copying be required. These check sums may not be identical to the "White point" data located below them because of round-off.

The following instructions, given in ASTM E308-06, section 7.3.2.2, should be applied when the values are not available at the top or at the bottom of the range:

Wavelength range less than 360-780 nm. When data for $R(\lambda)$ are not available for the full wavelength range, add the weights at the wavelengths for which data are not available to the weights at the shortest or longest wavelength for which spectral data are available, i.e.

a) add the weights for all wavelengths (360 nm, ...,) for which measured data are not available to the next higher weight for which such data are available, and

b) add the weights for all wavelengths (..., 780 nm) for which measured data are not available to the next lower weight for which such data are available.

Table A.1 — Weighting functions for instruments measuring at 10 nm or 20 nm intervals

Wavelength nm	**Y-weights** 10 nm	**Y-weights** 20 nm
360	0,000	0,000
370	0,000	
380	0,000	0,000

1) Reprinted, with permission, from ASTM E308-06, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM (www.astm.org).

Table A.1 *(continued)*

Wavelength nm	**Y-weights** 10 nm	**Y-weights** 20 nm
390	0,000	
400	0,002	0,001
410	0,007	
420	0,032	0,044
430	0,118	
440	0,259	0,491
450	0,437	
460	0,684	1,308
470	1,042	
480	1,600	3,062
490	2,332	
500	3,375	6,596
510	4,823	
520	6,468	12,925
530	7,951	
540	9,193	18,650
550	9,889	
560	9,898	20,143
570	9,186	
580	8,008	16,095
590	6,621	
600	5,302	10,537
610	4,168	
620	3,147	6,211
630	2,174	
640	1,427	2,743
650	0,873	
660	0,492	0,911
670	0,250	
680	0,129	0,218
690	0,059	
700	0,028	0,049
710	0,014	
720	0,006	0,011
730	0,003	
740	0,001	0,002
750	0,001	
760	0,000	0,001
770	0,000	
780	0,000	0,000
Check sum	**99,999**	**99,998**
White point	**100,000**	**100,000**

Annex B
(informative)

Relationship between transmittance and opacity

The transmittance of a paper is, in a sense, the opposite of its opacity, but the two properties are defined so that mathematically they are not simply related to each other.

If R_0 is defined as the reflectance factor of a single sheet over a black cavity and R_∞ as the reflectance factor over an opaque pad of the same material, then according to the equations given by Kubelka[2].

$$\text{Opacity} = R_0/R_\infty \tag{B.1}$$

$$\text{Transmittance} = [(R_\infty - R_0)(1/R_\infty - R_0)]^{1/2} \tag{B.2}$$

This means that transmittance is a function of both opacity and reflectivity, R_∞, as shown in Table B.1, and it is not possible to calculate the transmittance from an opacity value alone.

Table B.1 — Relationship between transmittance and opacity

Opacity	**Transmittance**			
	$R_\infty = 1,0$	$R_\infty = 0,9$	$R_\infty = 0,8$	$R_\infty = 0,7$
0,1	0,90	0,91	0,92	0,93
0,2	0,80	0,82	0,84	0,85
0,3	0,70	0,73	0,75	0,77
0,4	0,60	0,64	0,67	0,69
0,5	0,50	0,55	0,58	0,61
0,6	0,40	0,45	0,50	0,53
0,7	0,30	0,36	0,41	0,44
0,8	0,20	0,27	0,31	0,35
0,9	0,10	0,16	0,20	0,24
1,0	0,00	0,00	0,00	0,00

Annex C
(informative)

Precision

In 2012, 11 laboratories from six International countries, tested three samples of more or less transparent papers.

The calculations were carried out according to ISO/TR 24498[4] and TAPPI T 1200[5].

The repeatability standard deviation reported in Table C.1 is the “pooled” repeatability standard deviation, that is, the standard deviation is calculated as the root-mean-square of the standard deviations of the participating laboratories. This differs from the conventional definition of repeatability in ISO 5725-1[6].

The repeatability and reproducibility limits reported are estimates of the maximum difference which should be expected in 19 of 20 instances, when comparing two test results for material similar to those described under similar test conditions. These estimates might not be valid for different materials or different test conditions. Repeatability and reproducibility limits are calculated by multiplying the repeatability and reproducibility standard deviations by 2,77.

NOTE 2,77 = 1,96 $\sqrt{2}$, provided the test results have a normal distribution and that the standard deviation, s, is based on a large number of tests.

Table C.1 — Transmittance — Estimation of the repeatability

Sample	Number of laboratories	Mean transmittance %	Repeatability standard deviation s_r	Coefficient of variation $C_{V,r}$ %	Repeatability limit r
Translucent drawing paper	7[a]	75,0	0,5	1,8	1,3
Glassine paper	11	86,2	0,2	0,7	0,6
Vegetable parchment	10[b]	69,3	0,4	1,6	1,1

[a] Four outliers.

[b] One outlier.

Table C.2 — Transmittance — Estimation of reproducibility

Sample	Number of laboratories	Mean transmittance %	Reproducibility standard deviation s_R	Coefficient of variation $C_{V,R}$ %	Reproducibility limit R
Translucent drawing paper	7[a]	75,0	0,7	2,7	2,0
Glassine paper	11	86,2	0,6	2,1	1,8
Vegetable parchment	10[b]	69,3	0,6	2,4	1,7

a Four outliers.

b One outlier.

Bibliography

[1] ISO 2471, *Paper and board — Determination of opacity (paper backing) — Diffuse reflectance method*

[2] Kubelka P. New Contribution to the Optics of Intensely Light Scattering Materials, part I. *J. Opt. Soc. Am.* 1948, **38** (5) pp. 448–457

[3] Publication C.I.E. *17.4, International Lighting Vocabulary*. CIE, 1987

[4] ISO/TR 24498, *Paper, board and pulps — Estimation of uncertainty for test methods*

[5] TAPPI T1200, *Interlaboratory evaluation of test methods to determine TAPPI repeatability and reproducibility*

[6] ISO 5725-1, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions*

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