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Paper — Determination of light scattering and absorption coefficients (using Kubelka-Munk theory)

Papier — Détermination des coefficients de diffusion et d'absorption de la lumière (utilisation de la théorie de Kubelka-Munk)

Reference number
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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.

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.

International Standard ISO 9416 was prepared by Technical Committee ISO/TC 6, *Paper, board and pulps*.

Annex A forms an integral part of this International Standard. Annex B is for information only.

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Introduction

The opacity of a paper is dependent on its grammage, but it is also intrinsically dependent on the light absorption and light scattering coefficients of the material. These coefficients are calculated from the values of the reflectance factor over a black backing, the intrinsic reflectance factor and the grammage of the sheet.

The calculation of these coefficients requires luminous-reflectance-factor data obtained by measurement under specified conditions. 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.

NOTE — This method is based on a theory developed by Kubelka and Munk. This theory describes scattering and absorption processes with certain approximations and simplifications and may therefore yield questionable results in extreme cases. However, the Kubelka-Munk theory offers a simple method for determining these coefficients with the instrument used for the determination of optical properties of paper and pulps. Moreover, the method based on this theory has been successfully used in practical applications.

Paper — Determination of light scattering and absorption coefficients (using Kubelka-Munk theory)

1 Scope

This International Standard specifies a method for the calculation of light scattering and light absorption coefficients based upon diffuse reflectance measurements.

The use of the method is restricted to white and near-white uncoated papers with an opacity less than about 95 %. Paper that has been treated with a fluorescent dyestuff or exhibits significant fluorescence can only be dealt with if a filter with a cut-off wavelength of 420 nm is used to eliminate all the fluorescence effect.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 186:1994, *Paper and board — Sampling to determine average quality.*

ISO 187:1990, *Paper, board and pulps — Standard atmosphere for conditioning and testing and procedure for monitoring the atmosphere and conditioning of samples.*

ISO 536:1995, *Paper and board — Determination of grammage.*

ISO 2469:1994, *Paper, board and pulps — Measurement of diffuse reflectance factor.*

ISO 2471:1998, *Paper and board — Determination of opacity (paper backing) — Diffuse reflectance method.*

ASTM E 308-96, *Computing the Colors of Objects by Using the CIE System.*

CIE Publication No. 38:1977, *Radiometric and photometric characteristics of materials and their measurement.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 reflectance factor, *R***:** The ratio, expressed as a percentage, of the radiation reflected by a body to that reflected by the perfect reflecting diffuser under the same conditions.

3.2 luminous reflectance factor, R_y**:** The reflectance factor defined with reference to the CIE illuminant C and the CIE 1931 colour matching function $\bar{y}(\lambda)$, and corresponding to the attribute of visual perception of the reflecting surface.

3.3 single-sheet luminous reflectance factor, R_0**:** The luminous reflectance factor of a single sheet of paper with a black cavity as backing.

3.4 intrinsic luminous reflectance factor, R_∞**:** The luminous reflectance factor 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 reflectance factor.

3.5 opacity (paper backing): The ratio, expressed as a percentage, of the single-sheet luminous reflectance factor, R_0, to the intrinsic luminous reflectance factor, R_∞, of the same sample.

3.6 light scattering coefficient (Kubelka-Munk), s**:** The fraction of the diffuse light flux that is reflected on its passage through an infinitesimally thin layer of material. This may be related to the light reflected by a finite layer using the Kubelka-Munk theory which takes into account the grammage of the material, so that s has the units m^2/kg.

3.7 light absorption coefficient (Kubelka-Munk), k**:** The fraction of the diffuse light flux that is absorbed on its passage through an infinitesimally thin layer of material. This may be related to the light absorbed by a finite layer using the Kubelka-Munk theory which takes into account the grammage of the material, so that k has the units m^2/kg.

NOTE 1 Definitions 3.6 and 3.7 are strictly applicable to monochromatic light but for the purpose of this International Standard they apply to broad-band radiation. In research work, s and k can and should be determined at the relevant wavelength for the study concerned. As general descriptions of a given paper, they are defined here in relation to the C illuminant and the $\bar{y}(\lambda)$ function.

NOTE 2 More exact definitions of the Kubelka-Munk coefficients can be found in CIE Publication No. 38, Section 11.

4 Principle

The luminous reflectance factor of a single sheet of the paper over a black cavity and the intrinsic luminous reflectance factor of the paper are determined by measurement according to ISO 2471, and the grammage is determined according to ISO 536.

The light absorption and light scattering coefficients are then calculated from these data using the Kubelka-Munk theory.

NOTE — These measurements are the same as those required for the determination of opacity (ISO 2471).

5 Apparatus

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

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 colorimetric system of the test piece evaluated for the CIE standard 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 colorimetric system of the test piece evaluated for the CIE standard illuminant C using the weighting functions given in Annex A.

5.3 UV-cut-off filter. To eliminate any fluorescence effect, the instrument shall be equipped with a sharp cut-off, UV-absorbing filter having a transmittance not exceeding 0,5 % at and below a wavelength of 410 nm and not exceeding 50 % at a wavelength of 420 nm.

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.

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

5.5 Black cavity, having a reflectance factor which does not differ from its nominal value by more than 0,2 %, at all wavelengths. The black cavity should be stored upside down in a dust-free environment or with a protective cover.

NOTE — The condition of the black cavity should be checked by reference to the instrument maker.

6 Sampling

If the tests are being made to evaluate a lot, the sample should be selected in accordance with ISO 186. If the tests are made 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 rectangular test pieces approximately 75 mm x 150 mm. Assemble at least ten of the test pieces in a pad with their top sides uppermost; the number of test pieces should be such that doubling the number does not alter the reflectance factor. Protect the pad by placing an additional sheet on both the top and bottom of the pad; avoid contamination and unnecessary exposure to light or heat.

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

NOTE — 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 Remove the protecting sheets from the test-piece pad. Without touching the test area, use the procedure appropriate to the instrument, and the working standard, to measure the intrinsic reflectance factor R_∞ of the top side of the test-piece pad. Read and record the value to the nearest 0,05 % of the reflectance factor.

8.2 Remove the top test piece from the pad and, with the black cavity backing the test piece, measure the luminous reflectance factor R_0, for the same area of the test piece. Read and record the value to the nearest 0,05 % of the luminous reflectance factor.

8.3 Move the measured test piece to the bottom of the pad. Repeat the measurements of R_∞ and R_0, moving the top test piece to the bottom of the pad after each pair of measurements, until five pairs of measurements have been made.

8.4 Turn the pad upside down and repeat procedures 8.1 to 8.3 for the other side.

8.5 Determine the grammage of the material according to ISO 536 after conditioning in accordance with ISO 187.

NOTE — For greater accuracy, the grammage of each individual test piece should be determined.

9 Calculation of results

Calculate the means of R_∞ and R_0 for each side of the sample and use these figures to calculate the Kubelka-Munk coefficients as in the following equations.

Convert the percentage values to decimal fractions, and calculate the light scattering coefficient s and the light absorption coefficient k using the equations:

$$s = \frac{1000}{w} \times \frac{R_\infty}{\left(1 - R_\infty^2\right)} \times \ln \frac{R_\infty \left(1 - R_0 R_\infty\right)}{R_\infty - R_0}$$

$$k = \frac{s\left(1 - R_\infty\right)^2}{2R_\infty}$$

where w is the grammage in g/m^2.

NOTE — For greater accuracy, if the grammage of each individual test piece is known, calculate s and k for each pair of measurements, and then calculate the mean values.

Calculate these values to the nearest 0,1 m^2/kg for each set of measurements. Report the light scattering coefficients to the nearest whole number. If the light scattering coefficients for the two sides of the sample do not differ by more than 1,0 m^2/kg, report the overall average. If the two sides differ by more than 1,0 m^2/kg, report the average value for each side separately. Report the light absorption coefficients to the nearest 0,1 m^2/kg.

10 Precision

In "Round Robin" tests involving twelve laboratories, the standard deviation within laboratories was about 0,7 m^2/kg for the light scattering coefficient and about 0,05 m^2/kg for the light absorption coefficient.

The standard deviation between the different laboratories was about 2,0 m^2/kg for the light scattering coefficient and 0,2 m^2/kg for the light absorption coefficient.

11 Test report

The test report shall include the following details:

a) date and place of testing;

b) precise identification of the sample;

c) a reference to this International Standard;

d) the light scattering coefficient and light absorption coefficient;

e) the conditioning atmosphere;

f) the type of instrument used;

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

Annex A
(normative)

Spectral characteristics of reflectometers for measuring luminous reflectance factor

A.1 For filter colorimeters

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 following weighting functions (Table A.1), given in ASTM E 308-96 for the CIE 1931 (2°) observer and the CIE illuminant C.

The instructions given in A.3 should be followed.

A.3 Data available only for wavelength ranges shorter than 360 nm – 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 and longest wavelength for which spectral data are available. That is: add the weights for wavelengths of 360 nm...., up to the last wavelength for which measured data are not available, to the next higher weight, for which such data are available; add the weights for wavelengths of 780 nm...., down to the last wavelength for which measured data are not available, to the next lower weight, for which such data are available.

Table A.1 — ASTM E 308-96 weighting functions for instruments measuring at 10 nm and 20 nm intervals respectively

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