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

National foreword

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

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

This third edition cancels and replaces the second edition (ISO 9416:2009), which has been technically revised, to allow for calculations to use ASTM E308 for instruments that have bandpass correction and still maintain the procedure for instruments without bandpass correction.

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 luminance factor data obtained by measurement under specified conditions. Apart from the optical properties of the sample, the luminance factor depends on the conditions of measurement and particularly on the spectral and geometric characteristics of the instrument used for its determination. This document is therefore intended to 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 can 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 document specifies a method for the calculation of light-scattering and light-absorption coefficients based upon diffuse reflectance measurements made under the conditions specified in ISO 2469 using the colour matching function $\bar{y}(\lambda)$ and CIE illuminant C.

It is emphasized that the strict evaluation of the light-scattering and light-absorption coefficients requires conditions which cannot be achieved with the instrumentation specified here. The values obtained by application of this document are dependent on the application of the Kubelka-Munk equations, not to full reflectance data but to reflectance factor data obtained using the specified $d/0^\circ$ geometry and a gloss trap.

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 that 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 in the UVex(420) mode.

NOTE 1 The residual UV-level in the instrument may depend on whether the instrument is adjusted to UV(C) or UV(D65) conditions prior to switching to the UVex(420) mode, but it is considered that this uncertainty in the residual level can be ignored in the application of this document.

NOTE 2 Although this method is restricted to paper, it can be applied to pulp sheets, although this is not in accordance with this document. In general, when pulps are tested, the light-absorption coefficient at 457 nm corresponding to the ISO brightness value or the spectral absorption coefficients are of greater interest than the weighted value standardized in this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 187, *Paper, board and pulps — Standard atmosphere for conditioning and testing and procedure for monitoring the atmosphere and conditioning of samples*

ISO 536, *Paper and board — Determination of grammage*

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

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <http://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1 reflectance factor

R

ratio of the radiation reflected by a surface element of a body, in the direction delimited by a given cone with its apex at the surface element, to that reflected by the perfect reflecting diffuser under the same conditions of irradiation

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

3.2 luminance factor (C)

R_y

reflectance factor (3.1) defined with reference to the visual efficiency function $V(\lambda)$ and the CIE illuminant C

Note 1 to entry: The visual efficiency function describes the sensitivity of the eye to light, so that the luminance factor corresponds to the attribute of visual perception of the reflecting surface.

Note 2 to entry: For computational purposes, the $V(\lambda)$ function is identical to the CIE 1931 colour matching function $\bar{y}(\lambda)$.

3.3 single-sheet luminance factor (C)

$R_{y,0}$

luminance factor (C) (3.2) of a single sheet of paper with a black cavity as backing

3.4 intrinsic luminance factor (C)

$R_{y,\infty}$

luminance factor (C) (3.2) 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

[SOURCE: ISO 2471:2008, 3.4]

3.5 opacity (paper backing)

ratio of the single-sheet luminance factor (C), $R_{y,0}$, (3.3) to the intrinsic luminance factor (C), $R_{y,\infty}$, (3.4) of the same sample

Note 1 to entry: The opacity is expressed as a percentage.

3.6 light-absorption coefficient

k

fraction of the spectral radiant flux diffusely incident on a differential layer within a material that is absorbed when the flux passes through the layer, divided by the thickness of the layer

Note 1 to entry: The flux referred to is a radiant flux across the differential layer.

3.7 light-scattering coefficient

s

fraction of the spectral radiant flux diffusely incident on a differential layer within a material that is reflected when the flux passes through the layer, divided by the thickness of the layer

Note 1 to entry: The flux referred to is a radiant flux across the differential layer.

Note 2 to entry: It is assumed that no reflection occurs at the boundaries of the material.

Note 3 to entry: In a two-flux system, the scattering coefficient is equal to the net transfer of flux from the stronger flux to the weaker flux in a differential layer within a material divided by the product of the thickness of the layer and the difference between the fluxes (see ISO 186).

3.8 light-scattering coefficient by reflectance factor measurements

s_y
<Kubelka-Munk method> coefficient calculated by application of the Kubelka-Munk equations to luminance factor data weighted with respect to the CIE illuminant C, obtained in an instrument having a specified geometry and calibrated in a specified manner, on the basis of grammage

Note 1 to entry: s_y is expressed in square metres per kilogram (m^2/kg).

3.9 light-absorption coefficient by reflectance factor measurements

k_y
<Kubelka-Munk method> coefficient calculated by application of the Kubelka-Munk equations to luminance factor data weighted with respect to the CIE illuminant C, obtained in an instrument having a specified geometry and calibrated in a specified manner, on the basis of grammage

Note 1 to entry: k_y is expressed in square metres per kilogram (m^2/kg).

Note 2 to entry: Definitions in 3.6 and 3.7 are strictly applicable to monochromatic light but for the purpose of this document, they apply to broad-band radiation. In research work, s_y and k_y 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 $V(\lambda)$ function and the CIE illuminant C.

4 Principle

The luminance factor of a single sheet of the paper over a black cavity and the intrinsic luminance factor of the paper are determined. The grammage is determined in accordance with ISO 536.

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

5 Apparatus

5.1 Reflectometer, having the geometric, spectral and photometric characteristics described in ISO 2469, equipped for the measurement of 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 colorimetric 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 colorimetric system of the test piece evaluated for the CIE 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. Two plates of flat opal glass or ceramic or other suitable material, cleaned and calibrated as described in ISO 2469.

NOTE In some instruments, the function of the primary working standard can be taken over by a built-in internal standard.

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 1 The condition of the black cavity can be checked by reference to the instrument maker.

NOTE 2 The nominal value is given by the manufacturer.

6 Sampling and conditioning

If the tests are being made to evaluate a lot of paper or board, 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.

Conditioning according to ISO 187 is recommended but not required, but preconditioning with elevated temperatures should not be applied since it might change the optical properties.

7 Preparation of test pieces

Avoiding watermarks, dirt and obvious defects, cut rectangular test pieces approximately 75 mm × 150 mm. Assemble at least 10 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.

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 twin-wire machines, ensure that the same side of the sheet is uppermost.

8 Procedure

8.1 If the sample contains or may contain a fluorescent whitening agent, check that the 420 nm UV-cut-off filter is in the UVex(420) position.

8.2 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 luminance factor $R_{y,\infty}$ of the top side of the test-piece pad. Read and record the value to the nearest 0,01 % of the luminance factor.

8.3 Remove the top test piece from the pad and, with the black cavity backing the test piece, measure the single-sheet luminance factor, $R_{y,0}$, for the same area of the test piece. Read and record the value to the nearest 0,01 % of the luminance factor.

[8.2](#) and [8.3](#) describe the two independent measurements required to calculate the light absorption and scattering coefficients using the Kubelka-Munk theory in [Clause 9](#). This is not intended to imply that the two measurements shall necessarily be made in this order.

8.4 Move the measured test piece to the bottom of the pad. Repeat the measurements of $R_{y,\infty}$ and $R_{y,0}$, moving the top test piece to the bottom of the pad after each pair of measurements, until five pairs of measurements have been made.

This subclause implies that measurements of $R_{y,\infty}$ and $R_{y,0}$ shall be made alternately, but this is not an essential requirement of this document. The five measurements of $R_{y,0}$ may be made before or after the five measurements of $R_{y,\infty}$ if such a procedure is preferred, or the measurements may be made alternately.

8.5 Turn the pad upside down and repeat procedures 8.2 to 8.4 for the other side.

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

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

9 Calculation of results

Calculate the means of $R_{y,\infty}$ and $R_{y,0}$ for each side of the sample and use these values to calculate the Kubelka-Munk coefficients as in [Formulae \(1\)](#) and [\(2\)](#).

If $R_{y,\infty}$ and $R_{y,0}$ are expressed as percentages, convert the percentage values to decimal fractions and calculate the light-scattering coefficient s_y and the light-absorption coefficient k_y using [Formulae \(1\)](#) and [\(2\)](#):

$$s_y = \frac{1\,000}{w} \times \frac{R_{y,\infty}}{(1 - R_{y,\infty}^2)} \times \ln \frac{R_{y,\infty}(1 - R_{y,0} R_{y,\infty})}{R_{y,\infty} - R_{y,0}} \quad (1)$$

$$k_y = \frac{s_y (1 - R_{y,\infty})^2}{2R_{y,\infty}} \quad (2)$$

where w is the grammage, in grams per square metre (g/m^2).

For greater accuracy, if the grammage of each individual test piece is known, calculate s_y and k_y 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 coefficient 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. Similarly, report the light-absorption coefficient to the nearest 0,1 m^2/kg .

10 Test report

The test report shall include the following information:

- a reference to this document, i.e. ISO 9416;
- precise identification of the sample;
- date and place of testing;
- the light-scattering coefficient and light-absorption coefficient;
- the type of instrument used and whether or not the instrument was adjusted to UVex(420) conditions;
- the atmosphere used for conditioning;
- any departure from this document or any circumstances or influences that may have affected the results.

Annex A (informative)

Spectral characteristics of reflectometers for measuring luminance 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 detectors. 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 (2°) standard observer of the test piece established for the CIE illuminant C.

A.2 For abridged spectrophotometers

A.2.1 General

The desired reflectance factors are obtained by summing the products of the spectral reflectance factors and the weighting functions given in ASTM E308-08[3] for the C illuminant and CIE 1931 (2°) observer.

"Checksum" and "white point" data are given at the bottom of each column in [Tables A.1](#) and [A.2](#). The "check-sum" is the algebraic sum of the entries. It provides, for convenience, a check value to ensure that the tables have been copied correctly, should copying be required.

Apply the following instructions, given in ASTM E308-08:2008, 7.3.2.2, when the values are not available at the top or at the bottom of the range.

Wavelength range less than 360 nm to 780 nm. When data for $R_y(\lambda)$ 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.:

- 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;
- 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.

A.2.2 Procedure for using data without bandpass correction

Use [Table A.1](#) when the spectral data have not been corrected for bandpass dependence and for which the bandpass is approximately equal to the measurement interval; the second column in [Table A.1](#) is to be used when the data have been obtained at 10-nm measurement intervals; the third column in [Table A.1](#) is to be used when the data has been obtained at 20-nm measurement intervals. These tables apply a correction for spectral bandpass dependence built into the calculation of the tristimulus values.

A.2.3 Procedure for using data with bandpass correction

Use [Table A.2](#) when the spectral data have been already corrected for bandpass dependence (e.g. by the instrument manufacturer) and for which the bandpass is approximately equal to the measurement interval; the second column in [Table A.2](#) is to be used when the data have been obtained at 10-nm

measurement intervals; the third column in [Table A.2](#) is to be used when the data have been obtained at 20-nm measurement intervals.

NOTE 1 [Table A.2](#) was added to this document to allow for calculation using instrumentation that does not require bandpass correction, i.e. has already been built into the instrument and applied to the reported raw data.

NOTE 2 Raw reflectance data will differ for instruments with built-in bandpass correction from those without. However, after the appropriate weighting table is used, the resulting colorimetric values will be nearly identical.

Table A.1 — ASTM E308-08 weighting functions (C/2°) for instruments without bandpass correction and 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	

Source: ASTM E308-08[3].

Table A.1 (continued)

Wavelength nm	Y-weights 10 nm	Y-weights 20 nm
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

Source: ASTM E308-08[3].

Table A.2 — ASTM E308-08 weighting functions (C/2°) for instruments with bandpass correction and 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	0,001	
400	0,002	-0,001
410	0,009	
420	0,038	0,085
430	0,123	
440	0,261	0,511
450	0,443	
460	0,692	1,382
470	1,061	
480	1,612	3,206
490	2,358	
500	3,414	6,910
510	4,842	
520	6,449	12,876
530	7,936	
540	9,145	18,258
550	9,831	
560	9,834	19,588
570	9,148	
580	7,990	15,991
590	6,621	
600	5,321	10,696

Source: ASTM E308-08[3].

Table A.2 (continued)

Wavelength nm	Y-weights 10 nm	Y-weights 20 nm
610	4,177	
620	3,146	6,261
630	2,196	
640	1,442	2,902
650	0,887	
660	0,503	1,008
670	0,261	
680	0,132	0,257
690	0,062	
700	0,029	0,055
710	0,014	
720	0,007	0,012
730	0,003	
740	0,001	0,003
750	0,001	
760	0,000	0,001
770	0,000	
780	0,000	0,000
Check sum	100,000	100,001
White point	100,000	100,000

Source: ASTM E308-08[3].

Table A.2 (continued)

Wavelength nm	Y-weights 10 nm	Y-weights 20 nm
610	4,177	
620	3,146	6,261
630	2,196	
640	1,442	2,902
650	0,887	
660	0,503	1,008
670	0,261	
680	0,132	0,257
690	0,062	
700	0,029	0,055
710	0,014	
720	0,007	0,012
730	0,003	
740	0,001	0,003
750	0,001	
760	0,000	0,001
770	0,000	
780	0,000	0,000
Check sum	100,000	100,001
White point	100,000	100,000

Source: ASTM E308-08[3].

Table A.2 (continued)

Wavelength nm	Y-weights 10 nm	Y-weights 20 nm
610	4,177	
620	3,146	6,261
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710	0,014	
720	0,007	0,012
730	0,003	
740	0,001	0,003
750	0,001	
760	0,000	0,001
770	0,000	
780	0,000	0,000
Check sum	100,000	100,001
White point	100,000	100,000

Source: ASTM E308-08[3].

Table A.2 (continued)

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700	0,029	0,055
710	0,014	
720	0,007	0,012
730	0,003	
740	0,001	0,003
750	0,001	
760	0,000	0,001
770	0,000	
780	0,000	0,000
Check sum	100,000	100,001
White point	100,000	100,000

Source: ASTM E308-08[3].

Table A.2 (continued)

Wavelength nm	Y-weights 10 nm	Y-weights 20 nm
610	4,177	
620	3,146	6,261
630	2,196	
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680	0,132	0,257
690	0,062	
700	0,029	0,055
710	0,014	
720	0,007	0,012
730	0,003	
740	0,001	0,003
750	0,001	
760	0,000	0,001
770	0,000	
780	0,000	0,000
Check sum	100,000	100,001
White point	100,000	100,000

Source: ASTM E308-08^[3].

Table A.2 (continued)

Wavelength nm	Y-weights 10 nm	Y-weights 20 nm
610	4,177	
620	3,146	6,261
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740	0,001	0,003
750	0,001	
760	0,000	0,001
770	0,000	
780	0,000	0,000
Check sum	100,000	100,001
White point	100,000	100,000

Source: ASTM E308-08[3].