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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)

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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° 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.