INTERNATIONAL STANDARD

ISO 5-3

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Photography and graphic technology — Density measurements —

Part 3: Spectral conditions

Photographie et technologie graphique — Mesurages de la densité —

Partie 3: Conditions spectrales

Reference number
ISO 5-3:2009(E)

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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 5-3 was prepared by ISO/TC 42, *Photography*, and ISO/TC 130, *Graphic technology*, in a Joint Working Group.

This third edition cancels and replaces the second edition (ISO 5-3:1995), which has been technically revised. This technical revision takes into account, in particular, computation of ISO 5 standard density from spectral data, as well as graphic arts considerations. In the course of this technical revision, all parts of ISO 5 have been reviewed together, and the terminology, nomenclature and technical requirements have been made consistent across all parts.

ISO 5 consists of the following parts, under the general title *Photography and graphic technology — Density measurements:*

— *Part 1: Geometry and functional notation*

— *Part 2: Geometric conditions for transmittance density*

— *Part 3: Spectral conditions*

— *Part 4: Geometric conditions for reflection density*

Introduction

0.1 General

The ISO 5 series comprises four International Standards that specify the spatial and spectral conditions for optical densitometry for use in black-and-white and colour imaging applications, as practised in photographic and graphic technology applications. The term “ISO 5 standard density” is used within the ISO 5 series to refer to such specified conditions. The more general term “density” is used in its traditional sense when the basic optical principles and concepts are being discussed.

To define an ISO 5 standard density value fully, it is necessary to specify both the geometric and spectral conditions of the measuring system. Geometric conditions are described in ISO 5-2 for transmittance ISO 5 standard density, and in ISO 5-4 for reflection ISO 5 standard density. This part of ISO 5 specifies the spectral conditions for both transmittance and reflection ISO 5 standard density measurements. For many of these conditions, the term “status density” is used to identify them.

0.2 Density measurement

In photography, optical density is a measure of the modulation of light or other radiant flux by a given area of the recording medium. The measurement of density can be of interest for various reasons. It might be necessary to assess the lightness or darkness of an image, to predict how a film or paper will perform in a printing operation, or to determine a measure of the amounts of colorants in the image for the purpose of controlling a colour process. If the visual effect is of interest, the spectral conditions of measurement need to simulate an appropriate illumination and the spectral sensitivity of the eye. For photographic printing operations, the spectral power distribution of the source to be used in the printing operation and the spectral sensitivity of the print material need to be simulated. In evaluating original material for colour separation, the illuminant, the spectral sensitivity of the separation medium, and the spectral transmittance of the tricolour separation filters (and other optical components) need to be simulated.

In order to provide measurement data that can be properly interpreted by the various users who need to do so, the provision of standard specifications for the measurement procedure is necessary. ISO 5 provides that specification. In this part of ISO 5, a number of spectral conditions are specified, including a definition of the spectral response for each.

NOTE Spectral response is a function of the spectral sensitivity of the photodetector and the spectral modifications by any of the optics and filters between the plane of the specimen and the photodetector.

In many applications, it is considered desirable for the spectral response to match the spectral sensitivity of the intended receiver (eye, photographic paper, etc.) used in the practical applications of the product as described above. However, in other applications, the spectral response is defined somewhat arbitrarily (though frequently with some regard to the spectral characteristics of the media being measured) to facilitate unambiguous communication for issues of process control and thus the spectral product also becomes arbitrary in those instances.

The various spectral conditions specified in this part of ISO 5 have each been shown to be useful to the application identified. For example, certain types of density measurements are often made to generate sensitometric curves which are used to characterize the photographic properties of films and papers. Densities can also be used to perform a photographic tone-reproduction analysis or to monitor operations like photoprocessing. In graphic technology, reflection density measurements are used for the control of the ink film thickness, or, more generally, the amount of colorant per area and the determination of the tone values or other quantities.

In the early years of densitometry, the spectral responses of instruments were specified only in terms of the colour filters used in the construction. Although it was seldom the case, it was assumed that the spectral responses of the detector and the source spectral energy distributions, as well as all intervening optical components, were the same in all instruments. In more recent times, densitometry standards have specified that the combination of all these components equals a given set of published “documentary” values. If each of these components is approximated by a mathematical function, then their combination could be approximated by simply multiplying the spectral characteristics, wavelength by wavelength, and compiling the results into a table of numbers known as the spectral products. Such a specification allows flexibility to the manufacturer while providing for improved accuracy and precision. It also allows for reference materials to be manufactured and certified based on fundamental measurements.

0.3 Calculation of density

In this revision of this part of ISO 5, it has been recognized that the use of simple filter instruments is in decline. The more common method of “measuring” ISO 5 standard density makes use of computations based on measurements of the spectral reflectance factor or spectral transmittance of the specimen under study. Many users have achieved this calculation in the past by summing, over the full wavelength range, the product of the spectral reflectance factor or transmittance and the spectral products provided in previous editions of this international standard (defined at 10 nm intervals), after converting them to the linear domain. However, such a procedure is not strictly accurate. The spectral products are assumed to be the specification, at 10 nm intervals, of the physical spectral characteristics of a device obtained by combining spectral data pertaining to its illumination source and its optical components. Where measurements of samples made with a device conforming to this specification were compared to those computed from spectral data of the same samples, calculated by summing over the full wavelength range the product of the spectral data and the linear form of the 10 nm spectral products, small differences would be found. Although such errors are likely to be very small with the typical samples encountered in photography and graphic technology (probably in the third decimal place), such a situation is still undesirable.

Thus, for computation purposes, the older, coarsely sampled tables of spectral products have been supplemented in this revision with the concept of spectral weighting factors. To achieve these, the 10 nm spectral products defined in this and previous editions of this part of ISO 5 have been interpolated in the log domain to 1 nm intervals, using the method defined in Annex D, converted to the linear domain, and normalized to a peak value of 1. Additional sets of spectral weighting factors have then been derived from these for use with data measured at intervals greater than 1 nm and any densities calculated from these weighting factors, using the methodology defined in Annex B, will exactly match those obtained with filter instruments conforming exactly to the 10 nm spectral products. Of course, the values for the 10 nm spectral weighting factors differ slightly from those for the 10 nm spectral products, when converted to the linear domain, because the computation of ISO 5 standard density (as opposed to the direct measurement of ISO 5 standard density) is a convolution of spectral weighting factors and spectral reflectance factor (or transmittance) at discrete intervals over the appropriate wavelength range. Since the spectral weighting factors include both the densitometric spectral products and the coefficients of a polynomial for interpolating the spectral reflectance factor or transmittance, the table entry at a given wavelength might occasionally be a small negative value. This will not result in negative densities for any typical media, nor does it imply negative spectral products. The sums will always be positive and the logarithms will have the appropriate magnitude for the spectrally integrated readings.

It is important to note that the relative (normalized to the peak value) values for the spectral products have not changed. The interpolation to 1 nm intervals in all cases has left the 10 nm values for relative spectral products unchanged, except for a linear scaling. These data are still considered to be the primary definition of the spectral products in this part of ISO 5. Therefore, the spectral products that a filter instrument is expected to match are still the same, but they have now also been defined at finer data intervals. The assumption is made that at a data interval of 1 nm, the spectral products can also be used as weighting factors for computation from spectral data recorded at, or interpolated to, that same spectral resolution. However, for practical work, where the spectral data are usually sampled more coarsely than this, weighting factors have been calculated from these 1 nm tables. Such an approach is consistent with more recent practice in colorimetry and provides the “best” approximation to calculations made with finer resolution data. These weighting functions will also provide data that are consistent with those made with a “filter” instrument conforming to the 10 nm spectral products defined in this part of ISO 5. Thus it is recommended that the weighting factors, rather than the spectral products, are to be used when calculating ISO 5 standard density from spectral reflectance factor or transmittance data collected by practical instruments at 10 nm or 20 nm wavelength intervals.

See Annexes B, C and D for further discussion of spectral weighting factors and how they were calculated for this revision of this part of ISO 5.

0.4 Sources of illumination

The traditionally specified spectral power distribution of the incident flux for transmittance ISO 5 standard density measurements differs from that specified for reflection ISO 5 standard density measurements, although both are based on a Planckian radiation at a temperature of approximately 2 856 K as defined in ISO 11664-2. This is the spectral distribution known as CIE standard illuminant A, adopted by the CIE in 1931, and it can be approximated by an incandescent tungsten-filament lamp operated at a distribution temperature of 2 856 K. The spectral distribution for transmittance density measurements is modified by a heat-absorbing filter to protect the specimen and optical system from heat. The requirement to provide in densitometers a spectral power distribution close to that specified is particularly important because many graphic arts materials, especially print substrates, and some photographic materials contain optical brightening agents (OBAs) and exhibit significant fluorescence. If fluorescence is not an issue, the spectral power distribution of the incident flux is less significant and can deviate from that specified, so long as the specified spectral product is maintained. Furthermore, when fluorescence is not an issue, the same spectral reflectance factor data can be used for calculating both colorimetric quantities and reflection ISO 5 standard density.

In this edition of ISO 5, the requirement to use CIE standard illuminant A for reflection measurements and the modified illuminant A for transmittance measurements is maintained for photographic products. However, in an attempt to maintain compatibility with colorimetric measurements made in accordance with ISO 13655 in the graphic arts industry, three additional illumination conditions are introduced for graphic arts use. These are based on the conditions specified in ISO 13655 and are as follows:

— M1: illuminant D50,

— M2: source that only contains substantial radiation power in the wavelength range above 400 nm, and

— M3: addition of a polarization filter to condition 2.

For materials without optical brighteners, these variations in illumination have no effect, but because the level of OBAs present is often unknown it is important that the illumination condition used be clearly identified. Some process control density measuring devices are also being introduced that use a light emitting diode (LED) as the illumination source and meet the requirements of illumination condition M2. Care is advised when comparing measurements made with differing illumination conditions, particularly when used to compare process control measurements between colorants with significantly different spectral characteristics.

0.5 Calibration standards

Many older standards for reflection density specified the use of barium sulfate ($BaSO_4$) as the reference standard. However, pressed barium sulfate ($BaSO_4$) is fragile, variable from batch to batch of powder, variable from pressing to pressing, and its reflectance changes appreciably in the first few days after pressing. In 1969, the CIE recommended that all reflectance factors and, by inference, the corresponding reflection densities be reported relative to a perfectly reflecting and perfectly diffusing material. This is specified to be the reference for calibration in ISO 5.

In day-to-day operation, reflection densitometers are usually calibrated with materials from the instrument manufacturer or with certified reference materials (CRMs) available from a number of sources. These working standards need to be calibrated with respect to primary standards that are calibrated with respect to the perfect reflecting diffuser by absolute methods in national standards laboratories.

Photography and graphic technology — Density measurements —

Part 3:
Spectral conditions

1 Scope

This part of ISO 5 specifies spectral conditions and computational procedures for the definition of several types of ISO 5 standard densities used in imaging applications in photography and graphic technology.

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 5-1, *Photography and graphic technology — Density measurements — Part 1: Geometry and functional notation*

ISO 5-2, *Photography and graphic technology — Density measurements — Part 2: Geometric conditions for transmittance density*

ISO 5-4, *Photography and graphic technology — Density measurements — Part 4: Geometric conditions for reflection density*

ISO 11664-2, *Colorimetry — Part 2: CIE standard illuminants*

ISO 14807, *Photography — Transmission and reflection densitometers — Method for determining performance*

IEC 60050-845:1987[1)], *International Electrotechnical Vocabulary. Lighting*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5-1, IEC 60050-845:1987 | CIE 17.4:1987 and the following apply.

3.1
CIE standard illuminant A
Planckian radiation at a temperature of approximately 2 856 K, as defined in ISO 11664-2

NOTE 1 The radiation of a gas-filled coil tungsten filament lamp operated at a colour temperature of 2 856 K will approximate this spectral distribution, and thus can serve as a practical realization of this standard illuminant.

1) IEC 60050-845:1987 is a joint publication with the International Commission on Illumination (CIE). It is identical to CIE 17.4:1987, *International Lighting Vocabulary.*

NOTE 2 It is important to note the distinction between an illuminant and a source. An illuminant is defined by a table of relative spectral power distribution that might not be precisely realized in practice. A source is an object that produces radiant flux.

3.2
efflux spectrum
spectral power distribution of the radiant flux collected by the receiver from the reference plane

NOTE This is a function of the influx spectrum and the spectral reflectance or transmittance characteristics of the standard or specimen.

3.3
influx spectrum
S
spectral distribution of the radiometric quantity, such as radiance, irradiance or radiant flux, incident upon the sampling aperture

NOTE This is a function of the source and optics used for the illumination.

[ISO 5-1:2009, definition 3.11]

3.4
ISO 5 standard density
density value obtained using an instrument conforming to one of the geometries specified in ISO 5-2 or ISO 5-4, and one of the spectral definitions in ISO 5-3

[ISO 5-1:2009, definition 3.12]

3.5
peak wavelength
wavelength at which the spectral product or weighting factor is a maximum

3.6
receiver
portion of the densitometer that senses the efflux, including the collection optics and detector

[ISO 5-4:2009, definition 3.3]

3.7
sideband rejection
degree to which radiant flux outside a desired spectral bandwidth is blocked or suppressed

NOTE It is usually expressed as the ratio of the integrated energy within the desired bandwidth to the integrated radiant flux outside the bandwidth.

3.8
source
object that produces radiant flux

3.9
spectral bandwidth
wavelength interval between which the spectral product has decreased to a designated percentage of its maximum

3.10
spectral product
Π
product of the influx spectrum and the spectral responsivity

3.11
spectral reflectance factor
ratio of the reflected flux to the absolute reference reflected flux under the same geometrical and spectral conditions of measurement, as a function of wavelength

NOTE Adapted from ASTM E284.

3.12
spectral responsivity
s
output signal of a receiver per unit input of radiant flux as a function of wavelength

NOTE Adapted from ASTM E284.

[ISO 5-1:2009, definition 3.20]

3.13
spectral transmittance
ratio of the transmitted flux to the incident flux under specified geometrical and spectral conditions of measurement

3.14
spectral weighting factor
factor obtained from the spectral product, tabulated at specified wavelength intervals

NOTE To compute density values from spectral weighting factors, see Annex B.

4 Requirements

4.1 General

ISO 5 standard density is the logarithm to the base 10 of the ratio (see Annex B) of the integration of the spectral products and either spectral reflectance factor or spectral transmittance of the material under examination, and the integration of the spectral products alone. The spectral conditions for the various types of ISO 5 standard density specified in this part of ISO 5 are given by the various spectral products, defined at 10 nm intervals, specified in this, and previous editions, of this part of ISO 5. However, these have been extended to provide greater precision by means of tabulated values spaced at 1 nm intervals and normalized to a value of 1 at the peak wavelength. These data are directly equivalent to the 10 nm data, although defined in the linear domain. In addition, abridged weighting factors are provided for convenience in determining ISO 5 standard density using instruments where spectral reflectance factor or transmittance data are available at intervals of 10 nm or 20 nm. Further information pertaining to these weighting factors, and their derivation, is given in the Introduction and in Annexes B, C and D.

4.2 Influx spectrum

4.2.1 General

To unambiguously define the determination of ISO 5 standard density in the presence of materials which may fluoresce, it is necessary to also specify the spectral characteristics of the influx spectrum, S, as well as the spectral products.

The historic radiation source for densitometry has been an incandescent lamp with a relative spectral power distribution that matches CIE standard illuminant A as defined in ISO 11664-2 and as specified in 4.2.2.1. This source will continue to be used for measurements of ISO 5 standard reflection density for photographic applications and as one option for ISO 5 standard reflection density for applications in graphic technology. Other illuminant conditions that may be used and shall be noted when reporting ISO 5 standard reflection density in graphic technology are specified in 4.2.2.2.

For ISO 5 transmittance density, the radiation source shall be an incandescent lamp with a relative spectral power distribution that matches CIE standard illuminant A modified as specified in 4.2.3.

NOTE In transmittance densitometers, it is necessary to add a heat-absorbing filter to the influx side to protect the specimen and optical elements. If the absorber does not change the spectral power distribution of the source below 550 nm, as specified in 4.2.3, no significant effect on the measurement due to fluorescence is expected to be observed or be of concern.

4.2.2 Reflection ISO 5 standard density

4.2.2.1 Photographic applications

For reflection ISO 5 standard density measurements used in photographic applications, the relative spectral power distribution of the flux incident on the specimen surface should conform to CIE illuminant A (corresponding to a correlated colour temperature of 2 856 K). In practical instruments used to measure reflection ISO 5 standard density, the relative spectral power distribution of the flux incident on the specimen surface shall conform to a correlated colour temperature of (2 856 ± 100) K.

NOTE 1 The influx spectrum of CIE illuminant A is given in the “sources.csv” file that forms an integral part of this part of ISO 5, under the heading S_A (which is the symbol used in functional notation). For reference, an abridged version of the full definition is included in Table 1.

NOTE 2 For an instrument that does not precisely match CIE illuminant A, but is within the tolerance cited, the influx spectrum will not be significantly different from that of CIE illuminant A.

NOTE 3 The requirement to provide an influx spectrum close to S_A can be relaxed if samples to be measured do not exhibit fluorescence, so long as the specified spectral product is maintained.

4.2.2.2 Graphic technology application

For reflection ISO 5 standard density measurements used in graphic technology applications, four options are provided for the relative spectral power distribution of the flux incident on the specimen surface. The first, and historic source, is CIE illuminant A as defined in 4.2.2.1.

To maintain compatibility with instrumentation used to make colorimetric measurements in accordance with ISO 13655, three additional illumination conditions (M1, M2, and M3) defined in ISO 13655 may be used. The requirements specified in ISO 13655 shall be met if these conditions are used for the computation of density.

Measurements made using these influx spectra shall be accompanied by an identification of the particular condition used. These conditions are limited to measurements based on computation of reflection density from spectral measurements made for graphic arts applications. The influx spectrum notation used as identification for these conditions shall be M1, M2 or M3.

Measurement condition M1 requires that the instrument manufacturer provide either a spectral match of standard illuminant D50 (which is valid for both the measurement of fluorescence of optical brighteners in the substrate and fluorescent printing inks) or a compensation technique (valid only for the measurement of fluorescence of optical brighteners in the substrate).

Measurement condition M2, to exclude variations in measurement results between instruments due to fluorescence of optical brightening agents in the substrate, requires that the illumination only contain substantial radiation power in the wavelength range above 400 nm.

NOTE 1 If the specimen (substrate and marking materials) contains any fluorescent additives, then measurements under conditions M1 or M2 possibly will not report ISO 5 standard densities that will equal the values obtained from a traditional filter densitometer matching exactly the spectral product for the desired status density. When the only fluorescent additives are optical brightening agents in the substrate, the measurements under condition M2 are expected to be very similar to those of a traditional filter instrument.

NOTE 2 For density measurements in M2 mode, it is sufficient that the light source has no substantial radiation below 400 nm. Continuous spectral illumination above 400 nm is not required. Narrow-band LED instruments can be applied, if their spectral products match the density filter specification in this part of ISO 5.

Measurement condition M3 has the same general requirements as those of M2 but, in addition, requires the use of a means for polarization in order to suppress the influence of first-surface reflection on the reflectance factor measured.

4.2.3 Transmittance ISO 5 standard density

For transmittance ISO 5 standard density, the relative spectral power distribution of the flux incident on the specimen surface should conform to that given in the "sources.csv" file that forms an integral part of this part of ISO 5, under the heading S_H (which is the symbol used in functional notation). Practically, in measurements of transmittance ISO 5 standard density, the relative spectral power distribution of the flux incident on the specimen surface shall conform to the distribution temperature of (2 856 ± 100) K, with the modification in the region above 560 nm specified in S_H.

NOTE 1 This spectral power distribution is based on that of CIE standard illuminant A, modified in the region above 560 nm to protect the sample and optical elements from excessive heat that is typical for most transmittance densitometers. For reference, an abridged version of the full definition is included in Table 1.

NOTE 2 For an instrument that does not precisely match S_H, but is within the tolerance cited, the spectral power distribution will not be significantly different from that of S_H.

NOTE 3 The requirement to provide a spectral power distribution close to S_H can be relaxed if samples to be measured do not exhibit fluorescence, so long as the specified spectral product is maintained.

NOTE 4 The reference transmittance for the heat-absorbing filter can be found by taking the ratio of S_H and S_A of Table 1.

4.3 Types of instruments

Density measurements can be performed using two types of instrument, denoted as filter and spectral. A fully conforming filter instrument realizes the spectral product for the desired type of ISO 5 standard density, specified by Tables 2 to 7, by the appropriate combination of influx spectrum, given in 4.2, and spectral responsivity, usually achieved with a filtered detector. A filter instrument measures density directly. A spectral instrument measures the spectral transmittance or reflectance factor of a specimen and the desired type of ISO 5 standard density is calculated using the procedure specified in Annex B and the appropriate spectral weighting functions from Tables 8 to 13.

4.4 Spectral products

4.4.1 General

Spectral products, Π, are obtained at each wavelength by multiplying the influx spectrum, S, by the spectral responsivity, s.

4.4.2 Conformance

The spectral product of the densitometer (whether produced directly by a filter instrument or indirectly by calculation from a spectral instrument) shall be one of those specified in Tables 2 to 7. However, where greater accuracy is required, the 1 nm tables in the "Specprod.csv" file that forms an integral part of this part of ISO 5 may be used.

The spectral products at 10 nm intervals defined in Tables 2 to 7 provide the information necessary to define the spectral response of a "filter" instrument which claims conformance to this part of ISO 5. However, these data are not appropriate for calculation of ISO 5 standard density from spectral data. For this application, the methods specified in 4.5 shall be used.

NOTE The 10 nm spectral products specified in Tables 2 to 7 are defined in terms of logarithmic spectral product values specified at intervals of 10 nm, in order to be consistent with previous editions of this part of ISO 5. These are normalized to a peak value of 100 000. The logarithms to the base 10 of these values are used in this part of ISO 5 to define the various spectral types. The 1 nm spectral products are specified in the linear domain, normalized to a peak value of 1.

4.5 Computation of ISO 5 standard density from spectral data

4.5.1 General

When calculating ISO 5 standard density from spectral data, the measured spectral reflectance factor or spectral transmittance shall be multiplied by the spectral weighting factors appropriate for the measurement interval at which the data were collected.

4.5.2 Computation procedures

Computation of ISO 5 standard density shall be based on Simpson's rule of numerical integration at 1 nm intervals, using the tables of spectral weighting factors identified in Annex A and contained in the "Specprod.csv" file. However, for practical measuring instruments, this result may be sufficiently approximated by using the abridged spectral weighting factors specified at 10 nm and 20 nm intervals contained in Tables 8 to 13 (and electronically in the "10nmWeights.csv" and "20nmWeights.csv" files) together with the computational techniques defined in Annex B. For the computation of abridged tables at other intervals, the method described in Annex D shall be used.

NOTE 1 Spectral weighting factors for all of the types of ISO 5 standard density defined in this and previous editions of this part of ISO 5 are included in the "Specprod.csv", "10nmWeights.csv" and "10nmWeights.csv" files and Tables 8 to 13. The definitions and applications of these various types of ISO 5 standard density measurements are contained in Clause 6.

NOTE 2 Although the actual sum of the individual weighting factors in Tables 8 to 13 can vary because of rounding issues, the value shown as the sum is used in all calculations.

4.6 Sample conditions

The density of some materials changes with variations in temperature and relative humidity. Therefore, to avoid ambiguity, such materials should be at 23 °C ± 2 °C and 50 % ± 5 % relative humidity when determining ISO 5 standard density.

4.7 Reference standards

4.7.1 General

Reflectance factor or transmittance, and corresponding reflection or transmittance densities, are measured relative to a reference standard, which may be real or ideal. When working standards are required (usually only for reflection measurements) these are customarily calibrated relative to this reference standard by a basic standards laboratory.

4.7.2 Absolute reference standards

The reference standard for determining ISO 5 reflection density shall be an ideal, perfectly reflecting and perfectly diffusing material. Any working standard used shall not contain fluorescent additives or be intrinsically fluorescent, as this fluorescence will corrupt both the scaling of reflectance and the determination of the absolute zero level of ISO 5 standard density.

The reference standard for determining ISO 5 transmittance density shall be when no media is present (often known as "calibrating to air").

4.7.3 Relative density reference standards

In some reflection density applications, the reference white is the base on which an image may be produced, such as unexposed but processed photographic printing paper, or unprinted paper in graphic technology applications. In such cases, the measured density is called "relative reflection density" and the density of the reference white shall be stated. Great care should taken if the printing paper contains fluorescent brightening agents, as these will distort the scale of reflectance and the zero density calculation. Use of an instrument conforming to illumination condition M2 will minimize these issues.

In some transmittance density applications, the reference medium is the base on which an image may be produced, such as unexposed but processed photographic film. In such cases, the measured density is called “relative transmittance density” and the density of the reference medium shall be stated.

NOTE It is preferable to provide spectral data for the reference media where possible.

5 Notation

ISO 5-1 specifies functional notation of the form $D(G; S: g; s)$, where G and g symbolize the illuminator and receiver geometry, respectively, and S and s symbolize the influx spectrum and spectral responsivity, respectively. Since this part of ISO 5 is concerned only with spectral conditions, the notation is abbreviated to $D(S: s)$. To distinguish between ISO 5 transmittance density and ISO 5 reflection density, a subscript may be used. The subscript for transmittance density is the lower case Greek letter tau (D_τ) and that for reflection density is the upper case roman letter R (D_R).

While the spectral product, Π, is the product of the influx spectrum, S, and the spectral responsivity, s, in this part of the ISO 5 standard, the spectral responsivity s is given a subscript indicating which spectral product is to be realized. The actual spectral responsivity will be adjusted or modified so that the product of the actual instrument influx spectrum and the actual spectral responsivity will produce the specified spectral product when combined, wavelength by wavelength. This process is true for instruments with incandescent sources that approximate the standard CIE illuminant A spectrum, S_{A}, or any of the graphic arts influx spectra, S_{M1}, S_{M2} or S_{M3}. The various spectral responsivities are not equal to or identical with any set of spectral products.

6 Types of ISO 5 standard density

6.1 ISO 5 standard visual density

The notation for ISO 5 standard visual density is D_T (S_{H}:s_{V}) or D_R (S_{A}:s_{V}).

ISO 5 standard visual density is used to evaluate the darkness of an image which is to be viewed directly or by projection. Measurements of ISO 5 standard visual density are most often made on black-and-white images, but can be made on other types of images.

Where filter instruments are used to measure ISO 5 standard visual density, they shall comply with the spectral products of Table 2. Where ISO 5 standard visual density is computed from spectral data at 10 nm or 20 nm intervals, the weighting factors of Table 8 shall be used.

NOTE 1 These data are also included in the “10nmWeights.csv”, “20nmWeights.csv” and “Specprod.csv” files that form an integral part of this part of ISO 5.

NOTE 2 Spectral products and weighting factors for ISO 5 standard visual density are chosen to match the product of the spectral luminous efficiency function for photopic vision, V_λ, (as defined in CIE 18) and the relative spectral power distribution of the influx spectrum specified for reflection measurements, S_{A}. This is essentially the CIE tristimulus Y function of illuminant A.

6.2 ISO 5 standard printing density

6.2.1 General

The notation for ISO 5 standard printing density is D_T (S_{H}:s_{P}) or D_R (S_{A}:s_{P}).

Assessment of the printing of continuous-tone images onto light-sensitive materials requires a special metric called ISO 5 standard printing density. This is defined as the transmittance ISO 5 standard density of a spectrally non-selective modulator, using the appropriate spectral product defined in 6.2.2 or 6.2.3, which produces the same response as the film being evaluated when printed alongside it. To determine the contact-printing ISO 5 standard density of a film sample, it shall be contact-printed together with the spectrally non-selective modulator. In the case of projection-printing ISO 5 standard density, the film sample shall be projection-printed onto the print material. The spectrally non-selective modulator, however, shall be contact-printed onto the print material using the same projector, the same exposure time and the same lamp operating at the same voltage.

The spectral products and weighting factors for measurement or calculation of ISO 5 standard printing density are ISO 5 type 1 and ISO 5 type 2, as defined in 6.2.2 and 6.2.3.

Where filter instruments are used to measure ISO 5 standard printing density, they shall comply with the spectral products of Table 2. Where ISO 5 standard printing density is computed from spectral data at 10 nm or 20 nm intervals, the weighting factors of Table 8 shall be used.

NOTE 1 These data are also included in the “10nmWeights.csv”, “20nmWeights.csv” and “Specprod.csv” files that form an integral part of this part of ISO 5.

NOTE 2 Spectral products and weighting factors can be designed to provide printing densities directly for a particular print material. However, in most cases, it is possible to correlate such printing densities to ISO 5 standard density readings conforming to those specified in this part of ISO 5, using equations derived by regression analysis.

6.2.2 ISO 5 standard type 1 printing density

The notation for ISO 5 standard type 1 printing density is D_T (S_H:s_1) or D_R (S_A:s_1).

Type 1 printing density (see Tables 2 and 8, and the “10nmWeights.csv”, “20nmWeights.csv” and “Specprod.csv” files that form an integral part of this part of ISO 5) is intended to be representative of printing onto the diazo and vesicular films used in the microfilm industry for making prints from camera-original images or later generations. These print films normally have sensitivity in the blue and ultraviolet regions. They are generally exposed on printers equipped with additive high-pressure mercury vapour lamps. However, the extent to which ISO 5 type 1 printing density will match practical printing densities depends on the sensitivity of the print film and the spectral and geometrical characteristics of the printing system.

6.2.3 ISO 5 standard type 2 printing density

The notation for ISO 5 standard type 2 printing density is D_T (S_H:s_2) or D_R (S_A:s_2).

Type 2 printing density (see Tables 2 and 8, and the “10nmWeights.csv”, “20nmWeights.csv” and “Specprod.csv” files that form an integral part of this part of ISO 5) is intended to be representative of printing onto non-colour-sensitized silver halide photographic material (e.g. a black-and-white paper or film). These have been derived by using the average spectral sensitivity of print materials as modified by the transmission of an ultraviolet absorbing filter with a sharp cut-off at 360 nm.

6.3 ISO 5 standard status A density

The notation for ISO 5 standard status A density is D_T (S_H:s_A) or D_R (S_A:s_A).

ISO 5 standard status A densities are applicable to the measurement of colour photographic materials. They were originally defined to closely match the spectral products historically used in evaluating transparency films, whether viewed directly or by projection. Later, these spectral products were also applied to the measurement of similar colorants on reflective supports.

Where filter instruments are used to measure ISO 5 standard status A densities, they shall comply with the spectral products of Table 3. Where ISO 5 standard status A densities are computed from spectral data at 10 nm or 20 nm intervals, the weighting factors of Table 9 shall be used.

NOTE These data are also included in the “10nmWeights.csv”, “20nmWeights.csv” and “Specprod.csv” files that form an integral part of this part of ISO 5.

6.4 ISO 5 standard status M density

The notation for ISO 5 standard status M density is D_T (S_{H}:s_{M}) or D_R (S_{A}:s_{M}).

ISO 5 standard status M densities are applicable to the measurement of colour negative photographic materials. They were defined to closely match the spectral products historically used in evaluating colour negative photographic materials intended for printing, such as colour negative films.

Where filter instruments are used to measure ISO 5 standard status M densities, they shall comply with the spectral products of Table 4. Where ISO 5 standard status M densities are computed from spectral data at 10 nm or 20 nm intervals, the weighting factors of Table 10 shall be used.

NOTE These data are also included in the “10nmWeights.csv”, “20nmWeights.csv” and “Specprod.csv” files that form an integral part of this part of ISO 5.

6.5 ISO 5 standard status T density

The notation for ISO 5 standard status T density is D_T (S_{H}:s_{T}) or D_R (S_{A}:s_{T}).

ISO 5 standard status T densities are applicable to the measurement of artwork for colour separation and graphic arts materials such as ink-on-paper printed sheets, and off-press proofs. They were originally defined to closely match the spectral products historically used in evaluating original artwork to be colour separated, but were later applied, notably in the USA, to the measurement of suitable graphic arts materials.

Where filter instruments are used to measure ISO 5 standard status T densities, they shall comply with the spectral products of Table 5. Where ISO 5 standard status T densities are computed from spectral data at 10 nm or 20 nm intervals, the weighting factors of Table 11 shall be used.

NOTE These data are also included in the “10nmWeights.csv”, “20nmWeights.csv” and “Specprod.csv” files that form an integral part of this part of ISO 5.

6.6 ISO 5 standard status E density

The notation for ISO 5 standard status E density is D_T (S_{H}:s_{E}) or D_R (S_{A}:s_{E}).

ISO 5 standard status E densities are applicable to the measurement of graphic arts materials such as ink-on-paper printed sheets, and off-press proofs. They evolved from the wider of the two passband filter specifications of DIN 16536-2:1986, and the red and green spectral products were chosen to match those of status T. Status E spectral products have been applied, primarily in Europe, to the measurement of graphic arts materials. The narrower passband of the blue filter (compared to status T) produces values that are more similar for all three chromatic inks at typical printing densities.

Where filter instruments are used to measure ISO 5 standard status E densities, they shall comply with the spectral products of Table 6. Where ISO 5 standard status E densities are computed from spectral data at 10 nm or 20 nm intervals, the weighting factors of Table 12 shall be used.

NOTE These data are also included in the “10nmWeights.csv”, “20nmWeights.csv” and “Specprod.csv” files that form an integral part of this part of ISO 5.

6.7 ISO 5 standard narrow-band density

The notation for ISO 5 standard narrow-band density is D_T (S_H:$s_{\lambda,\sigma}$) or D_R (S_A:$s_{\lambda,\sigma}$).

ISO 5 standard narrow-band densitometry is designed to approximate spectral or monochromatic densitometry. It is defined by the three basic characteristics defined below.

a) Peak wavelength: any wavelengths appropriate to the application may be chosen.

b) Spectral bandwidth: the width, in nanometres, of the spectral products measured between the points where the spectral product shall have fallen to the indicated percentage of the peak, as follows:

— 50 %: shall be less than or equal to 20 nm;

— 0,1 %: shall be less than or equal to 40 nm.

NOTE A three-cavity Fabry-Pérot interference filter with a nominal 15 nm bandwidth (50 % points) would easily meet the above requirements.

c) Sideband rejection: the total integration of the spectral products outside the 0,01 % points shall not exceed a given fraction of the integration of the spectral products within the 0,01 % points. That fraction shall not be more than 1/10 000 (10^4 rejection) if 3,0 is the highest ISO 5 standard density to be measured, and not more than 1/100 000 (10^5 rejection) if 4,0 is the highest ISO 5 standard density to be measured.

The sideband rejection and peak wavelength shall be specified using the following subscript notation for the spectral responsivity s:

— the subscript λ identifies the peak wavelength, in nanometres, and

— the subscript σ identifies the exponent to the power of ten sideband rejection.

EXAMPLE 1 D_T (S_H : $s_{480,5}$) represents a peak wavelength of 480 nm and a sideband rejection of 10^5.

EXAMPLE 2 D_R (S_A : $s_{590,4}$) represents a peak wavelength of 590 nm and a sideband rejection of 10^4.

6.8 ISO 5 standard status I density

The notation for ISO 5 standard status I density is D_T (S_H:s_I) or D_R (S_A:s_I).

ISO 5 standard status I densities are applicable to the evaluation of graphic arts materials such as process ink on paper. It is a special case of the narrow-band densitometry defined in 6.7, with spectral bandwidth and sideband rejection as defined in 6.7, and peak wavelengths as follows:

— blue: 430 nm (±5 nm);

— green: 535 nm (±5 nm);

— red: 625 nm (±5 nm).

Where filter instruments are used to measure ISO 5 standard status I densities, they shall comply with the spectral products of Table 7. Where ISO 5 standard status I densities are computed from spectral data at 10 nm or 20 nm intervals, the weighting factors of Table 13 shall be used.

NOTE 1 These data are also included in the “10nmWeights.csv”, “20nmWeights.csv” and “Specprod.csv” files that form an integral part of this part of ISO 5.

NOTE 2 The data in Tables 7 and 13, and the respective electronic files, represent examples in which the required bandwidth and sideband rejection limits are achieved. Values showing improvements to these values are also acceptable.

6.9 ISO 5 standard type 3 density

The notation for ISO 5 standard type 3 density is D_T (S_{H}:s_3) or D_R (S_{A}:s_3).

ISO 5 standard type 3 density is applicable to the measurement of the optical sound records on three-component subtractive colour films made up of dye images plus silver or a metallic salt often used in sound reproduction systems employing an S-1 photosurface or a silicon photodetector response. A densitometer using a narrow-band filter with a peak transmission of 800 nm has proved to be useful in monitoring this type of sound record. The “effective” spectral sensitivity for this system is designated s_3. ISO 5 standard density values are identified as type 3 when they are obtained from a measurement having an overall response bandwidth of 20 nm peaking at 800 nm ± 5 nm, with at least 80 % of the overall response falling within the 20 nm bandwidth. The bandwidth shall be considered to lie between those wavelengths at which the spectral product is one-half the maximum value.

7 Spectral conformance, repeatability, stability and bias

7.1 Spectral conformance

Where instruments include polarizing optics, illumination condition M3, it is the responsibility of the manufacturer to ensure that the influence of the polarizers is taken into account when specifying the status density to which any instrument claims conformance, and to indicate that the density was obtained with polarizing means.

Guidance on the evaluation of the spectral conformance of a densitometer is given in Annex F.

7.2 Repeatability, stability and bias

ISO 14807 specifies the methods to be used for the determination of “ISO repeatability”, “ISO stability” and “ISO bias” estimate. Where these parameters are reported, they shall be determined in accordance with ISO 14807.

Table 1 — ISO 5 densitometer influx spectra

Wavelength nm	**Transmittance densitometer influx spectrum** S_H	**Reflection densitometer influx spectrum** S_A
340	4	4
350	5	5
360	6	6
370	8	8
380	10	10
390	12	12
400	15	15
410	18	18
420	21	21
430	25	25
440	29	29
450	33	33
460	38	38
470	43	43
480	48	48
490	54	54
500	60	60
510	66	66
520	72	72
530	79	79
540	86	86
550	93	93
560	100	100
570	107	107
580	111	114
590	115	122
600	116	129
610	119	136
620	117	144
630	113	151
640	107	158
650	102	165
660	96	172
670	89	179
680	80	185
690	72	192
700	62	198
710	53	204
720	45	210
730	37	216
740	31	222
750	24	227
760	19	232
770	15	237
NOTE Relative spectral power distributions are normalized to 100 at 560 nm.		

Table 2 — $\log_{10}$ spectral products for ISO 5 visual, type 1 and type 2 densities
(Normalized to 5,000 peak)

Wavelength λ, nm	**Visual** $\log_{10} \Pi_v$	**Type 1** $\log_{10} \Pi_1$ (Printing: diazo and vesicular)	**Type 2** $\log_{10} \Pi_2$ (Printing: silver halide)
340	−2,822	−2,020	1,136
350	−2,230	−0,800	2,708
360	−1,638	0,420	4,280
370	−1,046	1,640	4,583
380	−0,454	2,860	4,760
390	0,138	4,460	4,851
400	0,730	5,000	4,916
410	1,322	4,460	4,956
420	1,914	2,860	4,988
430	2,447	1,640	5,000
440	2,811	0,420	4,990
450	3,090	−0,800	4,951
460	3,346	−2,020	4,864
470	3,582	−3,240	4,743
480	3,818	−4,460	4,582
490	4,041	−5,680	4,351
500	4,276	−6,900	3,993
510	4,513	−8,120	3,402
520	4,702	−9,340	2,805
530	4,825	−10,560	2,211
540	4,905	−11,780	1,617
550	4,957	−13,000	1,023
560	4,989	−14,220	0,429
570	5,000	−15,440	−0,165
580	4,989	−16,660	−0,759
590	4,956	−17,880	−1,353
600	4,902	−19,100	−1,947
610	4,827	−20,320	−2,541
620	4,731	−21,540	−3,135
630	4,593	−22,760	−3,729
640	4,433	−23,980	−4,323
650	4,238	−25,200	−4,917
660	4,013	−26,420	−5,511
670	3,749	−27,640	−6,105
680	3,490	−28,860	−6,699
690	3,188	−30,080	−7,293
700	2,901	−31,300	−7,887
710	2,622	−32,520	−8,481
720	2,334	−33,740	−9,075
730	2,041	−34,960	−9,669
740	1,732	−36,180	−10,263
750	1,431	−37,400	−10,857
760	1,146	−38,620	−11,451
770	0,861	−39,840	−12,045

Table 3 — Status A - $\log_{10}$ spectral products Π_A
(Normalized to 5,000 peak)

Wavelength nm	Blue	Green	Red
340	–26,798	–33,550	–67,632
350	–22,998	–31,350	–64,932
360	–19,198	–29,150	–62,232
370	–15,398	–26,950	–59,532
380	–11,598	–24,750	–56,832
390	–7,798	–22,550	–54,132
400	–3,998	–20,350	–51,432
410	–0,198	–18,150	–48,732
420	3,602	–15,950	–46,032
430	4,819	–13,750	–43,332
440	5,000	–11,550	–40,632
450	4,912	–9,350	–37,932
460	4,620	–7,150	–35,232
470	4,040	–4,950	–32,532
480	2,989	–2,750	–29,832
490	1,566	–0,550	–27,132
500	0,165	1,650	–24,432
510	–1,235	3,822	–21,732
520	–2,635	4,782	–19,032
530	–4,035	5,000	–16,332
540	–5,435	4,906	–13,632
550	–6,835	4,644	–10,932
560	–8,235	4,221	–8,232
570	–9,635	3,609	–5,532
580	–11,035	2,766	–2,832
590	–12,435	1,579	–0,132
600	–13,835	–0,121	2,568
610	–15,235	–1,821	4,638
620	–16,635	–3,521	5,000
630	–18,035	–5,221	4,871
640	–19,435	–6,921	4,604
650	–20,835	–8,621	4,286
660	–22,235	–10,321	3,900
670	–23,635	–12,021	3,551
680	–25,035	–13,721	3,165
690	–26,435	–15,421	2,776
700	–27,835	–17,121	2,383
710	–29,235	–18,821	1,970
720	–30,635	–20,521	1,551
730	–32,035	–22,221	1,141
740	–33,435	–23,921	0,741
750	–34,835	–25,621	0,341
760	–36,235	–27,321	–0,059
770	–37,635	–29,021	–0,459

Table 4 — Status M - $\log_{10}$ spectral products Π_M
(Normalized to 5,000 peak)

Wavelength nm	Blue	Green	Red
340	–15,397	–12,628	–70,691
350	–12,897	–11,568	–68,091
360	–10,397	–10,508	–65,491
370	–7,897	–9,448	–62,891
380	–5,397	–8,388	–60,291
390	–2,897	–7,328	–57,691
400	–0,397	–6,268	–55,091
410	2,103	–5,208	–52,491
420	4,111	–4,148	–49,891
430	4,632	–3,088	–47,291
440	4,871	–2,028	–44,691
450	5,000	–0,968	–42,091
460	4,955	0,092	–39,491
470	4,743	1,152	–36,891
480	4,343	2,207	–34,291
490	3,743	3,156	–31,691
500	2,990	3,804	–29,091
510	1,852	4,272	–26,491
520	–0,348	4,626	–23,891
530	–2,548	4,872	–21,291
540	–4,748	5,000	–18,691
550	–6,948	4,995	–16,091
560	–9,148	4,818	–13,491
570	–11,348	4,458	–10,891
580	–13,548	3,915	–8,291
590	–15,748	3,172	–5,691
600	–17,948	2,239	–3,091
610	–20,148	1,070	–0,491
620	–22,348	–0,130	2,109
630	–24,548	–1,330	4,479
640	–26,748	–2,530	5,000
650	–28,948	–3,730	4,899
660	–31,148	–4,930	4,578
670	–33,348	–6,130	4,252
680	–35,548	–7,330	3,875
690	–37,748	–8,530	3,491
700	–39,948	–9,730	3,099
710	–42,148	–10,930	2,687
720	–44,348	–12,130	2,269
730	–46,548	–13,330	1,859
740	–48,748	–14,530	1,449
750	–50,948	–15,730	1,054
760	–53,148	–16,930	0,654
770	–55,348	–18,130	0,254

Table 5 — Status T - $\log_{10}$ spectral products Π_T
(Normalized to 5,000 peak)

Wavelength nm	**Blue**	**Green**	**Red**
340	0,699	–6,786	–18,347
350	1,000	–6,087	–17,472
360	1,301	–5,388	–16,597
370	2,000	–4,689	–15,722
380	2,477	–3,990	–14,847
390	3,176	–3,291	–13,972
400	3,778	–2,592	–13,097
410	4,230	–1,893	–12,222
420	4,602	–1,194	–11,347
430	4,778	–0,495	–10,472
440	4,914	0,204	–9,597
450	4,973	0,903	–8,722
460	5,000	1,602	–7,847
470	4,987	2,301	–6,972
480	4,929	3,000	–6,097
490	4,813	3,699	–5,222
500	4,602	4,447	–4,347
510	4,255	4,833	–3,472
520	3,699	4,964	–2,597
530	2,301	5,000	–1,722
540	1,602	4,944	–0,847
550	0,903	4,820	0,028
560	0,204	4,623	0,903
570	–0,495	4,342	1,778
580	–1,194	3,954	2,653
590	–1,893	3,398	4,477
600	–2,592	2,845	5,000
610	–3,291	1,954	4,929
620	–3,990	1,063	4,740
630	–4,689	0,172	4,398
640	–5,388	–0,719	4,000
650	–6,087	–1,610	3,699
660	–6,786	–2,501	3,176
670	–7,485	–3,392	2,699
680	–8,184	–4,283	2,477
690	–8,883	–5,174	2,176
700	–9,582	–6,065	1,699
710	–10,281	–6,956	1,222
720	–10,980	–7,847	0,745
730	–11,679	–8,738	0,268
740	–12,378	–9,629	–0,209
750	–13,077	–10,520	–0,686
760	–13,776	–11,411	–1,163
770	–14,475	–12,302	–1,640

Table 6 — Status E - $\log_{10}$ spectral products Π_E
(Normalized to 5,000 peak)

Wavelength nm	**Blue**	**Green**	**Red**
340	–1,569	–6,786	–18,347
350	–0,569	–6,087	–17,472
360	0,431	–5,388	–16,597
370	1,431	–4,689	–15,722
380	2,431	–3,990	–14,847
390	3,431	–3,291	–13,972
400	4,114	–2,592	–13,097
410	4,477	–1,893	–12,222
420	4,778	–1,194	–11,347
430	4,914	–0,495	–10,472
440	5,000	0,204	–9,597
450	4,959	0,903	–8,722
460	4,881	1,602	–7,847
470	4,672	2,301	–6,972
480	4,255	3,000	–6,097
490	3,778	3,699	–5,222
500	2,903	4,447	–4,347
510	1,699	4,833	–3,472
520	0,495	4,964	–2,597
530	–0,709	5,000	–1,722
540	–1,913	4,944	–0,847
550	–3,117	4,820	0,028
560	–4,321	4,623	0,903
570	–5,525	4,342	1,778
580	–6,729	3,954	2,653
590	–7,933	3,398	4,477
600	–9,137	2,845	5,000
610	–10,341	1,954	4,929
620	–11,545	1,063	4,740
630	–12,749	0,172	4,398
640	–13,953	–0,719	4,000
650	–15,157	–1,610	3,699
660	–16,361	–2,501	3,176
670	–17,565	–3,392	2,699
680	–18,769	–4,283	2,477
690	–19,973	–5,174	2,176
700	–21,177	–6,065	1,699
710	–22,381	–6,956	1,222
720	–23,585	–7,847	0,745
730	–24,789	–8,738	0,268
740	–25,993	–9,629	–0,209
750	–27,197	–10,520	–0,686
760	–28,401	–11,411	–1,163
770	–29,605	–12,302	–1,640

Table 7 — Status I - $\log_{10}$ spectral products Π_I (example)
(Normalized to 5,000 peak)

Wavelength nm	**430 nm Peak**	**535 nm Peak**	**625 nm Peak**
340	–145,230	–303,080	–303,080
350	–122,997	–303,080	–303,080
360	–100,764	–303,080	–303,080
370	–78,532	–303,080	–303,080
380	–56,299	–289,741	–303,080
390	–34,067	–267,508	–303,080
400	–15,015	–245,276	–303,080
410	–2,561	–223,043	–303,080
420	3,629	–200,811	–303,080
430	5,000	–178,578	–303,080
440	3,629	–156,346	–303,080
450	–2,561	–134,113	–303,080
460	–15,015	–111,881	–303,080
470	–34,067	–89,648	–289,741
480	–56,299	–67,416	–267,508
490	–78,532	–45,183	–245,276
500	–100,764	–23,705	–223,043
510	–122,997	–7,975	–200,811
520	–145,230	1,274	–178,578
530	–167,462	4,730	–156,346
540	–189,695	4,730	–134,113
550	–211,927	1,274	–111,881
560	–234,160	–7,975	–89,648
570	–256,392	–23,705	–67,416
580	–278,625	–45,183	–45,183
590	–300,857	–67,416	–23,705
600	–303,080	–89,648	–7,975
610	–303,080	–111,881	1,274
620	–303,080	–134,113	4,730
630	–303,080	–156,346	4,730
640	–303,080	–178,578	1,274
650	–303,080	–200,811	–7,975
660	–303,080	–223,043	–23,705
670	–303,080	–245,276	–45,183
680	–303,080	–267,508	–67,416
690	–303,080	–289,741	–89,648
700	–303,080	–303,080	–111,881
710	–303,080	–303,080	–134,113
720	–303,080	–303,080	–156,346
730	–303,080	–303,080	–178,578
740	–303,080	–303,080	–200,811
750	–303,080	–303,080	–223,043
760	–303,080	–303,080	–245,276
770	–303,080	–303,080	–267,508

NOTE The data in this table represent an example in which the required bandwidth and sideband rejection limits are achieved. Values showing improvements to these values are also acceptable.

Table 8 — ISO 5 visual, type 1 and type 2 abridged ISO 5 standard density weighting factors

10 nm abridged weighting factors				20 nm abridged weighting factors			
Wavelength nm	**ISO 5 visual**	**ISO 5 type 1**	**ISO 5 type 2**	**Wavelength** nm	**ISO 5 visual**	**ISO 5 type 1**	**ISO 5 type 2**
340	0,000	0,000	–0,018	340	0,000	–0,003	–0,282
350	0,000	0,001	0,048	360	0,000	–1,644	3,956
360	0,000	0,003	1,990	380	0,000	11,578	11,960
370	0,000	–0,109	4,188	400	0,000	80,137	17,397
380	0,000	–0,330	5,989	420	0,016	11,578	20,547
390	0,000	22,130	7,550	440	0,118	–1,644	20,605
400	0,001	56,608	8,685	460	0,410	–0,002	15,520
410	0,002	22,130	9,573	480	1,205	0,000	8,059
420	0,008	–0,330	10,272	500	3,7098	0,000	2,176
430	0,027	–0,109	10,572	520	9,443	0,000	0,076
440	0,061	0,003	10,336	540	15,186	0,000	–0,011
450	0,117	0,001	9,421	560	18,428	0,000	–0,002
460	0,209	0,000	7,740	580	18,409	0,000	0,000
470	0,362	0,000	5,852	600	15,106	0,000	0,000
480	0,620	0,000	4,034	620	10,107	0,000	0,000
490	1,039	0,000	2,375	640	5,146	0,000	0,000
500	1,792	0,000	1,042	660	1,955	0,000	0,000
510	3,087	0,000	0,273	680	0,567	0,000	0,000
520	4,754	0,000	0,062	700	0,145	0,000	0,000
530	6,321	0,000	0,016	720	0,038	0,000	0,000
540	7,598	0,000	0,001	740	0,010	0,000	0,000
550	8,569	0,000	0,000	760	0,000	0,000	0,000
560	9,220	0,000	0,000	—	—	—	—
570	9,456	0,000	0,000	—	—	—	—
580	9,219	0,000	0,000	—	—	—	—
590	8,547	0,000	0,000	—	—	—	—
600	7,545	0,000	0,000	—	—	—	—
610	6,358	0,000	0,000	—	—	—	—
620	5,077	0,000	0,000	—	—	—	—
630	3,716	0,000	0,000	—	—	—	—
640	2,559	0,000	0,000	—	—	—	—
650	1,6340	0,000	0,000	—	—	—	—
660	0,972	0,000	0,000	—	—	—	—
670	0,533	0,000	0,000	—	—	—	—
680	0,290	0,000	0,000	—	—	—	—
690	0,147	0,000	0,000	—	—	—	—
700	0,075	0,000	0,000	—	—	—	—
710	0,040	0,000	0,000	—	—	—	—
720	0,020	0,000	0,000	—	—	—	—
730	0,010	0,000	0,000	—	—	—	—
740	0,005	0,000	0,000	—	—	—	—
750	0,003	0,000	0,000	—	—	—	—
760	0,002	0,000	0,000	—	—	—	—
770	0,000	0,000	0,000	—	—	—	—
Sum	100,000	100,000	100,000	Sum	100,000	100,000	100,000

NOTE The “10nmWeights.csv” and “20nmWeights.csv” files provide the data included in Tables 8 to 13 in digital form.

Table 9 — ISO 5 status A abridged ISO 5 standard density weighting factors

10 nm abridged weighting factors				20 nm abridged weighting factors			
Wavelength nm	**Blue**	**Green**	**Red**	**Wavelength** nm	**Blue**	**Green**	**Red**
340	0,000	0,000	0,000	340	0,000	0,000	0,000
350	0,000	0,000	0,000	360	0,000	0,000	0,000
360	0,000	0,000	0,000	380	−0,002	0,000	0,000
370	0,000	0,000	0,000	400	−1,572	0,000	0,000
380	0,000	0,000	0,000	420	13,013	0,000	0,000
390	0,000	0,000	0,000	440	58,375	0,000	0,000
400	−0,003	0,000	0,000	460	29,692	0,000	0,000
410	−0,373	0,000	0,000	480	0,802	−0,280 0	0,000
420	2,763	0,000	0,000	500	−0,305	−0,355	0,000
430	20,848	0,000	0,000	520	−0,002	37,472	0,000
440	32,395	0,000	0,000	540	0,000	50,946	0,000
450	26,684	0,000	0,000	560	0,000	12,328	0,000
460	13,711	0,000	0,000	580	0,000	−0,003	−1,203
470	3,723	0,000	0,000	600	0,000	−0,105	7,671
480	0,275	0,000	0,000	620	0,000	−0,002	56,083
490	−0,022	−0,012	0,000	640	0,000	0,000	30,934
500	−0,002	−0,256	0,000	660	0,000	0,000	5,523
510	0,000	2,887	0,000	680	0,000	0,000	0,840
520	0,000	19,135	0,000	700	0,000	0,000	0,131
530	0,000	31,434	0,000	720	0,000	0,000	0,018
540	0,000	25,840	0,000	740	0,000	0,000	0,003
550	0,000	14,144	0,000	760	0,000	0,000	0,000
560	0,000	5,365	0,000	—	—	—	—
570	0,000	1,296	0,000	—	—	—	—
580	0,000	0,166	−0,000	—	—	—	—
590	0,000	0,004	−0,108	—	—	—	—
600	0,000	−0,002	−0,300	—	—	—	—
610	0,000	0,000	16,166	—	—	—	—
620	0,000	0,000	33,797	—	—	—	—
630	0,000	0,000	25,312	—	—	—	—
640	0,000	0,000	13,862	—	—	—	—
650	0,000	0,000	6,532	—	—	—	—
660	0,000	0,000	2,723	—	—	—	—
670	0,000	0,000	1,185	—	—	—	—
680	0,000	0,000	0,498	—	—	—	—
690	0,000	0,000	0,201	—	—	—	—
700	0,000	0,000	0,081	—	—	—	—
710	0,000	0,000	0,031	—	—	—	—
720	0,000	0,000	0,012	—	—	—	—
730	0,000	0,000	0,005	—	—	—	—
740	0,000	0,000	0,002	—	—	—	—
750	0,000	0,000	0,001	—	—	—	—
760	0,000	0,000	0,000	—	—	—	—
770	0,000	0,000	0,000	—	—	—	—
Sum	100,000	100,000	100,000	Sum	100,000	100,000	100,000

NOTE The “10nmWeights.csv” and “20nmWeights.csv” files provide the data included in Tables 8 to 13 in digital form.

Table 10 — ISO 5 status M abridged ISO 5 standard density weighting factors

10 nm abridged weighting factors				20 nm abridged weighting factors			
Wavelength nm	**Blue**	**Green**	**Red**	**Wavelength** nm	**Blue**	**Green**	**Blue**
340	0,000	0,000	0,0000	340	0,0000	0,0000	0,0000
350	0,000	0,000	0,000	360	0,000	0,000	0,000
360	0,000	0,000	0,000	380	–0,015	0,000	0,000
370	0,000	0,000	0,000	400	–0,756	0,000	0,000
380	0,000	0,000	0,000	420	8,058	0,000	0,000
390	–0,000	0,000	0,000	440	37,263	–0,000	0,000
400	–0,023	0,000	0,000	460	42,772	–0,027	0,000
410	–0,098	0,000	0,000	480	12,643	–0,073	0,000
420	3,497	0,000	0,000	500	0,144	2,968	0,000
430	10,684	0,000	0,000	520	–0,105	19,975	0,000
440	18,380	0,000	0,000	540	–0,003	43,253	0,000
450	24,516	0,000	0,000	560	0,000	29,721	0,000
460	22,212	0,000	0,000	580	0,000	4,447	–0,000
470	13,708	0,001	0,000	600	0,000	–0,233	–1,006
480	5,523	0,029	0,000	620	0,000	–0,030	5,555
490	1,373	0,318	0,000	640	0,000	–0,000	56,978
500	0,218	1,425	0,000	660	0,000	0,000	32,526
510	0,013	4,210	0,000	680	0,000	0,000	5,102
520	–0,003	9,512	0,000	700	0,000	0,000	0,730
530	–0,000	16,688	0,000	720	0,000	0,000	0,100
540	0,000	22,353	0,000	740	0,000	0,000	0,015
550	0,000	21,987	0,000	760	0,000	0,000	0,000
560	0,000	14,761	0,000	—	—	—	—
570	0,000	6,517	0,000	—	—	—	—
580	0,000	1,857	0,000	—	—	—	—
590	0,000	0,316	0,000	—	—	—	—
600	0,000	0,028	–0,000	—	—	—	—
610	0,000	0,000	–0,061	—	—	—	—
620	0,000	–0,000	–0,631	—	—	—	—
630	0,000	0,000	13,200	—	—	—	—
640	0,000	0,000	34,826	—	—	—	—
650	0,000	0,000	28,058	—	—	—	—
660	0,000	0,000	13,867	—	—	—	—
670	0,000	0,000	6,257	—	—	—	—
680	0,000	0,000	2,676	—	—	—	—
690	0,000	0,000	1,089	—	—	—	—
700	0,000	0,000	0,442	—	—	—	—
710	0,000	0,000	0,171	—	—	—	—
720	0,000	0,000	0,065	—	—	—	—
730	0,000	0,000	0,025	—	—	—	—
740	0,000	0,000	0,010	—	—	—	—
750	0,000	0,000	0,004	—	—	—	—
760	0,000	0,000	0,002	—	—	—	—
770	0,000	0,000	0,000	—	—	—	—
Sum	100,000	100,000	100,000	Sum	100,000	100,000	100,000
NOTE The “10nmWeights.csv” and “20nmWeights.csv” files provide the data included in Tables 8 to 13 in digital form.							

Table 11 — ISO 5 status T abridged ISO 5 standard density weighting factors

10 nm abridged weighting factors				20 nm abridged weighting factors			
Wavelength nm	**Blue**	**Green**	**Red**	**Wavelength** nm	**Blue**	**Green**	**Red**
340	0,000	0,000	0,000	340	0,000	0,000	0,000
350	0,001	0,000	0,000	360	−0,006	0,000	0,000
360	0,003	0,000	0,000	380	−0,000	0,000	0,000
370	0,013	0,000	0,000	400	1,823	0,000	0,000
380	0,039	0,000	0,000	420	10,876	0,000	0,000
390	0,210	0,000	0,000	440	22,684	−0,001	0,000
400	0,832	0,000	0,000	460	28,060	−0,091	0,000
410	2,454	0,000	0,000	480	23,738	−0,072	0,000
420	5,530	0,000	0,000	500	11,351	12,161	0,000
430	8,530	0,000	0,000	520	1,645	34,562	0,000
440	11,448	0,000	0,000	540	−0,168	33,459	−0,001
450	13,261	0,000	0,000	560	−0,004	16,285	−0,866
460	14,039	−0,001	0,000	580	0,000	3,592	4,822
470	13,648	−0,010	0,000	600	0,000	0,134	51,520
480	11,932	0,173	0,000	620	0,000	−0,027	36,521
490	9,143	0,964	0,000	640	0,000	−0,002	6,974
500	5,602	5,466	0,000	660	0,000	0,000	0,899
510	2,568	12,880	0,000	680	0,000	0,000	0,100
520	0,741	17,593	0,000	700	0,000	0,000	0,034
530	0,006	18,994	0,000	720	0,000	0,000	−0,001
540	0,000	16,786	0,000	740	0,000	0,000	0,000
550	0,001	12,597	0,000	760	0,000	0,000	0,000
560	0,000	8,011	0,003	—	—	—	—
570	0,000	4,208	−0,042	—	—	—	—
580	0,000	1,715	−0,373	—	—	—	—
590	0,000	0,482	11,492	—	—	—	—
600	0,000	0,125	30,713	—	—	—	—
610	0,000	0,016	27,283	—	—	—	—
620	0,000	0,001	17,361	—	—	—	—
630	0,000	0,000	8,037	—	—	—	—
640	0,000	0,000	3,198	—	—	—	—
650	0,000	0,000	1,521	—	—	—	—
660	0,000	0,000	0,495	—	—	—	—
670	0,000	0,000	0,153	—	—	—	—
680	0,000	0,000	0,091	—	—	—	—
690	0,000	0,000	0,048	—	—	—	—
700	0,000	0,000	0,016	—	—	—	—
710	0,000	0,000	0,003	—	—	—	—
720	0,000	0,000	0,001	—	—	—	—
730	0,000	0,000	0,000	—	—	—	—
740	0,000	0,000	0,000	—	—	—	—
750	0,000	0,000	0,000	—	—	—	—
760	0,000	0,000	0,000	—	—	—	—
770	0,000	0,000	0,000	—	—	—	—
Sum	100,000	100,000	100,000	Sum	100,000	100,000	100,000
NOTE The “10nmWeights.csv” and “20nmWeights.csv” files provide the data included in Tables 8 to 13 in digital form.							

Table 12 — ISO 5 status E abridged ISO 5 standard density weighting factors

10 nm abridged weighting factors				20 nm abridged weighting factors			
Wavelength nm	**Blue**	**Green**	**Red**	**Wavelength** nm	**Blue**	**Green**	**Red**
340	0,000	0,000	0,000	340	0,000	0,000	0,000
350	0,000	0,000	0,000	360	–0,047	0,000	0,000
360	0,000	0,000	0,000	380	–0,032	0,000	0,000
370	–0,003	0,000	0,000	400	5,075	0,000	0,000
380	0,039	0,000	0,000	420	22,254	0,000	0,000
390	0,536	0,000	0,000	440	36,413	0,000	0,000
400	2,422	0,000	0,000	460	28,070	–0,091	0,000
410	5,837	0,000	0,000	480	8,127	–0,073	0,000
420	11,200	0,000	0,000	500	0,225	12,161	0,000
430	15,793	0,000	0,000	520	–0,084	34,562	0,000
440	18,702	0,000	0,000	540	–0,001	33,459	–0,001
450	17,464	0,000	0,000	560	0,000	16,285	–0,866
460	14,343	–0,001	0,000	580	0,000	3,592	4,822
470	8,886	–0,010	0,000	600	0,000	0,134	51,520
480	3,517	0,172	0,000	620	0,000	–0,027	36,521
490	1,106	0,964	0,000	640	0,000	–0,002	6,974
500	0,159	5,466	0,000	660	0,000	0,000	0,899
510	–0,001	12,880	0,000	680	0,000	0,000	0,100
520	0,001	17,593	0,000	700	0,000	0,000	0,034
530	0,000	18,994	0,000	720	0,000	0,000	–0,001
540	0,000	16,786	0,000	740	0,000	0,000	0,000
550	0,000	12,597	0,000	760	0,000	0,000	0,000
560	0,000	8,011	0,003	—	—	—	—
570	0,000	4,208	–0,042	—	—	—	—
580	0,000	1,715	–0,373	—	—	—	—
590	0,000	0,482	11,492	—	—	—	—
600	0,000	0,125	30,713	—	—	—	—
610	0,000	0,016	27,283	—	—	—	—
620	0,000	0,001	17,361	—	—	—	—
630	0,000	0,000	8,037	—	—	—	—
640	0,000	0,000	3,198	—	—	—	—
650	0,000	0,000	1,521	—	—	—	—
660	0,000	0,000	0,495	—	—	—	—
670	0,000	0,000	0,153	—	—	—	—
680	0,000	0,000	0,091	—	—	—	—
690	0,000	0,000	0,048	—	—	—	—
700	0,000	0,000	0,016	—	—	—	—
710	0,000	0,000	0,003	—	—	—	—
720	0,000	0,000	0,001	—	—	—	—
730	0,000	0,000	0,000	—	—	—	—
740	0,000	0,000	0,000	—	—	—	—
750	0,000	0,000	0,000	—	—	—	—
760	0,000	0,000	0,000	—	—	—	—
770	0,000	0,000	0,000	—	—	—	—
Sum	100,000	100,000	100,000	Sum	100,000	100,000	100,000

NOTE The “10nmWeights.csv” and “20nmWeights.csv” files provide the data included in Tables 8 to 13 in digital form.

Table 13 — ISO 5 status I abridged ISO 5 standard density weighting factors

10 nm abridged weighting factors				20 nm abridged weighting factors			
Wavelength nm	**Blue**	**Green**	**Red**	**Wavelength** nm	**Blue**	**Green**	**Red**
340	0,000	0,000	0,000	340	0,000	0,000	0,000
350	0,000	0,000	0,000	360	0,000	0,000	0,000
360	0,000	0,000	0,000	380	−0,003	0,000	0,000
370	0,000	0,000	0,000	400	−5,215	0,000	0,000
380	0,000	0,000	0,000	420	55,218	0,000	0,000
390	0,000	0,000	0,000	440	55,218	0,000	0,000
400	−0,006	0,000	0,000	460	−5,215	0,000	0,000
410	−1,850	0,000	0,000	480	−0,003	0,000	0,000
420	15,673	0,000	0,000	500	0,000	−3,554	0,000
430	72,367	0,000	0,000	520	0,000	28,497	0,000
440	15,673	0,000	0,000	540	0,000	78,507	0,000
450	−1,850	0,000	0,000	560	0,000	−3,290	0,000
460	−0,006	0,000	0,000	580	0,000	−0,160	−0,160
470	0,000	0,000	0,000	600	0,000	0,000	−3,290
480	0,000	0,000	0,000	620	0,000	0,000	78,507
490	0,000	0,000	0,000	640	0,000	0,000	28,497
500	0,000	0,000	0,000	660	0,000	0,000	−3,554
510	0,000	−0,288	0,000	680	0,000	0,000	0,000
520	0,000	−1,282	0,000	700	0,000	0,000	0,000
530	0,000	51,569	0,000	720	0,000	0,000	0,000
540	0,000	51,569	0,000	740	0,000	0,000	0,000
550	0,000	−1,282	0,000	760	0,000	0,000	0,000
560	0,000	−0,288	0,000	—	—	—	—
570	0,000	0,000	0,000	—	—	—	—
580	0,000	0,000	0,000	—	—	—	—
590	0,000	0,000	0,000	—	—	—	—
600	0,000	0,000	−0,288	—	—	—	—
610	0,000	0,000	−1,282	—	—	—	—
620	0,000	0,000	51,569	—	—	—	—
630	0,000	0,000	51,569	—	—	—	—
640	0,000	0,000	−1,282	—	—	—	—
650	0,000	0,000	−0,288	—	—	—	—
660	0,000	0,000	0,000	—	—	—	—
670	0,000	0,000	0,000	—	—	—	—
680	0,000	0,000	0,000	—	—	—	—
690	0,000	0,000	0,000	—	—	—	—
700	0,000	0,000	0,000	—	—	—	—
710	0,000	0,000	0,000	—	—	—	—
720	0,000	0,000	0,000	—	—	—	—
730	0,000	0,000	0,000	—	—	—	—
740	0,000	0,000	0,000	—	—	—	—
750	0,000	0,000	0,000	—	—	—	—
760	0,000	0,000	0,000	—	—	—	—
770	0,000	0,000	0,000	—	—	—	—
Sum	100,000	100,000	100,000	Sum	100,000	100,000	100,000

NOTE The data in this table represent an example in which the required bandwidth and sideband rejection limits are achieved. Values showing improvements to these values are also acceptable.

Annex A
(normative)

Reference tables of spectral products and weighting factors

A.1 Influx spectrum

The “sources.csv” digital file that forms an integral part of this part of ISO 5 contains data, at 1 nm intervals, which shall define the ISO 5 densitometer influx spectrum for reflection and transmittance densitometry. The file format is comma-separated ASCII data. The data tabulated in Table 1 are the same as these data but are simply tabulated at a coarser increment.

NOTE Plots of these influx spectra are shown in Figure E.1.

A.2 Spectral products and weighting factors

The “Specprod.csv” digital file that forms an integral part of this part of ISO 5 gives spectral product data at 1 nm intervals for ISO 5 visual, type 1, type 2, status A, M, T, E, I and narrow-band densities. The file format is comma-separated ASCII data. These data enable, and shall form the basis of, the calculation of ISO 5 standard density from spectral reflectance factor or transmittance data. They also provide a more detailed specification of the 10 nm spectral products used for defining conformance of a filter-type instrument. For filter instruments, these spectral products (which are assumed to be continuously smooth functions passing through the points defined) shall include the optical effects of optical elements including polarization filters if they are present. Weights are normalized to 1 at the wavelength of each function’s maximum. Thus, reflectance factor data should be applied as fractions, and not as percentages.

Although the 1 nm data shall form the basis of any calculation of ISO 5 standard density from spectral data, the 10 nm and 20 nm weighting functions provided in Tables 8 to 13 (and the “10nmWeights.csv” and “20nmWeights.csv” files that form an integral part of this part of ISO 5) may be used for data obtained at the coarser 10 nm and 20 nm sampling intervals, subject to the caveats listed in Annex B.

NOTE 1 Plots of spectral products are shown in Figures E.2 to E.7.

NOTE 2 The “10nmWeights.csv” and “20nmWeights.csv” files that form an integral part of this part of ISO 5 give the data included in Tables 8 to 13 in digital form.

Annex B
(normative)

Computation of ISO 5 standard density from spectral data

B.1 General

This part of ISO 5 contains three tables of weighting factors for each of the following types of ISO 5 standard density: visual, type 1 and 2 printing ISO 5 standard density, and status A, M, E, I and T. The calculation technique to be used to combine the spectral product factors and spectral reflectance data is independent of the data spacing of the weighting factors. For computation of each of these ISO 5 standard density types, the 1 nm data shall be used as the definition of ISO 5 standard density. Where either the 10 nm or 20 nm reflectance factor or transmittance data are used, it shall be the responsibility of the user (or, where appropriate, the instrument manufacturer) to ensure that the measured spectral data change sufficiently slowly over the interval used so as not to introduce errors beyond the requirements of the intended application.

NOTE Since the spectral weighting factors include both the densitometric spectral products and the coefficients of a polynomial for interpolating the spectral reflectance factor or transmittance, the table entry at a given wavelength might occasionally be a small negative value. This will not result in negative densities for any typical media, nor does it imply negative spectral products. The sums will always be positive and the logarithms will have the appropriate magnitude for the spectrally integrated readings.

B.2 Wavelength range

For type 1 and type 2 printing ISO 5 standard density calculations, the measured data range shall be from at least 350 nm to 550 nm. For visual, and status A, M, E, I and T ISO 5 standard densities, the measured data range shall be at least from 400 nm to 700 nm. For any computation for which spectral reflectance or transmittance data are not available for the full range of the available weighting factors, the data at all wavelengths greater than the highest wavelength for which data are available shall be assumed to be equal to the value at that highest wavelength, and the data at all wavelengths less than the lowest wavelength for which data is available shall be assumed to be equal to the value at that lowest wavelength. Where less than the specified wavelength range is used, it shall be the responsibility of the user (or where appropriate the instrument manufacturer) to ensure that this does not introduce errors beyond the requirements of the intended application. The spectral weights are normalized to 100 and this value shall be used in the denominator of the sums.

NOTE In practice, the correction specified above can be more easily accomplished by summing the values of the weighting factors above or below the values for which spectral reflectance data are available, and adding these sums to the respective highest or lowest weighting function for which spectral reflectance data are available.

B.3 Calculation at 1 nm intervals

For the calculation of ISO 5 standard density using the 1 nm spectral weighting factor, the spectral reflectance or transmittance data shall be determined at 1 nm intervals by direct measurement at that interval or by interpolation of data measured at a wider spacing to a 1 nm interval. Data interpolation shall use the Lagrange method. Reflection ISO 5 standard density is defined as shown in Equation (B.1):

$$-\log_{10}\left[\sum_{\lambda}\frac{\Pi_{\lambda}\times R_{\lambda}}{\Pi_{\text{sum}}}\right] \tag{B.1}$$

where

Π_λ is the spectral product at wavelength λ, as defined in the “Specprod.csv” file that forms an integral part of this part of ISO 5;

R_λ is the spectral reflectance factor at wavelength λ;

Π_{sum} is the sum of the spectral product over the range of 340 nm to 770 nm.

NOTE Π_{sum} is included for convenience in the “Specprod.csv” file that forms an integral part of this part of ISO 5.

The summation shall be accomplished in 1 nm steps and should be over the range of 340 nm to 770 nm. Where the wavelength range is more limited, it shall be within the restrictions defined in B.2.

Transmittance ISO 5 standard density is computed in a similar fashion using spectral transmittance rather than spectral reflectance factor data. Spectral transmittance and spectral reflectance shall be measured in accordance with the geometry defined in ISO 5-2 and ISO 5-4.

B.4 Calculation at 10 or 20 nm intervals

Where abridged weighting factors are used to compute ISO 5 standard density, Equation (B.2) shall be used:

$$-\log_{10}\left[\sum_{\lambda}\frac{W_\lambda \times R_\lambda}{100}\right] \tag{B.2}$$

where

W_λ is the spectral weighting factor at wavelength λ, as defined in the “10nmWeights.csv” or “20nmWeights.csv” files that form an integral part of this part of ISO 5;

R_λ is the spectral reflectance factor at wavelength λ;

100 is the sum of the spectral weighting factor over the range of 340 nm to 770 nm.

The summation shall be accomplished in 10 nm or 20 nm steps over the range of 340 nm to 770 nm, within the restrictions defined in B.2.

The following caveats and restrictions also apply:

- the user shall determine that the reflectance factor data are suitable for calculation using abridged weighting factors as described in B.1;
- the instrument, or procedure, used to obtain the data at 10 nm or 20 nm intervals is assumed (and should be adjusted) to have a triangular bandpass where the half peak values correspond to the wavelength interval specified for the data;
- the summations shall be accomplished using the appropriate weighting factors of Tables 2 to 6 and shall be accomplished in steps of 10 nm or 20 nm, consistent with the weighting factors used.

ISO 5 standard transmittance density is computed in a similar fashion, using spectral transmittance rather than spectral reflectance factor data. Spectral transmittance and spectral reflectance factor shall be measured in accordance with the geometry defined in ISO 5-2 and ISO 5-4.

Although the actual sum of the individual weighting factors can vary because of rounding issues, the value of 100 should be used in all calculations.

Annex C
(informative)

Method used to derive spectral weighting factors based on historical spectral product data

Previous editions of this part of ISO 5 defined various type of density only by specifying the required spectral products of the spectral power distribution of the light source and the spectral responsivity of the filter-detector-based receiver. No provision was made for the calculation of ISO 5 standard density from spectral data.

Once the decision was made to follow the lead of the CIE, and to provide spectral weights for this revision of this part of ISO 5, it was necessary to convert the existing 10 nm spectral products to equivalent 1 nm data from which weighting factors at other intervals could be derived. In reviewing the spectral product tables, it became apparent that the factors do not behave as expected in the linear domain. This is not totally unexpected, since the linear factors are the result of the convolution of the light source and the spectral responsivity of the filter-detector-based receiver.

However, the logarithmic domain factors have several desirable properties. First, the curves tend to be smoother and broader with much lower kurtosis and very little skew. Second, the tails of curves are defined to be linear with a constant slope, rather than exponentially decaying. These two factors provided the impetus to perform our interpolation and extrapolation of the 10 nm in the logarithmic domain. Since it was known that the ends of the factors are linear, a natural cubic spline system was selected from the numerical analysis package Mathcad®[2], which had as one of its boundary conditions the requirement that the end points be linear, i.e. the second derivatives are zero and the first derivatives are constant.

This resulted in a very smooth and consistent interpolation of the spectral ISO 5 standard density factors. Following the linear end point assumption, it was then easy to extrapolate the factors out to the lowest wavelength (340 nm) and the highest wavelength (770 nm). For many of the spectral products, these extrapolations are very small and probably completely unimportant, but it was felt to be important to follow through with consistency, rather than make arbitrary judgements about when to stop extrapolating.

Following interpolation as described above, these data were converted to the linear domain and normalized to have a peak value of 1. These 1 nm data then become both a more detailed specification of the required spectral products for filter-based measurement of ISO 5 standard density, and the reference weighting factors for the computation of ISO 5 standard density from spectral data.

The abridged spectral weighting functions for use with 10 nm and 20 nm reflectance or transmittance data were calculated from these 1 nm data, as described in Annex D.

It should be noted that, for compatibility with previous editions of this part of ISO 5, the 10 nm spectral products specified in Tables 2 to 7 are expressed in the logarithmic domain (normalized to a peak value of 5 in the logarithmic domain). The 1 nm spectral products (and hence 1 nm weighting functions) are normalized to a peak value of 1. The abridged weighting functions are normalized to sum to 100 in each channel.

2) Mathcad® is produced by the company PTC, Needham, Massachusetts, USA. Mathcad® is an example of a suitable product available commercially. This information is given for the convenience of users of this part of ISO 5 and does not constitute an endorsement by ISO of this product.

Annex D
(informative)

Method used to derive abridged spectral weighting factors from 1 nm reference spectral product data

The method used to develop the ISO 5 standard density weighting factors at intervals of 10 nm and 20 nm is very similar to that used to develop the tristimulus weighting factors given in ASTM E308. In the ASTM approach, the cross-product of the relative spectral power distribution and the standard observer factors becomes the equivalent of the ISO 5 reference spectral product data.

As indicated in both Annex B and ASTM E308, the primary definition for the computation of the convolution of the spectral reflectance or transmittance data and the reference spectral product function is simply summation at 1 nm intervals. If the spectral reflectance or transmittance data have been collected at such small intervals, then the direct application of the 1 nm reference spectral product factors can be performed. However, if the spectrodensitometer makes readings with a measurement interval greater than 5 nm, then the measurement data should be interpolated down to 1 nm. In a report from the CIE working group on tristimulus integration[10], it was demonstrated that a local Lagrange interpolation scheme could provide interpolated values of most coloured materials, either reflecting or transmitting. The few exceptions, mostly analytical filters designed to test the wavelength scale or bandwidth of analytical spectrometers, were not of commercial interest in colorimetry or densitometry. The local Lagrange interpolator used by the CIE, and subsequently adopted by the ASTM committee that developed ASTM E308, uses four equally-spaced points to interpolate all missing reflectance values inside the spectral region just higher in wavelength than the second measured point and just lower in wavelength than the next-to-last measured point, and three equally-spaced points to interpolate all missing values in the spectral interval at each end of the visible spectrum.

In principle, one could let the user or manufacturer choose their own interpolation scheme and have the instrument or local software provide 1 nm interpolated data, which could then be multiplied and summed with the 1 nm spectral product data. What the CIE committee discovered is that the efficiency and error rates of different interpolation schemes are not equivalent. As a result, allowing the use of any arbitrary interpolation scheme on the abridged measurement data actually increased the errors due to computation. Specifying a mathematical procedure for interpolation, such as a given type and order of B-spline, seemed too complicated for most colorimetrists. The Lagrange method offered the ability to create interpolatory weights based only on the ordinate and did not include the abscissa in the same way that either complete or parametric spline algorithms do. Thus it would be possible to compute the spline coefficients in advance and provide the user with a table of coefficients. Still, this was cumbersome since the wavelength range for colorimetry was 360 nm to 830 nm, or 471 individual points, each of which had an interpolation equation with three or four coefficients at each wavelength.

The paradigm that the ASTM subcommittee derived is described here. Lagrange interpolating coefficients are calculated for the missing wavelengths. The Lagrange coefficients, when multiplied into the appropriate measured spectral data, interpolate the abridged spectrum to a 1 nm interval. The 1 nm interval spectrum is then multiplied into the 1 nm spectral product data in accordance with ISO 5. Each separate term of this multiplication is collected into a value associated with a measured spectral wavelength, thus forming weighting factors for densitometric integration. Tables D.1 to D.4 give the precomputed Lagrange interpolation values for both 20 nm and 10 nm measurement intervals. Note that some of the Lagrange coefficients exhibit negative values indicating that the influence of that measured value is subtracted from the influence at other nearby measured values.

Table D.1 — The Lagrange quadratic interpolation coefficients applicable to the first and last missing interval for calculation of 10 nm weighting factors for spectral product integration

Index of missing wavelength	L0	L1	L2
1	0,855	0,190	−0,045
2	0,720	0,360	−0,080
3	0,595	0,510	−0,105
4	0,480	0,640	−0,120
5	0,375	0,750	−0,125
6	0,280	0,840	−0,120
7	0,195	0,910	−0,105
8	0,120	0,960	−0,080
9	0,055	0,990	−0,045

Table D.2 — The Lagrange cubic interpolation coefficients applicable to the interior missing intervals for calculation of 10 nm weighting factors for spectral product integration

Index of missing wavelength	L0	L1	L2	L3
1	−0,028 5	0,940 5	0,104 5	−0,016 5
2	−0,048 0	0,864 0	0,216 0	−0,032 0
3	−0,059 5	0,773 5	0,331 5	−0,045 5
4	−0,064 0	0,672 0	0,448 0	−0,056 0
5	−0,062 5	0,562 5	0,562 5	−0,062 5
6	−0,056 0	0,448 0	0,672 0	−0,064 0
7	−0,045 5	0,331 5	0,773 5	−0,059 5
8	−0,032 0	0,216 0	0,864 0	−0,048 0
9	−0,016 5	0,104 5	0,940 5	−0,028 5

Table D.3 — The Lagrange quadratic interpolating coefficients applicable to the first and last missing interval for calculation of 20 nm weighting factors for spectral product integration

Index of missing wavelength	L0	L1	L2
1	0,926 25	0,097 5	–0,023 75
2	0,855 00	0,190 0	–0,045 00
3	0,786 25	0,277 5	–0,063 75
4	0,720 00	0,360 0	–0,080 00
5	0,656 25	0,437 5	–0,093 75
6	0,595 00	0,510 0	–0,105 00
7	0,536 25	0,577 5	–0,113 75
8	0,480 00	0,640 0	–0,120 00
9	0,426 75	0,697 5	–0,123 75
10	0,375 00	0,750 0	–0,125 00
11	0,326 25	0,797 5	–0,123 75
12	0,280 00	0,840 0	–0,120 00
13	0,236 25	0,877 5	–0,113 75
14	0,195 00	0,910 0	–0,105 00
15	0,156 25	0,937 5	–0,093 75
16	0,120 00	0,960 0	–0,080 00
17	0,086 25	0,977 5	–0,063 75
18	0,055 00	0,990 0	–0,045 00
19	0,026 25	0,997 5	–0,023 75

Table D.4 — The Lagrange cubic interpolating coefficients applicable to the interior missing intervals for calculation of 20 nm weighting factors for spectral product integration

Index of missing wavelength	L0	L1	L2	L3
1	–0,015 437 5	0,972 562 5	0,051 187 5	–0,008 312 5
2	–0,028 500 0	0,940 500 0	0,104 500 0	–0,016 500 0
3	–0,039 312 5	0,904 187 5	0,159 562 5	–0,024 437 5
4	–0,048 000 0	0,864 000 0	0,216 000 0	–0,032 000 0
5	–0,054 687 5	0,820 312 5	0,273 437 5	–0,039 062 5
6	–0,059 500 0	0,773 500 0	0,331 500 0	–0,045 500 0
7	–0,062 562 5	0,723 937 5	0,389 812 5	–0,051 187 5
8	–0,064 000 0	0,672 000 0	0,448 000 0	–0,056 000 0
9	–0,063 937 5	0,618 062 5	0,505 687 5	–0,059 812 5
10	–0,062 500 0	0,562 500 0	0,562 500 0	–0,062 500 0
11	–0,059 812 5	0,505 687 5	0,618 062 5	–0,063 937 5
12	–0,056 000 0	0,448 000 0	0,672 000 0	–0,064 000 0
13	–0,051 187 5	0,389 812 5	0,723 937 5	–0,062 562 5
14	–0,045 500 0	0,331 500 0	0,773 500 0	–0,059 500 0
15	–0,039 062 5	0,273 437 5	0,820 312 5	–0,054 687 5
16	–0,032 000 0	0,216 000 0	0,864 000 0	–0,048 000 0
17	–0,024 437 5	0,159 562 5	0,904 187 5	–0,039 312 5
18	–0,016 500 0	0,104 500 0	0,940 500 0	–0,028 500 0
19	–0,008 312 5	0,051 187 5	0,972 562 5	–0,015 437 5

Following this procedure and using the coefficients from Table D.2 to predict the unmeasured data at 503 nm from measurements taken at 10 nm intervals, one would find the two points below and two points above 503 nm and use the third row of coefficients, as shown in Equation (D.1):

$$R(503) = [-0{,}0595 \times R(490)] + [0{,}7735 \times R(500)] + [0{,}3315 \times R(510)] - [0{,}0455 \times R(520)] \quad \text{(D.1)}$$

Similarly, to predict the unmeasured data at 823 nm from measurements taken at 10 nm intervals, where the highest wavelength for which data are available is 830 nm, one would use Table D.1 and the seventh row of coefficients (seven back from the last measured point), as shown in Equation (D.2):

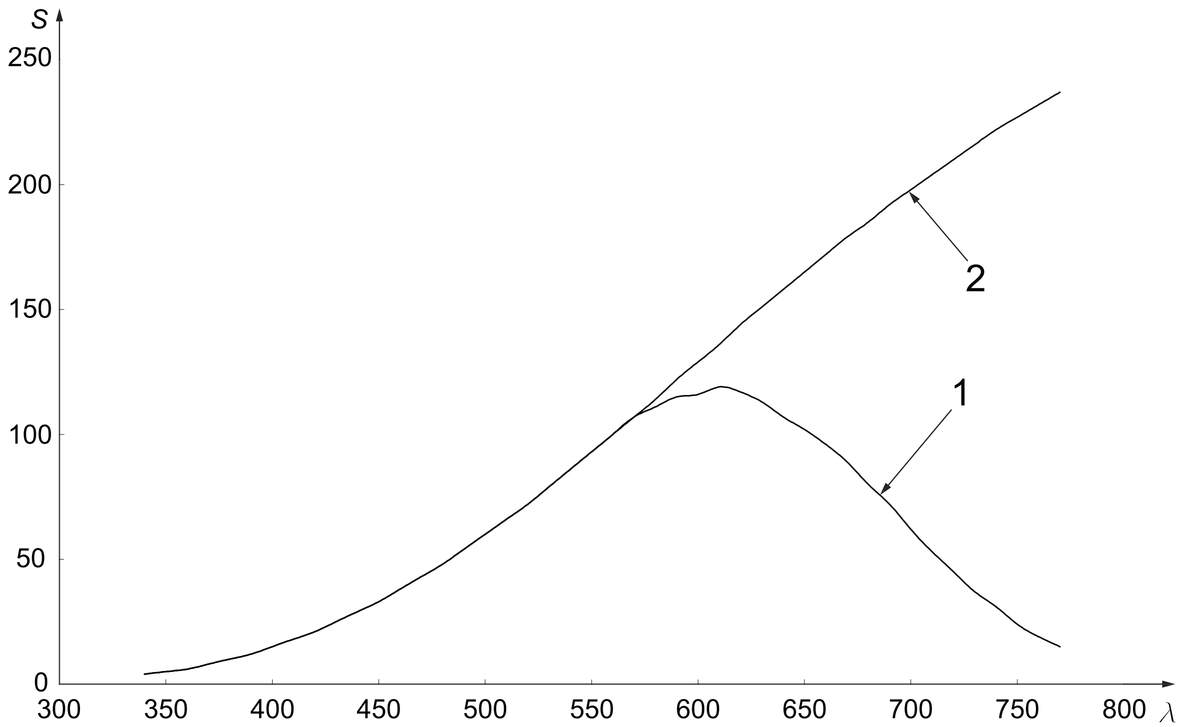
$$R(823) = [0{,}195 \times R(810)] + [0{,}910 \times R(820)] - [0{,}105 \times R(830)] \quad \text{(D.2)}$$

Tables D.3 and D.4 are used in a similar fashion to predict the 19 unmeasured points from data collected at 20 nm intervals. You will notice that there are both positive and negative coefficients in the interpolation equation, as there almost always are for any polynomial interpolation method. Also note that the measured value at 520 nm will be used in every interpolation calculation between 500 nm and 540 nm. Since the final computation is numerical integration by summation, the distributive rule of algebra allows one to collect all of the coefficients involving $R(520)$ and sum the weights together before multiplying by the measured reflectance $R(520)$. If one repeats this process at each of the measured points, then the interpolation problem is reduced from 471 equations to 48 equations. This is the source of the 10 nm and 20 nm spectral weighting factors. Details on how to derive the coefficients in the four tables can be found in ASTM E2022 or Reference [11].

Annex E
(informative)

Plots of relative spectral power distributions for influx spectra, and spectral products for ISO 5 standard density

Figure E.1 shows the relative spectral power distribution for the influx spectra specified for transmittance and reflection densitometry. Figures E.2 to E.7 show the spectral weighting factors for the various types of ISO 5 standard density specified in this part of ISO 5.



Key

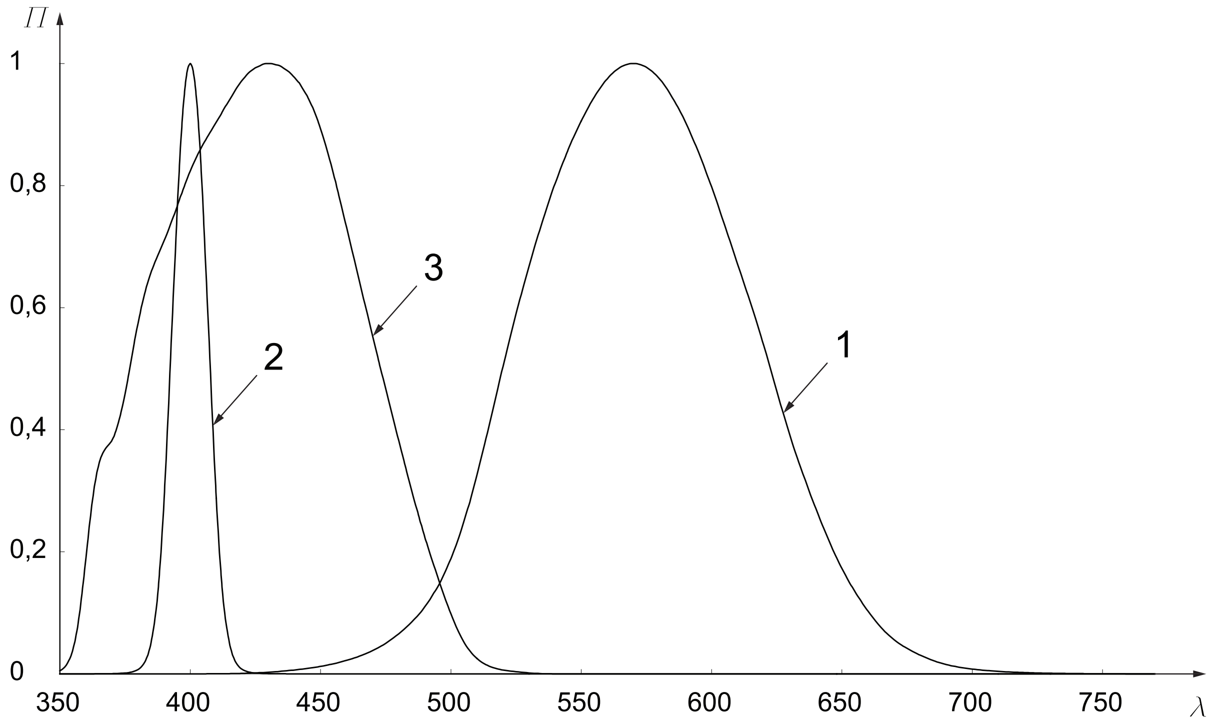
λ wavelength, in nm

S relative spectral power distribution

1 transmission

2 reflection

Figure E.1 — Influx relative spectral power distributions



Key

λ wavelength, in nm

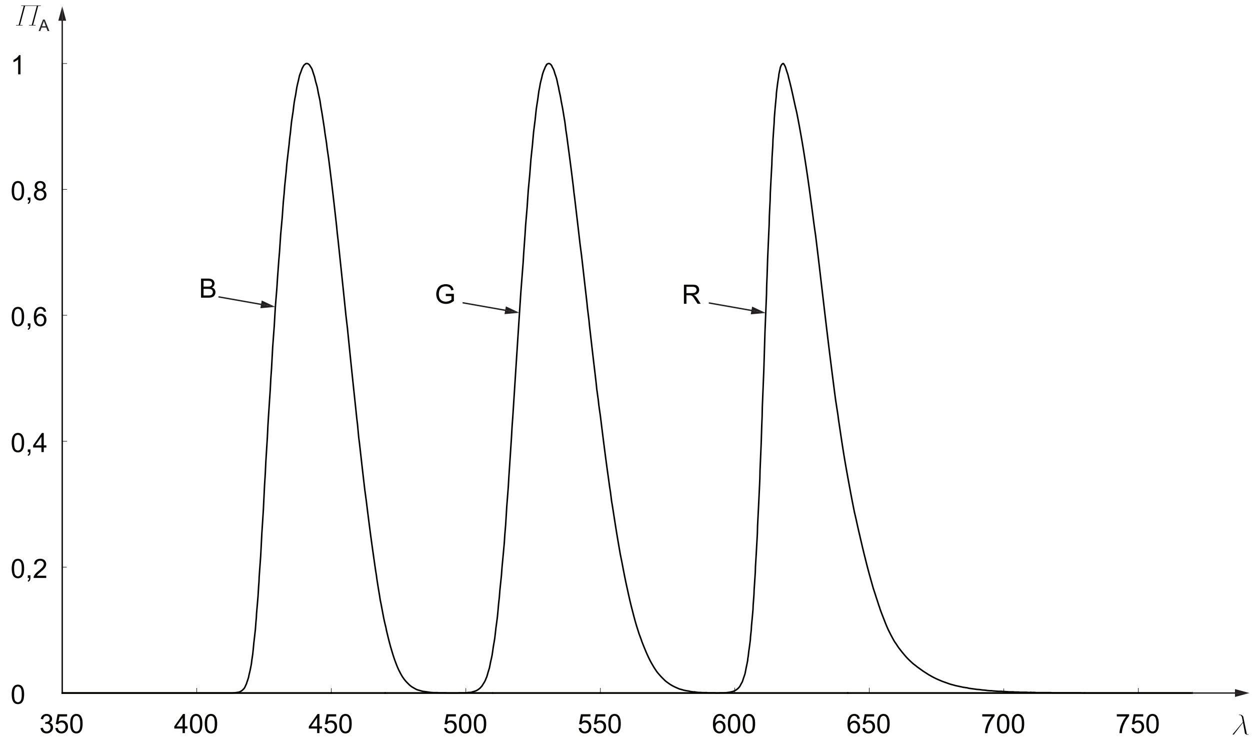
Π spectral products

1 visual

2 type 1

3 type 2

Figure E.2 — Spectral products for type 1, type 2 and visual ISO 5 densities



Key

λ wavelength, in nm

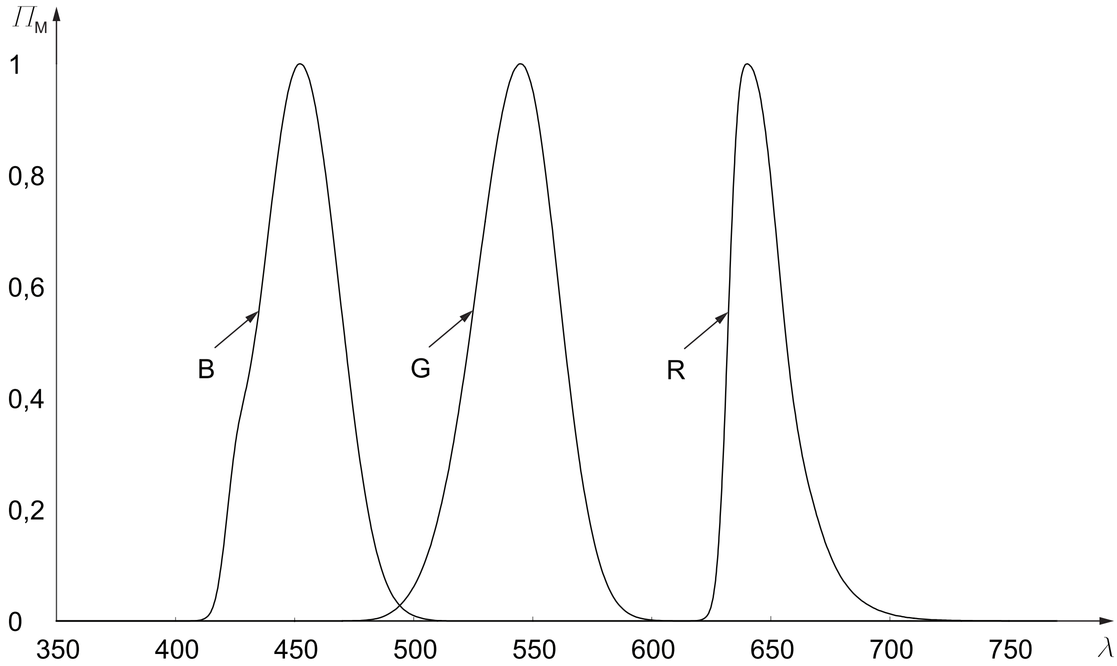
Π_A spectral products

B blue

G green

R red

Figure E.3 — Spectral products for status A densities



Key

λ wavelength, in nm

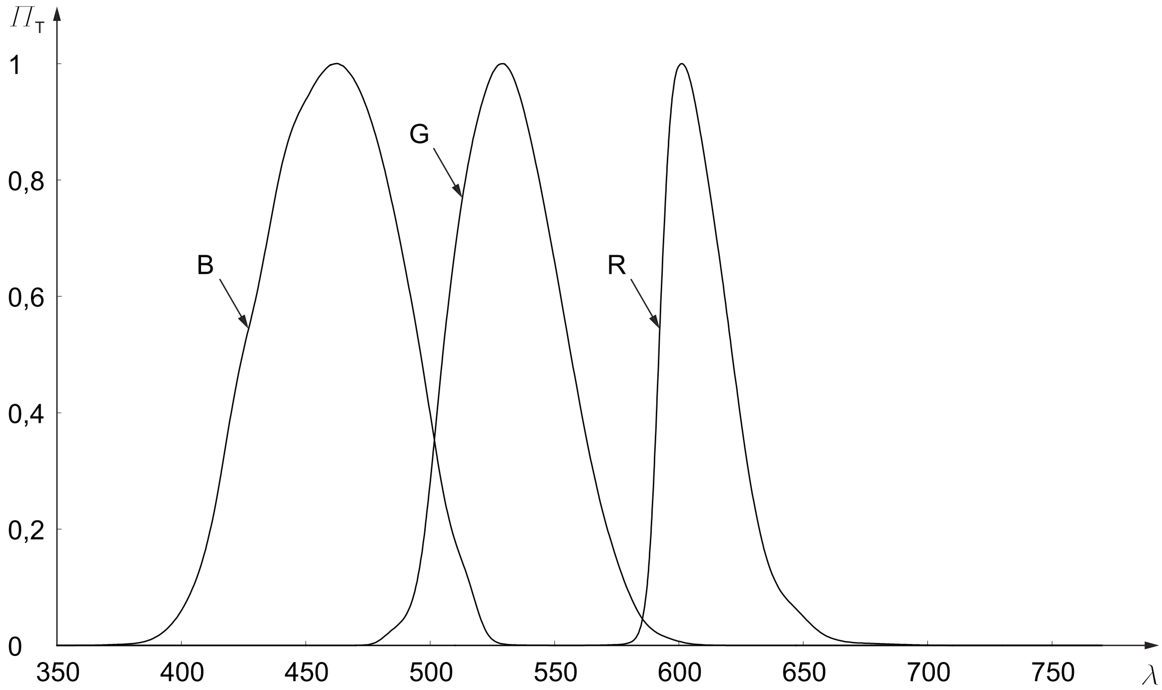
Π_M spectral products

B blue

G green

R red

Figure E.4 — Spectral products for status M densities



Key

λ wavelength, in nm

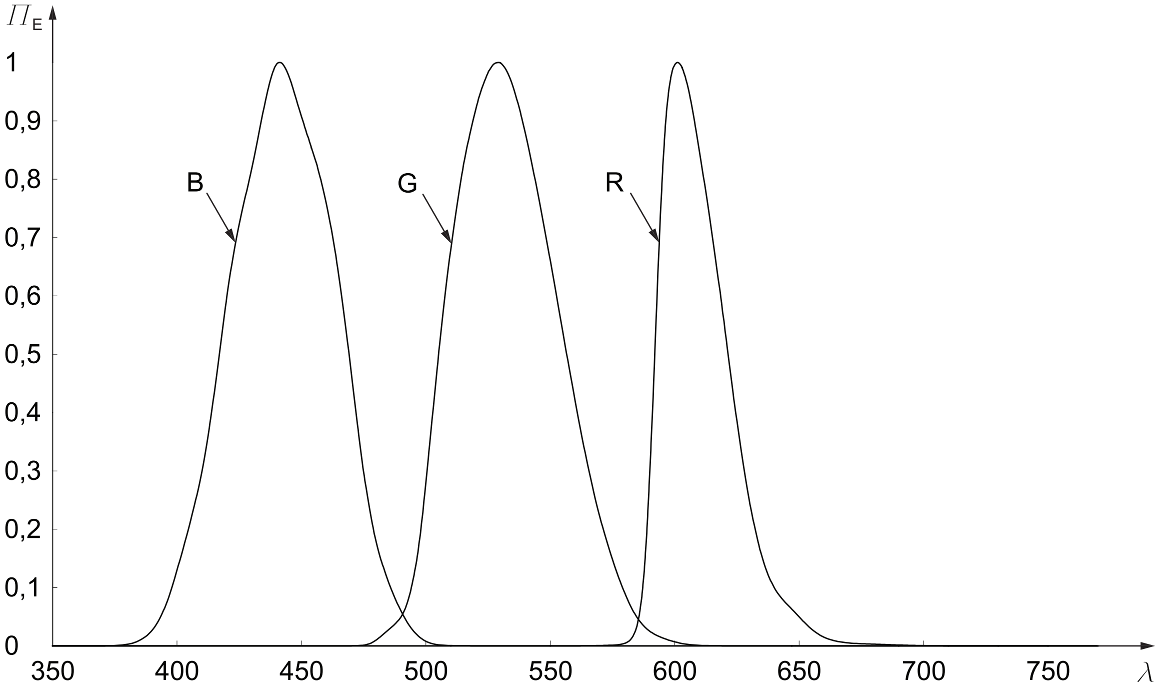
Π_T spectral products

B blue

G green

R red

Figure E.5 — Spectral products for status T densities



Key

λ wavelength, in nm

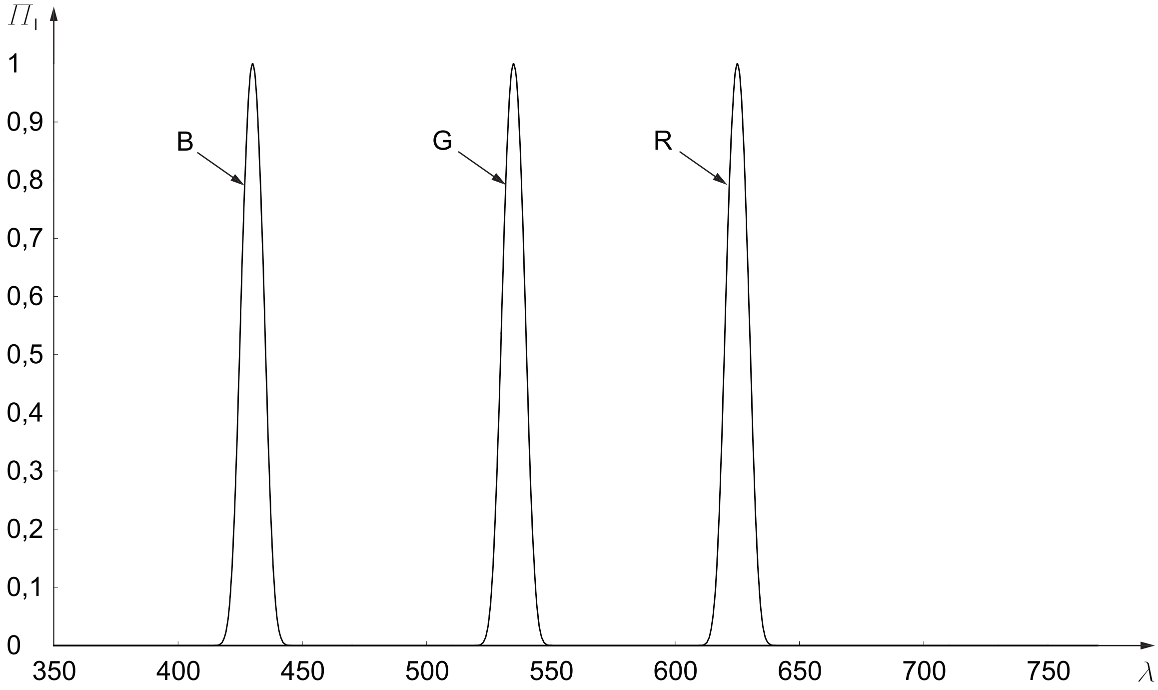
Π_E spectral products

B blue

G green

R red

Figure E.6 — Spectral products for status E densities



Key

λ wavelength, in nm

Π_I spectral products

B blue

G green

R red

Figure E.7 — Spectral products for status I densities

Annex F
(informative)

Spectral conformance

For filter-based instruments, the deviations from specified spectral conditions that can be tolerated in a densitometer depend on the nature of the application and the spectral characteristics of the materials to be measured. For non-selective (i.e. “neutral”) and non-fluorescent materials, variations in spectral conditions have no effect. However, as discussed in 4.2, highly selective or fluorescent materials might demand close conformance to specified conditions. The use of spectral instruments similarly requires that the wavelength scale and response characteristics of the reflectometer be monitored and verified appropriately.

To determine the conformance of the measurement of ISO 5 standard density by a particular instrument, either filter or spectrally-based, the use of certified reference materials (CRMs) is recommended, as described in ISO 15790. These CRMs should have spectral reflectance factors (or spectral transmittance) similar to the materials to be measured. Where suitable CRMs are not available, references can be created using samples of the types of material to be measured. These need to be measured using spectrophotometers whose performance has been verified through CRMs traceable to national standards institutions. Care should be taken to ensure that such instruments meet both the geometric requirements and the illumination requirements specified for ISO 5 densitometry. Reference densities for these secondary references can be computed from the spectral data using the procedures specified in Annex B.

Multiple readings (10 or more) of the CRM or secondary reference should be made, using the measuring instrument under test, to determine a mean and distribution. Where the indicated values, including appropriate uncertainty, are within the historically accepted error of 0,03 or 3 % (whichever is the greater) of the calibrated values, the densitometer can be considered to be in conformance with the spectral specifications of this part of ISO 5. In this case, the measurement can be designated as “ISO 5 visual”, “ISO 5 status A”, “ISO 5 status M”, “ISO 5 status T”, “ISO 5 status E”, “ISO 5 status I”, “ISO 5 type 1”, “ISO 5 type 2”, or “ISO 5 type 3”.

Where instruments with polarization means are to be evaluated, the CRMs or secondary references need to be calibrated using polarization means that conform to ISO 5-4:2009, 6.7, which indicates that the gloss suppression factor of the polarization means is not less than 50. It should be noted that addition or removal of polarizing filters will normally change the relative spectral response of the receiver, and that instruments intended for use both with and without polarization means need to be tested separately for each condition.

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