42

International Standard ISO 5/3

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Photography — Density measurements — Part 3: Spectral conditions

Photographie — Mesurage des densités — Partie 3: Conditions spectrales

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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 developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been authorized 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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 5/3 was developed by Technical Committee ISO/TC 42, *Photography*, and was circulated to the member bodies in December 1982.

It has been approved by the member bodies of the following countries:

Australia	Hungary	South Africa, Rep. of
Belgium	Italy	United Kingdom
Czechoslovakia	Japan	USA
Egypt, Arab Rep. of	Mexico	USSR
France	Netherlands	
Germany, F.R.	Poland	

No member body expressed disapproval of the document.

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Photography — Density measurements — Part 3: Spectral conditions

0 Introduction

This International Standard is one of a series which specifies the spectral conditions for optical densitometry as practiced in black-and-white and colour photography.

To define a 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 transmission density, and in ISO 5/4 for reflection density. This part of ISO 5 specifies the spectral conditions for both transmission and reflection. It represents a revision of the spectral conditions described in the first edition of ISO 5, but has been expanded to include additional spectral types commonly used in photography.

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

Certain types of density measurements are often made to generate sensitometric curves which are used to characterize the photographic properties of films and paper. Densities can also be used to monitor various photographic operations such as processing.

The specified spectral power distribution of the incident flux for transmission measurements differs from that for reflection measurements. For reflection measurements, incandescent tungsten illumination of the type known as CIE standard illuminant A, adopted by the International Commission on Illumination in 1931 is specified. This illuminant is used throughout the world as the standard incandescent source for measurements of colour. Its use in densitometry is preferred because national standardizing laboratories are generally prepared to make spectrophotometric measurements and perform colorimetric computations of visual reflection factors on the basis of CIE standard illuminant A. This usage facilitates the procurement of physical standards for reflection densitometry.

For transmission measurements, the spectral distribution of the influx is CIE standard illuminant A as modified by a typical infrared filter to protect the specimen and optical system from heat.

The definition of visual density adopted in this International Standard differs slightly from that in the previous edition. Previously specified were an influx spectrum having a distribution temperature of 3 000 K and a receiver sensitivity in accordance with the CIE photopic luminous efficiency function, which defines the standard observer for photometry. CIE standard illuminant A has now been adopted for the actual influx in reflection measurements and for the definition of the spectral product in both reflection and transmission measurements. Thus, for the first time the spectral conditions of measurement of visual density are in essential accord with the spectral conditions internationally adopted in all fields of photometry and colorimetry for the measurement of luminous reflectance factors or luminous transmittances. However, it should be emphasized that most colour-measuring equipment does not have the geometric conditions specified for standard densitometry. Although the adoption of a distribution temperature of 2 856 K instead of 3 000 K may require the assignment of new values that are spectrally selective to laboratory standards of visual density, the new temperature is more representative of the illumination in the practical densitometers in general use.

Many standards for reflection density specify the use of barium sulphate as the reference standard. However, pressed barium sulphate is fragile, variable from lot to lot of powder, variable from pressing to pressing, and the reflectance drifts appreciably in the first few days after pressing.

In 1969, the International Commission on Illumination recommended that all reflectance factors and, by inference, the corresponding reflection densities be reported relative to a perfectly reflecting and perfectly diffusing material. Reflection densitometers are almost always calibrated with enamelled metal working standards. These working standards are calibrated with respect to primary standards that are calibrated by absolute methods in national standards laboratories.

1 Scope and field of application

This part of ISO 5 specifies spectral conditions for the measurement of several types of densities used in photography, to evaluate processed black-and-white or coloured images of films, papers and plates.

2 References

ISO 5, *Photography — Density measurements —*

Part 1: Terms, symbols and notations.

Part 2: Geometric conditions for transmission density.[1)]

Part 4: Geometric conditions for reflection density.

CIE Publication No. 15 — *Colorimetry,* 1971.

3 Definition

CIE standard illuminant A: The radiant flux from a gas-filled coil tungsten filament lamp operating at a distribution temperature of 2 856 K based on Planck's second constant (c_2 = 1,438 8 × 10^{-2} m·K).

4 Influx spectrum, S

To completely define a type of density spectrally, it is necessary to specify the light source, optics, and spectral response of the measuring system. The influx spectrum is the radiant flux incident on the specimen surface or sampling aperture. It is a function of the energy source and the optical system.

The basic light source for densitometry is CIE standard illuminant A (see clause 3).

In some reflection and almost all transmission 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 relative power distribution of CIE A below 550 nm, no significant fluorescence effect should be observed or be of concern.

4.1 Reflection densitometry (S_A)

For reflection density measurements, the relative spectral power distribution of the incident flux shall be CIE standard illuminant A which is given in table 1 under the heading S_A, which is the symbol used in functional notation.

4.2 Transmission densitometry (S_H)

For transmission density measurements, the relative spectral power distribution of the incident flux shall be that given in table 1 under the heading S_H, which is the symbol used in functional notation. This is based on the spectral power distribution of the CIE standard illuminant A modified in the infrared region to protect the sample and optical elements from excessive heat which is typical for most transmission densitometers.

4.3 Sample conditions

Some materials change density with variations in temperature and relative humidity. Therefore, to avoid ambiguity, specimens shall be at 23 ± 2 °C and 50 ± 5 % relative humidity when determining ISO density.

Table 1 — ISO densitometer illuminants (influx spectra)
(Relative spectral power distributions normalized to 100 at 560 nm)

Wavelength nm	Transmission densitometer illuminant S_H	Reflection densitometer illuminant 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	94	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

5 Spectral response, s

The spectral response of a densitometer is a function of the spectral sensitivity of the photodetector, and the spectral transmittance of the optics and filters associated with it. Theoretically, it is desirable for the spectral response to match the spectral sensitivity of the receiver (eye, photographic paper, etc.) used in the practical applications of the product.

1) At present at the stage of draft. (Revision of ISO 5-1974.)

6 Spectral products

If the spectral power of the influx spectrum, S, is multiplied by the spectral response, s, of the receiver, wavelength by wavelength, spectral products are obtained. If there is no fluorescence in the optical elements or the specimen, it is not necessary to specify the spectral characteristics of the influx and receiver separately as long as the correct spectral products are obtained. The spectral products for a densitometer may be denoted as

$$\Pi = Ss$$

where

S is the relative spectral power of the influx;

s is the relative spectral response of the receiver.

7 Notation

ISO 5/1 specifies functional notation of the form $D\ (G\ ;\ S : g\ ;\ s)$, where G and g symbolize the influx geometry and efflux geometry respectively. Since this part of ISO 5 is only concerned with spectral conditions, the notation is abbreviated to $D\ (S : s)$. To distinguish between reflection density (D_R) and transmission density (D_T), a subscript may be used.

8 Types of density

Several spectral types of densitometry are used to evaluate photographic materials. These are defined in terms of logarithmic spectral product values specified at 10 nanometre (nm) intervals. Spectral product, Π, values are obtained by multiplying the relative spectral energy values of the densitometer illuminant, S, at 10 nm intervals by the relative spectral response values, s, of the receiver of the pertinent wavelength region. The resultant products are normalized to yield a peak value of 100,000. The logarithms to the base 10 of these values are used in this International Standard to define the various spectral types.

8.1 ISO visual density, $D_T(S_H : V_T)$, $D_R(S_A : V)$

To evaluate the darkness of an image which is to be viewed directly or by projection, visual density is measured. Such measurements are most often made on black-and-white images, but can be made on other types of images.

For the reflection density, the combined spectral sensitivity of the receiver and the spectral characteristics of the components on the efflux section of the densitometer shall match the spectral luminous efficiency in photopic vision, $V(\lambda)$[1]. The product of $V(\lambda)$ and S_A, wavelength by wavelength, defines the spectral products the whole densitometer shall have to provide ISO visual densities. The logarithms of the products are given in table 2.

The spectral products required for visual transmission densitometry are the same as those used for reflection. However, since the influx is different, the spectral response of the receiver, V_T, must compensate so that $S_H V_T = S_A V$ at every 10 nm interval.

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

Wavelength nm	Π_v (Visual)	Π_1 (Type 1)	Π_2 (Type 2)
340			< 1,000
350			2,708
360		< 1,000	4,280
370		1,640	4,583
380		2,860	4,760
390		4,460	4,851
400	< 1,000	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	< 1,000	4,990
450	3,090		4,951
460	3,346		4,864
470	3,582		4,743
480	3,818		4,582
490	4,041		4,351
500	4,276		3,993
510	4,513		3,402
520	4,702		2,805
530	4,825		2,211
540	4,905		< 1,000
550	4,957		
560	4,989		
570	5,000		
580	4,989		
590	4,956		
600	4,902		
610	4,827		
620	4,731		
630	4,593		
640	4,433		
650	4,238		
660	4,013		
670	3,749		
680	3,490		
690	3,188		
700	2,901		
710	2,622		
720	2,334		
730	2,041		
740	1,732		
750	1,431		
760	1,146		
770	< 1,000		

1) See CIE Publication No. 15. The values for $V(\lambda)$ are those adopted in 1933 by the *International Committee of Weights and Measures.*

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

Wavelength (λ) nm	Blue	Green	Red
	↑	↑	↑
400	slope = 0,380/nm		
410			
420	3,602		
430	4,819	slope = 0,220/nm	
440	5,000		slope = 0,270/nm
450	4,912		
460	4,620		
470	4,040		
480	2,989		
490	1,566		
500	0,165	1,650	
510		3,822	
520		4,782	
530		5,000	
540		4,906	
550		4,644	
560	slope = −0,140/nm	4,221	
570		3,609	
580		2,766	
590		1,579	
600			2,568
610			4,638
620		slope = −0,170/nm	5,000
630			4,871
640			4,604
650			4,286
660			3,900
670			3,551
680			3,165
690			2,776
700			2,383
710			1,970
720			1,551
730			1,141
740			0,741
750			0,341
	↓	↓	slope = −0,040/nm ↓

8.2 ISO status A density

By transmission $D_T(S_H : A_B)$, $D_T(S_H : A_G)$, $D_T(S_H : A_R)$.

By reflection $D_R(S_A : A'_B)$, $D_R(S_A : A'_G)$, $D_R(S_A : A'_R)$.

Status A densities are measured to evaluate the densities in the blue, green, and red regions of the spectrum for films or prints to be viewed directly or by projection. The log spectral products for the whole instrument shall conform to the values in table 3. The symbols A_B, A_G and A_R, shall be used for the transmission status A blue, green, and red spectral responses respectively in the functional notation. Similarly, A'_B, A'_G and A'_R are designated the spectral responses for reflection status A densitometry.

8.3 ISO status M density

By transmission $D_T(S_H : M_B)$, $D_T(S_H : M_G)$, $D_T(S_H : M_R)$.

Status M densities are mostly used to evaluate colour photographic materials intended for printing such as colour negative film. The log spectral products shall conform to the values in table 4. The symbols M_B, M_G, and M_R, shall be used to designate status M transmission spectral responses.

8.4 ISO status T density

By transmission $D_T(S_H : T_B)$, $D_T(S_H : T_G)$, and $D_T(S_H : T_R)$.

By reflection $D_R(S_A : T'_B)$, $D_R(S_A : T'_G)$ and $D_R(S_A : T'_R)$.

To evaluate the modulation produced by an image from which a colour separation process is to be performed in preparation for a three-colour process. For status T densities, the log

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

Wavelength (λ) nm	Blue	Green	Red
	↑	↑	↑
400	slope = 0,250/nm		
410	2,103		
420	4,111		
430	4,632	slope = 0,106/nm	
440	4,871		
450	5,000		
460	4,955		
470	4,743	1,152	
480	4,343	2,207	
490	3,743	3,156	
500	2,990	3,804	slope = 0,260/nm
510	1,852	4,272	
520		4,626	
530		4,872	
540		5,000	
550	slope = −0,220/nm	4,995	
560		4,818	
570		4,458	
580		3,915	
590		3,172	
600		2,239	
610		1,070	
620			2,109
630			4,479
640			5,000
650			4,899
660			4,578
670		slope = −0,120/nm	4,252
680			3,875
690			3,491
700			3,099
710			2,687
720			2,269
730			1,859
740			1,449
750			1,054
760			0,654
770			0,254
	↓	↓	slope = −0,040/nm ↓

spectral products shall conform to the values listed in table 5. The symbols T_B, T_G, and T_R shall be used for the transmission status T blue, green, and red spectral responses respectively in the functional notation. Similarly T_B', T_G', and T_R' are designated the spectral responses for reflection Status T densitometry.

8.5 Printing density[1)]

The spectral conditions required for measuring the printing density of a processed photographic material are a function of the spectral power distribution of the illuminant, the spectral characteristics of the optical system, and the spectral sensitivity of the print material. The contact printing density of a film specimen is equal to the transmission density of a spectrally nonselective modulator when they both produce the same response on the print material when contact printed together.

In the case of projection printing density, the film sample shall be projection printed. The modulator, however, shall be contact printed on the print material. The exposure time and lamp intensity shall be the same for the two prints.

The spectral characteristics of a densitometer may be designed to provide printing densities directly for a particular print material through the proper selection of light source, attenuators, and photodectors. However, in most cases it is

1) See *The theory of the photographic process,* Third edition, Mees and James, page 453, MacMillan Co., 1971.

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

Wavelength nm	Blue	Green	Red
340	< 1,000		
350	1,000		
360	1,301		
370	2,000		
380	2,477		
390	3,176		
400	3,778		
410	4,230		
420	4,602		
430	4,778		
440	4,914		
450	4,973		
460	5,000		
470	4,987	< 1,000	
480	4,929	3,000	
490	4,813	3,699	
500	4,602	4,447	
510	4,255	4,833	
520	3,699	4,964	
530	2,301	5,000	
540	1,602	4,944	
550	< 1,000	4,820	< 1,000
560		4,623	1,000
570		4,342	1,778
580		3,954	2,653
590		3,398	4,477
600		2,845	5,000
610		1,954	4,929
620		1,000	4,740
630		< 1,000	4,398
640			4,000
650			3,699
660			3,176
670			2,699
680			2,477
690			2,176
700			1,699
710			1,000
720			< 1,000

possible to correlate density readings from a commercially available densitometer to printing densities using equations derived by regression analysis.

8.5.1 ISO Type 1 density $D_T(S_H : s_1)$

Diazo and vesicular films are used extensively 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. It has been determined that under these film-light source conditions, density measurements from the original image, using a densitometer with a narrow band filter having peak transmission at 400 nm, provide printing density values. The effective spectral sensitivity of the print materials is denoted as s_1. For ease of reference, densities determined from a densitometer which has the log spectral product values ($\log_{10} \Pi_1$) given in table 2 are designated type 1. However, the extent to which such a densitometer will measure printing densities depends on the sensitivity of the print film and the spectral and geometrical characteristics of the printing system.

8.5.2 ISO Type 2 density, $D_T(S_H : s_2)$

When printing is done onto non-colour sensitized silver-halide photographic material (for example a black-and-white paper or film), the log spectral products found useful are indicated as $\log_{10} \Pi_2$ in table 2. These have been derived by using the average spectral sensitivity of a print material as modified by the transmission of an ultraviolet absorbing filter with a sharp cut-off at 360 nm. The resultant sensitivity is designated s_2. The filter is included to minimize effects caused by variations in the optics of printing systems, and the absorption band of silver deposits at 320 nm. Multiplying the spectral sensitivity values by the relative spectral power distribution of the illuminant yields the spectral product values required in order for a densitometer to provide printing density values directly from the material being printed.

8.6 ISO Type 3 density $D_T(S_H : s_3)$

Optical sound records on three-component subtractive colour films made up of dye images plus silver or a metallic salt are often used in sound reproduction systems employing an S-1 photosurface. A densitometer using a narrow band filter with a peak transmission of 800 nm has been found useful in monitoring this type of sound record. The "effective" spectral sensitivity for this system is designated s_3. This International Standard, therefore, identifies density values as type 3 when they are obtained from a densitometer having an overall response bandwidth of 20 nm peaking at 800 ± 5 nm with at least 80 % of the overall response of the instrument 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.

8.7 Monochromatic density (D_λ)

Monochromatic measurements may offer some advantage in instrument standardization or in analysis of multicomponent dye systems. This eliminates errors associated with the spectral calibration of densitometer components and provides a method for evaluating their performance and calibration.

Specific emission lines of mercury (436 and 546 nm) and cadmium (644 nm) are specified in this International Standard, and their spectral densities are denoted as follows :

ISO monochromatic blue D_{436}

ISO monochromatic green D_{546}

ISO monochromatic red D_{644}

8.8 Narrow-band densities

Narrow-band spectral products should be used to minimize the magnitude of errors attributable to variations in lamps, filters, and photosensors. The measured densities approach monochromatic densities at the wavelength of the centroid of the spectral product. When such densities are used, the density of superimposed absorbing layers in optical contact closely approaches the sum of the densities of the individual layers. A spectral product is considered narrow-band if the distribution is so limited in wavelength extent that densities measured are not affected significantly by variations in form of the distribution. The distribution is specified by the peak wavelength and the wavelength range over which the values exceed half the peak value. In functional notation, these spectral conditions are given in that order, separated by a comma. For example, a case where the influx spectrum is S_A and the receiver spectral sensitivity is a narrow-band, peaking at 560 nm and having a bandwidth of 20 nm, would be specified as $D_T(S_A : 560 \text{ nm}, 20 \text{ nm})$.

9 Spectral tolerances

The deviations from specified spectral conditions that may be tolerated in a densitometer depend on the spectral nature of the application and the materials to be measured. For completely nonselective nonfluorescent materials, variations in spectral conditions have no effect. Highly selective materials or those that fluoresce may demand close conformance to specified conditions. Given some specimens of the materials to be measured, a basic standards laboratory can measure the spectral modulation (spectral reflectance factor or spectral transmittance factor) of the specimens and compute the densities that would be indicated by a densitometer with specified spectral conditions. The geometry of the spectrophotometric system used for such calibrations shall match that of the densitometry and the influx spectrum and shall be specified to avoid errors due to fluorescence effects. If a densitometer indicates values within 0,03 or 3 % (whichever is the greater) of the calibrated values of such specimens, the spectral specifications of this International Standard shall be considered adequately satisfied. In this case, the measurement may be designated as ISO visual, ISO status A, M or T, and ISO type 1, 2 or 3.

10 Absolute reference standard (white)

Reflectance factors and corresponding reflection densities are measured relative to some reference standard, which may be real or ideal. Unless otherwise stated, the reference standard for determining ISO reflection density shall be an ideal perfectly reflecting and perfectly diffusing material. Working standards, such as enamelled metal plaques, are customarily calibrated relative to an ideal perfectly white diffuser by a basic standards laboratory.

In many applications, the reference standard is the base on which an image may be placed, such as unexposed but processed photographic printing paper. In such cases, the measured density is called "relative reflection density" and the reference standard shall be stated.