International Standard ISO 7724/1

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Paints and varnishes — Colorimetry — Part 1: Principles

Peintures et vernis — Colorimétrie — Partie 1: Principes

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Foreword

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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. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

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Paints and varnishes — Colorimetry — Part 1: Principles

0 Introduction

This International Standard, ISO 7724, comprises the following parts :

Part 1 : Principles.

Part 2 : Colour measurement.

Part 3 : Calculation of colour differences.

Parts 1, 2 and 3 of ISO 7724 describe methods for the instrumental determination of the colour co-ordinates and colour differences of paint films, as required for such purposes as

a) the objective description of colour differences between a test specimen (a test panel coated with a paint, or a specimen from a painted article) and a reference specimen;

b) determining colour deviations in the production of painted articles so that the results may be used for the control or regulation of the process;

c) the objective description of changes in colour caused by weathering and other chemical or physical influences;

d) the objective supervision of colour reference standards.

NOTE — Colour reference standards are subject to ageing, which may lead in the course of time to pronounced changes in colour. High accuracy colorimetry is required for the timely detection of these changes. This is of particular importance when ordering against such reference standards.

1 Scope and field of application

This part of ISO 7724 describes the colorimetric terms and fundamental requirements necessary for determining the colour co-ordinates of paint films and related materials.

2 References

ISO 2813, *Paints and varnishes — Measurement of specular gloss of non-metallic paint films at 20°, 60° and 85°.*

ISO 3668, *Paints and varnishes — Visual comparison of the colour of paints.*

ISO 7724/2, *Paints and varnishes — Colorimetry — Part 2 : Colour measurement.*

ISO 7724/3, *Paints and varnishes — Colorimetry — Part 3: Calculation of colour differences.*

CIE Publication No. 15, *Colorimetry, Official CIE Recommendations.*

CIE Publication No. 15, Supplement No. 2, *Recommendations on uniform color spaces — Color difference equations — Psychometric color terms.*

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

3 Colour co-ordinates

A colour is uniquely characterized for a defined observer and a defined light source by the co-ordinates of a point in a space formed by three mutually perpendicular vectors. From among the various colour co-ordinates recommended by the Commission Internationale de l'Éclairage (CIE), the colour co-ordinates given in 3.1 and 3.2 are specified for colorimetric measurements on paint films in accordance with this International Standard.

3.1 Colour co-ordinates in the CIE 1964 supplementary standard colorimetric system

The colour co-ordinates in this system (see CIE Publication No. 15) are the tristimulus value Y_{10} and the chromaticity co-ordinates x_{10} and y_{10}.

$$Y_{10} = k_{10} \sum_{\lambda = l}^{\lambda = u} \varphi(\lambda)\, \bar{y}_{10}(\lambda)\, \triangle\lambda$$

$$x_{10} = \frac{X_{10}}{X_{10} + Y_{10} + Z_{10}}, \quad y_{10} = \frac{Y_{10}}{X_{10} + Y_{10} + Z_{10}}$$

The chromaticity co-ordinates are formed by the tristimulus values

$$X_{10} = k_{10} \sum_{\lambda = l}^{\lambda = u} \varphi(\lambda)\, \bar{x}_{10}(\lambda)\, \triangle\lambda,$$

$$Z_{10} = k_{10} \sum_{\lambda = l}^{\lambda = u} \varphi(\lambda)\, \bar{z}_{10}(\lambda)\, \triangle\lambda \text{ and}$$

$$Y_{10}$$

where

$\varphi(\lambda)$ denotes the colour stimulus function, which is the product of the relative spectral power distribution S_λ for the standard illuminant (see clause 4) and the spectral function that characterizes the reflectance of the paint film (see clause 5);

$\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$ and $\bar{z}_{10}(\lambda)$ are the colour-matching functions (see note 1) used to define the CIE 1964 standard colorimetric observer for observation fields of angular subtense larger than 4° (10° observer) (see table 1);

l and u are the respective summation limits for the short-wave and long-wave limits of the visible spectrum;

$\triangle\lambda$ is the width of the wavelength interval (for the choice of l and u, and $\triangle\lambda$, see ISO 7724/2);

k_{10} is a normalizing factor calculated by using the equation

$$k_{10} = 100 \Bigg/ \left(\sum_{\lambda = l}^{\lambda = u} S_\lambda\, \bar{y}_{10}(\lambda)\, \triangle\lambda \right)$$

which causes the tristimulus value Y_{10} for the perfect reflecting diffuser to assume a value of 100.

In this system, the colour co-ordinates do not provide a perceptually uniform colour space (see 3.2).

NOTES

1 The coefficients $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$ and $\bar{z}_{10}(\lambda)$ were formerly termed CIE spectral tristimulus values or CIE trichromatic weighting coefficients.

2 Colour co-ordinates in the CIE 1931 standard colorimetric system are defined by analogous equations using the colour-matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ of the CIE 1931 standard colorimetric observer for the 2° observation field. Colour-matching functions at 5 nm wavelength intervals are given in CIE Publication No. 15.

The 10° observation field corresponds more closely with practice than the 2° observation field and is consistent with the viewing conditions recommended in ISO 3668 for the visual comparison of the colour of paints.

3.2 Colour co-ordinates in the CIE 1976 ($L^* a^* b^*$) colour space

In comparison with the CIE 1964 colorimetric system (see 3.1), the colour co-ordinates in the perceptually more uniform CIE 1976 ($L^* a^* b^*$) colour space (see CIE Publication No. 15 Supplement No. 2) are specified for the evaluation of colour differences.

The colour co-ordinates are calculated from the following equations :

$$L^* = 116\,(Y/Y_n)^{1/3} - 16 \qquad \text{for } Y/Y_n > 0{,}008\,856$$

$$L^* = 903{,}3\,(Y/Y_n) \qquad \text{for } Y/Y_n < 0{,}008\,856$$

$$a^* = 500\,[f(X/X_n) - f(Y/Y_n)]$$

$$b^* = 200\,[f(Y/Y_n) - f(Z/Z_n)]$$

where

$$f(X/X_n) = (X/X_n)^{1/3} \qquad \text{for } X/X_n > 0{,}008\,856$$

$$f(X/X_n) = 7{,}787\,(X/X_n) + 16/116 \qquad \text{for } X/X_n < 0{,}008\,856$$

$$f(Y/Y_n) = (Y/Y_n)^{1/3} \qquad \text{for } Y/Y_n > 0{,}008\,856$$

$$f(Y/Y_n) = 7{,}787\,(Y/Y_n) + 16/116 \qquad \text{for } Y/Y_n < 0{,}008\,856$$

$$f(Z/Z_n) = (Z/Z_n)^{1/3} \qquad \text{for } Z/Z_n > 0{,}008\,856$$

$$f(Z/Z_n) = 7{,}787\,(Z/Z_n) + 16/116 \qquad \text{for } Z/Z_n < 0{,}008\,856$$

X, Y, Z denote the 10° tristimulus values of the paint film;

X_n, Y_n, Z_n are the 10° tristimulus values of the perfect reflecting diffuser under the chosen standard illuminant (see table 2).

NOTE — If 2° tristimulus values are used, L^*, a^*, b^* co-ordinates for the 2° observer will be obtained. The corresponding values for X_n and Z_n can be calculated from the 2° chromaticity co-ordinates for the standard illuminants D 65 and A (see CIE Publication No. 15) with $Y_n = 100$.

It is sometimes convenient to express colour not in terms of the rectangular co-ordinates L^*, a^*, b^*, but in terms of the rectilinear lightness and the polar co-ordinates chroma and hue (see CIE Publication No. 15 Supplement No. 2).

These may be calculated from L^*, a^*, b^* to give

CIE 1976 psychometric lightness	L^*
CIE 1976 *a b* chroma	$C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$
CIE 1976 *a b* hue angle	$h_{ab} = \arctan(b^*/a^*)$ between 0° and 360°

Table 1 — Colour-matching functions for the 10° observer at 5 nm wavelength intervals

λ nm	$\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$
380	0,0002	0,0000	0,0007
385	0,0007	0,0001	0,0029
390	0,0024	0,0003	0,0105
395	0,0072	0,0008	0,0323
400	0,0191	0,0020	0,0860
405	0,0434	0,0045	0,1971
410	0,0847	0,0088	0,3894
415	0,1406	0,0145	0,6568
420	0,2045	0,0214	0,9725
425	0,2647	0,0295	1,2825
430	0,3147	0,0387	1,5535
435	0,3577	0,0496	1,7985
440	0,3837	0,0621	1,9673
445	0,3867	0,0747	2,0273
450	0,3707	0,0895	1,9948
455	0,3430	0,1063	1,9007
460	0,3023	0,1282	1,7454
465	0,2541	0,1528	1,5549
470	0,1956	0,1852	1,3176
475	0,1323	0,2199	1,0302
480	0,0805	0,2536	0,7721
485	0,0411	0,2977	0,5701
490	0,0162	0,3391	0,4153
495	0,0051	0,3954	0,3024
500	0,0038	0,4608	0,2185
505	0,0154	0,5314	0,1592
510	0,0375	0,6067	0,1120
515	0,0714	0,6857	0,0822
520	0,1177	0,7618	0,0607
525	0,1730	0,8233	0,0431
530	0,2365	0,8752	0,0305
535	0,3042	0,9238	0,0206
540	0,3768	0,9620	0,0137
545	0,4516	0,9822	0,0079
550	0,5298	0,9918	0,0040
555	0,6161	0,9991	0,0011
560	0,7052	0,9973	0,0000
565	0,7938	0,9824	0,0000
570	0,8787	0,9556	0,0000
575	0,9512	0,9152	0,0000
580	1,0142	0,8689	0,0000
585	1,0743	0,8256	0,0000
590	1,1185	0,7774	0,0000
595	1,1343	0,7204	0,0000
600	1,1240	0,6583	0,0000
605	1,0891	0,5939	0,0000
610	1,0305	0,5280	0,0000
615	0,9507	0,4618	0,0000
620	0,8563	0,3981	0,0000
625	0,7549	0,3396	0,0000
630	0,6475	0,2835	0,0000
635	0,5351	0,2283	0,0000
640	0,4316	0,1798	0,0000
645	0,3437	0,1402	0,0000
650	0,2683	0,1076	0,0000
655	0,2043	0,0812	0,0000
660	0,1526	0,0603	0,0000
665	0,1122	0,0441	0,0000
670	0,0813	0,0318	0,0000
675	0,0579	0,0226	0,0000
680	0,0409	0,0159	0,0000
685	0,0286	0,0111	0,0000
690	0,0199	0,0077	0,0000
695	0,0138	0,0054	0,0000
700	0,0096	0,0037	0,0000
705	0,0066	0,0026	0,0000
710	0,0046	0,0018	0,0000
715	0,0031	0,0012	0,0000
720	0,0022	0,0008	0,0000
725	0,0015	0,0006	0,0000
730	0,0010	0,0004	0,0000
735	0,0007	0,0003	0,0000
740	0,0005	0,0002	0,0000
745	0,0004	0,0001	0,0000
750	0,0003	0,0001	0,0000
755	0,0002	0,0001	0,0000
760	0,0001	0,0000	0,0000
765	0,0001	0,0000	0,0000
770	0,0001	0,0000	0,0000
775	0,0000	0,0000	0,0000
780	0,0000	0,0000	0,0000

Table 2 — 10° tristimulus values for the perfect reflecting diffuser for standard illuminants D 65 and A

Tristimulus value	Standard illuminant	
	D 65	A
X_n	94,81	111,14
Y_n	100,00	100,00
Z_n	107,34	35,20

4 Standard illuminants

The CIE standard illuminant D 65 which corresponds to natural daylight at a correlated colour temperature of about 6 500 K (see CIE Publication No. 15), should be specified for colour measurements in accordance with this International Standard.

NOTE — The standard illuminant C corresponds to natural daylight at a correlated colour temperature of 6 744 K. Its spectral distribution does not approach that of natural daylight so closely as that of standard illuminant D 65, especially in the ultraviolet region.

The standard illuminant A, which represents the light of a tungsten lamp and corresponds in its spectral distribution to a perfect black body at a temperature of 2 856 K, should be specified for the colorimetric determination of a special metamerism index (see clause 5 of ISO 7724/2).

Numerical values for the relative spectral power distribution S_λ of standard illuminants D 65 and A are given in table 3.

5 Spectral radiometric characteristics

5.1 General

Of the various possible spectral radiometric characteristics that describe the reflecting properties of materials (see CIE Publication No. 38), the three characteristics defined in 5.1.1 to 5.1.3 are used in this part of ISO 7724 for paint film colorimetry.

Table 3 — Relative spectral power distribution S_λ of standard illuminants D 65 and A at 5 nm wavelength intervals

λ nm	S_{λ}, D 65	S_{λ}, A
380	50,0	9,80
385	52,3	10,90
390	54,6	12,09
395	68,7	13,35
400	82,8	14,71
405	87,1	16,15
410	91,5	17,68
415	92,5	19,29
420	93,4	21,00
425	90,1	22,79
430	86,7	24,67
435	95,8	26,64
440	104,9	28,70
445	110,9	30,85
450	117,0	33,09
455	117,4	35,41
460	117,8	37,81
465	116,3	40,30
470	114,9	42,87
475	115,4	45,52
480	115,9	48,24
485	112,4	51,04
490	108,8	53,91
495	109,1	56,85
500	109,4	59,86
505	108,6	62,93
510	107,8	66,06
515	106,3	69,25
520	104,8	72,50
525	106,2	75,79
530	107,7	79,13
535	106,0	82,52
540	104,4	85,95
545	104,2	89,41
550	104,0	92,91
555	102,0	96,44
560	100,0	100,00
565	98,2	103,58
570	96,3	107,18
575	96,1	110,80
580	95,8	114,44
585	92,2	118,08
590	88,7	121,73
595	89,3	125,39
600	90,0	129,04
605	89,8	132,70
610	89,6	136,35
615	88,6	139,99
620	87,7	143,62
625	85,5	147,23
630	83,3	150,84
635	83,5	154,42
640	83,7	157,98
645	81,9	161,52
650	80,0	165,03
655	80,1	168,51
660	80,2	171,96
665	81,2	175,38
670	82,3	178,77
675	80,3	182,12
680	78,3	185,43
685	74,0	188,70
690	69,7	191,93
695	70,7	195,12
700	71,6	198,26
705	73,0	201,36
710	74,3	204,41
715	68,0	207,41
720	61,6	210,36
725	65,7	213,27
730	69,9	216,12
735	72,5	218,92
740	75,1	221,67
745	69,3	224,36
750	63,6	227,00
755	55,0	229,59
760	46,4	232,12
765	56,6	234,59
770	66,8	237,01
775	65,1	239,37
780	63,4	241,68

5.1.1 spectral reflectance factor $R(\lambda)$: The ratio of the radiant flux reflected in the directions within a given cone to that reflected in the same directions by a perfect reflecting diffuser identically irradiated in the observed wavelength interval.

NOTE — In contrast to the recommendations of the CIE (see CIE Publication No. 15), this part of ISO 7724 specifies the spectral reflectance factor instead of the spectral radiance factor. The instruments commercially available are not suitable for accurate measurement of the spectral radiance factor because of systematic errors caused by the divergence of the reflected light beams.

5.1.2 spectral reflectance $\varrho(\lambda)$: The ratio of the reflected radiant flux to the incident flux in the observed wavelength interval.

5.1.3 spectral diffuse reflectance $\varrho_{(d)}(\lambda)$: The ratio of the reflected radiant flux to the incident flux in the observed wavelength interval measured with the specularly reflected light (gloss) excluded.

5.2 Illumination and viewing conditions

The various modes for measuring the reflected radiation to be specified for colour measurements in accordance with this International Standard are listed in table 4.

In the directional illumination and viewing beams the angle between the beam axis and any ray shall not exceed 5°.

The diffuse illumination and viewing takes place in an integrating sphere with an internal coating chosen such that the light is diffused by the wall of the sphere uniformly and non-selectively with respect to wavelength. The total area of the sample port of the integrating sphere shall not exceed 10 % of the total internal reflecting sphere area.

Specularly reflected light can be partly suppressed for the illumination and viewing conditions 8/d and d/8 by means of a gloss trap. The results of the measurements are dependent on the size, the position, and the structure of the gloss trap.

It has proved practical to use only gloss traps which exclude at least 95 % of the light reflected by a highly polished black glass plate. These traps should be tested using a primary standard with a refractive index of between 1,50 and 1,55 as specified in ISO 2813 for the measurement of specular gloss. The quotient of the spectral reflectances of the higly polished black glass plate measured with and without gloss trap shall fulfil the condition

$$\frac{\varrho_{(d)8/d}(\lambda)}{\varrho_{8/d}(\lambda)} \leqslant 0{,}05 \quad \text{for any wavelength.}$$

Table 4 — Spectral radiometric characteristics for colorimetry of paint films

Spectral radiometric characteristics		Measurement conditions		
	Symbol	Illumination	Viewing	Designation (Abbreviation)
Spectral reflectance factor	$R_{45/0}(\lambda)$	directional 45° ± 5°	directional 0° ± 10°	45°/normal (45/0)
	$R_{0/45}(\lambda)$	directional* 0° ± 10°	directional 45° ± 5°	normal/45° (0/45)
	$R_{d/8}(\lambda)$	diffuse, integrating sphere	directional** 8° ± 2°	diffuse/8° (d/8)
	$R_{(d)\,d/8}(\lambda)$	diffuse, integrating sphere with gloss trap	directional** 8° ± 2°	diffuse/8° (d/8) specular reflection excluded
Spectral reflectance	$\varrho_{8/d}(\lambda)$	directional** 8° ± 2°	diffuse, integrating sphere	8°/diffuse (8/d)
Spectral diffuse reflectance	$\varrho_{(d)\,8/d}(\lambda)$	directional** 8° ± 2°	diffuse, integrating sphere with gloss trap	8°/diffuse (8/d) specular reflection excluded

* The possibility of interreflections between a high gloss specimen and the illuminating optics should be considered.

** This is contrary to the recommendations of the CIE (see CIE Publication No. 15) which permits the illumination or the viewing normal to the specimen (measurement conditions 0/d and d/0). The illumination or observation angle with a small defined deviation from zero as specified in this part of ISO 7724 prevents interreflections between the specimen and the illuminating or viewing optics when measuring high gloss specimens.