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Optics and photonics — Specification of raw optical glass

Optique et photonique — Spécification d'un verre d'optique brut

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Foreword

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

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

This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 3, *Optical materials and components.*

This third edition cancels and replaces the second edition (ISO 12123:2010), which has been technically revised.

The main changes compared to the previous edition are as follows:

a) definition of relative partial dispersion and its deviation from normal line and definition of internal transmittance have been added;

b) grade abbreviations at all tolerances in Clause 4 have been added;

c) all abbreviations have been written with two capital letters with relation to characteristics’ names;

d) in 4.6, an indication for required minimum aperture has been added;

e) in 4.7, striae indication for two and three perpendicular inspection directions has been added;

f) for partial dispersion and its deviation from normal line, the following has been added: dispersion data for standard crown and flint glass for normal environment, general formula for normal lines for the relative partial dispersions for any wavelength pairs, examples for six specific line pairs in Clause 5 and a calculation method and data for calculating dispersion data at temperatures other than 20 °C (see A.3);

g) in Clause 6, Example 1 for specification of optical raw glass with tolerances grades has been introduced and extended by adding a second case;

h) in Clause 6, Example 2 has been added and illustrates lens element specification from element over pressing to raw glass specification;

i) Tables have been renumbered.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Raw optical glass comes as strip glass, pressings block glass or large castings. Its characteristics are widely the same as those for optical elements such as lenses and prisms. However, the tolerance limits and their applicability are not the same. This comes from the fact that as a rule the raw optical glass delivery forms are much larger than the optical elements which will be made out of them. A glass strip of 280 mm length, 160 mm width and 40 mm thickness renders hundreds of small lenses. Simply transferring the glass requirements on the single lens to the total strip will lead to confusion or to severe over-specification. Required complete absence of bubbles and inclusions in a lens cannot mean the same requirement on the strip. A high homogeneity requirement for a small lens extended to the total strip without restricting it to the intended lens diameter will result in a uselessly narrow tolerance. It is even detrimental since it will lead to unnecessary high costs or even inability of the glass manufacturer to deliver the material requested.

The absolute refractive index and the Abbe number as a measure of dispersion apply for the raw optical glass formats as well as for the optical elements to be made out of them. Two variations of the refractive index have to be distinguished clearly: the first is the variation among different pieces of a common delivery lot and the second is the limited variation within a single piece, which is called optical homogeneity. The variation within a delivery lot is a symmetric tolerance with the test certificate value of the refractive index as reference. The optical homogeneity has no such practically determinable reference value. It is given as a span width (peak-to-valley) tolerance.

Refering to the size of the optical elements to be made out of the raw glass items will expedite offers and delivery. This holds especially for all homogeneity characteristics (refractive index variation: optical homogeneity, short-range refractive index variation: striae, material contiguity: bubbles and inclusions and refractive index polarization homogeneity: stress birefringence). In general, homogeneity tolerances increase requirements on quality strongly.

This edition introduces grade denominations for tolerance limits for the main properties of optical raw glass. The characteristics colour code and UV cut-off edge are different possibilities to describe position and slope of the UV-transmission edge of optical glasses.

Furthermore, this edition introduces definitions, reference formulae and data needed for calculating the deviation of the relative partial dispersion from the normal line. This quantity serves to value the suitability of optical glasses for colour aberration correction beyond achromatic correction of only two colours. The key element is the definition of two reference dispersion curves, one of a standard crown and one of a standard flint glass. Based on these curves normal line parameters can be derived for partial dispersions of any two wavelengths between 365 nm and 1 014 nm. In order to support the main target of improving comparison of glass types from different vendors examples for normal lines are given for six wavelength pairs covering the spectral range as specified above. The dispersion data of the reference glass types are valid for the temperature 20 °C. The annex contains the method for calculating the dispersion data for temperatures different from 20 °C.

The Annex of the document gives some explanations and recommendations for applying the document in ways which avoid over-specification and its unfavourable consequences.

This document was prepared in coordination with the preparation of ISO 10110-18, which provides a notation for the material tolerances of finished optical elements.

Optics and photonics — Specification of raw optical glass

1 Scope

This document gives rules for the specification of raw optical glass. It serves as a complement to the ISO 10110 series, which provides rules specifying finished optical elements. Since raw optical glass can be quite different in shape and size from the optical elements, its specification also differs from that of optical elements.

This document provides guidelines for the essential specification characteristics of raw optical glass in order to improve communication between glass suppliers and optical element manufacturers. For specific applications (e.g. lasers, the infrared spectral range), specifications based on this document need supplements.

While the intent of this document is to address the specific needs of raw optical glass, many of the parameters and characteristics are common to other optical materials, which are not necessarily glass. While this document can be used for non-glass materials, the user is informed that only optical glass has been considered in the development of this document, and other materials can have issues, which have not been taken into consideration.

NOTE Additional information on how to translate optical element specifications into raw optical glass specifications is given in Annex A.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
refractive index
n
ratio of the velocity of the electromagnetic waves at a specific wavelength in a vacuum to the velocity of the waves in the medium

Note 1 to entry: See ISO 7944.

Note 2 to entry: For practical reasons, this document refers to the refractive index in air.

3.2
principal refractive index
refractive index in the middle range of the visible spectrum commonly used to characterize an optical glass

Note 1 to entry: This principal refractive index is usually denoted as n_d, the refractive index at the wavelength 587,56 nm, or n_e, the refractive index at the wavelength 546,07 nm.

Note 2 to entry: The specific values for different glass types refer to standard environmental conditions (20 °C and 1 013 hPa according to ISO 1[1]). For all other temperatures and pressures, the specific temperature and pressure of interest shall be indicated.

3.3
refractive index variation
maximum difference of refractive index between samples of optical glasses

3.4
dispersion
measure of the change of the refractive index with wavelength

3.5
partial dispersion
difference of refractive index $n_{\lambda 1} - n_{\lambda 2}$ between two wavelengths λ_1 and λ_2

EXAMPLE $n_F - n_C$; $n_F{}' - n_C{}'$

n_F and n_C are the refractive indices at wavelengths 486,13 nm and 656,27 nm;

and $n_F{}'$ and $n_C{}'$ are the refractive indices at wavelengths 479,99 nm and 643,85 nm.

$n_F - n_C$ frequently serving as reference it is often called principal partial dispersion.

3.6
relative partial dispersion
difference of refractive index $n_{\lambda 1} - n_{\lambda 2}$ between two wavelengths λ_1 and λ_2 related to another partial dispersion $n_{\lambda 3} - n_{\lambda 4}$ between two other wavelengths λ_3 and λ_4

$$P_{\lambda 1,\lambda 2,\lambda 3,\lambda 4} = (n_{\lambda 1} - n_{\lambda 2}) / (n_{\lambda 3} - n_{\lambda 4})$$

EXAMPLE $P_{g,F,F,C} = (n_g - n_F) / (n_F - n_C) = P_{g,F}$

n_g is the refractive index at wavelength 435,83 nm.

If related to the principal partial dispersion, $n_F - n_C$ indices for λ_1 and λ_2 are usually omitted.

3.7
Abbe number
most common characterization of the dispersion of optical glasses

EXAMPLE 1 The Abbe number for the d-line is defined as

$$\nu_d = \frac{(n_d - 1)}{(n_F - n_C)}$$

where

n_F is the refractive index at wavelength 486,13 nm;

n_C is the refractive index at wavelength 656,27 nm.

EXAMPLE 2 The Abbe number for the e-line is defined as

$$\nu_e = \frac{(n_e - 1)}{\left(n_{F'} - n_{C'}\right)}$$

where

$n_F{}'$ is the refractive index at wavelength 479,99 nm;

$n_C{}'$ is the refractive index at wavelength 643,85 nm.

3.8
glass type
letter/number designation used in the manufacturer's catalogue to designate or characterize the glasses offered

Note 1 to entry: An alphanumeric designation is the manufacturer's option and is usually a proprietary trade name, and therefore indeterminate. For example, borosilicate crown glass is designated N-BK by one manufacturer, but S-BSL and BSC by others.

Note 2 to entry: An alternative way to specify a glass type is the glass code. It is a six-digit number and refers to the optical position of the individual glass types. The first three digits refer to the refractive index n_d, the second three digits to the Abbe number v_d. For N-BK7 e.g. it is 517642. This glass code, however, does not denominate a glass type unequivocally. The same glass code can be valid for glass types of very different chemical compositions and hence other properties can differ also very significantly.

3.9
deviation of the relative partial dispersion
glass type specific distance of the relative partial dispersion $P_{\lambda 1,\lambda 2}$ (glass type) from that of the normal line $P_{\lambda 1,\lambda 2}$ (normal line)

$$\Delta P_{\lambda 1,\lambda 2} \text{ (glass type)} = P_{\lambda 1,\lambda 2} \text{ (glass type)} - P_{\lambda 1,\lambda 2} \text{ (normal line)}$$

$$\Delta P_{\lambda 1,\lambda 2} \text{ (glass type)} = P_{\lambda 1,\lambda 2} \text{ (glass type)} - (\mathrm{a}_{\lambda 1,\lambda 2} + \mathrm{b}_{\lambda 1,\lambda 2} \cdot v_d)$$

The line parameters $\mathrm{a}_{\lambda 1,\lambda 2}$ and $\mathrm{b}_{\lambda 1,\lambda 2}$ define the normal line

$$\Delta P_{\lambda 1,\lambda 2} \text{ (normal line)} = \mathrm{a}_{\lambda 1,\lambda 2} + \mathrm{b}_{\lambda 1,\lambda 2} \cdot v_d$$

for each partial dispersion.

Note 1 to entry: They are calculated from the partial dispersion/Abbe number combinations of a standard crown and a standard flint glass type.

Note 2 to entry: The deviation of the relative partial dispersion is a measure how suitable a glass type is for the correction of colour aberrations in imaging.

3.10
transmittance
ratio of the transmitted radiant flux to the incident radiant flux of a collimated, monochromatic beam that passes, at normal incidence, through a plane parallel polished plate

3.11
spectral transmittance
measure of the variation of the transmittance with wavelength

3.12
internal transmittance
ratio of the radiant flux to the incident radiant flux of a collimated beam that passes, at normal incidence, through a plane parallel polished plate, excluding reflection losses at the surfaces

3.13
spectral internal transmittance
measure of the variation of the internal transmittance with wavelength

3.14
UV cut-off edge
UVC 80/10
position and the slope of the transmittance cut-off edge in the short wavelength range and given by the wavelengths at 80 % and 10 % internal transmittance

3.15
colour code
CC
position and slope of the transmittance cut-off edge in the short wavelength range, given by the wavelengths at 80 % and 5 % transmittance including reflection losses

3.16
optical homogeneity
gradual refractive index variation within a single piece of optical glass given by the difference between the maximum and minimum values of the refractive index within the optical glass

Note 1 to entry: Interferometric inspection records only lateral relative refractive index changes within the measured aperture accumulated over the glass thickness and with higher order than linear. For changes along the sight axis and linear changes across the aperture it is insensitive. Such inspection is not fully in accordance with the definition of optical homogeneity but suitable for almost all applications except for very thick or large glass pieces.

3.17
striae
short spatial range variation of refractive index in glass with typical spatial extent from below one millimetre up to several millimetres

3.18
inclusion
localized bulk material imperfections

EXAMPLE Bubbles, striae knots, small stones, sand and crystals.

3.19
bubble
gaseous void in the bulk optical material, of generally circular cross section

Note 1 to entry: Bubbles and solid inclusions are treated the same in assessing the quality of optical glass.

3.20
stress birefringence
birefringence caused by residual stresses within the glass, generally as a result of different cooling histories of different partial volumes of a given piece of glass during the forming and/or annealing process, and producing an optical path difference between the ordinary and extraordinary rays for plane polarized light passing through the glass

Note 1 to entry: The optical path length difference is proportional to the magnitude of mechanical stress.

4 Tolerances

4.1 Principal refractive index

The preferred tolerance ranges for the principal refractive index (Grade denomination NP) are given in Table 1.

Table 1 — Tolerances for principal refractive index

Grade	Principal refractive index tolerance limits
NP200	$\pm 200 \times 10^{-5}$
NP100	$\pm 100 \times 10^{-5}$
NP050	$\pm 50 \times 10^{-5}$
NP030	$\pm 30 \times 10^{-5}$
NP020	$\pm 20 \times 10^{-5}$
NP010	$\pm 10 \times 10^{-5}$

4.2 Refractive index variation

Fine annealed raw glasses will be arranged in delivery lots based on the refractive index variation. Therefore, the refractive index variation shall also be specified (Grade denomination NV). All parts of a delivery lot shall meet the tolerances for refractive index given in Table 2.

Table 2 — Tolerances for refractive index variation within a delivery lot

Grade	Refractive index variation tolerance limits
NV30	$\pm 30 \times 10^{-5}$
NV20	$\pm 20 \times 10^{-5}$
NV10	$\pm 10 \times 10^{-5}$
NV05	$\pm 5 \times 10^{-5}$
NV02	$\pm 2 \times 10^{-5}$

4.3 Abbe number

The tolerances for the Abbe number (Grade denomination AN) are given in Table 3.

Table 3 — Tolerances for Abbe number

Grade	Abbe number tolerance limits
AN8	±0,8 %
AN5	±0,5 %
AN3	±0,3 %
AN2	±0,2 %
AN1	±0,1 %

Alternative indication of absolute Abbe number tolerance limits based on the grades of Table 3 is also acceptable.

4.4 Spectral internal transmittance

Spectral internal transmittance data shall be reported for thicknesses of 10 mm, and optionally 3 mm, 5 mm or 25 mm thicknesses. The reference thickness shall be listed in the manufacturer's catalogue or data sheet. The data shall be the typical spectral internal transmittance for a given glass type. It can be the median value of several different melts. If the buyer's requirement for melt data or minimum values for spectral internal transmittance are critical, the requirement shall be specified on the drawing or in the purchase order.

4.5 UV cut-off edge and colour code

4.5.1 General

For the description of the UV transmittance cut-off edge the so-called colour code is used. Its advantage is that it can be measured easily and cost-effectively. On the other hand, especially high index glass types hardly reach the 80 % transmittance level because of their high reflection losses. Therefore, their quality is not described very distinctly and adequately to their application as coated elements in any case. The 5 % limit can lead to ambiguous results with glass types showing fluorescence in the UV-region. Such problems can be avoided by use of the UV cut-off edge UVC 80/10.

4.5.2 UV cut-off edge

The UV cut-off edge lists the wavelengths λ_{80} and λ_{10}, in which the spectral internal transmittance (excluding reflection losses) is 0,80 and 0,10 at 10 mm thickness. The reflection losses can be calculated using catalogue refractive index data. A UVC 80/10 measurement result, for example, can be quoted as 332/303 indicating the internal transmittances of 80 % at λ_{80} = 332 nm and of 10 % at λ_{10} = 303 nm.

4.5.3 Colour code

The colour code lists the wavelengths λ_{80} and λ_5, at which the spectral transmittance (including reflection losses) is 0,80 and 0,05 at 10 mm thickness in units of 10 nm. The values are rounded to 10 nm and are written by eliminating the last digit. For example, colour code 33/30 indicates λ_{80} = 330 nm and λ_5 = 300 nm. For glass types with refractive index n_d higher than 1,84, the reflection losses prevent transmission from exceeding 80 %. In this case the wavelength corresponding to 70 % is given instead. This is indicated by an asterisk (*) for example as 42*/38.

4.6 Optical homogeneity

The refractive index homogeneity that is achievable from a given glass type depends on the volume and the form of the individual glass pieces. Therefore, if it is necessary to specify the optical homogeneity of the raw glass, then this should be done with respect to the final dimensions of the optical elements to be manufactured out of the raw glass parts. In general the optical homogeneity values specified are peak-to-valley values and contain all aberrations. In many cases it is acceptable to subtract certain aberration terms that are of no importance or can easily be corrected (e.g. focal terms). This should be specified in advance.

Table 4 gives the preferred homogeneity tolerances (Grade denomination NH). Lower homogeneity grades are already covered by the variation tolerances.

Table 4 — Tolerances for the homogeneity of optical raw glass

Grade	Homogeneity tolerance limits (peak-to-valley)	Generally applicable for
NH100	100×10^{-6}	common application sizes
NH040	40×10^{-6}	
NH010	10×10^{-6}	partial volumes of the raw glass
NH004	4×10^{-6}	
NH002	2×10^{-6}	partial volumes of the raw glass but not for all glass types
NH001	1×10^{-6}	

The minimum contingent aperture, for which the homogeneity tolerances shall be valid, should be added in brackets as diameter in mm, e.g. (50 mm). For rectangular and square apertures, e.g. for use as prisms, the edge lengths should be added in brackets, e.g. (30 mm × 50 mm) or (80 mm × 80 mm).

4.7 Striae

Striae tolerances of optical raw glasses are defined in terms of wavefront deviations.

Striae are generally detected by means of the shadowgraph method using comparison standards. The wavefront deviation of the comparison standard is certified in advance using an interferometer set-up. Table 5 gives the striae wavefront deviation tolerance limits (Grade denomination SW).

Table 5 — Striae wavefront deviation tolerances

Grade	Traditional striae grades	Striae wavefront deviation tolerance limit per 50 mm path length nm	Generally applicable for
SW60	D	≤60	raw glass
SW30	C	≤30	
SW15	B	≤15	partial volumes of the raw glass
SW10	A	≤10	
NOTE The traditional striae grades are not simply synonyms for the SW grades. The traditional striae grades apply to an entire piece of glass of any size. They are equivalent to the SW grades only when the path length through the piece is exactly 50 mm.			

Striae are highly directionally dependent. If striae are perceived during a test, they are usually no longer detectable if inspected in a direction perpendicular to the original test direction.

Striae in optical raw glasses are in general band-like, therefore the striae wavefront deviation is dependent on the sampling thickness to a certain extent. In general the raw glass parts are inspected through the total thickness. The thickness of the finished parts is in most cases only a fraction of the initial thickness, therefore the striae wavefront deviation will also be much lower. A reference thickness of 50 mm is therefore introduced to specify striae quality of general purpose raw glass.

For extremely low striae content glass pieces, it is necessary to know the optical path length and direction for the final application in order to perform adequate inspection.

In exceptional cases striae inspection can be performed for multiple orthogonal directions.

This shall be indicated by appending ⊥2 for two orthogonal directions or ⊥3 for three orthogonal directions.

4.8 Bubbles and inclusions

Inclusions in glass, such as stones or crystals are treated as bubbles of equivalent cross sectional area.

The characterization of the bubble content of a glass is performed by reporting the total cross section in mm^2 of a 100 cm^3 glass volume, calculated as the sum of the detected cross sections of bubbles. Additionally, the maximum permissible number per 100 cm^3 and the size-dependent diameter of bubbles are defined for each cross section. The evaluation includes all bubbles and inclusions with dimensions ≥0,03 mm equivalent diameter.

Standard permissible quantities of bubbles and inclusions in raw optical glass are given in Table 6 (Grade denomination IC for inclusion cross section and IN for inclusion number). The rows of the table define different bubble and inclusion quality grades of optical glass combining the maximum permitted cross section and number per glass volume. It is acceptable to specify any combination of cross section and number per volume.

Bubbles and inclusions can be distributed. Instead of one bubble or inclusion with a prescribed size, a larger number of bubbles or inclusions of smaller dimensions is permissible.

The inclusion quality will be assessed by visual inspection. In critical cases measurements will be performed.

Table 6 — Permissible bubbles and inclusions within optical raw glass (any combinations are possible)

Grade	Maximum permissible cross section of any bubbles and inclusions in a given glass volume mm^2 per 100 cm^3	Grade	Maximum allowable number per 100 cm^3
IC50	0,5	IN140	140
IC25	0,25	IN070	70
IC10	0,1	IN030	30
IC03	0,03	IN010	10

4.9 Stress birefringence

The size and distribution of permanent internal stresses in glasses depend on the annealing conditions (e.g. annealing rate and temperature distribution around the glass being annealed), the glass type and the dimensions. The stresses cause birefringence that is dependent on the glass type.

Stress birefringence is measured as optical path length difference using the de Sénarmont and Friedel method and is stated in nanometres per centimetre based on the test thickness. A detailed description of the measurement method is given in ISO 11455.

The preferred tolerance limits (Grade denomination SB) are given in Table 7.

The stress birefringence in raw optical glass parts is, in most cases, larger than in the final product.

In raw glass destined to be hot processed, higher stresses are permitted, as long as they do not restrict mechanical processing.

Table 7 — Stress birefringence preferred tolerance limits for optical raw glass

Grade	Stress birefringence preferred tolerance limits nm/cm	Generally applicable for
—	≥20	raw glass
SB20	<20	
SB12	≤12	
SB06	≤6	
SB04	≤4	
SB02	≤2	cut parts from the raw glass

5 Deviation of the relative partial dispersion from the normal line — Definition of the normal lines

Calculating the deviations of the relative partial dispersion from normal lines for a given glass type requires standard normal lines defined by the refractive index values of two glass types, a standard crown and a standard flint glass type. Reference for normal lines for any relative partial dispersions $P_{\lambda 1,\lambda 2}$ with wavelengths combinations in the range 365 nm (i-line) $< \lambda_1, \lambda_2 <$ 1 014 nm (t-line) shall be derived from the Sellmeier type dispersion curves of the standard crown and standard flint glass types:

$$n(\lambda)=\left(\frac{B_1\lambda^2}{\lambda^2-C_1}+\frac{B_2\lambda^2}{\lambda^2-C_2}+\frac{B_3\lambda^2}{\lambda^2-C_3}+1\right)^{\frac{1}{2}}$$

where

n	is the refractive index;
λ	is the wavelength in µm;
B_1, B_2, B_3 and C_1, C_2, C_3	are the glass type specific constants.

Table 8 provides the nominal Sellmeier constants for the standard crown and flint glass type for calculating refractive index values in the wavelength range from 0,365 µm to 1,014 µm. Additionally, it lists example values for selected frequently used spectral lines, Abbe numbers and partial dispersions.

Table 8 — Data of optical glasses serving as reference for the definition of the normal lines

	Wavelength µm	Standard crown	Standard flint
B_1		1,127 355 50E+00	1,345 333 59E+00
B_2		1,244 123 03E-01	2,090 731 76E-01
B_3		8,271 005 31E-01	9,373 571 62E-01
C_1		7,203 417 07E-03	9,977 438 71E-03
C_2		2,698 359 16E-02	4,704 507 67E-02
C_3		1,003 845 88E+02	1,118 867 64E+02
n_d	0,587 562 1	1,511 120 9	1,620 040 1
$n_F - n_C$		0,008 461 6	0,017 050 1
ν_d		60,405	36,366
n_e	0,546 075 0	1,513 138 7	1,624 080 3
ν_e		60,151	36,108
n_i	0,365 015 8	1,531 893 5	1,666 225 1
n_h	0,404 656 5	1,525 398 0	1,650 638 6
n_g	0,435 833 5	1,521 590 3	1,642 018 1
$n_{F'}$	0,479 991 2	1,517 483 1	1,633 100 7
n_F	0,486 133 3	1,517 002 2	1,632 081 4
n_e	0,546 075 0	1,513 138 7	1,624 080 3
n_d	0,587 562 1	1,511 120 9	1,620 040 1
$n_{C'}$	0,643 847 0	1,508 952 2	1,615 817 1
n_C	0,656 279 0	1,508 540 6	1,615 031 3
n_r	0,706 519 0	1,507 067 0	1,612 265 5
$n_{A'}$	0,768 193 2	1,505 579 5	1,609 560 6
n_s	0,852 113 2	1,503 941 4	1,606 708 7
n_t	1,013 975 0	1,501 504 7	1,602 785 8
$P_{i,g}$		1,217 66	1,419 76
$P_{g,F}$		0,542 23	0,582 80
$P_{F,e}$		0,456 59	0,469 27
$P_{e,C}$		0,543 41	0,530 73
$P_{C,s}$		0,543 54	0,488 13
$P_{C,t}$		0,831 51	0,718 21

All refractive index values, Abbe numbers and partial dispersions in Table 8 result from the parameters B_1 to C_3 used with the Sellmeier dispersion equation given above. The wavelengths (Source: See Reference [9] in the Bibliography) are rounded to 7 digits. The refractive index and dispersion values are given with sufficient precision to avoid rounding errors. They are valid for 20 °C and 1 013,25 hPa air pressure.

These reference dispersion curves allow calculating normal lines for the relative partial dispersions for any wavelength pairs λ_1, λ_2 according to the general formula

$$\Delta P_{\lambda_2,\lambda_1} = \frac{n_{\lambda_2} - n_{\lambda_1}}{n_F - n_C} - \left(a_{\lambda_2,\lambda_1} - b_{\lambda_2,\lambda_1} \cdot \nu_d\right)$$

with the pair specific line parameters $a_{\lambda 2,\lambda 1}$ and $b_{\lambda 2,\lambda 1}$.

EXAMPLE 1 Normal lines for relative partial dispersions $P_{i,g}$, $P_{g,F}$, $P_{F,e}$, $P_{e,C}$, $P_{C,s}$ and $P_{C,t}$ at standard environmental conditions 20 °C and 1 013,25 hPa are:

$$\Delta P_{i,g} = \frac{n_i - n_g}{n_F - n_C} - (1{,}725\,5 - 0{,}008\,407 \cdot \nu_d)$$

$$\Delta P_{g,F} = \frac{n_g - n_F}{n_F - n_C} - (0{,}644\,2 - 0{,}001\,688 \cdot \nu_d)$$

$$\Delta P_{F,e} = \frac{n_F - n_e}{n_F - n_C} - (0{,}488\,4 - 0{,}000\,527 \cdot \nu_d)$$

$$\Delta P_{e,C} = \frac{n_e - n_C}{n_F - n_C} - (0{,}511\,6 + 0{,}000\,527 \cdot \nu_d)$$

$$\Delta P_{C,s} = \frac{n_C - n_s}{n_F - n_C} - (0{,}404\,3 + 0{,}002\,305 \cdot \nu_d)$$

$$\Delta P_{C,t} = \frac{n_C - n_t}{n_F - n_C} - (0{,}546\,8 + 0{,}004\,713 \cdot \nu_d)$$

EXAMPLE 2 For reference, Table 9 lists example values calculated using formulae for $\Delta P_{g,F}$ and $\Delta P_{C,s}$.

Table 9 — Calculation results for selected glass types

Code	n_g	n_F	n_d	n_C	n_s
804465	1,825 946	1,816 296	1,804 200	1,799 002	1,790 011
607568	1,620 697	1,614 834	1,607 379	1,604 144	1,598 494
497816	1,504 504	1,501 229	1,497 000	1,495 139	1,491 840

Code	ν_d	$P_{g,F}$	$\Delta P_{g,F}$	$P_{C,s}$	$\Delta P_{C,s}$
804465	46,501 7	0,557 97	−0,007 74	0,519 92	0,008 44
607568	56,815 0	0,548 39	0,000 09	0,528 54	−0,006 72
497816	81,608 7	0,537 66	0,031 22	0,541 70	−0,050 71

NOTE The examples are calculated from the formulae as given above.

For calculating normal lines for temperatures different from 20 °C, see A.3.

6 Indications for ordering raw glass parts

The order request for raw glass parts should contain at least the following information:

a) manufacturer of the glass and glass type;

b) refractive index and refractive index tolerance;

c) Abbe number and Abbe number tolerance.

For most applications, the refractive index homogeneity, striae, bubble and inclusion content and stress birefringence do not have to be specified explicitly. Standard quality will be sufficient.

In cases where tighter refractive index variation, homogeneity, striae and bubble and inclusion tolerances are needed, the customer should indicate the tolerances necessary for the final parts together with its dimensions in the order request. The supplier will select raw glass that fulfils the desired tolerances within the necessary partial volumes.

The transmission tolerance and UV cut-off edge or colour code can optionally be specified.

EXAMPLE 1 For reference Table 10 lists example values for a specification of optical raw glass with tolerances and with grades.

Table 10 — Specification of optical raw glass with tolerances and with grades

Glass Specification	Glass type 516642 block glass 190 mm × 180 mm × 140 mm	Grades	Glass type 522595 strip glass 300 mm × 150 mm × 40 mm	Grades
Refractive index n_d lot variation	1,516 80 ± 0,001 0 ± 10 × 10^{-5}	NP010 NV010	1,522 49 ± 0,003 0 ± 30 × 10^{-5}	NP030 NV030
Abbe number ν_d	64,17 ± 0,5 %	AN5	59,8 ± 0,3 %	AN3
Inclusions cross section number	0,1 mm^2/100 cm^3 30/100 cm^3	IC10 IN030	0,25 mm^2/100 cm^3 70/100 cm^3	IC25 IN070
Optical homogeneity in any zone of	4 × 10^{-6} (pv) 50 mm × 30 mm	NH004 (50 × 30)	10 × 10^{-6} (pv) Ø50 mm	NH010 (50)
Striae perpendicular directions	15 nm 1	SW15	30 nm 1	SW30
Stress birefringence	6 nm/cm	SB06	4 nm/cm	SB04

EXAMPLE 2 For reference Table 11 lists example values for a lens element specification from element over pressing to raw glass specification.

Table 11 — Lens element specification from element over pressing to raw glass specification

	Optical element (lens)	Pressing	Raw glass strip
	Tolerance/(Grade)	**Tolerance/Grade**	**Dim/Grade**
Diameter [mm]	24,6 ± 0,1	25,6 ± 0,1	Length [mm] ≥ 280
Centre thickness [mm]	$5,71 {}^{+0,020}_{-0,041}$	6,7 ± 0,3	Width [mm] ≥ 160
Radius 1 [mm]	110 CX	110 CX	Thickness [mm] ≥ 20
Radius 2 [mm]	56 CC	56 CC	—
Refractive index NP (n_e)	1,525 88 ± 0,000 2 (20)	NP020	NP020
Refractive index variation NV	n.a.	NV020	NV010
Abbe number AN (ν_e)	51,26 ± 0,5 % (5)	AN5	AN5
Homogeneity NH	2/NH010;SW60	NH010	NH010 (25 mm)
Striae SW	2/NH010;SW60	SW60	SW60
Bubbles/Inclusions CS	1/2 × 0,1	IC03	IC03
Bubbles/Inclusions N	1/2 × 0,1	IN010	IN010
Stress birefringence SB	0/10	SB12	SB30
NOTE CC means concave, CX means convex.			

NOTE With centre thickness of 5,71 mm the light path length in the glass is not much longer than 10 mm even for inclined light rays. The striae grade SW60 therefore means 60 nm/50 mm × 10 mm = 12 nm wavefront distortion at maximum for the example lens. This is far below any detectable effect in image quality.

Annex A
(informative)

Recommendation for the specification of raw optical glass for a given optical element specification

A.1 General

The applications of optical glass are spread over large ranges in dimensions and specifications: from small lenses of several millimetres, used in large quantities in consumer optics, up to single lenses greater than 300 mm in diameter, e.g. for use with photogrammetry and astronomical telescopes. The quality requirements span from low cost consumer optics, with only moderate requirements, to diffraction-limited objectives and high power laser optics driving the material to its very limits.

This document and the optical element specification standards, the ISO 10110 series, are intended to cover a wide range of all these applications.

Part of the optical design is to specify the material quality from which the optical elements will be fabricated. This quality, however, cannot be used directly to specify the raw material from which they will be manufactured. In most cases the finished optical element comes out of only a small volume fraction of the raw glass delivery form, e.g. lenses for digital still cameras are made out of strips with volumes more than a thousand times larger than that of the lens. If one simply extends the requirements for the small optical element to those of the delivery forms, this will lead to unnecessarily high requirements, production and inspection costs. Extending the requirement of zero inclusions in a digital camera lens to the total strip glass volume, i.e. no inclusion in the total strip, would certainly make subsequent quality assurance easier, but it is not relevant to real glass production.

Additionally, due to similar economic and technical reasons the specification methods for raw glass cannot be the same for all applications. Some quality characteristics have to be treated separately for different applications or sizes or delivery forms. It makes a difference whether a lens is to be manufactured out of pressings or to be cut from a larger piece of fine annealed glass. In the first case it is a matter of the yield of the pressings. In the latter case one can optimize the lens quality by shifting the position of the lens in the gross volume. This Annex gives guidance on how to proceed in some typical cases. It covers the following parameters:

— refractive index variation;

— optical homogeneity;

— striae;

— bubbles and inclusions;

— stress birefringence.

A.2 Refractive index variation

By far the most optical glass is produced in continuous melting tanks. With such production the refractive index changes with time. In order to provide material with equal properties, suppliers form delivery lots out of the continuous production with restricted variations of refractive index. Standard tolerances for these refractive index variations are given in 4.2.

The refractive index is inspected by taking samples from strips or blocks.

A.3 Deviation of the relative partial dispersions from the normal line

The deviation of the relative partial dispersion from the normal line is a quantity frequently given in optical glass data sheets to indicate the suitability of the glass type for colour aberration correction. This had been introduced with the SCHOTT®[1)] optical glass catalogue of 1966. The glass types used for defining the normal line for different relative partial dispersions were the crown glass K7 and the flint glass F2 as representatives following Ernst Abbe's rule for "normal" glasses, which lie on a straight line when plotted against the Abbe number. Glass types well suited for colour correction are recognizable by their large distance from this line, e.g. the fluor-phosphate glass types in the lower left corner of the Abbe diagram. Over the course of many years the definitions of the straight lines' parameters have diverged between the different glass suppliers leading to wrong results in comparing glass types from different vendors with each other. This document defines the parameters of the straight lines based on the same glass types K7 and F2 as before in order to maintain backward compatibility. It uses the dispersion data available for these glass types referring to the standard environmental conditions temperature T_0 = 20 °C and air pressure p_0 = 1 013,25 hPa.

If normal lines are requested for temperatures other than 20 °C, the dispersion data of the standard crown glass K7 and the standard flint glass F2 can be calculated as follows.

The refractive index data for different wavelengths λ of the standard crown glass K7 and the standard flint glass F2 in the original data sheet are refractive index values relative to air at standard conditions: $n_{rel}(\lambda, T_0 = 20\ °C, p_0 = 1\ 013,25\ hPa)$. In order to calculate the refractive index of a glass, for a given temperature different from 20 °C surrounded by air of the same different temperature but with constant standard air pressure, first the absolute refractive index at T_0 = 20 °C has to be calculated.

$$n_{abs}(\lambda, T_0) = n_{rel}(\lambda, T_0) \cdot n_{air}(\lambda, T_0)$$

The following formulae allow calculating the absolute refractive index change with temperature

$$n_{abs}(\lambda, T) = n_{abs}(\lambda, T_0) + \Delta n_{abs}(\lambda, T, T_0)$$

where

$$\Delta n_{abs}(\lambda, T, T_0) = \frac{n^2(\lambda, T_0) - 1}{2n(\lambda, T_0)} \cdot \left[D_0 \Delta T + D_1 \Delta T^2 + D_2 (\Delta T)^3 + \frac{E_0 \Delta T + E_1 \Delta T^2}{\lambda^2 - \lambda_{TK}^2} \right]$$

and $\Delta T = T - T_0$, D_0, D_1, D_2, E_0, E_1 and λ_{TK} are glass type specific constants.

Finally the absolute refractive index at temperature T will be converted into the relative refractive index at temperature T:

$$n_{rel}(\lambda, T) = n_{abs}(\lambda, T) / n_{air}(\lambda, T)$$

The refractive index of air at 15 °C for different wavelengths (in unit µm) follows from

$$n_{air}\left(\lambda, T = 15\ °C, p_0 = 1\ 013,25\ hPa\right) = 1 + \left[6\ 432,8 + \frac{2\ 949\ 810 \cdot \lambda^2}{146 \cdot \lambda^2 - 1} + \frac{25\ 540 \cdot \lambda^2}{41 \cdot \lambda^2 - 1} \right] \cdot 10^{-8}$$

and for other temperatures from

$$n_{air}(\lambda, T, p) = 1 + \frac{n_{air}(\lambda, T = 15\ °C, p_0) - 1}{1 + 3,478\ 5 \cdot 10^{-3} \cdot \left[T(°C) - 15 \right]} \cdot \frac{p}{p_0}$$

Table A.1 lists the temperature constants for K7 and F2 needed for the calculations and the constants of thermal expansion.

1) SCHOTT® is a trademark of SCHOTT AG Germany. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named.

Table A.1 — Temperature constants for standard crown glass K7 and standard flint glass F2

	Standard crown glass K7	Standard flint glass F2
D0	$-1{,}67 \times 10^{-6}$	$1{,}51 \times 10^{-6}$
D1	$8{,}80 \times 10^{-9}$	$1{,}56 \times 10^{-8}$
D2	$-2{,}86 \times 10^{-11}$	$-2{,}78 \times 10^{-11}$
E0	$5{,}42 \times 10^{-7}$	$9{,}34 \times 10^{-7}$
E1	$7{,}81 \times 10^{-10}$	$1{,}04 \times 10^{-9}$
λ_{TK} [µm]	$1{,}72 \times 10^{-1}$	$2{,}50 \times 10^{-1}$
CTE(−30 °C to +70 °C) [1/K]	$8{,}4 \times 10^{-6}$	$8{,}2 \times 10^{-6}$

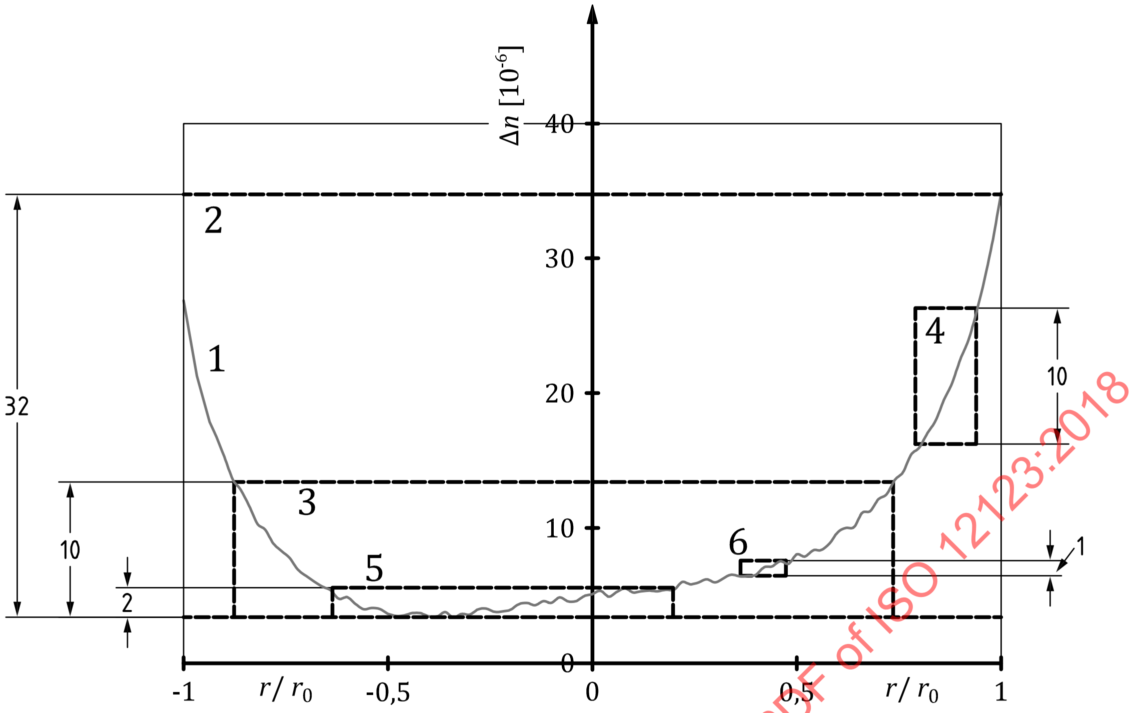
A.4 Optical homogeneity

Optical homogeneity is the relative variation of the refractive index within a single piece of optical glass. Usually it is measured with an interferometer. Reference to the absolute value of the refractive index is not possible and not necessary.

Optical glass is specially optimized with respect to its homogeneity. For most applications it is far better than actually needed. Therefore, as a rule it is necessary to perform interferometric measurements only in cases where extreme quality has to be guaranteed.

Within cast pieces of glass, the refractive index changes smoothly in the inner part of the volume while slopes are getting steeper when one approaches the surface. Very close to the surface, in about the last millimetre, homogeneity and striae quality can degrade because of the contact with other material during production or because of some evaporation of volatile constituents of the glass. Hence, staying away from the very edge zones will improve material quality significantly.

Smaller cut pieces have much better homogeneity than the total cast piece. Within short ranges the refractive index will change only slightly. Extending the range to the full size of the casting adds all small variations coherently. This means that a piece of glass with high homogeneity over 30 mm diameter might easily have only moderate quality over a total diameter of 180 mm. See Figure A.1.



Key

1 relative refractive index profile through inspection aperture without relation to absolute refractive index values

2 homogeneity over total width, here 32 × 10^{-6}

3 maximum homogeneity range with difference of refractive index 10 × 10^{-6}

4 small partial profile with difference of refractive index 10 × 10^{-6}

5 maximum homogeneity range with difference of refractive index 2 × 10^{-6}

6 small partial profile with difference of refractive index 1 × 10^{-6}

Figure A.1 — Homogeneity of optical glass: sample refractive index profile within a glass blank (demonstrating homogeneity on short ranges to be higher than that over the total width)

For small lenses, for consumer optics, the homogeneity is far beyond critical application limits. Therefore, it is generally not necessary to specify it explicitly.

For larger pieces, especially for industrial optics, it can, however, become necessary to specify the optical homogeneity. In this case, it is highly recommended not to specify the homogeneity to the gross dimensions of the cut part to be delivered, but to denote the size of the finished parts. Without knowing the final element size the supplier will have to guarantee the homogeneity over the total volume of the delivery form. This can lead to high measurement effort, cost or even delivery problems, if no material fulfilling the requirement over the total volume is available.

EXAMPLE A customer orders cut glass 200 mm × 150 mm × 20 mm specifying homogeneity to be better than 2 × 10^{-6}. If the supplier got no additional information, he might assume that the requirement referred to the total area of 200 mm × 150 mm. As a consequence, he would inspect this area and it could happen that, as he has no part available that fulfils the requirement, he would lose money for the preparation and for making the measurement and the customer would not get any glass. But the customer meant the homogeneity specification to be valid for lenses of 50 mm diameter, which the glass blank might fulfil easily.

There is another aspect, which might relieve delivery problems for high-end applications. In general, the optical homogeneity values specified are peak-to-valley values and contain all aberration components. In many cases, it is acceptable to subtract certain aberration terms that are of no importance or can easily be corrected by adapting the geometry of the final part or during the adjustment of the objective (e.g. focal terms, which can amount up to one third of the total peak-to-valley value). It can be helpful to specify this in advance, such as: required residual homogeneity, 2 × 10^{-6} after subtraction of focal term.

