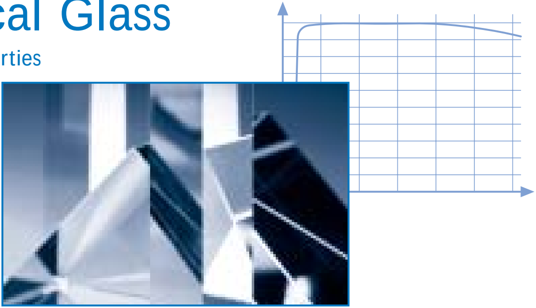
Optical Glass

Description of Properties



SCHOTT
glass made of ideas

Table of Contents

Foreword

We gladly present you the new revised issue of our pocket catalog.

Our range mainly comprises lead-free and arsenic-free glass identified by an„N“ in front of the glass name. Because of their very specific and indispensable properties, we will continue to offer lead containing glass types.

Please consider our new classification of deliveries into delivery note and delivery lot numbers which replaces the old system of melting and group numbers (see chapter 1.2). The new system allows us to be more flexible in replying to your inquiries.

The data section contains the most important properties of our 101 preferred glass types. New are the glass types N-SF19 and N-SF 57. In addition to this, we are glad to offer you glass types with different properties or combinations of properties upon your inquiry. For the complete data sheets of our preferred glass type range, please see our website at http://www.schott.com/optics_devices.

We reserve the right of changing properties due to improvements of the production process.

1. Optical Properties

1.1 Refractive Index, Abbe Number, Dispersions, Glass Designations

The most common identifying features for characterizing an optical glass are the refractive index n_d in the middle range of the visible spectrum and the Abbe number $\nu_d = (n_d - 1)/(n_F - n_C)$ as a measure for dispersion. The difference $n_F - n_C$ is called the principal dispersion.

In specifying optical components the quantities based on the e-line n_e and $\nu_e = (n_e - 1)/(n_{F'} - n_{C'})$ are usually used.

Glass Type	n_d	ν_d	Density	Glass Code
N-SF6	1.80518	25.36	3.37	805254.337 lead-arsenic free glass
SF6	1.80518	25.43	5.18	805254.518 classical lead silicate glass

Table 1.1: Glass Code Example.

The glasses in the product line are summarized as families in the n_d/ν_d diagram. The designation of each glass type is composed of the abbreviated family designation and a number. The glass families are arranged by decreasing Abbe value in the data section.

One other common designation method for the optical glasses is the listing of a numerical code. SCHOTT uses a nine-digit code. The first six places correspond to the common international glass code. They indicate the optical position of the individual glass. The first three digits reflect the refractive index n_d, the second three digits the Abbe value ν_d. The additional three digits indicate the density of the glass.

1.2 Tolerances for Refractive Index and Abbe Number

The tolerances for the refractive index and Abbe number are listed in table 1.2. The normal delivery quality is Step 3 for n_d and Step 4 for ν_d. We will supply material in tighter steps upon demand. The tolerance is doubled for high index glasses with $n_d > 1.83$ for all n_d steps. If you need tighter tolerances, please inquire.

	$n_d \leq 1.83$	$n_d > 1.83$	ν_d
Step 4	–	–	± 0.8%
Step 3	± 0.0005	± 0.001	± 0.5%
Step 2	± 0.0003	± 0.0006	± 0.3%
Step 1	± 0.0002	± 0.0004	± 0.2%

Table 1.2: Tolerances for refractive index and Abbe number.

All deliveries of fine annealed block glass and fabricated glass are made in lots of single batches. The batch may be a single block or some few strip sections. The delivery lots are formed based on the refractive index and Abbe number variation from glass part to glass part and are identified by a delivery lot number. As the batches may have different fine-annealing histories, such delivery lots are not suitable for repressing.

All parts of a delivery lot meet the following tolerances for the refractive index and Abbe value based on the nominal values in the data sheets. If requested, pressings can also be supplied in lots with limited refractive index variation. See table 1.3 for the tolerances.

Fine annealed glass		Pressings	
	Refractive Index Variation	All Variation Tolerances for Pressings Upon Request Only	Refractive Index Variation
Normal Quality SN	$\pm 1 \times 10^{-4}$	Normal Quality LN	$\pm 2 \times 10^{-4}$
S0	$\pm 5 \times 10^{-5}$	LH 1	$\pm 1 \times 10^{-4}$
S1	$\pm 2 \times 10^{-5}$	LH 2	$\pm 5 \times 10^{-5}$

Table 1.3: Tolerances for the refractive index variation within a lot of fine annealed glass and within a pressings lot.

1.3 Test Reports for Refractive Indices and Dispersions

1.3.1 Standard Test Reports

We provide standard test reports according to ISO 10474/ DIN EN 10204 for all deliveries of fine annealed optical glass. The information they contain based on sampling tests refers to the median position of the optical values of a delivery lot. The value of the individual parts may deviate by the variation tolerance from the reported values.

The measurements are performed using a method with an accuracy of $\pm 3 \times 10^{-5}$ for refractive index and $\pm 2 \times 10^{-5}$ for dispersion. The numerical data are listed to 5 decimal places.

n_d	ν_d	$n_F - n_C$	$n_F - n_d$	$n_{F'} - n_{C'}$	
n_e	ν_e	$n_d - n_C$	$n_F - n_e$	$n_{F'} - n_e$	$n_g - n_F$

Table 1.4: Refractive index and dispersion information in standard test reports.

Test certificates with enhanced accuracy can be prepared for individual glass parts upon request (± 2 x 10^{-5} for refractive index and ± 1 x 10^{-5} for dispersion).

1.3.2 Precision Test Certificates VIS, UV – IR and Super Precision Test Certificates VIS

These test certificates are issued upon request. They generally refer to individual glass parts.
The precision test certificates VIS for the visible spectral range contain the same data as the test reports for standard accuracy, with the only difference that the dispersion data are given to 6 decimal places. The values apply for an air pressure of 1013.3 hPa. The measurement is done with a prism goniometer.

The accuracy is ± 1 x 10^{-5} for refractive index and ± 3 x 10^{-6} for dispersion.

With an increased sampling and measurement effort the refractive indices can be determined with an accuracy of ± 5 x 10^{-6} and the dispersion with ± 2 x 10^{-6} if there is sufficient transmittance in the spectral range between 0.405 µm and 0.656 µm. The measurement results are listed on a test certificate with super precision accuracy.

The precision test certificates UV – IR contain additional refractive index data for an expanded spectral range, which spans a maximum range of 248 nm to 2325 nm.

The accuracy of the refractive indices is better than ± 1 x 10^{-5}. In the infrared range above 2 µm it is ± 2 x 10^{-5}. The constants of the Sellmeier dispersion formula are also listed for the applicable spectral range from a complete measurement series.

1.4 Refractive Index Homogeneity

The refractive index homogeneity is a measure to designate deviations of refractive index within individual pieces of glass. With special efforts in melting and fine annealing it is possible to produce pieces of glass having high homogeneity. The achievable refractive index homogeneity for a given glass type depends on the volume and the form of the individual glass pieces.

The availability of glasses with increased requirements for refractive index homogeneity comprises 5 classes in accordance with the standard ISO 10110 Part 4 (see table 1.5). For class 0 of the standard, please refer to the variance tolerances in section 1.2.

Homogeneity Class	Maximum Deviation of Refractive Index	Applicability, Deliverability
H 1	$\pm 2 \times 10^{-5}$	For individual cut pieces of glass
H 2	$\pm 5 \times 10^{-6}$	For individual cut pieces of glass
H 3	$\pm 2 \times 10^{-6}$	For individual cut pieces of glass, not in all dimensions
H 4	$\pm 1 \times 10^{-6}$	For individual cut pieces of glass, not in all dimensions, not for all glass types
H 5	$\pm 5 \times 10^{-7}$	For individual cut pieces of glass, not in all dimensions, not for all glass types

Table 1.5: Homogeneity of optical glasses.

1.5 Internal Transmittance, Color Code

The internal transmittance, i. e. the light transmittance excluding reflection losses, is closely related to the optical position of the glass type according to general dispersion theory. Using the purest raw materials and sophisticated melting technology it is possible to approach the dispersion limits for internal transmittance in the short wave spectral range.

SCHOTT seeks to achieve the best possible internal transmittance. Due to the laws of economics, however, slight variations in the purity of the raw materials must be taken into account. SCHOTT maintains a minimum standard for the related variations in internal transmittance of the glasses melted.

The information in the data section comprises median values from several melts of a glass type.
Upon special request minimum values for internal transmittance can be maintained. Prior clarification of the delivery situation is required.

The internal transmittance at 400 nm for a sample thickness of 25 mm is listed in the data section.

The limit of the transmittance ranges of optical glasses towards the UV area is of special interest in high index glasses as it shifts closer to the visible spectral range with increasing refractive index. A simple description of the position and slope of the UV absorption curve is described by the color code.

The color code lists the wavelengths λ_{80} and λ_5, at which the transmittance (including reflection losses) is 0.80 and 0.05 at 10 mm thickness. The values are rounded to 10 nm and are noted by eliminating the first digit. Color code 33/30 means, for example λ_{80} = 330 nm and λ_5 = 300 nm.

For high index glass types with n_d > 1.83 the data of the color codes (marked by *) refer to the transmittance values 0.70 and 0.05 (λ_{70} and λ_5) because of the high reflection loss of this glass.

2. Internal Properties

2.1 Striae

Deviations of the refractive index in glass of short range are called striae.
They resemble bands in which the refractive index deviates with a typical period of tenths to several millimeters.

The standard ISO 10110 Part 4 contains a classification with reference to striae. Since it refers to finished optical components, however, it is only conditionally applicable to optical glass in its usual forms of supply. It evaluates the striae into classes 1–4 according to their area based on the optically effective total surface of the component. Thereby, it only considers striae that deform a plane wavefront by more than 30 nm.

The fifth class identifies glass with extreme freedom from striae. It also includes striae below 30 nm wavefront distortion, but directs the user to make arrangements with the glass manufacturer.

The production formats of all optical glasses from SCHOTT meet the requirements of classes 1 – 4 of ISO 10110 Part 4. The tested glass thickness is usually much larger than that of the finished optical components. The effective striae quality in the optical system is therefore *much better.*

SCHOTT generally uses the shadow graph method to test all optical glasses. The high sensitivity of the method is sufficient to characterize the glass, even for the most stringent requirements.

Quality step VS1, increased striae selection, identifies glass with especially high requirements. Glass in this step contains no striae detectable with the shadow method. For prism applications SCHOTT offers quality step VS2. Such glass parts meet the requirements of step VS1 in two directions perpendicular to one another.

2.2 Bubbles and Inclusions

The optical glasses exhibit remarkable freedom from bubbles. Bubbles in glass cannot, however, be completely avoided due to the often complicated glass composition and manufacturing process.

The characterization of the bubble content of a glass is done by reporting the total cross section in mm^2 of a glass volume of 100 cm^3, calculated from the sum of the detected cross section of bubbles. Inclusions in glass, such as stones or crystals are treated like bubbles of the same cross section. The evaluation considers all bubbles and inclusions $\geq$ 0.03 mm.

The bubble classes and the maximum allowable quantities and diameters of bubbles and inclusions are listed in table 2.1. In the increased quality steps VB (increased bubble selection) and EVB (extra increased bubble selection) the glasses can only be supplied as fabricated pieces of glass.
In accordance with ISO 10110 Part 3, bubbles may be distributed. Instead of a bubble with a given dimension, a larger quantity of bubbles of smaller dimensions is allowable.

Special applications, such as in high energy lasers, in beam splitter prisms or as streak imaging cameras and high pitch gratings, allow only glasses that have a low quantity of very small bubbles/inclusions. We can offer glasses that meet these requirements upon request.

Bubble Class According to Catalog Data Sheet of the Concerned Glass Type	**Quality Step**	**B0**	**B0 VB**	**B0 EVB**	**B1**	**B1 VB**	**B1 EVB**
Maximum allowable cross section of all bubbles and inclusions in mm^2 per 100 cm^3 of glass volume		0.03	0.01	0.006	0.1	0.03	0.02
Maximum allowable quantity per 100 cm^3		10	4	2	30	10	4
Maximum allowable diameter of bubbles or inclusions in mm[1)] within parts of diameter or max. edge length in mm.	50	0.10	0.10	0.10	0.15	0.15	0.10
	100	0.15	0.15	0.10	0.20	0.15	0.10
	200	0.20	0.15	0.10	0.30	0.20	0.10
	300	0.25	0.20	–	0.40	0.25	–
	500	0.40	–	–	0.60	–	–
	800	0.55	–	–	0.80	–	–

1) Note: In the strip and block forms of supply from which much smaller finished parts are usually produced, occasional, isolated bubbles with larger diameters are allowed if the limit values for the total cross section and quantity per volume are maintained.

Table 2.1: Tolerances for bubbles and inclusions in optical glasses.

2.3 Stress Birefringence

The size and distribution of permanent inherent stress in glass depends on the annealing conditions (for example, annealing rate and temperature distribution around the object being annealed), the glass type, and the dimensions. The stress causes birefringence that depends on the glass type.

Stress birefringence is measured as a path difference using the de Sénarmont and Friedel Method and is listed in nm/cm based on the test thickness. Its accuracy is 3 – 5 nm for simple geometric test sample forms. The measurement is performed on round discs at a distance of 5% of the diameter from the edge. For rectangular plates the measurement is performed in the center of the longer side at a distance of 5% of the plate width. A detailed description of the method can be found in ISO Standard 11455.

The de Sénarmont and Friedel Method is insufficient for measurements of low stress birefringence and low thickness. In these cases we have methods to measure an order of magnitude more accurately instead.

With our annealing methods we are able to achieve both good optical homogeneity and very low stress birefringence values. Pieces of glass to be delivered generally have a symmetrical stress distribution. The glass surface is usually in compression. The stress birefrigence is considerably reduced when block or strip glass is cut. If the optical elements are much smaller than the raw glass format from which they were made, then the remaining stress birefrigence is even much lower than the limit values shown in table 2.2.

The limit values for stress birefringence in parts larger than 600 mm are available upon request.
Higher stresses are permitted in glass to be hot processed. The mechanical processing is not affected by this.

	Stress Birefringence		
Dimensions	Fine Annealing [nm/cm]	Special Annealing (SK) [nm/cm]	Precision Annealing (SSK) [nm/cm]
Ø ≤ 300 mm d ≤ 60 mm	≤ 10	≤ 6	≤ 4
Ø > 300–600 mm d > 60–80 mm	≤ 12	≤ 6	≤ 4

Table 2.2: Limit values of stress birefringence in processed glasses for various dimensions.

3. Delivery Quality

3.1 Standard Delivery Quality

If no special quality steps are requested, the glass will be delivered in refractive index/Abbe number step 3/4 with a standard test report. The standard test report refers to a delivery lot which fulfills the standard variation tolerance.The refractive index of all parts of a lot will not deviate by more than $\pm 1 \times 10^{-4}$ ($\pm 2 \times 10^{-4}$ for pressings, if requested) from the test report. The glass is tested for bubbles and inclusions, striae, and stress birefringence.

3.2 Increased Delivery Quality

The entire range of increased quality steps cannot be offered for all forms of supply. For information on this, refer to the following table.

	Strip Glass for Hot Processing	Block Glass	Pressings	Processed Glass
Refractive index – Abbe number steps	Suitable for 2, 1 3, 2, 1	2, 1 3, 2, 1	2, 1 3, 2, 1	2, 1 3, 2, 1
Test certificates Measurement accuracy, measurement ranges	Annealing schedule With data on the annealing rates for the achievable refractive index – Abbe number steps after fine annealing	Standard (S) Standard with enhanced accuracy (SE)	Standard (S) If a variation tolerance is requested	Standard (S) Standard with enhanced accuracy (SE) Precision (PZ) Super precision (SPZ) Precision UV – IR (PZUI) dn/dT (DNDT)
Refractive index scattering	S0, S1	S0, S1	LH1, LH2	S0, S1
Homogeneity	–	–	–	H2 – H5
Stress birefringence	–	SK	SK	SK, SSK
Striae	–	–	VS	VS1, VS2
Bubbles/inclusions	–	–	VB, EVB	VB, EVB
Remarks		At least one surface is worked		Striae and homogeneity measured in the same direction

Table. 3.1: Increased quality steps for various forms of supply.

The quality steps listed within a form of supply can be combined with one another. However, melts suitable for various combinations are not always available.

We recommend to check availability with us as soon as possible.

Requirements that exceed the mentioned quality steps may also be met. Please inquire about availability.

4. Forms of Supply and Tolerances

4.1 Raw Glass

4.1.1 Blocks

Blocks have five unworked, as-cast surfaces.
Usually at least one surface is worked.
The edges are rounded.
Blocks are fine annealed and therefore suitable for cold working.
Described by: *length, width, thickness*

4.1.2 Strips

Strips have unworked surfaces and broken or cut ends.
Strips are coarse annealed and therefore only suitable for hot working.
Described by: *length, width, thickness*

4.2 Fabricated Glass

4.2.1 Plates

Plates are quadrilateral, fabricated parts. All six sides are worked; the edges have protective bevels.
Described by: *length, width, thickness*

Greatest Edge Length [mm]	Admissible Tolerances				Minimum Thickness[1] [mm]
	For edge length		For thickness		
	Standard [mm]	VAT[2]	Standard [mm]	VAT[2]	
> 3–80	± 0.2	± 0.1	± 0.3	± 0.15	2
> 80–120	± 0.3	± 0.15	± 0.5	± 0.25	4
> 120–250	± 0.5	± 0.25	± 0.5	± 0.25	6
> 250–315	± 0.9	± 0.45	± 0.8	± 0.4	8
> 315–400	± 1.2	± 0.6	± 0.8	± 0.4	8
> 400–500	± 1.3	± 0.65	± 0.8	± 0.4	20
> 500–630	± 1.5	± 0.75	± 0.8	± 0.4	20
> 630–800	± 1.8	± 0.9	± 0.8	± 0.4	20
> 800–1000	± 2.0	± 1.0	± 0.8	± 0.4	20
> 1000	Inquire	Inquire	Inquire	Inquire	

1) Lower thicknesses than listed are possible. Please inquire.

2) VAT = closer dimensional tolerances.

Table 4.2.1: Dimensional tolerances and minimum dimensions for plates.

We achieve surface roughness of R_t = 20 – 25 µm with standard processing. Plates with closer dimensional tolerances and finer surfaces are possible upon request.

4.2.2 Round Plates

Round plates are completely worked; cylindrical parts the diameter of which is larger than the thickness. Described by: *diameter, thickness*

Diameter [mm]	Admissible Tolerances				Minimum Thickness[1] [mm]
	For diameter		For thickness		
	Standard [mm]	VAT[2] [mm]	Standard [mm]	VAT[2] [mm]	
> 3–80	± 0.2	± 0.1	± 0.3	± 0.15	2
> 80–120	± 0.3	± 0.15	± 0.5	± 0.25	4
> 120–250	± 0.3	± 0.15	± 0.5	± 0.25	6
> 250–500	± 0.5	± 0.25	± 0.8	± 0.4	20
> 500–800	± 0.8	± 0.4	± 0.8	± 0.4	20
> 800–1250	± 1.0	± 0.5	± 0.8	± 0.4	40
> 1250	Inquire	Inquire	Inquire	Inquire	

[1] Lower thicknesses than listed are possible. Please inquire. [2] VAT = closer dimensional tolerances.

Table 4.2.2: Dimensional tolerances and minimum dimensions for round plates.

We achieve surface roughness of R_t = 20 – 25 µm with standard processing.
Round plates with closer dimensional tolerances and finer surfaces are possible upon request.

4.2.3 Rods, Worked

Worked rods are cylindrical parts that are worked on all sides the length of which is greater than the diameter.
Described by: *diameter, length*

Diameter [mm]	Standard tolerance [mm]	Tolerances, drilled and rounded per DIN ISO 286				Length range [mm]	Tolerance for length [%]
		[mm]	[mm]	[mm]	[mm]		
6 – 10	± 0.2	h11 +0/–0.090	h10 +0/–0.058	h9 +0/–0.036	h8 +0/–0.022	max. 130	± 2
> 10 – 18	± 0.2	h11 +0/–0.110	h10 +0/–0.070	h9 +0/–0.043	h8 +0/–0.027	max. 130	± 2
> 18 – 30	± 0.2	h11 +0/–0.130	h10 +0/–0.084	h9 +0/–0.052	h8 +0/–0.033	max. 130	± 2
> 30 – 50	± 0.2	h11 +0/–0.160	h10 +0/–0.100	h9 +0/–0.062	h8 +0/–0.039	max. 130	± 2
> 50 – 80	± 0.3	h11 +0/–0.190	h10 +0/–0.120	h9 +0/–0.074			

Table 4.2.3: Dimensions and tolerances for worked rods in the 6–80 mm diameter range.

4.2.4 Milled Blanks

Lens blanks produced by milling having at least one spherical surface.
Described by: *diameter, center thickness, radius 1, radius 2, bevels*

4.2.5 Cut Prisms

Cut prisms are prisms produced by cutting and possibly grinding on all sides. Using different fabrication technologies, equilateral and non-equilateral prisms can be produced in various forms (ridge-, penta-, triple prisms …).
Described by: *drawing*

Maximum Edge Length [mm]	**Tolerances**	
	For dimensions [mm]	**For width [mm]**
< 50	+ 1.0/– 0	± 0.5
50–100	+ 1.5/– 0	± 1.0
>100	+ 2.0/– 0	± 1.0

Table 4.2.4: Dimensions and tolerances for cut prisms.

4.3 Pressings

Pressings are hot-formed parts with mostly round cross section, with defined radii and bevels. Described by: *Diameter, center thickness, radius 1, radius 2, bevels*

Other forms (angled, prismatic, diverse) are possible upon request. Described by: *drawing*

Diameter [mm]	Tolerances				
	For diameter [mm]	For thickness [mm]	Minimum center thickness [mm]	Minimum edge thickness [mm]	Maximum edge thickness [mm]
5–18	+0 / –0.18	± 0.4	2	1	0.6 * Ø
> 18–30	+0 / –0.25	± 0.4	3	1.5	0.45 * Ø
> 30–60	+0 / –0.3	± 0.3	5	3	0.4 * Ø
> 60–90	+0 / –0.4	± 0.3	6	4	0.3 * Ø
> 90–120	+0 / –0.6	± 0.4	7	5	0.3 * Ø
> 120–140	+0 / –0.7	± 0.5	8	5	0.3 * Ø
> 140–180	+0 / –0.9	± 0.5	8	6	0.3 * Ø
> 180–250	+0 / –1.15	± 0.5	10	8	0.3 * Ø
> 250–320	+0 / –1.5	± 0.6	10	8	0.3 * Ø

Table 4.3.1: Dimensions and tolerances for pressings according to DIN 58 926, Part 2.

Depending on the quantity and dimensions of the part, the production of direct pressings may be more economical. We will discuss specifications upon request.

5. Optical Properties, Theoretical Explanations

For this information we refer you to our website:
http://www.schott.com/optics_devices

Chapter 9 of this pocket catalog contains a selection of useful formulas.

6. Chemical Properties

The five test methods described below are used to assess the chemical behavior of polished glass surfaces.

6.1 Climatic Resistance (ISO/WD 13384), Classification into Climatic Resistance Classes CR 1 – 4

Climatic resistance describes the behavior of optical glasses at high relative humidity and high temperatures. In sensitive glasses a cloudy film can appear that generally cannot be wiped off.

An accelerated procedure is used to test the climatic resistance of the glasses, in which polished, uncoated glass plates are exposed to a water vapor saturated atmosphere, the temperature of which is alternated between 40 °C and 50 °C. This produces a periodical change from moist condensation on the glass surface and subsequent drying.

After an exposure time of 30 hours the glasses are removed from the climatic chamber. The difference ΔH between the haze before and after testing is used as a measure of the resulting surface change. The measurements are performed using a spherical hazemeter. The classifications are done based on the increase in transmission haze ΔH after a 30-hour test period.

The glasses in class CR 1 display no visible attack after being exposed to 30 hours of climatic change. In normal humidity conditions during the fabrication and storing of optical glasses in class CR 1, no surface attack should be expected. On the other hand, the fabrication and storing of optical glasses in class CR 4 should be done with

Climatic Resistance Classes CR	1	2	3	4
Increase in Transmission Haze ΔH	<0.3%	≥0.3% <1.0%	≥1.0% <2.0%	≥2.0%

Table 6.1: Classification of the optical glasses into climatic resistance classes CR 1 – 4.

caution because these glasses are very sensitive to climatic influences.

For storage of optical polished elements we recommend to apply a protective coating and/or assure that the relative humidity is kept as low as possible.

6.2 Stain Resistance, Classification into Stain Resistance Classes FR 0 – 5

The test procedure gives information on possible changes in the glass surface (stain formation) under the influence of lightly acidic water (for example perspiration, acidic condensates) without vaporization.

The stain resistance class is determined according to the following procedure: The plane polished glass sample to be tested is pressed onto a test cuvette, which has a spherical depression of max. 0.25 mm depth containing a few drops of a test solution.

Test solution I: Standard Acetate pH = 4.6
Test solution II: Sodium Acetate Buffer pH = 5.6

Interference color stains develop as a result of decomposition of the surface of the glass by the test solution. The measure for classifying the glasses is the time that elapses before the first brown-blue stain occurs at a temperature of 25 °C. This change in color indicates a chemical change in the previously defined surface layer of 0.1 µm thickness insofar the glass can form layers at all.

Stain resistance classes FR	0	1	2	3	4	5
Test solution Time (h) Color change	I 100 no	I 100 yes	I 6 yes	I 1 yes	II 1 yes	II 0.2 yes

Table 6.2: Classification of optical glasses into stain resistance classes FR 0 – 5.

Stain resistance class FR 0 contains all glasses that exhibit virtually no interference colors, even after 100 hours of exposure to test solution I.
Glasses in classification FR 5 must be handled with particular care during processing.

6.3 Acid Resistance (ISO 8424: 1987), Classification into Acid Resistance Classes SR 1 – 4, 5, 51 – 53

Acid resistance classifies the behavior of optical glasses that come in contact with large quantities of acidic solutions (from a practical standpoint for example, perspiration, laminating substances, carbonated water, etc.).

Acid resistance is denoted by a two or a three digit number. The first or the first two digits indicate the acid resistance class SR. The last digit (separated by decimal point) tells the change in the surface visible to the unaided eye that occurs through exposure (see 6.5).

The time t required to dissolve a layer with a thickness of 0.1 µm serves as a measure of acid resistance. Two aggressive solutions are used in determining acid resistance.

A strong acid (nitric acid, c = 0.5 mol/l, pH 0.3) at 25 °C is used for the more resistant glass types. For glasses with less acid resistance, a weakly acidic solution with a pH value of 4.6 (standard acetate) is used, also at 25 °C.

Class SR 5 forms the transition point between the two groups. It includes glasses for which the time for removal of a layer thickness of 0.1 µm at a pH value of 0.3 is less than 0.1 h and at a pH value of 4.6 is greater than 10 hours.

Acid Resistance Class SR	**1**	**2**	**3**	**4**	**5**		**51**	**52**	**53**
pH value Time (h)	0.3 >100	0.3 10-100	0.3 1-10	0.3 0.1-1	0.3 <0.1	4.6 >10	4.6 1-10	4.6 0.1-1	4.6 <0.1

Table 6.3: Classification of the optical glasses into acid resistance classes SR 1 – 53.

6.4 Alkali Resistance (ISO 10629), Classification into Alkali Resistance Classes AR 1–4 Phosphate Resistance (ISO 9689), Classification into Phosphate Resistance Classes PR 1–4

Both test methods serve to show the resistance to aqueous alkaline solution in excess and use the same classification scheme.

The alkali resistance indicates the sensitivity of optical glasses in contact with warm, alkaline liquids, such as cooling liquids in grinding and polishing processes.
The phosphate resistance describes the behavior of optical glasses during cleaning with phosphate containing washing solutions (detergents).

The alkali and phosphate resistance is denoted using two digits separated by a decimal point. The first digit lists the alkali resistance class AR or the phosphate resistance class PR, and the decimal indicates the surface changes visible to the unaided eye that occur through exposure.

The alkali resistance class AR indicates the time required to remove a layer thickness of glass of 0.1 µm in an alkaline solution (sodium hydroxide, c = 0.01 mol/l, pH = 12) at a temperature of 50 °C.

The phosphate resistance class PR indicates the time required to remove a layer thickness of glass of 0.1 µm in an alkaline phosphate containing solution (pentasodium triphosphate $Na_5P_3O_{10}$, c = 0.01 mol/l, pH = 10) at a temperature of 50 °C.

The layer thickness is calculated from the weight loss per surface area and the density of the glass.

Alkali Resistance Classes AR Phosphate Resistance Classes PR	1	2	3	4
Time (h)	> 4	1–4	0.25–1	< 0.25

Table 6.4: Classification of the optical glasses in alkali resistance classes AR 1 – 4 and phosphate resistance classes PR 1 – 4.

6.5 Identification of Visible Surface Changes

Meaning of the digits behind the classification for acid, alkali, and phosphate resistance:

.0 no visible changes
.1 clear, but irregular surface
.2 interference colors (light, selective leaching)
.3 firmly adhered thin white layer (stronger, selective leaching, cloudy surface)
.4 loosely adhering, thicker layers, for example, insoluble reaction products on the surface (this can be a projecting and/or flaking crust or a projecting surface; strong attack)

6.6 Addendum

Our glasses contain no more than 0.05 weight percent thorium oxide or other radioactive material. Negligible inherent radioactivity can be present as in many everyday substances as a result of the natural radioactivity of raw materials.

7. Mechanical Properties

7.1 Knoop Hardness

The Knoop hardness of a material is a measure for remaining surface changes after applying pressure with a test diamond. The standard ISO 9385 describes the measurement procedure for glasses. In accordance with this standard, the values for Knoop hardness HK are listed in the data sheets for a test force of 0.9807 N (corresponds to 0.1 kp) and an effective test period of 20 s. The test is performed on polished glass surfaces at room temperature. The data for hardness values are rounded to 10 HK 0.1/20. The microhardness is a function of the magnitude of the test force and decreases with increasing test force.

7.2 Grindability with Diamond Grains According to ISO 12844

The grindability according to ISO 12844 allows the comparison of the grinding process of different glasses (to one another). Twenty samples of the glass to be classified are ground for 30 seconds in a standardized diamond pellet tool under predetermined conditions. Then the removed volume of glass is compared to that of a reference glass, N-SK16.

The classification occurs according to the following scheme. The value for N-SK16 has arbitrarily been set to 100.

Grindability Class	Grindability	
HG 1		≤ 30
HG 2	> 30	≤ 60
HG 3	> 60	≤ 90
HG 4	> 90	≤ 120
HG 5	> 120	≤ 150
HG 6	> 150	
The grindability of N-SK 16 is defined as 100.		

Table 7.1: Grindability according to ISO 12844.

According to this scheme, the removal in the lower classifications is less and is higher in the upper classifications than the reference glass N-SK16.

7.3 Viscosity

Glasses run through three viscosity ranges between the melting temperature and room temperature: the melting range, the supercooled melt range, and the solidification range. The viscosity of glass constantly increases during the cooling of the melt ($10^0 - 10^4$ dPa·s). A transition from liquid to plastic state can be observed between 10^4 and 10^{13} dPa·s.

The so-called softening point EW identifies the plastic range in which glass parts rapidly deform under their own weight. This is the temperature $T_{10^{7.6}}$ at which glass exhibits a viscosity of $10^{7.6}$ dPa·s. The glass structure can be described as solidified or “frozen” above 10^{13} dPa·s. At this viscosity the internal stress in glass equalizes in approx. 15 minutes. The temperature $T_{10^{13}}$ is very important in the annealing of glasses.

Another possibility for identifying the transformation range is the change in the rate of relative linear thermal expansion. In accordance with ISO 7884-8, this can be used to determine the so-called transformation temperature T_g. It generally lies right at $T_{10^{13}}$.

Precision optical surfaces may deform and refractive indices may change if a temperature of $T_{10^{13}}$ – 200 K is exceeded during any thermal treatment.

7.4 Coefficient of Linear Thermal Expansion

The typical curve of the linear thermal expansion of glasses starts near absolute zero with an obvious increase in slope to approximately room temperature.Then a nearly linear increase to the beginning of the noticeable plastic behavior follows. The transformation range is distinguished by a distinct bending of the expansion curve that results from the increasing structural movement in the glass. Above this range the expansion again exhibits a nearly linear increase, but with a noticeably greater rate of increase.

Due to the dependence of the coefficient of linear thermal expansion α on temperature, two average linear thermal expansion coefficients α are usually given for the following temperature ranges:

α(–30 °C; +70 °C) as the relevant information for room temperature (listed in the data sheets).

α(20 °C; +300 °C) as the standard international value for comparison purposes and for orientation during melting processes and temperature change loading.

8. Thermal Properties

8.1 Thermal Conductivity

The range of values for thermal conductivity for glasses at room temperature extends from 1.38 W/(m·K) (pure quartz glass) to about 0.5 W/(m·K) (high lead containing glasses). The most commonly used silicate glasses have values between 0.9 and 1.2 W/(m·K).

The thermal conductivities shown in the data sheets apply for a glass temperature of 90 °C with an accuracy of ±5%.

8.2 Heat Capacity

The mean isobaric specific heat capacity c_p (20 °C; 100 °C) is listed for some glasses as measured from the heat transfer of a hot glass at 100 °C in a liquid calorimeter at 20 °C. The range of values for c_p (20 °C; 100 °C) and also for the true heat capacity c_p (20 °C) for silicate glasses lies in-between 0.42 and 0.84 J/(g·K).

9. Collection of Formulas and Wavelength Table

Relative Partial Dispersion $P_{x,\,y}$ for the wavelengths *x* and *y* based on the blue *F* and red *C* hydrogen line

$$P_{x,\,y} \quad = \quad (n_x - n_y) / (n_F - n_C) \qquad (9.1)$$

or based on the blue *F'* and red *C'* cadmium line

$$P'_{x,\,y} \quad = \quad (n_x - n_y) / (n_{F'} - n_{C'}) \qquad (9.2)$$

Linear relationship between the Abbe number and the relative partial dispersion for "normal glasses"

$$P_{x,\,y} \quad \approx \quad a_{xy} + b_{xy} \cdot \nu_d \qquad (9.3)$$

Deviation ΔP from the "normal lines"

$$P_{x,\,y} \quad = \quad a_{xy} + b_{xy} \cdot \nu_d + \Delta P_{x,\,y} \qquad (9.4)$$

$$\Delta P_{C,\,t} \quad = \quad (n_C - n_t) / (n_F - n_C) - (0{,}5450 + 0{,}004743 \cdot \nu_d) \qquad (9.5)$$

$$\Delta P_{C,\,s} \quad = \quad (n_C - n_s) / (n_F - n_C) - (0{,}4029 + 0{,}002331 \cdot \nu_d) \qquad (9.6)$$

$$\Delta P_{F,\,e} \quad = \quad (n_F - n_e) / (n_F - n_C) - (0{,}4884 - 0{,}000526 \cdot \nu_d) \qquad (9.7)$$

$$\Delta P_{g,\,F} \quad = \quad (n_g - n_F) / (n_F - n_C) - (0{,}6438 - 0{,}001682 \cdot \nu_d) \qquad (9.8)$$

$$\Delta P_{i,\,g} \quad = \quad (n_i - n_g) / (n_F - n_C) - (1{,}7241 - 0{,}008382 \cdot \nu_d) \qquad (9.9)$$

The position of the normal lines was determined based on value pairs of glass types K 7 and F 2.

Sellmeier Dispersion Formula

$$n^2(\lambda)-1 = B_1\lambda^2 / (\lambda^2-C_1) + B_2\lambda^2 / (\lambda^2-C_2) + B_3\lambda^2 / (\lambda^2-C_3) \qquad (9.10)$$

Change in Refractive Index and Abbe Number during Annealing at Different Annealing Rates

$$n_d(h_x) = n_d(h_0) + m_{nd} \cdot \log(h_x/h_0) \qquad (9.11)$$

$$\nu_d(h_x) = \nu_d(h_0) + m_{\nu d} \cdot \log(h_x/h_0) \qquad (9.12)$$

$$m_{\nu_d} = (m_{nd} - \nu_d(h_0) \cdot m_{nF-nC}) / ((n_F - n_C) + 2 \cdot m_{nF-nC} \cdot \log(h_x/h_0)) \qquad (9.13)$$

h_0	Beginning annealing rate
h_x	New annealing rate
m_{nd}	Annealing coefficient for the refractive index, depending on the glass type
$m_{\nu d}$	Annealing coefficient for the Abbe number, depending on the glass type
m_{nF-nC}	Annealing coefficient for the principal dispersion, dependent on the glass type

Measurement Accuracy of the Abbe Number

$$\sigma_{\nu d} \approx \sigma_{(nF-nC)} \cdot \nu_d / (n_F - n_C) \qquad (9.14)$$

Spectral Internal Transmittance

$\tau_{i\lambda} \quad = \quad \Phi_{e\lambda} / \Phi_{i\lambda}$ (9.15)

Spectral Transmittance

$\tau_{\lambda} \quad = \quad \tau_{i\lambda} \cdot P_{\lambda}$ (9.16)

P_{λ} Reflection factor

Fresnel Reflectivity for a light beam with normal incidence, independent of polarization

$R \quad = \quad ((n - 1) / (n + 1))^2$ (9.17)

Reflection Factor Considering Multiple Reflections

$P \quad = \quad (1 - R)^2 / (1 - R^2) = 2n / (n^2 + 1)$ (9.18)

n Refractive index for the wavelength λ.

Converting of Internal Transmittance to Another Layer Thickness

$\log \tau_{i1} / \log \tau_{i2} = d_1 / d_2$ or (9.19)

$\tau_{i2} \quad = \quad \tau_{i1}^{(d_2 / d_1)}$ (9.20)

τ_{i2}, τ_{i1} Internal transmittances at the thicknesses d_1 and d_2

Stress Birefringence, difference optical path

$$\Delta s = 10 \cdot K \cdot d \cdot \sigma \quad \text{in nm} \tag{9.21}$$

K Stress optical constant, dependent on the glass type in 10^{-6} mm^2/N

d Length of light path in the sample in cm

σ Mechanical stress (positive for tensile stress) in N/mm^2 (= MPa)

Homogeneity from Interferometrically Measured Wave Front Deviations

$$\Delta n = \Delta W / (2 \cdot d) \tag{9.22}$$

$$= \Delta W\, [\lambda] \cdot 633 \cdot 10^{-6} / (2 \cdot d\, [mm])$$

when listing the wave front deformation in units of the wavelength and a test wavelength of 633 nm (He-Ne laser)

ΔW Wave front deformation with double beam passage (interferometric testing)

d Thickness of test piece

Note: The formulas have been carefully chosen and listed.
However, SCHOTT can assume no responsibility for errors resulting from their use.

Wavelength [nm]	Designation	Spectral Line Used	Element
2325.42		Infrared mercury line	Hg
1970.09		Infrared mercury line	Hg
1529.582		Infrared mercury line	Hg
1060.0		Neodymium glass laser	Nd
1013.98	t	Infrared mercury line	Hg
852.11	s	Infrared cesium line	Cs
706.5188	r	Red helium line	He
656.2725	C	Red hydrogen line	H
643.8469	C'	Red cadmium line	Cd
632.8		Helium-neon gas laser	He-Ne
589.2938	D	Yellow sodium line	Na
		(center of the double line)	
587.5618	d	Yellow helium line	He
546.0740	e	Green mercury line	Hg
486.1327	F	Blue hydrogen line	H
479.9914	F'	Blue cadmium line	Cd
435.8343	g	Blue mercury line	Hg
404.6561	h	Violet mercury line	Hg
365.0146	i	Ultraviolet mercury line	Hg
334.1478		Ultraviolet mercury line	Hg
312.5663		Ultraviolet mercury line	Hg
296.7278		Ultraviolet mercury line	Hg
280.4		Ultraviolet mercury line	Hg
248.3		Ultraviolet mercury line	Hg

Table 9.1: Wavelengths for a selection of frequently used spectral lines.

10. Explanation of the Designations in the Data Section

Glass Code	–	International glass code of refractive index n_d and Abbe number ν_d with density
n_x, ν_x, $n_x - n_y$	–	Refractive index, Abbe number, and dispersion at various wavelengths
CR	–	Climatic resistance class (ISO/WD 13384)
FR	–	Stain resistance class
SR	–	Acid resistance class (ISO 8424)
AR	–	Alkali resistance class (ISO 10629)
PR	–	Phosphate resistance class (ISO 9689)
α	–	Coefficient of linear thermal expansion α (–30 °C; +70 °C) in 10^{-6}/K
T_g	–	Transformation temperature in °C (ISO 7884-8)
$T_{10^{7,6}}$	–	Temperature of the glass at a viscosity of $10^{7.6}$ dPa s
ρ	–	Density in g/cm^3
HK	–	Knoop hardness (ISO 9385)
HG	–	Grindability class (ISO 12844)
B	–	Bubble class
τ_i	–	Internal transmittance at 400 nm; glass thickness: 25 mm
Color Code	–	Wavelengths for transmission 0.80 (at*: 0.70) and 0.05; glass thickness: 10 mm (JOGIS)

The data are the best currently known.
We reserve the right of changes due to technical progress.

11. Logistics

11.1 Preferred Glasses

The glass types listed in the current product line are preferred glasses. Delivery from stock is generally guaranteed.

11.2 Inquiry Glasses

A stock of inquiry glasses is not maintained. Availability will have to be checked in each case. They are in most cases produced on demand of a customer. For technical and economic reasons the customer has to buy a complete melt. The minimum melting quantity primarily depends on the melting method and the glass type. Specifications and delivery time are individually stipulated prior receipt of an order.

11.3 Article Definition

SCHOTT defines an article by glass type, form of supply, dimensions, and quality.

11.4 Preferred and Inquiry Articles

All preferred optical glasses in the current product line are represented by at least one preferred article.

Preferred articles are considered in sales planning from available data and are therefore normally always available.

Special articles can be produced from the preferred articles by fabrication, selection, or quality testing. These customer-specific articles deviate in form of supply, dimensions, or quality from preferred articles and are considered inquiry articles.

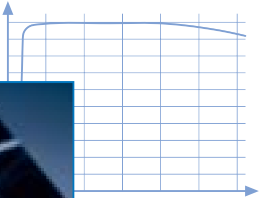
Inquiry articles are usually not stocked. They are made upon customer´s requests.

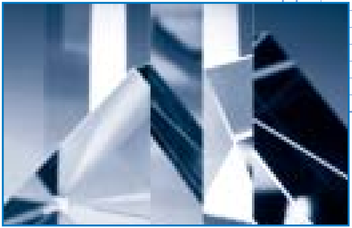
11.5 Preferred Product Line

Information on the current preferred product line can be found on our website:
http://www.schott.com/optics_devices

Optical Glass

Properties





SCHOTT
glass made of ideas

Properties

Glass Code	–	International glass code of refractive index n_d and Abbe number ν_d with density
n_x, ν_x, $n_x - n_y$	–	Refractive index, Abbe number, and dispersion at various wavelengths
CR	–	Climatic resistance class (ISO/WD 13384)
FR	–	Stain resistance class
SR	–	Acid resistance class (ISO 8424)
AR	–	Alkali resistance class (ISO 10629)
PR	–	Phosphate resistance class (ISO 9689)
α	–	Coefficient of linear thermal expansion α (–30 °C; +70 °C) in 10^{-6}/K
T_g	–	Transformation temperature in °C (ISO 7884-8)
$T_{10}{}^{7,6}$	–	Temperature of the glass at a viscosity of $10^{7.6}$ dPa s
ρ	–	Density in g/cm^3
HK	–	Knoop hardness (ISO 9385)
HG	–	Grindability class (ISO 12844)
B	–	Bubble class
τ_i	–	Internal transmittance at 400 nm; glass thickness: 25 mm
Color Code	–	Wavelengths for transmission 0.80 (at*: 0.70) and 0.05; glass thickness: 10 mm (JOGIS)

The data are the best currently known.
We reserve the right of changes due to technical progress.

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}$-$n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-FK5 487704.245	1.48749	70.41	0.006924	1.48914	70.23	0.006965	1.48410	1.48535	1.49266	1.49593	1.49894
N-FK51 487845.368	1.48656	84.47	0.005760	1.48794	84.07	0.005804	1.48379	1.48480	1.49088	1.49364	1.49618
N-PK51 529770.396	1.52855	76.98	0.006867	1.53019	76.58	0.006923	1.52527	1.52646	1.53372	1.53704	1.54010
N-PK52A 497816.368	1.49700	81.61	0.006090	1.49845	81.21	0.006138	1.49408	1.49514	1.50157	1.50450	1.50720
N-PSK3 552635.291	1.55232	63.46	0.008704	1.55440	63.23	0.008767	1.54811	1.54965	1.55885	1.56302	1.56688
N-PSK53 620635.360	1.62014	63.48	0.009769	1.62247	63.19	0.009851	1.61547	1.61717	1.62749	1.63223	1.63662

CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC
2	1	4	2	2.3	9.2	466	672	2.45	520	3	1	0.993	30/25
2	0	52.3	2.2	4.3	13.3	420		3.69	430	5	1	0.993	34/28
2	0	51.2	3.3	4.3	12.7	496		3.96	400	6	1	0.984	35/29
1	0	52.3	3.3	4.3	12.9	453	523	3.69	370	6	1	0.992	34/28
3	0	2.2	2	2	6.2	599	736	2.91	630	2	1	0.986	33/28
2	1	52.3	1.2	4.3	9.4	618	709	3.60	440	6	1	0.950	37/33

FK
PK
PSK

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}$-$n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-BK7 517642.251	1.51680	64.17	0.008054	1.51872	63.96	0.008110	1.51289	1.51432	1.52283	1.52668	1.53024
N-BK10 498670.239	1.49782	66.95	0.007435	1.49960	66.78	0.007481	1.49419	1.49552	1.50337	1.50690	1.51014
N-K5 522595.259	1.52249	59.48	0.008784	1.52458	59.22	0.008858	1.51829	1.51982	1.52910	1.53338	1.53734
K7 511604.253	1.51112	60.41	0.008461	1.51314	60.15	0.008531	1.50707	1.50854	1.51748	1.52159	1.52540
K10 501564.252	1.50137	56.41	0.008888	1.50349	56.15	0.008967	1.49713	1.49867	1.50807	1.51243	1.51649
N-ZK7 508612.249	1.50847	61.19	0.008310	1.51045	60.98	0.008370	1.50445	1.50592	1.51470	1.51869	1.52238

CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC
2	0	1	2	2.3	7.1	557	719	2.51	610	3	0	0.992	33/29
1	0	1	1	1	5.8	551	753	2.39	560	4	1	0.990	31/27
1	0	1	1	1	8.2	546	720	2.59	530	3	1	0.988	34/30
3	0	2	1	2.3	8.4	513	712	2.53	520	3	1	0.990	33/30
1	0	1	1	1.2	6.5	459	691	2.52	470	4	1	0.986	33/30
1	0	2	1.2	2.2	4.5	539	721	2.49	530	4	1	0.975	34/29

BK
K
ZK

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}-n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-BAK1 573575.319	1.57250	57.55	0.009948	1.57487	57.27	0.010039	1.56778	1.56949	1.58000	1.58488	1.58941
N-BAK2 540597.286	1.53996	59.71	0.009043	1.54212	59.44	0.009120	1.53564	1.53721	1.54677	1.55117	1.55525
N-BAK4 569560.304	1.56883	55.98	0.010162	1.57125	55.70	0.010255	1.56400	1.56575	1.57649	1.58149	1.58614
N-SK2 607567.355	1.60738	56.65	0.010722	1.60994	56.37	0.010821	1.60230	1.60414	1.61547	1.62073	1.62562
N-SK4 613586.353	1.61272	58.63	0.010450	1.61521	58.37	0.010541	1.60774	1.60954	1.62059	1.62568	1.63042
N-SK5 589613.330	1.58913	61.27	0.009616	1.59142	61.02	0.009692	1.58451	1.58619	1.59635	1.60100	1.60530
N-SK10 623570.363	1.62278	56.98	0.010929	1.62539	56.70	0.011029	1.61759	1.61947	1.63102	1.63638	1.64137
N-SK11 564608.308	1.56384	60.80	0.009274	1.56605	60.55	0.009349	1.55939	1.56101	1.57081	1.57530	1.57946
N-SK14 603606.344	1.60311	60.60	0.009953	1.60548	60.34	0.010034	1.59834	1.60008	1.61059	1.61542	1.61988
N-SK15 623580.362	1.62296	58.02	0.010737	1.62552	57.75	0.010832	1.61785	1.61970	1.63105	1.63629	1.64116

CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC	
2	1	3.3	1.2	2	7.6	592	746	3.19	530	2	1	0.990	33/29	
2	0	1	1	2.3	8.0	554	727	2.86	530	2	1	0.993	32/28	
1	0	1.2	1	1	7.0	581	725	3.05	550	2	0	0.980	36/33	
														BAK SK
2	0	2.2	1	2.3	6.0	659	823	3.55	550	2	0	0.984	35/30	
3	1	51.2	2	2	6.5	658	769	3.54	580	3	1	0.975	36/32	
3	1	4.4	2	1.3	5.5	660	791	3.30	590	3	1	0.981	34/29	
3	3	52.2	2	2.2	6.8	633	758	3.64	550	3	1	0.970	36/32	
2	0	2	1	2.3	6.5	610	760	3.08	570	2	1	0.975	34/29	
4	2	51.3	2	2.3	6.0	649	773	3.44	600	3	1	0.975	35/29	
3	3	52.2	2	3.2	6.7	641	752	3.62	620	3	1	0.960	36/31	

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}$-$n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-SK16 620603.358	1.62041	60.32	0.010285	1.62286	60.08	0.010368	1.61548	1.61727	1.62814	1.63312	1.63773

CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC
4	4	53.3	3.3	3.2	6.3	636	750	3.58	600	4	1	0.970	36/30

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}$-$n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-KF9 523515.249	1.52346	51.54	0.010156	1.52588	51.26	0.010258	1.51867	1.52040	1.53114	1.53620	1.54096
N-BALF4 580539.311	1.57956	53.87	0.010759	1.58212	53.59	0.010863	1.57447	1.57631	1.58769	1.59301	1.59799
N-BALF5 547536.261	1.54739	53.63	0.010207	1.54982	53.36	0.010303	1.54255	1.54430	1.55510	1.56016	1.56491
N-SSK2 622533.352	1.62229	53.27	0.011681	1.62508	52.99	0.011795	1.61678	1.61877	1.63112	1.63691	1.64232
N-SSK5 658509.371	1.65844	50.88	0.012940	1.66152	50.59	0.013075	1.65237	1.65455	1.66824	1.67471	1.68079
N-SSK8 618498.326	1.61773	49.83	0.012397	1.62068	49.54	0.012529	1.61192	1.61401	1.62713	1.63335	1.63923
N-LAK7 652585.384	1.65160	58.52	0.011135	1.65425	58.26	0.011229	1.64628	1.64821	1.65998	1.66539	1.67042
N-LAK8 713538.374	1.71300	53.83	0.013245	1.71616	53.61	0.013359	1.70668	1.70897	1.72297	1.72944	1.73545

CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC
1	0	1	1	1	9.6	476	640	2.50	480	1	1	0.965	37/34
1	0	1	1	1	6.5	578	661	3.11	540	2	1	0.964	37/33
1	0	1	2	1	7.3	558	711	2.61	600	2	1	0.957	37/34
1	0	1.2	1	1	5.8	653	801	3.53	570	3	1	0.954	37/33
2	3	52.2	2.2	3.2	6.8	645	751	3.71	590	5	1	0.900	38/34
1	0	1	1.3	1	7.2	616	742	3.27	570	3	1	0.880	39/35
3	2	53.3	3.3	4.3	7.1	618	716	3.84	600	5	0	0.943	37/30
3	2	52.3	1	3.3	5.6	643	717	3.75	740	2	0	0.943	37/30

KF
BALF
SSK
LAK

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}$-$n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-LAK9 691547.351	1.69100	54.71	0.012631	1.69401	54.48	0.012738	1.68497	1.68716	1.70051	1.70667	1.71239
N-LAK10 720506.368	1.72003	50.62	0.014224	1.72341	50.39	0.014357	1.71328	1.71572	1.73077	1.73779	1.74438
N-LAK12 678552.410	1.67790	55.20	0.012281	1.68083	54.92	0.012396	1.67209	1.67419	1.68717	1.69320	1.69882
LAKL12 678549.332	1.67790	54.92	0.012342	1.68084	54.69	0.012450	1.67201	1.67415	1.68720	1.69322	1.69882
N-LAK14 697554.363	1.69680	55.41	0.012575	1.69980	55.19	0.012679	1.69077	1.69297	1.70626	1.71237	1.71804
N-LAK21 640601.374	1.64049	60.10	0.010657	1.64304	59.86	0.010743	1.63538	1.63724	1.64850	1.65366	1.65844
N-LAK22 651559.376	1.65113	55.89	0.011650	1.65391	55.63	0.011755	1.64560	1.64760	1.65992	1.66562	1.67092
N-LAK33A 754523.421	1.75393	52.27	0.014424	1.75737	52.04	0.014554	1.74707	1.74956	1.76481	1.77187	1.77845
N-LAK34 729545.402	1.72916	54.50	0.013379	1.73235	54.27	0.013493	1.72277	1.72509	1.73923	1.74575	1.75180

CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC
3	3	52	1.2	4.3	6.3	656	722	3.51	700	3	0	0.950	37/30
2	2	52.3	1	3	5.7	636	714	3.69	780	2	0	0.900	39/34
3	1	53.3	3.3	4.3	7.6	614	714	4.10	560	6	1	0.940	37/31
3	3	53.3	2.2	3.3	6.8	636	764	3.32	700	2	0	0.953	37/30
3	2	52.3	1	3	5.5	661	734	3.63	730	2	0	0.940	37/29
4	2	53.2	4.3	4.3	6.8	639	716	3.74	600	5	0	0.950	37/31
2	2	51.2	1	2.3	6.6	689		3.77	600	4	0	0.964	36/30
1	1	51	1	2	5.8	669	744	4.22	740	2	0	0.940	38/30
1	0	52.3	1	3.3	5.8	668	740	4.02	740	2	0	0.952	37/28

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}$-$n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
LLF1 548458.294	1.54814	45.75	0.011981	1.55099	45.47	0.012118	1.54256	1.54457	1.55725	1.56333	1.56911
N-BAF3 583466.279	1.58272	46.64	0.012495	1.58569	46.35	0.012637	1.57689	1.57899	1.59222	1.59857	1.60463
N-BAF4 606437.288	1.60568	43.72	0.013853	1.60897	43.43	0.014021	1.59926	1.60157	1.61624	1.62336	1.63022
N-BAF10 670471.374	1.67003	47.11	0.014222	1.67341	46.83	0.014380	1.66339	1.66578	1.68083	1.68801	1.69480
N-BAF51 652450.333	1.65224	44.96	0.014507	1.65569	44.67	0.014677	1.64551	1.64792	1.66328	1.67065	1.67766
N-BAF52 609466.304	1.60863	46.60	0.013061	1.61173	46.30	0.013211	1.60254	1.60473	1.61856	1.62521	1.63157

CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC
1	0	1	2	1	8.1	414	628	2.94	450	3	1	0.993	33/31
1	0	1	1	1	7.2	583	714	2.79	560	2	1	0.900	39/35
1	0	1	1.2	1.3	7.2	580	709	2.89	610	3	1	0.870	39/35
1	0	4.3	1.3	1	6.2	660	790	3.75	620	4	1	0.880	39/35
2	0	5.4	1.3	1	8.4	569	712	3.33	560	5	1	0.890	39/34
1	0	1	1.3	1	6.9	594	723	3.05	600	3	1	0.880	39/35

LLF
BAF

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}$-$n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
LF5 581409.322	1.58144	40.85	0.014233	1.58482	40.57	0.014413	1.57489	1.57723	1.59231	1.59964	1.60668
N-F2 620364.265	1.62005	36.43	0.017020	1.62408	36.16	0.017258	1.61229	1.61506	1.63310	1.64209	1.65087
F2 620364.361	1.62004	36.37	0.017050	1.62408	36.11	0.017284	1.61227	1.61503	1.63310	1.64202	1.65064
F4 617366.358	1.61659	36.63	0.016834	1.62058	36.37	0.017064	1.60891	1.61165	1.62949	1.63828	1.64679
F5 603380.347	1.60342	38.03	0.015867	1.60718	37.77	0.016078	1.59616	1.59875	1.61556	1.62381	1.63176

CR	FR	SR	AR	PR	α	T_g	$T_{10}^{7.6}$	ρ	HK	HG	B	τ_i	FC
2	0	1	2.3	2	9.1	419	585	3.22	450	2	1	0.992	34/31
1	0	1	1	1	7.8	566	688	2.65	600	2	1	0.870	39/36
1	0	1	2.3	1.3	8.2	432	593	3.61	420	2	0	0.984	35/32
1	0	1	2.3	2	8.3	436	614	3.58	420	2	1	0.971	35/32
1	0	1	2.3	2	8.0	438	608	3.47	450	3	0	0.984	35/32

LF
F

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}$-$n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-BASF2 664360.315	1.66446	36.00	0.018457	1.66883	35.73	0.018720	1.65607	1.65905	1.67862	1.68838	1.69792
N-BASF64 704394.320	1.70400	39.38	0.017875	1.70824	39.12	0.018105	1.69578	1.69872	1.71765	1.72690	1.73581

CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC
1	0	1	1	1	7.1	619	766	3.15	580	3	1	0.750	41/36
1	0	3.2	1.2	1	7.3	582	712	3.20	650	4	0	0.820	40/35

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}$-$n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-LAF2 744449.429	1.74397	44.85	0.016588	1.74791	44.57	0.016780	1.73627	1.73903	1.75659	1.76500	1.77298
N-LAF3 717480.414	1.71700	47.96	0.014950	1.72055	47.68	0.015112	1.71001	1.71252	1.72834	1.73585	1.74293
N-LAF7 749348.373	1.74950	34.82	0.021525	1.75459	34.56	0.021833	1.73972	1.74320	1.76602	1.77741	1.78854
LAFN7 750350.438	1.74950	34.95	0.021445	1.75458	34.72	0.021735	1.73970	1.74319	1.76592	1.77713	1.78798
N-LAF21 788475.434	1.78800	47.49	0.016594	1.79195	47.24	0.016763	1.78019	1.78301	1.80056	1.80883	1.81659
N-LAF32 795455.432	1.79457	45.53	0.017453	1.79872	45.28	0.017640	1.78640	1.78934	1.80780	1.81656	1.82482
N-LAF33 786441.436	1.78582	44.05	0.017839	1.79007	43.80	0.018038	1.77751	1.78049	1.79937	1.80837	1.81687
N-LAF34 773496.424	1.77250	49.62	0.015568	1.77621	49.38	0.015719	1.76515	1.76780	1.78427	1.79196	1.79915
N-LAF35 743494.411	1.74330	49.40	0.015047	1.74688	49.16	0.015194	1.73620	1.73876	1.75467	1.76212	1.76908
N-LAF36 800424.443	1.79952	42.37	0.018871	1.80400	42.12	0.019090	1.79076	1.79390	1.81387	1.82345	1.83252

CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC
2	3	52.2	1	2.2	8.1	653	742	4.30	530	6	1	0.840	40/34
2	3	52.3	1.2	3.3	7.6	646	740	4.14	580	5	1	0.890	39/34
1	2	51.3	1.2	1.2	7.3	568	669	3.73	530	5	1	0.490	46/36
3	1	53.3	2.2	4.3	5.3	500	573	4.38	520	3	0	0.850	40/35
1	1	51.3	1	1.3	6.2	663	724	4.34	780	2	1	0.880	40/33
1	1	51.2	1	2	5.9	643		4.33	760	2	1	0.860	40/34
1	2	52.2	1	3	5.6	600	673	4.36	730	1	0	0.895	39/32
1	1	51.3	1	1	5.8	668	745	4.24	770	2	0	0.920	39/32
2	1	52.3	1	3.3	5.3	589	669	4.12	660	2	0	0.940	38/30
1	2	52.3	1	3.3	5.7	579	670	4.43	680	1	0	0.870	40/33

LAF

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}$-$n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
LASFN9 850322.444	1.85025	32.17	0.026430	1.85651	31.93	0.026827	1.83834	1.84256	1.87059	1.88467	1.89844
N-LASF31 881410.541	1.88067	41.01	0.021475	1.88577	40.76	0.021731	1.87074	1.87429	1.89702	1.90793	1.91824
N-LASF40 834373.454	1.83404	37.30	0.022363	1.83935	37.04	0.022658	1.82380	1.82745	1.85114	1.86275	1.87393
N-LASF41 835431.493	1.83501	43.13	0.019361	1.83961	42.88	0.019578	1.82599	1.82923	1.84972	1.85949	1.86872
N-LASF43 806406.426	1.80610	40.61	0.019850	1.81081	40.36	0.020089	1.79691	1.80020	1.82122	1.83137	1.84106
N-LASF44 804465.444	1.80420	46.50	0.017294	1.80832	46.25	0.017476	1.79609	1.79901	1.81731	1.82594	1.83405
N-LASF45 801350.362	1.80107	34.97	0.022905	1.80650	34.72	0.023227	1.79066	1.79436	1.81864	1.83068	1.84237
N-LASF46 901316.446	1.90138	31.64	0.028490	1.90811	31.41	0.028916	1.88851	1.89307	1.92329	1.93849	1.95341

LASF

CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC
2	0	2	1	1	7.4	698	825	4.44	630	4	1	0.563	*41/36
1	0	2	1	1	6.8	758		5.41	770	2	1	0.820	*38/32
1	1	51.2	1	2	5.8	585	673	4.55	690	1	0	0.750	*39/35
1	0	4	1	1	6.2	668	742	4.93	760	1	0	0.876	*37/32
1	1	51.3	1	2	5.5	614	699	4.26	720	1	1	0.810	42/34
1	1	4	1	1	6.2	655	742	4.44	770	1	0	0.910	40/31
1	0	3.2	1	1	7.4	647	773	3.63	630		0	0.680	44/35
1	0	3.3	1	1	6.0	638	735	4.46	730	1	0	0.140	*46/38

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}$-$n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-SF1 717296.302	1.71736	29.62	0.024219	1.72308	29.39	0.024606	1.70651	1.71035	1.73605	1.74919	1.76224
SF1 717295.446	1.71736	29.51	0.024307	1.72310	29.29	0.024687	1.70647	1.71031	1.73610	1.74916	1.76201
SF2 648338.386	1.64769	33.85	0.019135	1.65222	33.60	0.019412	1.63902	1.64210	1.66238	1.67249	1.68233
N-SF4 755274.314	1.75513	27.38	0.027583	1.76164	27.16	0.028044	1.74286	1.74719	1.77647	1.79158	1.80668
SF4 755276.479	1.75520	27.58	0.027383	1.76167	27.37	0.027829	1.74300	1.74730	1.77636	1.79121	1.80589
N-SF5 673323.285	1.67271	32.25	0.020858	1.67763	32.00	0.021177	1.66330	1.66664	1.68876	1.69998	1.71106
SF5 673322.407	1.67270	32.21	0.020885	1.67764	31.97	0.021195	1.66327	1.66661	1.68876	1.69986	1.71069
N-SF6 805254.337	1.80518	25.36	0.031750	1.81266	25.16	0.032304	1.79114	1.79608	1.82980	1.84738	1.86506
SF6 805254.518	1.80518	25.43	0.031660	1.81265	25.24	0.032201	1.79117	1.79609	1.82970	1.84707	1.86436
N-SF8 689313.290	1.68894	31.31	0.022005	1.69413	31.06	0.022346	1.67904	1.68254	1.70589	1.71775	1.72948
N-SF10 728285.305	1.72828	28.53	0.025524	1.73430	28.31	0.025941	1.71688	1.72091	1.74800	1.76191	1.77578

CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC
1	0	1	1	1	9.1	553	660	3.03	540	5	1	0.700	41/36
2	1	3.2	2.3	3	8.1	417	566	4.46	390	1	1	0.920	39/34
1	0	2	2.3	2	8.4	441	600	3.86	410	2	0	0.954	37/33
1	0	1.3	1	1	9.5	570	661	3.15	520	6	1	0.550	44/37
1	2	4.3	2.3	3.3	8.0	420	552	4.79	390	1	1	0.890	40/35
1	0	1	1	1	7.9	578	693	2.86	620	3	1	0.780	40/36
1	1	2	2.3	3	8.2	425	580	4.07	410	2	1	0.950	37/33
1	0	2	1	1	9.0	594	694	3.37	550	4	1	0.570	45/37
2	3	51.3	2.3	3.3	8.1	423	538	5.18	370	1	0	0.790	42/37
1	0	1	1	1	8.6	567	678	2.90	600	4	1	0.770	41/36
1	0	1	1	1	9.4	559	652	3.05	540	5	1	0.640	42/36

SF

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}$-$n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
SF10 728284.428	1.72825	28.41	0.025633	1.73430	28.19	0.026051	1.71681	1.72085	1.74805	1.76198	1.77579
SF11 785258.474	1.78472	25.76	0.030467	1.79190	25.55	0.030997	1.77125	1.77599	1.80834	1.82518	1.84208
SF14 762265.454	1.76182	26.53	0.028719	1.76859	26.31	0.029211	1.74910	1.75357	1.78407	1.79989	1.81573
N-SF15 699302.292	1.69892	30.20	0.023142	1.70438	29.96	0.023511	1.68854	1.69222	1.71677	1.72933	1.74182
SF15 699301.406	1.69895	30.07	0.023246	1.70444	29.83	0.023612	1.68853	1.69221	1.71688	1.72940	1.74176
N-SF19 667331.290	1.66679	33.12	0.020131	1.67154	32.86	0.020435	1.65769	1.66092	1.68228	1.69309	1.70377
N-SF56 785261.328	1.78470	26.10	0.030071	1.79179	25.89	0.030587	1.77137	1.77607	1.80800	1.82460	1.84126
SF56A 785261.492	1.78470	26.08	0.030092	1.79180	25.87	0.030603	1.77136	1.77605	1.80800	1.82449	1.84092
SFL57 847236.355	1.84666	23.62	0.035841	1.85510	23.43	0.036489	1.83089	1.83643	1.87451	1.89456	1.91488
N-SF57 847238.353	1.84666	23.78	0.035604	1.85504	23.59	0.036247	1.83099	1.83650	1.87432	1.89423	1.91440
SF57 847238.551	1.84666	23.83	0.035536	1.85504	23.64	0.036166	1.83102	1.83650	1.87425	1.89393	1.91366

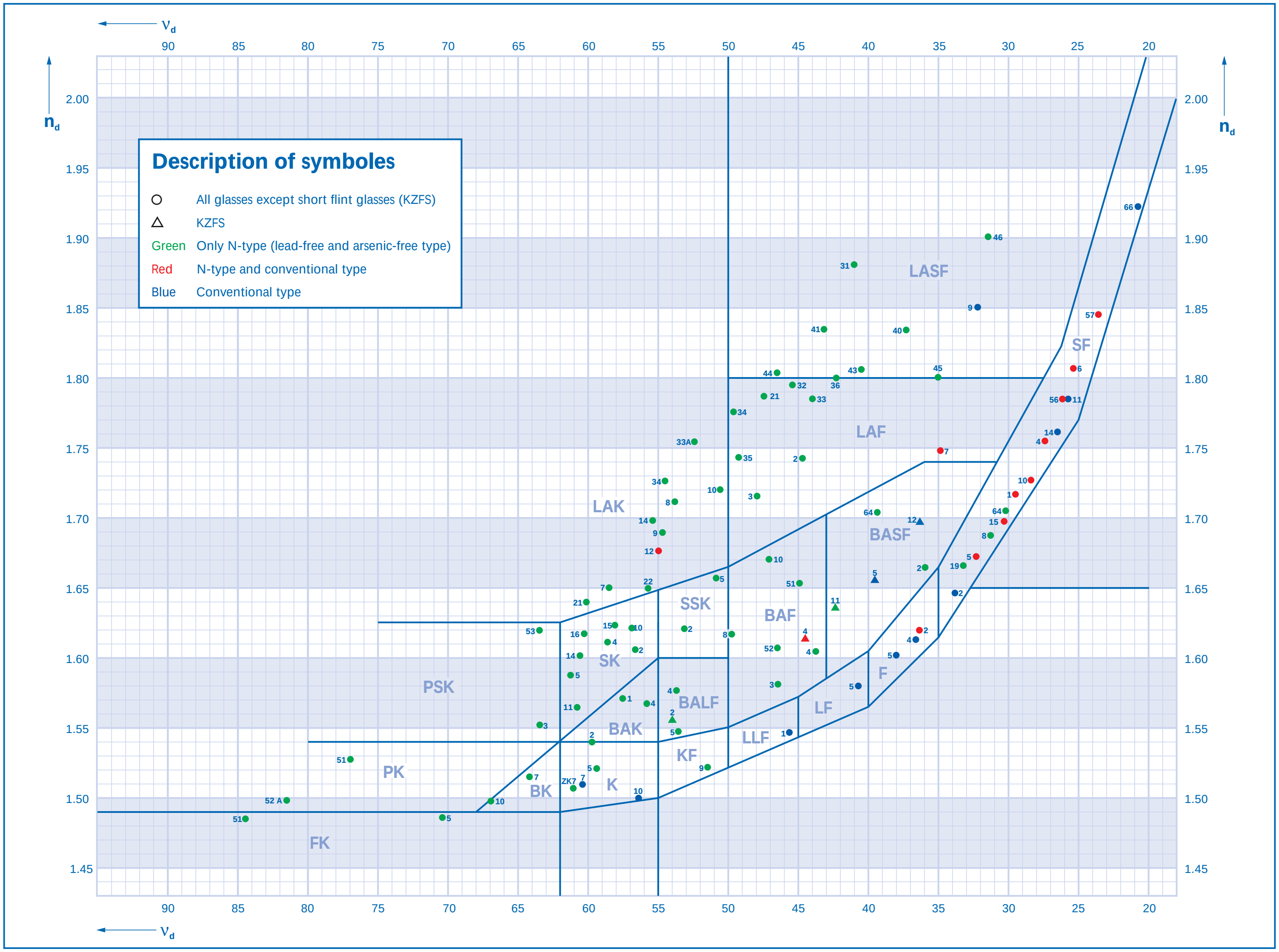
CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC
1	0	1	1.2	2	7.5	454	595	4.28	430	1	0	0.690	41/37
1	0	1	1.2	1	6.1	503	635	4.74	450	1	1	0.200	44/39
1	0	1	1.2	1	6.6	478	617	4.54	430	1	1	0.280	43/38
1	0	1	1	1	8.0	580	692	2.92	610	3	1	0.680	42/37
1	0	1	1.2	2.3	7.9	455	595	4.06	420	2	1	0.780	40/37
1	0	1	1.2	1	7.2	598	707	2.90	630	3	1	0.770	40/36
1	0	1	1.3	1	8.7	592	691	3.28	560	5	1	0.570	44/37
1	1	3.2	2.2	3.2	7.9	429	556	4.92	380	1	1	0.680	42/37
1	0	1.3	1	1.3	8.7	598	700	3.55	580	3	1	0.200	*44/38
1	0	1	1	1	8.5	629	716	3.53	520	4	1	0.460	*42/37
2	5	52.3	2.3	4.3	8.3	414	519	5.51	350	1	0	0.660	*40/37

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}-n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-SF64 706302.298	1.70591	30.23	0.023350	1.71142	29.99	0.023720	1.69544	1.69914	1.72392	1.73657	1.74912
SF66 923209.602	1.92286	20.88	0.044189	1.93325	20.73	0.045030	1.90361	1.91033	1.95730	1.98229	2.00775

CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC
1	0	1	1.2	1	8.5	572	688	2.99	620	4	1	0.670	42/37
2	5	53.4	2.3	4.2	9.0	384	482	6.03	310	2	1	0.240	*42/38

Glass type	n_d	ν_d	n_F-n_C	n_e	ν_e	$n_{F'}$-$n_{C'}$	n_r	n_C	$n_{F'}$	n_g	n_h
N-KZFS2 558540.255	1.55836	54.01	0.010338	1.56082	53.83	0.010418	1.55337	1.55519	1.56612	1.57114	1.57580
N-KZFS4 613445.300	1.61336	44.49	0.013785	1.61664	44.27	0.013929	1.60688	1.60922	1.62380	1.63071	1.63723
KZFSN4 613443.320	1.61340	44.29	0.013848	1.61669	44.07	0.013994	1.60689	1.60924	1.62389	1.63085	1.63745
KZFSN5 654396.346	1.65412	39.63	0.016507	1.65803	39.40	0.016701	1.64644	1.64920	1.66668	1.67512	1.68319
N-KZFS11 638424.319	1.63775	42.41	0.015038	1.64132	42.20	0.015198	1.63069	1.63324	1.64915	1.65670	1.66385
KZFS12 696363.383	1.69600	36.29	0.019179	1.70055	36.06	0.019425	1.68717	1.69033	1.71065	1.72059	1.73017

CR	FR	SR	AR	PR	α	T_g	$T_{10^{7.6}}$	ρ	HK	HG	B	τ_i	FC
1	4	52.3	4.3	4.2	4.4	491	600	2.55	490	3	1	0.963	34/30
1	1	3.4	1.2	1	7.3	547	675	3.00	520	3	1	0.948	36/32
3	2	52.3	4.3	4.3	4.5	492	594	3.20	450	5	1	0.974	36/30
3	2	52.3	4.3	4.3	4.5	501		3.46	460	5	1	0.940	37/34
1	1	3.4	1	1	6.6	551		3.20	530	3	1	0.968	36/30
4	1	53.3	4.3	4.3	5.2	492	549	3.84	440	4	1	0.810	40/35



Version 1.5 · 06/2003

Abbe-Diagram

SCHOTT
glass made of ideas