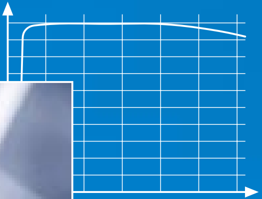
Optical Glass

Description of properties



SCHOTT
glass made of ideas

UNTERNEHMENSBEREICH OPTIK GESCHÄFTSBEREICH OPTIK POCKET CATALOGUE

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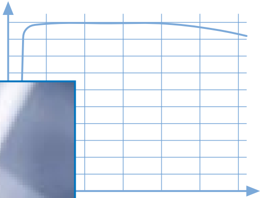

SCHOTT

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Foreword

We present herewith a completely reworked edition of our pocket catalog of optical glasses. This pocket catalog provides an excerpt of the important properties of the optical glasses from our main catalog, which will only be published on CD* or on the internet.

The focal point of our product line is 112 glass types, of which we are providing data for 105 types in this first edition. The additional 7 glasses will follow over the next several months. Increased efforts in environmental protection, along with close cooperation with our customers have led to the new development of 84 lead- and arsenic-free glasses. To round out the product line, we will offer a number of glass types in both lead-containing and lead-free versions.

We improved the actualized edition in many places; for example, we have added information on the grindability of optical glasses. New too is the nine-digit glass code that, in addition to the 6 positions for n_d and ν_d, also includes an additional 3 positions for density to distinguish between lead-containing and lead-free glasses.

* CD Catalog, Version 1.1, 06/2000

1. Optical Properties

1.1 Refractive Index, Abbe Value, 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 value $\nu_d = (n_d-1)/(n_F-n_C)$ as a measure for dispersion. The difference n_F-n_C is called the principal dispersion.

In specifying optical components the units 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 Value

The tolerances for the refractive index and Abbe value 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 the 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	ν_d
Step 4	–	± 0.8%
Step 3	± 0.0005	± 0.5%
Step 2	± 0.0003	± 0.3%
Step 1	± 0.0002	± 0.2%

Table 1.2: Tolerances for refractive index and Abbe value.

All deliveries of fine annealed block glass and fabricated glass are from partial lots from melts that we designate as groups. The groups are arranged based on refractive index scattering from glass unit to glass unit and are identified by a melt number and a group number.

All parts of a group 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 groups with limited refractive index scattering. See Table 1.3 for the tolerances.

		Pressings	
	Refractive Index Scattering	All Scattering Tolerances for Pressings Upon Request Only	Refractive Index Scattering
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 scattering within a group and within a pressings group.

1.3 Test Certificates for Refractive Indices and Dispersions

1.3.1 Standard Test Certificates

We provide standard test certificates for all deliveries of fine annealed optical glass. The information they contain refers to the average position of the optical values of a group, which is identified by its melt number and group number. The value of the individual parts may deviate by the scattering tolerance of the information.

The measurements are done using a procedure that has a tolerance 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 certificates.

Test certificates with higher 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 certificates for standard accuracy, but the dispersion data are given to 6 decimal places. The values apply for an air pressure of 0.10133 x 10^{6} Pa. The measurement is done on a prism goniometer.

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

With an increased sample and measurement cost the refractive indices can be determined to an accuracy of ± 5 x 10^{-6} and the dispersion to ± 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 used 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 refractive index homogeneity achievable 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 4 classes in accordance with ISO Standard 10110 Part 4 (see Table 1.5). For classes 0 and 1 of the standard, please refer to the scattering tolerances in section 1.2.

Homogeneity Class	Maximum Deviation of Refractive Index	Applicability, Deliverability
H 2	$\pm 5 \times 10^{-6}$	For individual pieces of fabricated glass
H 3	$\pm 2 \times 10^{-6}$	For individual pieces of fabricated glass, not in all dimensions
H 4	$\pm 1 \times 10^{-6}$	For individual pieces of fabricated glass, not in all dimensions, not for all glass types
H 5	$\pm 5 \times 10^{-7}$	For individual pieces of fabricated 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 transmission 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 costly 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 deviations in the purity of the raw materials must be taken into account. SCHOTT maintains a minimum standard for the related deviations in internal transmittance of the glasses melted.

The information in the data section comprises average 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 of lead- and arsenic-free glasses, in which lead has been replaced by other chemical elements, is markedly less than in the lead-containing predecessor glasses.
In the case of high requirements for internal transmittance in the violet and ultraviolet spectral range, the classical glasses that remain in the product line may be used.
The internal transmittance at 400 nm for a sample thickness of 25 mm is listed in the data section.

The limit of the transmission ranges of optical glasses towards the UV area is of special interest in high index glasses because, with increasing refractive index, shift closer to the visible spectral range. 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 transmission (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 one position. Color code 33/30 means, for example λ_{80} = 330 nm and λ_5 = 300 nm.

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 recently released 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. In so doing, it only considers striae that deform an even 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 normally 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 determinable 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 compositions and manufacturing processes.

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 ≥ 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 Color Cubes 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 VB**	**B0 EVB**	**B0**	**B1 VB**	**B1 EVB**	**B1**
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)]	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 stresses in glasses depends on the annealing conditions (for example, annealing speed and temperature distribution around the object being annealed), the glass type, and the dimensions. The stresses cause birefringence that is dependent upon 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 done 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 that we can use to measure an order of magnitude more accurately.

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 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, but they may not limit mechanical processing.

	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 Performance

3.1 Standard Delivery Performance

If no special quality steps are requested, the glass will be delivered in refractive index/Abbe value step 3/4 with a standard test certificate. The standard test certificate refers to a refractive index group that is identified by its melt number and group number. The refractive indices of all parts belonging to a group will not deviate by more than ± 1 x 10^{-4} (± 2 x 10^{-4} for pressings, if requested). The glass is tested for bubbles and inclusions, striae, and stress birefringence.

3.2 Increased Delivery Performance

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 value steps	Suitable for 2-1 3-1	2-1 3-1	2-1 3-1	2-1 3-1
Test certificates	Annealing procedure	Standard (S)	Standard (S)	Standard (S)
Measurement accuracy, measurement ranges	With data on the annealing rates for the achievable refractive index – Abbe value steps after fine annealing	Standard with increased accuracy (SE)	If a scattering tolerance is requested	Standard with increased 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	–	VS1, VS2	–	VS1, VS2
Bubbles/inclusions	–	VB	VB	VB, EVB
Remarks		At least one surface is worked		Striae and homogeneity measured in the same direction

Table 12: Possible 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 that you 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.
At least one surface is worked as a rule.
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 are 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]	Allowable 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 13: Dimensional tolerances and minimum dimensions for plates.

We achieve surface roughness of R_t = 20 – 25 µm with standard processing. Plates having much 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]	Allowable 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 14: Dimensional tolerances and minimum dimensions for round plates.

We achieve surface roughness of R_t = 20 – 25 µm with standard processing.
Round plates having much 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 15: Dimensions and tolerances for worked rods in the 6 – 80 mm diameter range.

4.2.4 Milled Blanks

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

The dimensional tolerances correspond to at least the tolerances of pressings with surface roughness of R_t = 20 – 25 µm.

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 16: 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, production of direct pressings may make economic sense. We will discuss specifications upon request.

5. Optical Properties, Theoretical Explanations

For this information we refer you to our catalog on CD-ROM that contains detailed information on the subject.

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), Distribution 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 subjected 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 conducted 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 subjected 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: Distribution of the optical glasses into climatic resistance classes CR 1 – 4.

caution because these glasses are very sensitive to climatic influences.

For storage of optically polished elements we recommend the application of protective coatings and/or assuring that the relative humidity be kept as low as possible.

6.2 Stain Resistance, Distribution 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 as the glass can form layers at all.

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

Table 6.2: Distribution 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), Distribution 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 2 or 3 digit number. The first or the first two digits indicate the acid resistance class SR. The last digit (separated by a period 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. Included in it are 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	0.3	0.3	0.3	0.3	0.3	4.6	4.6	4.6	4.6
Time (h)	>100	10-100	1-10	0.1-1	<0.1	>10	1-10	0.1-1	<0.1

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

6.4 Alkali Resistance (ISO 10629), Distribution into Alkali Resistance Classes AR 1–4 Phosphate Resistance (ISO 9689), Distribution 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 is based on 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 is based on the time required to remove a layer thickness of glass of 0.1 mm 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: Distribution 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 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 residual surface changes after the application of 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 was 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 Particles According to ISO DFIS 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 samples are compared by weighing the samples and considering the density of the removed volume of the glass with that of a reference glass, N-SK 16.

The classification occurs according to the following scheme.

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-SK 16.

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 $T_{10^{7.6}}$ identifies the plastic range in which glass parts rapidly deform under their own weight. This is the temperature 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 stresses in glass equalized in ca. 15 minutes. The temperature at which the viscosity of glass is 10^{13} dPa·s is called the upper annealing point $T_{10^{13}}$. It 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 at an absolute zero point begins 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 (see the data sheet in the CD-ROM catalog).

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; the degree of accuracy is ±5%.

8.2 Specific Thermal Capacity

The mean isobaric specific heat capacity c_ρ (20 °C; 100 °C) is listed for a portion of the 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_ρ (20 °C; 100 °C) and also for the true thermal capacity c_ρ (20 °C) for silicate glasses is between 0.42 and 0.84 J/(g·K).

The data on thermal properties are contained in the CD-ROM catalog.

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

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

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

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

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

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

Deviation ΔP from the "normal lines"

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

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

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

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

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

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

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

Sellmeier Dispersion Formula

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

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

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

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

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

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 value, depending on the glass type
m_{nF-nC}	Annealing coefficient for the principal dispersion, dependent on the glass type

Measurement Accuracy of the Abbe Value

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

Spectral Internal Transmittance

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

Spectral Transmission

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

P_{λ} Reflection factor

Fresnel Reflectivity for a light beam perpendicularly striking the surface, independent of polarization

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

Reflection Factor Considering Multiple Reflections

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

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

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

Stress Birefringence, change in optical path

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

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

$$\Delta n = \Delta W / (2 \cdot d) \qquad (9.22)$$

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

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 value ν_d with density
n_x, ν_x, $n_x - n_y$	–	Refractive index, Abbe value, 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 $T_{10}{}^{7.6}$ 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 and 0.05; glass thickness 10 mm (JOGIS)

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. They are produced upon specific customer demand. When ordering, a complete melt must be taken. The minimum melting quantity primarily depends upon the melting method and the glass type. Delivery times and specifications are individually determined upon 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.

The minimum order quantity for preferred articles is 1 block or strips, which can be shipped within one week, depending on the order quantity.

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 for specific customer orders.

11.5 Preferred Product Line

Information on the current preferred product line is contained in the CD-ROM.

11.6 Comparison Table of Optical Glasses

The following comparison table gives an overview of the preferred glasses from Schott, Hoya, and Ohara. The glass types are listed in order of increasing refractive index.

Schott		Hoya		Ohara	
Code	Glass type	Code	Glass type	Code	Glass type
434950	N-FK56				
				439950	S-FPL53
				456903	S-FPL52
487704	N-FK5	487704	FC5	487702	S-FSL5
487845	N-FK51				
497816	N-PK52	497816	FCD1	497816	S-FPL51
498670	N-BK10				
501564	K10				
508612	N-ZK7				
511604	K7				
		517522	CF6		
		517524	E-CF6	517524	S-NSL36
517642	N-BK7	517642	BSC7	516641	S-BSL7
				517696	S-APL1
		518590	E-C3	518590	S-NSL3
				521526	SSL5
522595	N-K5				
				522598	S-NSL5
523515	N-KF9				
				529517	SSL2

Schott		Hoya		Ohara	
Code	Glass type	Code	Glass type	Code	Glass type
529770	N-PK51				
		532488	FEL6		
532488	N-LLF6	532489	E-FEL6	532489	S-TIL6
540597	N-BAK2			540595	S-BAL12
		541472	E-FEL2	541472	S-TIL2
		541472	FEL2		
547536	N-BALF5				
548458	LLF1	548458	FEL1		
548458	N-LLF1	548458	E-FEL1	548458	S-TIL1
		551496	SbF1		
552635	N-PSK3				
558542	N-KZFS2				
				560612	S-BAL50
564608	N-SK11	564607	E-BaCD11	564607	S-BAL41
		567428	FL6	567428	PBL26
569561	N-BAK4	569563	BaC4	569563	S-BAL14
569713	N-PSK58				
				571508	S-BAL2
				571530	S-BAL3
573576	N-BAK1			573578	S-BAL11

Schott		Hoya		Ohara	
Code	Glass type	Code	Glass type	Code	Glass type
				575415	S-TIL27
580537	N-BALF4				
581409	N-LF5	581407	E-FL5	581407	S-TIL25
581409	LF5	581409	FL5		
583465	N-BAF3			583464	BAM3
		583594	BaCD12	583594	S-BAL42
589613	N-SK5	589613	BaCD5	589612	S-BAL35
592683	N-PSK57				
				593353	S-FTM16
		594355	FF5		
		596392	E-F8	596392	S-TIM8
		596392	F8		
		603380	E-F5	603380	S-TIM5
603380	F5			603380	F5
603606	N-SK14	603606	BaCD14	603607	S-BSM14
				603655	S-PHM53
606439	N-BAF4			606437	S-BAM4
607567	N-SK2	607568	BaCD2	607568	S-BSM2
609464	N-BAF52				
		613370	F3	613370	PBM3

Schott		Hoya		Ohara	
Code	Glass type	Code	Glass type	Code	Glass type
613443	KZFSN4	613443	ADF10	613443	BPM51
613445	N-KZFS4				
613586	N-SK4	613587	BaCD4	613587	S-BSM4
				614550	BSM9
617366	F4				
				617628	S-PHM51
618498	N-SSK8			618498	S-BSM28
		618634	PCD4	618634	S-PHM52
620364	N-F2	620363	E-F2	620363	S-TIM2
620364	F2	620364	F2		
620603	N-SK16	620603	BaCD16	620603	S-BSM16
		620622	ADC1		
620635	N-PSK53				
				621359	TIM11
621603	SK51				
				622532	BSM22
622532	N-SSK2				
623569	N-SK10	623570	E-BaCD10	623570	S-BSM10
623580	N-SK15	623582	BaCD15	623582	S-BSM15
		624470	BaF8		

Schott		Hoya		Ohara	
Code	Glass type	Code	Glass type	Code	Glass type
		626357	F1		
		626357	E-F1	626357	S-TIM1
639421	N-KZFS11				
				639449	S-BAM12
639554	N-SK18	639554	BaCD18	639554	S-BSM18
		640345	E-FD7	640345	S-TIM27
640601	N-LAK21	640601	LaCL60	640601	S-BSM81
				641569	S-BSM93
				643584	S-BSM36
648339	SF2	648339	FD2		
		648338	E-FD2	648338	S-TIM22
		649530	E-BaCED20	649530	S-BSM71
651559	N-LAK22				
		651562	LaCL2	651562	S-LAL54
652449	N-BAF51				
652585	N-LAK7	652585	LaC7	652585	S-LAL7
654396	KZFSN5	654396	ADF50	654397	BPH5
658509	N-SSK5	658509	BaCED5	658509	S-BSM25
				658573	S-LAL11
664360	N-BASF2				

Schott		Hoya		Ohara	
Code	Glass type	Code	Glass type	Code	Glass type
				667330	S-TIM39
		667484	BaF11	667483	S-BAH11
				670393	BAH32
670471	N-BAF10			670473	S-BAH10
		670473	BaF10		
				670573	S-LAL52
673322	N-SF5	673321	E-FD5	673321	S-TIM25
673322	SF5	673322	FD5		
		678507	LaCL9	678507	S-LAL56
678549	LAKL12				
678552	N-LAK12	678553	LaC12	678553	S-LAL12
689312	N-SF8	689311	E-FD8	689311	S-TIM28
		689312	FD8		
691547	N-LAK9	691548	LaC9	691548	S-LAL9
		694508	LaCL5	694508	LAL58
694533	LAKN13	694532	LaC13	694532	S-LAL13
				695422	S-BAH54
		697485	LaFL2	697485	LAM59
697554	N-LAK14	697555	LaC14	697555	S-LAL14
				697565	S-LAL64

Schott		Hoya		Ohara	
Code	Glass type	Code	Glass type	Code	Glass type
699301	N-SF15	699301	E-FD15	699301	S-TIM35
699301	SF15	699301	FD15		
				700481	S-LAM51
		702412	BaFD7	702412	S-BAH27
704394	N-BASF64				
706303	N-SF64				
713538	N-LAK8	713539	LaC8	713539	S-LAL8
717295	N-SF1	717295	E-FD1		
717295	SF1	717295	FD1	717295	PBH1
717480	N-LAF3	717480	LaF3	717479	S-LAM3
				720347	BPH8
				720420	LAM58
				720437	S-LAM52
				720460	LAM61
720506	N-LAK10	720504	LaC10	720502	S-LAL10
				722292	S-TIH18
724381	N-BASF51			723380	S-BAH28
724381	BASF51	724381	BaFD8		
				726536	S-LAL60
728284	SF10	728284	FD10		

Schott		Hoya		Ohara	
Code	Glass type	Code	Glass type	Code	Glass type
728285	N-SF10	728285	E-FD10	728285	S-TIH10
729547	N-LAK34	729547	TaC8	729547	S-LAL18
		734515	TaC4	734515	S-LAL59
				740283	PBH3W
		741276	FD13	740283	PBH3
		741278	E-FD13	741278	S-TIH13
		741527	TaC2	741527	S-LAL61
743492	N-LAF35	743493	NbF1	743493	S-LAM60
744447	N-LAF2	744447	LaF2	744448	S-LAM2
750350	LaFN7	750353	LaF7	750353	LAM7
750350	N-LAF7				
754524	N-LAK33	755523	TaC6	755523	S-YGH51
755276	N-SF4	755275	E-FD4	755275	S-TIH4
755276	SF4	755276	FD4		
				756251	TPH55
		757478	NbF2	757478	S-LAM54
762265	N-SF14	762265	FD140	762265	S-TIH14
762265	SF14	762266	FD14		
				762401	S-LAM55
772496	N-LAF34	772496	TaF1	772496	S-LAH66

Schott		Hoya		Ohara	
Code	Glass type	Code	Glass type	Code	Glass type
785258	SF11	785258	FD11		
		785258	FD110	785257	S-TIH11
785261	SF56A				
785261	N-SF56	785261	FDS30	785263	S-TIH23
786441	N-LAF33	786439	NBFD11	786442	S-LAH51
				787500	S-YGH52
788475	N-LAF21	788475	TAF4	788474	S-LAH64
794454	N-LAF32			795453	S-LAH67
800423	N-LAF36	800423	NBFD12	800422	S-LAH52
801350	N-LASF45			801350	S-LAM66
				804396	S-LAH63
804466	N-LASF44	804465	TAF3	804466	S-LAH65
805254	N-SF6	805254	FD60	805254	S-TIH6
805254	SF6	805254	FD6		
		805396	NBFD3		
		806333	NBFD15		
806407	N-LASF43	806407	NBFD13	806409	S-LAH53
				808228	S-NPH1
		816445	TAFD10	816444	S-LAH54
		816466	TAF5	816466	S-LAH59

Schott		Hoya		Ohara	
Code	Glass type	Code	Glass type	Code	Glass type
834374	N-LASF40	834373	NBFD10	834372	S-LAH60
835430	N-LASF41	835430	TAFD5	835427	S-LAH55
847238	N-SF57	847238	FDS90	847238	S-TIH53
847236	SFL57				
847238	SF57	847238	FDS9	847238	TIH53
850322	LASFN9				
				874353	S-LAH75
881410	N-LASF31				
		883408	TAFD30	883408	S-LAH58
901315	N-LASF46			901315	LAH78
923209	SF66	923209	E-FDS1		
				923213	PBH71
				1003283	S-LAH79
1022291	N-LASF35				

Tab. 11.6: Comparison table of preferred glasses

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