OPTICAL GLASS

Technical Information

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Preface

OHARA GmbH is pleased to present our updated optical glass catalogue. Our newest version replaces our previous catalogue which was published in 1996. In our current publication we have basically concentrated on our range of 175 recommended glass types.

We hope you will enjoy the design and format of our new catalogue and look forward to serving your optical glass requirements. We would like to hear from you.

Table of Contents

1. Designation of Optical Glass Types

In the course of OHARA's long history, many types of optical glasses have been developed. In this catalogue, you will find 175 glasses that we have selected as our "recommended glass types". Each optical glass has its own properties that are closely connected with the key chemical element contained.

With this in mind, we have developed a new glass type designation system. Our new names are used in this catalogue.

On the n_d – ν_d diagram provided in this catalogue, you will see we have divided our glasses into groups. For each glass type, we have selected one or two chemical elements contained which are considered the most important and have used the symbols of these for the first two letters of the glass type designation. The third letter of the glass type designation refers to the refractive index of each glass type within its glass group: H, M or L for high, middle or low. Lastly, we assign a one or two digit number to each glass type within a given glass family. Thus, each glass type is represented by the above mentioned three letters plus a one or two digit number.

We are also adding the prefix "S-" to indicate which of the glass types are ECO optical glasses and are environmentally "Safe". These glass types do not contain any lead or arsenic.

For example, the glass type designation for S-BSL7 is composed as follows:

S-	stands for environmentally Safe
B	represents Boron, one of the key compositional elements
S	represents Silicon, one of the key compositional elements
L	indicates a Low index within the BS glass group
7	indicates this is the 7^{th} glass within this glass family

Along with OHARA's glass type designation, the technical data sheet will show the six-digit code for each glass type. For your convenience we have included both the n_d/ν_d (in bold type) and $n_{e/}\nu_e$ codes. These six-digit codes are internationally recognized within the optical community.

2. Optical Properties

2.1 Refractive Index

The refractive indices listed in this catalogue were determined to the fifth decimal place for the following 20 lines of the spectrum. The refractive indices for d-line (587.56 nm) and e-line (546.07 nm) were determined to the sixth decimal place.

Spectral Line Symbol					t	s	A'	r	C	C'
Light Source	Hg	Hg	Hg	Hg	Hg	Cs	K	He	H	Cd
Wavelength (nm)	2325.42	1970.09	1529.58	1128.64	1013.98	852.11	768.19	706.52	656.27	643.85
Spectral Line Symbol	He-Ne	D	D	e	F	F'	He-Cd	g	h	i
Light Source	Laser	Na	He	Hg	H	Cd	Laser	Hg	Hg	Hg
Wavelength (nm)	632.8	589.29	587.56	546.07	486.13	479.99	441.57	435.835	404.656	365.015

Table 1

The catalogue technical data sheets give the wavelength of each line in μm units next to the corresponding spectrum line symbol.

Please note that all the Ohara refractive index measurements are taken under a room-temperature of 25 degree Celsius.

2.2 Dispersion

We have indicated n_F - n_C and $n_{F'}$ - $n_{C'}$ as the main dispersion. Abbe numbers were determined from the following ν_d and ν_e formula and calculated to the second decimal place:

$$\nu_d = \frac{n_d - 1}{n_F - n_C} \qquad \nu_e = \frac{n_e - 1}{n_{F'} - n_{C'}}$$

We have also listed 12 partial dispersions (n_x-n_y), 8 relative partial dispersions for the main dispersion n_F - n_C and 4 for $n_{F'}$ - $n_{C'}$.

To make achromatization effective for more than two wavelengths, glasses which have favourable relationships between ν_d and the relative partial dispersion $\theta_{x,y}$ for the wavelengths x and y are required. These may be defined as follows:

$$\theta_{x,y} = \frac{n_x - n_y}{n_F - n_C}$$

2.3 Dispersion Formula

The refractive indices for wavelengths other than those listed in this catalogue can be computed from a dispersion formula. As a practical dispersion formula, we have adopted the use of the Sellmeier formula shown below.

$$n^2 - 1 = \frac{A_1 \lambda^2}{\lambda^2 - B_1} + \frac{A_2 \lambda^2}{\lambda^2 - B_2} + \frac{A_3 \lambda^2}{\lambda^2 - B_3}$$

The constants A_1, A_2, A_3, B_1, B_2, B_3 were computed by the method of least squares on the basis of refractive indices at standard wavelengths, which were measured accurately from several melt samples.

By using this formula, refractive indices for any wavelength between 365 nm and 2325 nm can be calculated to have an accuracy of approximately $\pm 5 \times 10^{-6}$. These constants A_1, A_2, A_3, B_1, B_2, B_3 are listed on the left side of the individual catalogue pages. However, for some glass types, not all refractive indices in the standard spectral range are listed on the data sheet.

In such cases, the applicable scope of this dispersion formula is limited to the given refractive indices.

When calculating a respective refractive index, please bear in mind that each wavelength is expressed in μm units.

2.4 Effect of Temperature on Refractive Index (dn/dT)

Refractive Index is affected by changes in glass temperature (see Fig. 1). This can be ascertained through the temperature coefficient of refractive index. The temperature coefficient of refractive index is defined as dn/dT from the curve showing the relationship between glass temperature and refractive index. The temperature coefficient of refractive index (for light of a given wavelength) changes with wavelength and temperature. Therefore, the Abbe number also changes with temperature.

There are two ways of showing the temperature coefficient of refractive index. One is the absolute coefficient ($dn/dT_{absolute}$) measured under vacuum and the other is the relative coefficient ($dn/dT_{relative}$) measured at ambient air (101.3 kPa {760 torr} dry air).

Figures of the relative coefficients are listed in this catalogue.

The temperature coefficients of refractive index dn/dt were determined by measuring the refractive index from –40°C to +80°C at wavelengths of 1,013.98 nm (t), 643.85 nm (C'), 632.8 nm (He-Ne laser), 589.29 nm (D), 546.07 nm (e), 479.99 nm (F') and 435.835 nm (g). These measurements are shown in the temperature range from –40°C to + 80°C in 20°C intervals, and are listed in the lower part of each catalogue page.

The absolute temperature coefficient of refractive index ($dn/dT_{absolute}$) can be calculated using the following formula:

$$\frac{dn}{dT}_{absolute} = \frac{dn}{dT}_{relative} + n \cdot \frac{dn_{air}}{dT}$$

dn_{air}/dT is the temperature coefficient of refractive index of air listed in table 2.

Temperature Range (°C)	dn_{air}/dT ($x10^{-6}$/°C)						
	t	C'	He-Ne	D	e	F'	g
-40 ~ -20	-1.34	-1.35	-1.36	-1.36	-1.36	-1.37	-1.38
-20 ~ 0	-1.15	-1.16	-1.16	-1.16	-1.16	-1.17	-1.17
0 ~ +20	-0.99	-1.00	-1.00	-1.00	-1.00	-1.01	-1.01
+20 ~ +40	-0.86	-0.87	-0.87	-0.87	-0.87	-0.88	-0.88
+40 ~ +60	-0.76	-0.77	-0.77	-0.77	-0.77	-0.77	-0.78
+60 ~ +80	-0.67	-0.68	-0.68	-0.68	-0.68	-0.69	-0.69

Table 2

2.5 Refractive Indices in Ultraviolet and Infrared Range

The refractive indices in the ultraviolet and infrared can be measured down to 157 nm in the ultraviolet and up to 2,325.42 nm in the infrared.

2.6 Internal Transmittance (τ_i)

Most types of OHARA optical glass are transparent and colourless because they are composed of very pure materials. However, some optical glasses show remarkable absorption of light near the ultraviolet spectral range. For certain glasses with extreme optical properties, such as high refractive index, absorption extends to the visible range. This not only depends on the chemical composition, but also on unavoidable impurities. In this catalogue the internal transmittance is given – i. e., reflection losses are eliminated. This catalogue lists internal transmittance measurements in the range 280 nm to 2400 nm (10 mm sample thickness). As glass varies slightly from melt to melt, these measured values have been selected from many melts and are considered typical.

Note: Our 13 i-line glass data sheets include internal transmittance measurement values using a sample thickness of 10 mm and 25 mm.

3. Thermal Properties

Thermal properties are extremely important for the annealing, heat treatment, and coating of optical glasses. Our technical data sheets include the strain point, annealing point, softening point, transformation point, yield point, and thermal conductivity. The linear coefficient of thermal expansion is given for two temperature ranges.

3.1 Strain Point (StP)

The strain point corresponds to the lowest temperature in the annealing range at which viscous flow of glass will not occur. Viscosity of the glass is $10^{14.5}$ dPa·s {poise} at this temperature. The strain point is measured in accordance with the Fibre Elongation Method prescribed in JIS-R3103 and ASTM-C336.

3.2 Annealing Point (AP)

The annealing point corresponds to the maximum temperature in the annealing range at which the internal strain of glass will be substantially eliminated. Viscosity of the glass is 10^{13} dPa·s {poise} at this temperature. The annealing point is measured in accordance with the Fibre Elongation Method prescribed in ASTM-C338.6.

3.3 Softening Point (SP)

The softening point is the temperature at which glass deforms under its own weight. Viscosity of the glass is $10^{7.65}$ dPa·s {poise} at this temperature. The softening point is measured in accordance with the Fibre Elongation Method prescribed in JIS-R3104 and ASTM-C338.

3.4 Transformation Temperature (Tg) and Yield Point (At)

The transformation region is that temperature range in which a glass gradually transforms from its solid state into a “plastic” state. The transformation temperature (Tg) can be determined from the thermal expansion curve (Fig. 1). Viscosity coefficient at this temperature is approximately 10^{13} dPa·s {poise}.

Yield point (At) is the deformation point temperature on the thermal expansion curve, or the point at which elongation becomes zero.

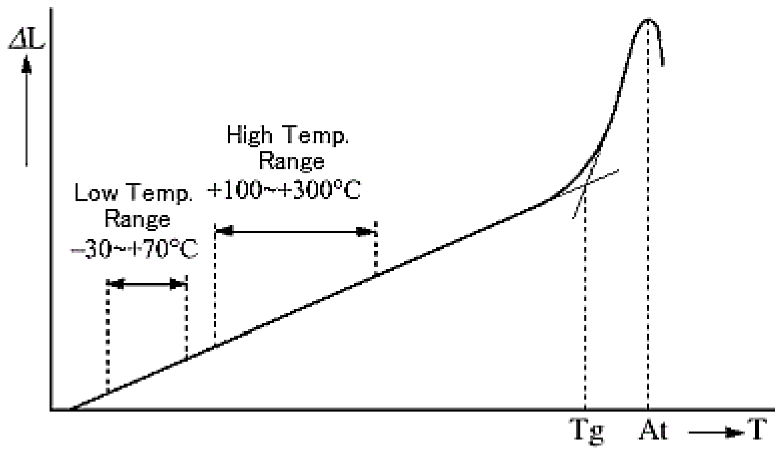

Fig. 1: Thermal Expansion Curve

3.5 Linear Coefficient of Thermal Expansion (α)

The thermal expansion curve is obtained by measuring a well-annealed glass rod of 4 mm diameter by 50 mm long heated at a rate of 2°C/min in the low temperature range and at a rate of 4°C/min in the high temperature range. From the temperature and elongation of the sample glass, the mean linear coefficient of thermal expansion between -30°C to +70°C and +100°C to +300°C is determined with a resolution up to 10^{-7} /°C and given on each technical data sheet.

3.6 Thermal Conductivity (k)

At room temperature, the thermal conductivity of most optical glasses is located between 1.126 W/(m·K) which is that of S-BSL7 and 0.546 W/(m·K) which is that of PBH71. The thermal conductivity is measured in accordance with methods prescribed in JIS-R2618. The thermal conductivity of glass at 35°C is listed in the catalogue. Accuracy is ±5%.

4. Chemical Properties

There are some glasses that lack durability. This is due to the chemical behaviour of certain constituents utilized in the composition.

Such glasses can be affected by water vapour, acid, gases, etc., as well as ions in the polishing slurry. As a consequence, dimming and staining may appear on the surfaces of these glasses during processing and storage.

Since such phenomena have to do with surface conditions and environment, no single test can be accepted as a criterion of durability under all conditions.

We have listed resistance to water and acid by the powder test method and resistance to weather by the surface test method. We have also listed resistance to acid and phosphate in accordance with the test methods prescribed in ISO8024 and ISO9689.

4.1 Water Resistance RW(p) and Acid Resistance RA(p) (Powder Method)

The glass to be tested is crushed to 425 μm ~ 600 μm grains. A sample of this powder equivalent to the specific gravity in grams is placed on a platinum basket. It is then placed in a flask of silica glass containing a reagent and boiled for 60 minutes. The sample is then carefully dried and re-weighed to determine loss of weight (percent) and classified as per tables 3 and 4.

The reagent used for the water resistance test is distilled water (pH 6.5 ~ 7.5). 1/100 N nitric acid is used for the acid resistance test.

Class	1	2	3	4	5	6
Loss of wt %	<0.05	≥0.05 <0.10	≥0.10 <0.25	≥0.25 <0.60	≥0.60 <1.10	≥1.10

Table 3: Water Resistance

Class	1	2	3	4	5	6
Loss of wt %	<0.20	≥0.20 <0.35	≥0.35 <0.65	≥0.65 <1.20	≥1.20 <2.20	≥2.20

Table 4: Acid Resistance

4.2 Weathering Resistance W(s) (Surface Method)

This test is carried out by placing freshly polished glass plates in a chamber at +50°C, 85% humidity for 24 hours. If the glass surface is severely attacked, another 6 hours test is carried out with new test pieces. A classification into four groups is then undertaken by inspecting the treated surface through a 50x microscope as per table 5.

Group	Classification
1	When there is no fading on the glass exposed in the chamber for 24 hours – inspected at 6000 luxes
2	When there is no fading observed on the glass exposed in the chamber for 24 hours at 1500 luxes but fading is observed at 6000 luxes
3	When fading is observed on the glass exposed in the chamber for 24 hours – inspected at 1500 luxes
4	When fading is observed on the glass exposed in the chamber for 6 hours – inspected at 1500 luxes

Table 5

4.3 ISO Method

4.3.1 Acid Resistance (SR)

Glass samples with dimensions of 30 x 30 x 2 mm are prepared with all surfaces polished to given specifications. They are hung by platinum wire and placed in a nitric acid solution (pH 0.3) or an acetic acid buffer solution (pH 4.6) at 25°C for the length of times specified (10 minutes, 100 minutes, 16 hours, or 100 hours).

After this treatment, the loss of mass of the sample is determined using an analytical balance. Calculation of the time $t_{0.1}$ in hours, necessary to etch a surface layer to a depth of 0.1 μm is performed using the following formula:

$$t_{0.1} = \frac{t_e \cdot d \cdot S}{(m_1 - m_2) \cdot 100}$$

$t_{0.1}$: the time (h) necessary to etch a surface layer to a depth of 0.1 μm
t_e : the time (h) for attack in the experiment
d : the specific gravity of the sample
S : the surface area (cm^2) of the sample
m_1 : the mass (mg) of the sample before the test
m_2 : the mass (mg) of the sample after the test

The calculation is carried out by using the value of the loss of mass that is observed by the minimum test condition (i. e., test solution and test time) for obtaining a loss of mass greater than 1 mg/sample. If the loss of mass is less than 1 mg/sample after 100 hours exposure to pH 0.3, this value shall be accepted.

The acid resistance class SR is obtained by comparison of the pH of the test solution and the time required for the attack to a depth of 0.1 μm (h). Time scales are given in table 6.

Acid resistance class SR	1	2	3	4	5		51	52	53
pH of the attacking solution	0.3	0.3	0.3	0.3	0.3	4.6	4.6	4.6	4.6
Time $t_{0.1}$ needed to etch to a depth of 0.1 μm (h)	>100	100~ 10	10~1	1~ 0.1	<0.1	>10	10~1	1~ 0.1	<0.1

Table 6

In addition, changes in the surface of the sample following this test procedure are qualitatively evaluated with the naked eye. Additional classification numbers are given in table 7.

Additional Number	Changes in the Surface
.0	No visible changes
.1	Clear, but irregular surface (wavy, pockmarked)
.2	Interference colours (slight selective leaching)
.3	Tenacious thin whitish layer (stronger selective leaching)
.4	Loosely adhering thick layer (surface crust)

Table 7

For example, it is indicated that the acid resistance class (SR) is SR 3.2 for an optical glass that needs 2 hours for the attack to a depth of 0.1 μm (attacking solution of pH 0.3) and with interference colours after attack.

4.3.2 Phosphate Resistance (PR)

Glass samples with dimensions of 30 x 30 x 2 mm are prepared with all surfaces polished to given specifications. They are hung by platinum wire and placed in an aqueous solution containing 0.01 mol/l purified tripolyphosphate at 50°C for specified lengths of time (15 minutes, 1 hour, 4 hours, or 16 hours).

After this treatment, the loss of mass of the sample is determined using an analytical balance. Calculation of the time $t_{0.1}$ necessary to etch a surface layer to a depth of 0.1 μm is made using the same formula as described in the previous section for obtaining the acid resistance (SR). In this case, however, the time unit is minutes.

The calculation is carried out, as a rule, using the value of the loss of mass that is observed under the minimum test conditions (i. e., test solution and test time for obtaining a loss of mass greater than 1 mg/sample).

The phosphate resistance class PR is obtained by comparison of the time required for the attack to a depth of 0.1 μm (min). Time scales are given in table 8.

Phosphate Resistance Class PR	1	2	3	4
Time $t_{0.1}$ needed to etch to a depth of 0.1 μm (min)	>240	240~60	60~15	<15

Table 8

In addition, changes in the surface of the sample following this test procedure are qualitatively evaluated with the naked eye. Additional classification numbers are given in table 7 which can be found in the previous section. For example, it is indicated that the phosphate resistance class (PR) is PR 2.0 for optical glass that needs 120 minutes for attack to a depth of 0.1 μm, with no visible changes in the surface after the attack.

5. Mechanical Properties

5.1 Modulus of Elasticity

Youngs's modulus, Modulus of rigidity, and Poisson's ratio are determined by measuring, at room temperature, the velocities of the longitudinal and transverse elastic waves in a well annealed rod of size 100 ~ 150 x 10 x 10 mm.

Young's modulus (E), Modulus of rigidity (G), and Poisson's ratio (σ) are calculated using the following equations. Accuracy is ±1%.

Modulus of rigidity $$G = \upsilon_t^2 \cdot \rho$$

Young's Modulus $$E = \frac{9KG}{3K + G}$$

Bulk Modulus $$K = \upsilon_l^2 \cdot \rho - \frac{4}{3} G$$

Poisson's ratio $$\sigma = \frac{E}{2G} - 1$$

υ_l : Velocity of longitudinal waves
υ_t : Velocity of transverse waves
ρ : Density

5.2 Knoop Hardness (Hk)

The indentation hardness of optical glass is determined with the aid of a micro hardness tester. One face of the specimen with the necessary thickness is polished. The diamond indentor is formed rhombic so that the vertically opposite angle from two axes is 172° 30' and 130°. The load time is 15 seconds and the load is 0.98 N {0.1 kgf}. The glass specimen is indented at 5 places. Knoop hardness can be computed with the following equation:

Knoop hardness $$Hk = 1.451\ F/l^2$$

F : Load (N)
l : Length of longer diagonal line (mm)

Table 9 shows how the glasses are classified according to Knoop hardness. Please note the Knoop hardness figures have been rounded to the nearest 5 (e. g. a value of 158 is shown as 160).

Group	1	2	3	4	5	6	7
Knoop Hardness	<150	≥150 <250	≥250 <350	≥350 <450	≥450 <550	≥550 <650	≥650

Table 9

5.3 Abrasion (Aa)

A sample of size 30 x 30 x 10 mm is lapped on a 250 mm diameter cast iron flat, rotating at 60 rpm. The test piece is located 80 mm from the centre of the flat and is under a 9.8 N {1kgf} load. 20 ml of water containing 10 g of aluminous abrasive as the lapping material, with mean grain size 20 μm (#800), is supplied evenly to the test piece for 5 minutes. The weight loss of the test piece is then measured and compared to the standard glass by using the following equation:

$$\text{Abrasion} = \frac{\text{Weight loss of sample / Specific gravity}}{\text{Weight loss of standard sample / Specific gravity}} \cdot 100$$

Glasses showing a higher value are less resistant to abrasion.

5.4 Photoelastic Constant (β)

Optical glass is usually free of strain, but when mechanical or thermal stress is exerted upon it, glass shows birefringence. Stress F (Pa), optical path difference δ (nm) and thickness of glass d (cm) have the following relationship:

$$\delta = \beta \cdot d \cdot F$$

In this case, proportional constant β is called the photoelastic constant. It is listed in this catalogue at a unit of (nm/cm/10^5 Pa). The photoelastic constant is the material constant that will change by glass type. By using it, optical path difference can be computed from given stress. Internal stress can also be computed from optical path difference.

6. Other Properties

6.1 Bubbles and Inclusions

It is most desirable to manufacture bubble-free optical glass, but the existence of bubbles to some extent is inevitable. Bubbles in optical glass vary in size and number from one glass to another due to the many different compositions and production methods utilized. The classification of bubble content is established by specifying in mm^2 the total bubble cross section existing in 100 ml of glass volume. Inclusions such as small stones or crystals are treated as bubbles. Our five bubble classes are shown in table 10. Our classification includes all bubbles and inclusions measuring larger than 0.03 mm.

Bubble Class	1	2	3	4	5
The total cross section of bubbles in 100 ml of glass mm^2	<0.03	≥0.03 <0.1	≥0.1 <0.25	≥0.25 <0.50	≥0.5

Table 10

6.2 Colouring

Each technical data sheet lists the internal transmittance (τ_i) from 280 nm to 2400 nm. To express absorption, a column headed “Colouring” is provided in the data sheet. Colouring can be determined by measuring spectral transmission (10 mm sample thickness) including reflection losses. The wavelengths corresponding to 80% transmission and 5% transmission are given. For example, a glass with the following transmission:

80% at wavelength of 404 nm
5% at wavelength of 355 nm

is indicated in the catalogue as 40/36.

Please note, for the glass types S-TIH53 and S-LAH58, reflection losses are so large that the wavelength corresponding to 70% has been used in place of 80%.

6.3 Specific Gravity (d)

Specific gravity is the density value of well-annealed glass referenced against pure water at 4°C. Each specific gravity value is given to the second decimal place.

7. Guarantees of Quality

7.1 Refractive Index and Abbe Number

The measured refractive index and Abbe number values of our fine annealed products will vary from catalogue standards by:

Refractive index: n_d ±0.0005
Abbe number: ν_d ±0.8%

Upon request, we will supply blanks of optical glass to the following tolerances:

Refractive index: n_d ±0.0002
Abbe number: ν_d ±0.3%

Please consult us when there exists a special demand for tolerances other than the above.

We urge our customers to enjoy the cost savings and benefits of our close index control, melt to melt, over long periods of production. Usually, this is done at no extra cost. As a standard, we send certification (melt data) of refractive indices measured at the spectral lines: C, d, F, g and ν_d. On special request, we can supply measurement values of refractive index taken at other spectral lines.

The following is the accuracy of standard measurements of refractive index and dispersion for raw glass and normal pressed blanks:

Refractive index: ±0.00003
Dispersion: ±0.00002

On request, we shall provide precision measurements of refractive index and dispersion with the following accuracies:

Refractive index: ±0.00001
Dispersion: ±0.000003

Please note, the above accuracies are achieved with the use of our Moeller Wedel Type I Spectrometer. Please contact us for further details concerning our super precision measurement capabilities.

Fig. 2: Spectrometer

We will report the environmental temperature, humidity and atmospheric pressure of the room where the precision measurement was undertaken. Please contact us for “ultra-precision measurements” and measurements of spectral lines not included in this catalogue.

Please note that all the Ohara refractive index measurements are taken under a room-temperature of 25 degree Celsius.

7.2 Homogeneity

It is sometimes necessary to measure the index variation across a blank. In such cases, OHARA pays special attention to each process and can supply high homogeneity “Grade Special A” blanks. Grade Special A is our term for precision annealed high homogeneity (Low Δn) optical glasses. Our Grade Special A glasses are available (depending on glass type and dimensions) in the following homogeneity levels:

Classification	Homogeneity (Δn)
Grade Special A0.5	$\pm$ 0.5 x 10^{-6}
Grade Special A1	$\pm$ 1 x 10^{-6}
Grade Special A2	$\pm$ 2 x 10^{-6}
Grade Special A5	$\pm$ 5 x 10^{-6}
Grade Special A20	$\pm$ 20 x 10^{-6}

Table 11

Please note that the Grade Special A number indicates Δn in the sixth decimal place. The annealing required must be specified in terms of birefringence (nm/cm). Generally, low Δn implies low birefringence from precision annealing. Using phase measuring interferometers, we measure transmitted wavefront of each test piece. Interferograms are supplied with each blank when a Grade Special A5 or higher homogeneity level is specified. The more detailed analysis of homogeneity gradients, astigmatisms, and spherical aberrations are an important part of our daily measurement requirements. We are using state of the art phase measuring interferometers produced by ZYGO USA. Our interferometers are able to make precision measurements on 9, 12 and 18 inch apertures.

7.3 Stress Birefringence

Depending on the annealing condition, optical glass retains slight residual strain in most cases. This can be observed as optical birefringence. It is measured by optical path differences and specified in nm/cm.

Stress birefringence of a rectangular plate is measured at the middle of the long side where maximum values occur at a point 5% of the width from the edge. A disc is measured at 4 points located 5% of the diameter from edge. The maximum value of the 4 points is shown as the birefringence value.

We guarantee the strain according to the grade of anneal as follows:

Anneal	Birefringence (nm/cm)
Coarse	>10
Fine	≤ 10
Precision	On Request

Table 12

On request, we shall supply birefringence data for precision annealed blanks in a “BMC” (Birefringence Measurement Chart) certification.

7.4 Striae

Striae are thread-like veins or cords that are visual indications of abruptly varying density. Striae can also be considered as a lack of homogeneity caused by incomplete stirring of the molten glass. Some glasses contain components that evaporate during melting causing layers of varying density, and therefore the appearance of parallel striae.

Striations in glass are detected by means of a striaescope consisting of a point source of light and a collimating lens. Polished samples are examined at several different angles in the striaescope. They are then compared with the standards and graded. These established standard glasses are of a high order of quality and are certified to U.S. military specification MIL-G-174B.

Striae Grade	Striae Content Using Striaescope
A	No visible striae
B	Striae is light and scattered
C	Striae is heavier than Grade B

Table 13

7.5 Bubble Quality

Bubble content is determined by taking a sample of glass from each melt. The total bubble cross-section per 100 ml of glass volume is measured. See table 10 in this catalogue.

7.6 Colouring

Variation of colouring between melts is generally within ± 10 nm.

On special request, we shall report the colouring or the transmission (including reflection losses) of the melt to be supplied by measuring spectral transmission.

8. Forms of Supply

8.1 Raw Glass

8.1.1 Strip Glass

Strips are made by drawing glass out of a continuous flow furnace. Strips are rectangular in shape, have slightly rippled fire-polished surfaces (un-worked), and are flame cut to required length. The corners are radiused. Strips are coarse or fine annealed. This is the lowest cost form of supply.

Fig. 3 Strip Glass

8.1.2 Slab Glass

Slabs are blocks or rectangles of raw glass that have been ground on all sides and then polished on two opposite ends for inspection. Generally, slabs are fine annealed.

Fig. 4: Slab Glass

8.2 Pressings (Reheat Pressings - RP)

Reheat (RP) or hand pressings are blanks formed by manually pressing softened glass. We urge our customers to specify the following:

- Diameter (including grinding stock)
- Centre thickness (including grinding stock)
- Radii of curvature
- Glass quality (striae, bubble, inclusions)
- Bevel
- First processing side

Diameter (mm)	Dimensional Tolerance	
	Thickness (mm)	Diameter (mm)
Less than 18	± 0.5	± 0.10
18 ~ 30	± 0.4	± 0.15
30 ~ 50	± 0.4	± 0.20
50 ~ 100	± 0.3	± 0.30
100 ~ 150	± 0.3	± 0.40
over 150	± 0.4	± 0.50

Table 14


Fig. 5: Pressings

8.3 Cut Blanks

Cut discs, cut rectangles, and cut prisms are blanks that are cut or core drilled from annealed strips or slabs. These forms are generally specified when delivery is urgent and quantities are small.

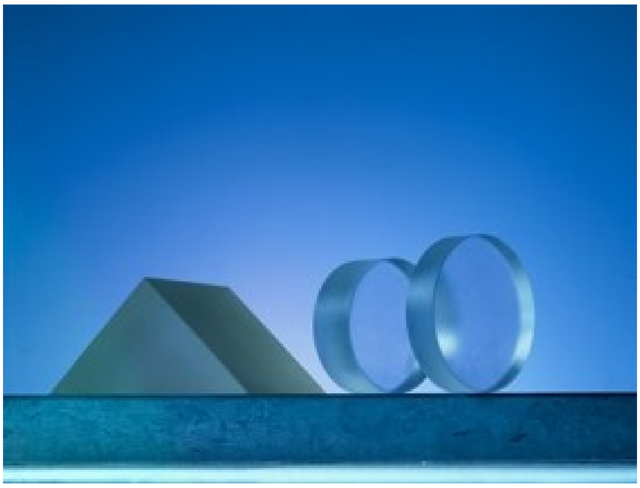

Fig. 6: Cut Blanks

8.4 Saw cut Centre-less Ground Cylindrical Blanks

These blanks are cut from a precisely ground rod formed on a centre-less grinding machine. This process is very useful for making lenses that:

- Are small in diameter but quite thick
- Are small in diameter with shallow radii
- Are such that the precise blank dimension can eliminate lens centreing operations
- Can utilize precision spot blocks

Diameter range of these blanks is 3 mm to 20 mm. The dimensional tolerances are given in table 15.

Diameter	Dimensional Tolerance	
	Thickness	Diameter
3 ~ 20 mm	±0.15 mm	±0.015 mm

Table 15

Centre-less ground blanks can be supplied in any glass type.

8.5 Mouldings

Pressing large blanks over 300 mm in diameter or of an excessive thickness is difficult. Such large blanks are gravity moulded. Blanks made by this method are generally supplied plano-plano. However, we can also produce large plano-convex or plano-concave mouldings.

8.6 High Homogeneity Glass

OHARA utilizes our leading edge technology to provide high homogeneity blanks in various glass types. Interferograms indicating the homogeneity of these blanks are typically provided with each shipment.

8.7 Fine Gob (FG)

We supply small diameter pre-formed “Fine Gobs” suitable for mould pressing into commercial lenses. FG is produced by direct moulding of molten glasses with low softening properties. Shape of standard FG is convex on both sides as shown in the sketch below.

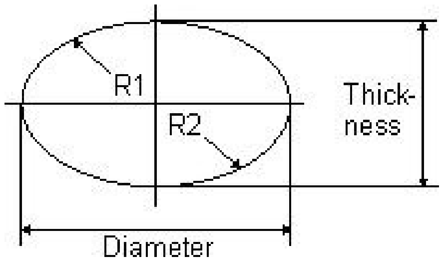

Fig. 7

Table 16 shows the current supply sizes for FG. When ordering, please specify necessary dimensions such as diameter, centre thickness and radius of curvature. Optical properties (refractive indices, Abbe number, etc.) will change depending on thermal conditions during mould pressing. Refractive indices of FG products will be within the tolerances shown in this catalogue when FG is heat-treated using conditions stipulated by OHARA.

Volume (cc)	0.1	0.2	0.3	0.5	0.7
Diameter (mm)	6.0 ~ 6.5	7.5 ~ 8.5	9.0 ~ 10.0	11.0 ~12.5	12.0 ~ 14.5
Central thickness (mm)	4.5 ~ 5.0	5.5 ~ 6.5	6.0 ~ 7.0	7.0 ~ 8.0	7.5 ~ 8.5
R1 (mm)	3.0 ~ 4.5	4.5 ~ 5.5	6.0 ~ 7.5	8.5 ~ 11.0	12.0 ~ 17.5
R2 (mm)	3.0 ~ 4.5	4.5 ~ 7.0	5.0 ~ 8.5	6.0 ~ 10.0	6.5 ~ 12.0

Table 16

Figures of R1 and R2 are radius curvatures within the scope of diameter 4 mm.

9. Table of Recommended Glasses

On the following pages you will find a cross-reference guide comparing glass types from OHARA and Schott.

Cross Reference Chart of Recommended Glasses

Code: Along with OHARA's glass type designation, the technical data sheets will show the six-digit code for each glass type. In the six-digit code (in bold type) the first three decimal digits represent the refractive index at the helium line (n_d) and the last three digits represent the Abbe number (ν_d). This six-digit code is internationally recognized within the optical community.

Glass Type: We have shown OHARA recommended glass types and corresponding glass types from Schott.

Table of Recommended Glasses				
OHARA			SCHOTT	
Code	Name	MF*	Code	Name
439948	S-FPL55	N		
439950	S-FPL53	S		
487702	S-FSL5	S	487704	N-FK5
497816	S-FPL51	S	497816	N-PK52A
516641	S-BSL7	S	517642	N-BK7
517524	S-NSL36	A		
518590	S-NSL3	C		
522598	S-NSL5	D	522595	N-K5
532489	S-TIL6	B		
538747	S-FPM3	N		
540595	S-BAL12	C	540597	N-BAK2
541472	S-TIL2	B		
548458	S-TIL1	B	548458	LLF1
564607	S-BAL41	D	564608	N-SK11
567428	S-TIL26	C		
569563	S-BAL14	B	569560	N-BAK4
571508	S-BAL2	B		
571530	S-BAL3	B		
575415	S-TIL27	C		
581407	S-TIL25	B	581409	LF5
583594	S-BAL42	A		
589612	S-BAL35	A	589613	N-SK5
593353	S-FTM16	B		
595677	S-FPM2	A		
596392	S-TIM8	B		
603380	S-TIM5	B	603380	F5
603607	S-BSM14	S	603606	N-SK14
603655	S-PHM53	C		
606437	S-BAM4	B	606437	N-BAF4
607568	S-BSM2	D	607567	N-SK2
613443	S-NBM51	A	613445	N-KZFS4
613587	S-BSM4	C	613586	N-SK4
618498	S-BSM28	D	618498	N-SSK8
618634	S-PHM52	A	618634	N-PSK53A
620363	S-TIM2	A	620364	N-F2
620603	S-BSM16	B	620603	N-SK16
622532	S-BSM22	D	622533	N-SSK2
623570	S-BSM10	D		
623582	S-BSM15	S		

Table of Recommended Glasses				
OHARA			SCHOTT	
Code	Name	MF*	Code	Name
626357	S-TIM1	D		
639449	S-BAM12	D		
639554	S-BSM18	S		
640345	S-TIM27	A		
640601	S-BSM81	C	640601	N-LAK21
648338	S-TIM22	A	648338	N-SF2
649530	S-BSM71	B		
651562	S-LAL54	D	651559	N-LAK22
651562	S-LAL54Q			
652585	S-LAL7	B	652585	N-LAK7
654397	S-NBH5	S	654397	N-KZFS5
658509	S-BSM25	A	658509	N-SSK5
667330	S-TIM39	D		
667483	S-BAH11	B		
670393	S-BAH32	C		
670473	S-BAH10	C	670471	N-BAF10
673321	S-TIM25	A	673323	N-SF5
673382	S-NBH52	C		
673383	S-NBH52V			
678507	S-LAL56	E		
678553	S-LAL12	A	678552	N-LAK12
689311	S-TIM28	B	689313	N-SF8
691548	S-LAL9	C	691547	N-LAK9
694508	S-LAL58	B		
694532	S-LAL13	D		
697485	S-LAM59	E		
697555	S-LAL14	S	697554	N-LAK14
699301	S-TIM35	A	699302	N-SF15
699511	S-LAL20			
702412	S-BAH27	A		
713539	S-LAL8	S	713538	N-LAK8
717295	S-TIH1	B	717296	N-SF1
717479	S-LAM3	B		
720347	S-NBH8	A	720347	N-KZFS8
720420	S-LAM58	D		
720437	S-LAM52	B		
720460	S-LAM61	D		
720502	S-LAL10	A	720506	N-LAK10
722292	S-TIH18	C		

Table of Recommended Glasses				
OHARA			SCHOTT	
Code	Name	MF*	Code	Name
723380	S-BAH28	C		
728285	S-TIH10	A	728285	N-SF10
729541	S-LAL19	N		
729547	S-LAL18	S	729545	N-LAK34
734515	S-LAL59	C	743494	N-LAF35
738323	S-NBH53	C		
740283	S-TIH3	C		
741278	S-TIH13	D		
741527	S-LAL61	D		
743493	S-LAM60	A		
744448	S-LAM2	B	744449	N-LAF2
750353	S-LAM7	B	749348	N-LAF7
750353	S-NBH51	A		
754317	S-LAM73	N		
755275	S-TIH4	B	755274	N-SF4
755523	S-LAH97			
755523	S-YGH51	A	755523	N-LAK33B
757478	S-LAM54	B		
762265	S-TIH14	A	762265	N-SF14
762401	S-LAM55	B		
764485	S-LAH96			
773496	S-LAH66	S	773496	N-LAF34
785257	S-TIH11	S	785257	N-SF11
785263	S-TIH23	A		
786442	S-LAH51	B	786441	N-LAF33
788474	S-LAH64	B	788475	N-LAF21
800299	S-NBH55	D		
800422	S-LAH52	A		
800422	S-LAH52Q			
801350	S-LAM66	A	801350	N-LASF45
804396	S-LAH63	D		
804396	S-LAH63Q	N		
804465	S-LAH65VS	N		
804466	S-LAH65V	S	804465	N-LASF44
805254	S-TIH6	S	805254	N-SF6
806409	S-LAH53	S	806406	N-LASF43
806409	S-LAh53V			
808228	S-NPH1	A		
808228	S-NPH1W	N		
816466	S-LAH59	A		
834372	S-LAH60	S	834373	N-LASF40
834372	S-LAH60V			
835427	S-LAH55V	S	835431	N-LASF41

Table of Recommended Glasses				
OHARA			SCHOTT	
Code	Name	MF*	Code	Name
835427	S-LAH55VS	N		
847238	S-TIH53	S	847238	N-SF57
847238	S-TIH53W	N	847238	N-SF57HTultra
847239	S-NPH53	C		
850300	S-NBH57	N		
850323	S-LAH71	D	850322	N-LASF9
852408	S-LAH89	N		
855248	S-NBH56	N		
859227	S-NPH5	N		
883408	S-LAH58	S	883408	N-LASF31A
892371	S-LAH92	N		
893204	S-NPH4	N		
904313	S-LAH95			
905350	S-LAH93	N		
917316	S-LAH88	N		
923189	S-NPH2	A	923209	N-SF66
963241	S-TIH57			
959175	S-NPH3	A		
2003283	S-LAH79	D		

516641	L-BSL7	A	516641	P-BK7
583594	L-BAL42	S		
586592	L-BAL42P			
586597	L-BAL43	N		
589612	L-BAL35	A	589612	P-SK58A
592610	L-BAL35P			
689311	L-TIM28	C	689313	P-SF8
693529	L-LAL15	N		
694532	L-LAL13	B	693532	P-LAK35
695307	L-TIM28P			
731405	L-LAM69	D		
743493	L-LAM60	B		
765491	L-LAH91	N		
806409	L-LAH53	C	806409	P-LASF47
809404	L-LAH84	C	809405	P-LASF50
812403	L-LAH84P			
832401	L-LAH90	N		
854404	L-LAH85V	B		
861371	L-LAH94	N		
903310	L-LAH86	E		

Table 17: Recommended Glasses

*Melt Frequency (MF)	
S	Production amount is especially large
A	Production amount is large
B	Production amount is average
C	Production amount is average
D	Production amount is small
E	Production amount is especially small
N	No data, new product

10. I-Line Glasses

10.1 Internal Transmittance (τ_i)

Internal transmittance of the glass is indicated as guaranteed minimum transmittance at 365nm (10 and 25 mm sample thickness). Please note this is internal transmittance, reflection losses are not included.

Fig. 8: i-Line Glasses

10.2 Solarization

The degree of solarization is indicated as a decrease in transmittance caused by radiation from a super high pressure mercury-vapor lamp. The datailed measurement method is described in the “Japanese Optical Glass Industrial Standard (JOGIS)”.

10.3 Optical Homogeneity

Optical Homogeneity (Δn) is guaranteed by use of our He-Ne laser interferometers. The Δn specification is indicated for three diameter ranges (∅ 160 mm or less, ∅ 210 mm or less, ∅ 260 mm or less) due to the Δn variances caused by glass type, size, and shape. Please note, if the ordered thickness is less than 25 mm, we will use a 25 mm thick test piece for Δn measurement. Please contact us when lower Δn specifications are required.

10.4 Refractive Index (n_i) Variation within one Lot (Sn Standard)

The indicated Sn value is the refractive index variation after annealing within a single batch (same melt, same annealing run).

10.5 Refractive Index Tolerance

The standard refractive index (ni) of our i-line glasses is higher than our catalogue nominal values. This is due to the longer annealing times which are necessary to obtain the desired homogeneity levels. Longer annealing times result in higher refractive indices.

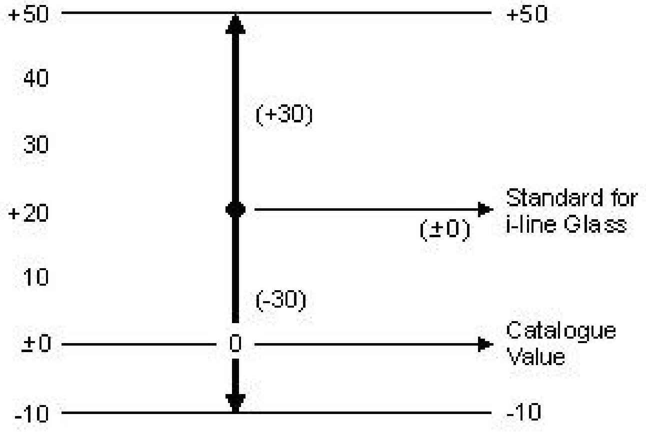

Fig. 9

Example: +20±30 (x 10^{-5})

+20 (+0.00020) means the increase against our catalogue nominal ni value. The ±30 (±0.00030) is then the tolerance on the new nominal value. i.e. a glass type having a tolerance of +20±30 can vary from -10 (-0.00010) to +50 (+0.00050) against standard catalogue nominal. Please consult us when tighter tolerances are required.

10.6 Table of i-Line Glasses

Glass Type	Internal Trans-mittance 10mm thick (365nm)	Solarization Resistance	Optical Homogeneity Guaranteed (x10^{-6})			Deviation of n_i within a single lot (x10^{-5})	Tolerance of Refractive Index (x10^{-5})
			Dia160 or less	Dia210 or less	Dia260 or less		
S-FPL51Y	0.997	Good	±1.0	-	-	±2	+20±20
S-FSL5Y	0.999	Good	±0.5	±0.8	±1.0	±2	+15±20
BSL7Y	0.998	Good	±0.5	±0.8	±1.0	±1	+20±20
BAL15Y	0.994	Good	±0.5	±0.8	±1.0	±2	+10±20
BAL35Y	0.996	Good	±0.5	±0.8	±1.0	±2	+20±20
BSM51Y	0.995	Good	±0.5	±0.8	±1.0	±2	+30±20
PBL1Y	0.997	Good	±0.5	±0.8	±1.0	±2	+10±20
PBL6Y	0.998	Good	±0.5	±0.8	±1.0	±2	+10±20
PBL25Y	0.995	Good	±0.5	±0.8	±1.0	±2	+10±20
PBL26Y	0.996	Good	±0.5	±0.8	±1.0	±2	+10±20
PBL35Y	0,997	Good	±0,5	±0,8	±1,0	±2	+10±20
PBM2Y	0.986	Good	±0.5	±0.8	±1.0	±2	+10±20
PBM8Y	0.991	Good	±0.5	±0.8	±1.0	±2	+10±20
PBM18Y	0.993	Good	±0.5	±0.8	±1.0	±2	+10±20

Table 18: i-Line Glasses

11. Low Tg Glasses

Low transformation temperature (Tg) optical glasses that are suitable for precision molding.

Ohara's low softening temperature optical glasses have similar properties (refractive index, dispersion, and chemical durability) when compared to conventional optical glasses, and can be formed at relatively lower temperatures. These glasses are very suitable for precision molding applications. In addition, for the protection of our environment, these glasses do not contain Lead and Arsenic. Please contact us for further information.