OHARA

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 135 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 135 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/ν_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.

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.

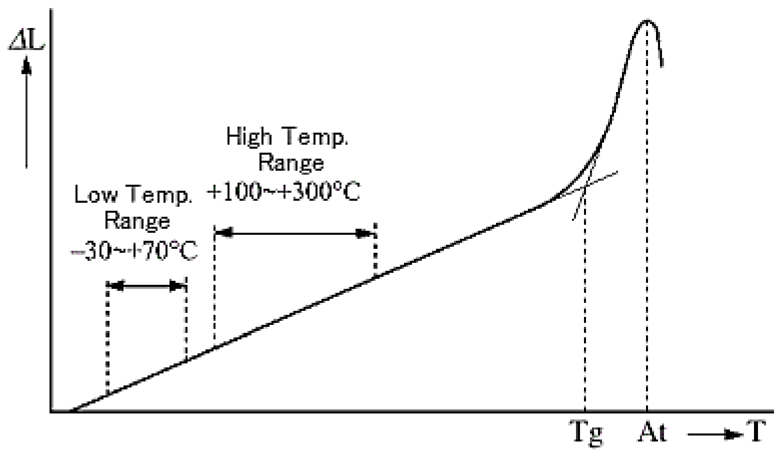

Fig. 1: Thermal Expansion Curve

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 glass type S-TIH53, 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 $\nu_{d.}$ 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.

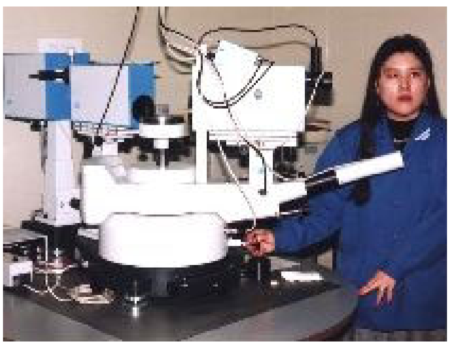

Fig. 2: Spectrometer

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.

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	$\pm 0.5 \times 10^{-6}$
Grade Special A1	$\pm 1 \times 10^{-6}$
Grade Special A2	$\pm 2 \times 10^{-6}$
Grade Special A5	$\pm 5 \times 10^{-6}$
Grade Special A20	$\pm 20 \times 10^{-6}$

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

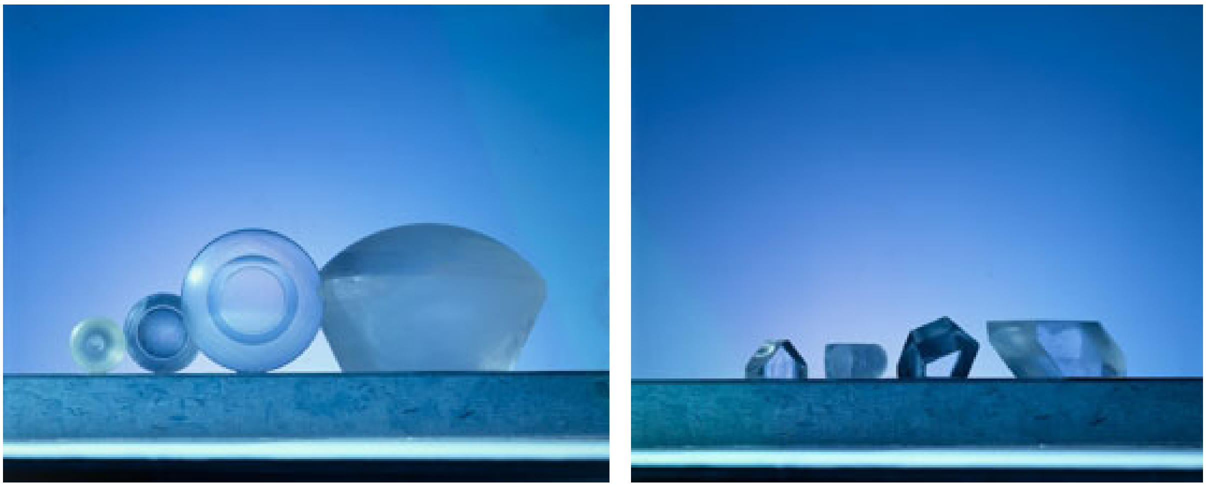

Fig. 5: Pressings

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.

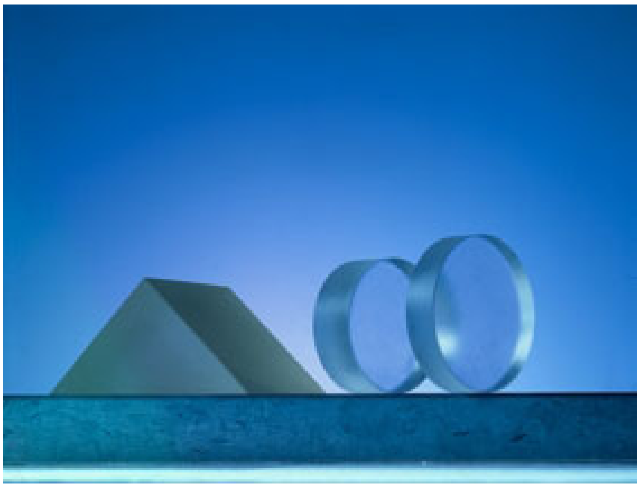

Fig. 6: Cut Blanks

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.

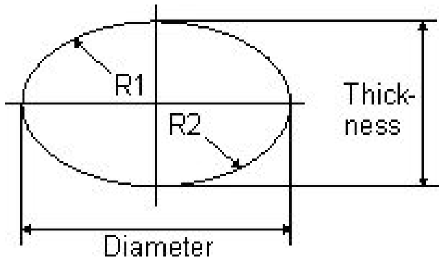

Fig. 7

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 two other companies.

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 (GT): We have shown OHARA recommended glass types and corresponding glass types from Schott and Hoya.

Table of Recommended Glasses					
OHARA		Schott		Hoya	
Code	Glass Type	Code	Glass Type	Code	Glass Type
439 950	S-FPL53				
456 903	S-FPL52				
487 702	S-FSL5	487 704	N-FK5	487 704	FC5
497 816	S-FPL51	497 816	N-PK52	497 816	FCD1
516 641	L-BSL7				
516 641	S-BSL7	517 642	N-BK7	517 642	BSC7
517 524	S-NSL36			517 522	E-CF6
518 590	S-NSL3			518 590	E-C3
522 598	S-NSL5	522 595	N-K5		
532 489	S-TIL6	532 488	N-LLF6	532 488	E-FEL6
540 595	S-BAL12	540 597	N-BAK2		
541 472	S-TIL2			541 472	E-FEL2
548 458	S-TIL1	548 458	N-LLF1	548 458	E-FEL1
559 625	L-PHL2				
564 607	S-BAL41	564 608	N-SK11	564 608	E-BaCD11
565 608	L-PHL1				
567 428	S-TIL26			567 428	E-FL6
569 563	S-BAL14	569 561	N-BAK4	569 560	BaC4
571 508	S-BAL2				
571 530	S-BAL3				
573 578	S-BAL11	573 576	N-BAK1		
575 415	S-TIL27				
581 407	S-TIL25	581 409	N-LF5	581 407	E-FL5
583 464	S-BAM3	583 465	N-BAF3		
583 594	L-BAL42				
583 594	S-BAL42			583 595	BaCD12
589 612	L-BAL35				
589 612	S-BAL35	589 613	N-SK5	589 613	BaCD5
593 353	S-FTM16			593 355	FF5
596 392	S-TIM8			596 392	E-F8

Table of Recommended Glasses					
OHARA		Schott		Hoya	
603 380	S-TIM5			603 380	E-F5
603 607	S-BSM14	603 606	N-SK14	603 606	BaCD14
603 655	S-PHM53				
606 437	S-BAM4	606 439	N-BAF4		
607 568	S-BSM2	607 567	N-SK2	607 568	BaCD2
613 370	S-TIM3			613 370	E-F3
613 443	S-NBM51	613 445	N-KZFS4	613 444	E-ADF10
613 587	S-BSM4	613 586	N-SK4	613 586	BaCD4
614 550	S-BSM9				
618 498	S-BSM28	618 498	N-SSK8		
618 634	S-PHM52	620 635	N-PSK53	618 634	PCD4
620 363	S-TIM2	620 364	N-F2	620 363	E-F2
620 603	S-BSM16	620 603	N-SK16	620 603	BaCD16
622 532	S-BSM22	622 532	N-SSK2		
623 570	S-BSM10	623 569	N-SK10	623 570	E-BaCD10
623 582	S-BSM15	623 580	N-SK15	623 582	BaCD15
626 357	S-TIM1			626 357	E-F1
639 449	S-BAM12				
639 554	S-BSM18	639 554	N-SK18	639 554	BaCD18
640 345	S-TIM27			640 345	E-FD7
640 601	S-BSM81	640 601	N-LAK21	640 601	LaCL60
648 338	S-TIM22			648 338	E-FD2
649 530	S-BSM71			649 530	E-BaCED20
651 562	S-LAL54	651 559	N-LAK22	651 562	LaCL2
652 585	S-LAL7	652 585	N-LAK7	652 585	LaC7
654 397	S-NBH5	654 396	KZFSN5	654 396	E-ADF50
658 509	S-BSM25	658 509	N-SSK5	658 509	BaCED5
667 330	S-TIM39				
667 483	S-BAH11			667 484	BaF11
670 393	S-BAH32				
670 473	S-BAH10	670 471	N-BAF10	670 473	BaF10
673 321	S-TIM25	673 322	N-SF56	673 321	E-FD5
678 507	S-LAL56			678 507	LaCL9
678 549	L-LAL12				
678 553	S-LAL12	678 552	N-LaK12	678 555	LaC12
689 311	L-TIM28				
689 311	S-TIM28	689 312	N-SF8	689 311	E-FD8
691 548	S-LAL9	691 547	N-LaK9	691 548	LaC9
694 508	S-LAL58			694 508	LaCL5
694 532	L-LAL13				
694 532	S-LAL13	694 533	LAKN13	694 532	LaC13
697 485	S-LAM59			697 485	LaFL2
697 555	S-LAL14	697 554	N-LAK14	697 555	LaC14
699 301	S-TIM35	699 301	N-SF15	699 301	E-FD15
700 481	S-LAM51				
702 412	S-BAH27			702 412	BaFD7
713 539	S-LAL8	713 538	N-LAK8	713 539	LaC8

Table of Recommended Glasses					
OHARA		Schott		Hoya	
717 295	S-TIH1	717 295	N-SF1	717 295	E-FD1
717 479	S-LAM3	717 480	N-LAF3	717 480	LaF3
720 347	S-NBH8				
720 420	S-LAM58				
720 437	S-LAM52				
720 460	S-LAM61				
720 502	S-LAL10	720 506	N-LAK10	720 504	LaC10
722 292	S-TIH18				
723 380	S-BAH28	724 381	N-BASF51	723 380	BaFD8
728 285	S-TIH10	728 285	N-SF10	728 285	E-FD10
729 547	S-LAL18	729 547	N-LAK34	729 547	TaC8
731 405	L-LAM69				
734 515	S-LAL59			734 511	TaC4
740 283	S-TIH3				
741 278	S-TIH13			741 278	E-FD13
741 527	S-LAL61			741 526	TaC2
743 493	S-LAM60	743 492	N-LAF35	743 492	NbF1
744 448	S-LAM2	744 447	N-LaF2	744 449	LaF2
750 353	S-LAM7	750 350	N-LAF7	750 350	E-LaF7
750 353	S-NBH51				
755 275	S-TIH4	755 276	N-SF4	755 275	E-FD4
755 523	S-YGH51	754 524	N-LAK33	755 523	TaC6
757 478	S-LAM54			757 477	NbF2
762 265	S-TIH14	762 265	N-SF14	762 265	FD140
762 401	S-LAM55				
773 496	S-LAH66	772 496	N-LAF34	772 496	TaF1
785 257	S-TIH11				
785 263	S-TIH23	785 261	N-SF56	785 261	FDS30
786 442	S-LAH51	786 441	N-LAF33	786 439	NbFD11
788 474	S-LAH64	788 475	N-LAF21	788 475	TaF4
800 422	S-LAH52	800 423	N-LAF36	800 423	NbFD12
801 350	S-LAM66	801 350	N-LASF45		
804 396	S-LAH63			805 396	NbFD3
804 466	S-LAH65	804 466	N-LASF44	804 465	TaF3
805 254	S-TIH6	805 254	N-SF6	805 254	FD60
806 409	L-LAH53				
806 409	S-LAH53	806 407	N-LASF43	806 407	NbFD13
808 228	S-NPH1				
816 466	S-LAH59			816 466	TaF5
834 372	S-LAH60	834 374	N-LASF40	834 373	NbFD10
835 427	S-LAH55	835 430	N-LASF41	835 430	TaFD5
847 238	S-TIH53	847 238	N-SF57	847 238	FDS90
883 408	S-LAH58	881 410	N-LASF31	883 408	TaFD30
923 189	S-NPH2			923 209	E-FDS1
2003 283	S-LAH79				

Table 17: Recommended Glasses

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.

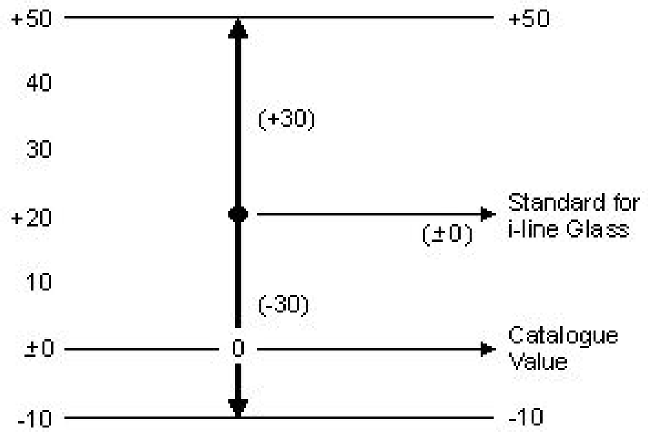

Fig. 9

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
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