Optical Glass

Technical Catalogue

POTAPENKO GLASS & FILTERS

EXPORT DIVISION

IN UKRAINIAN OPTICAL GLASS FACTORY

Version 01-2004

www.opticalglass.com.ua

CONTENTS

Note 1:

- Optical properties are tagged with an asterisk (*) have been measured in compliance with Ukrainian Industrial Optical Glass Standards (Governmental Standard - GOST).

1. OPTICAL GLASS COLLECTION

1.1. Glass Type

Optical glasses are classified by their main chemical components and are identified by refractive index (**n**$_d$) and Abbe-number (ν_d). They are divided into groups. Each glass type within a group is designated by the abbreviated group symbol and a number.

The alphabetic designation corresponds to traditionally developed practice of division of optical glasses into the crown glasses and the flint glasses. This alphabetic designation which used by experts in calculations of optical systems is kept in this version of the catalogue.

Optical glass types are designated by symbols of the factory options per GOST 3514 Optical glass - Specification or DIN 58925 Optical glass - Principal concepts.

For example,

- UKRAINE GOST **K8**

- GERMANY SCHOTT BK7

- JAPAN HOYA BSC7

Table 1. Optical Glass Collection

Group Glass	GOST	SCHOTT	HOYA
Light Crown	LK	FK	FC
Phosphate Crown	FK	PK	PC
Dense Phosphate Crown	TFK	PSK	PCD, PCS
Crown	K	K, BK	C, BSC
Zinc Crown	K515	ZK	ZnC
Barium Crown	BK	BaK	BaC
Dense Crown	TK	SK	BaCD
Extra Dense Crown	CTK	SSK, LaK	BaCED, LaC
Crown Flint	KF	KF	CF
Light Flint	LF	LF, LLF	FL, FEL
Flint	F	F	F
Barium Flint	BF	BaF	BaF, BaFL
Dense Barium Flint	TBF	BaSF	BaFD
Dense Flint	TF	SF	FD
Extra Dense Flint	CTF	SFS, LaF	FDS, LaF
Abnormal Dispersion Crown	OK	-	ADC
Abnormal Dispersion Flint	OF	KzF	ADF

1.2. Glass Code

In addition to our glass type designation, a six-digit code number is listed in this catalog. The first three digits indicate the $\mathbf{n}_d$ after the decimal point, and the last three digits represent the v_d.

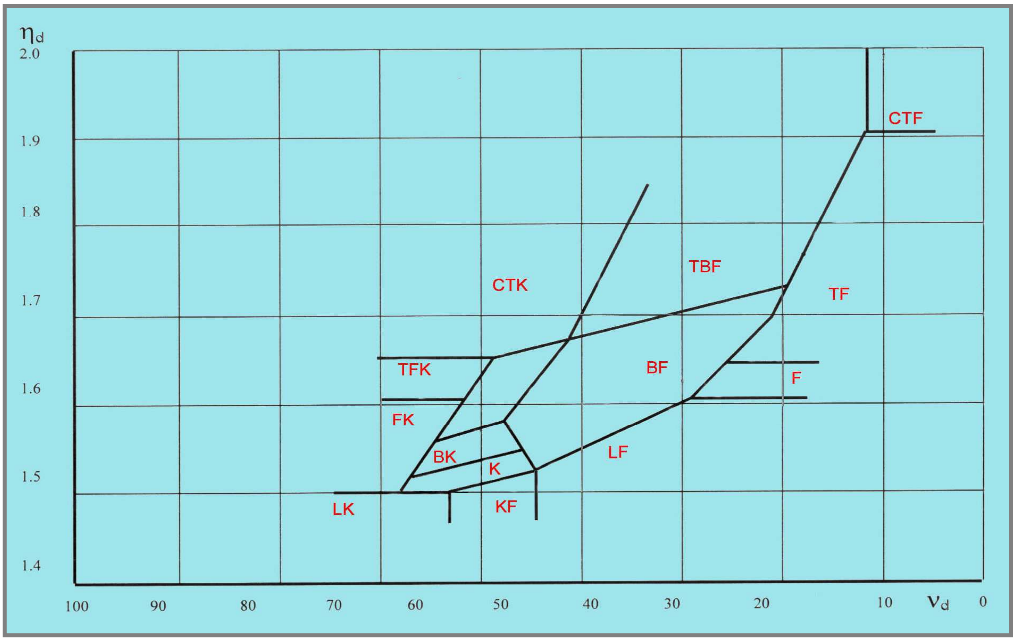
For example,

In **K8** the $\mathbf{n}_d$ is 1,51637 and the v_d is 64,07, which we indicate as glass code 516-640.

1.3. Abbe-diagram

Abbe-diagram $\mathbf{n}_d$ - V_d is included into catalogue as figure 1.

Figure 1. Abbe-diagram



2. OPTICAL PROPERTIES

2.1. Refractive Indices, n_x

Refractive indices to five decimal places are given for the following standard spectral lines:

Table 2. Standard Spectral Lines

Wavelength (nm)	Spectral Line	Element
1060.00	-	Nd Glass
1013.98	t	Hg
852.11	s	Cs
706.52	r	He
694.30	-	$Cr\text{-}Al_2O_3$
656.27	C	H
643.85	C′	Cd
632.80	-	He-Ne Laser
589.29	D	Na
587.56	d	He
546.07	e	Hg
488.00	-	Ar
486.13	F	H
479.99	F′	Cd
435.83	g	Hg
404.66	h	Hg
365.01	i	Hg

These Refractive Indices are listed glass data of each optical glass type and are indicated in the glass data sheet as followings:

Figure 2. Refractive Indices

Refractive Indices													
n_i	n_h	n_g	$n_{F'}$	$n_{488,0}$	n_e	n_d	$n_{632,8}$	$n_{C'}$	$n_{694,3}$	n_r	n_s	n_t	$n_{1060,0}$

2.2. Dispersion Formula, $\mathbf{n}_x^2$ - 1

The refractive index at a wavelength other than those covered in this catalog can be calculated from a dispersion formula. For practical approximation, the following dispersion formula, derived from a series expansion of the theoretical formula, is available:

$$\mathbf{n}_x^2 - 1 = A_1 \cdot \lambda^2 + A_2 \cdot \lambda^{-2} + A_3 \cdot \lambda^{-4} + A_4 \cdot \lambda^{-6} + A_5 \cdot \lambda^{-8} \qquad (1)$$

Where λ is the wavelength in nm, and A_1, A_2, A_3, A_4, A_5 are coefficients to be determined in each glass, using the method of least squares.

The accuracy of a calculated refractive index at a wavelength between the range of 365 ~ 1060,00 nm is ± 5 x 10^{-6} for typical glass with refractive indices denoted in this catalog.

2.3. Partial Dispersion, $\mathbf{n}_x$ - $\mathbf{n}_y$

The Partial Dispersion is defined:

$$(\mathbf{n}_x - \mathbf{n}_y) \qquad (2)$$

The Main dispersion is expressed by

$$(\mathbf{n}_F - \mathbf{n}_C) \text{ and } (\mathbf{n}_{F'} - \mathbf{n}_{C'}) \qquad (3)$$

The Partial Dispersions are listed glass data of each optical glass type and are indicated in the glass data sheet as followings:

Figure 3. Partial Dispersions

Partial Dispersions						
$\mathbf{n}_i$-$\mathbf{n}_{F'}$	$\mathbf{n}_h$-$\mathbf{n}_g$	$\mathbf{n}_{F'}$-$\mathbf{n}_{C'}$	$\mathbf{n}_{F'}$-$\mathbf{n}_e$	$\mathbf{n}_F$-$\mathbf{n}_C$	$\mathbf{n}_e$-$\mathbf{n}_{C'}$	$\mathbf{n}_{C'}$-$\mathbf{n}_t$

2.4. Abbe-number, V_d

Abbe-number is defined:

$V_d = (\mathbf{n}_d - 1) / (\mathbf{n}_F - \mathbf{n}_C)$ (4)

$V_e = (\mathbf{n}_e - 1) / (\mathbf{n}_{F'} - \mathbf{n}_{C'})$ (5)

Abbe-number is listed glass data of each optical glass type and indicated in the glass data sheet as followings:

Figure 4. Principal Properties

Principal Properties					
$\mathbf{n}_d$	V_d	$\mathbf{n}_F$-$\mathbf{n}_C$	$\mathbf{n}_e$	V_e	$\mathbf{n}_{F'}$-$\mathbf{n}_{C'}$

2.5. Relative Partial Dispersion, $P_d(x,y)$

The relative partial dispersion $P_d(x,y)$ and the alternate relative partial dispersion $P_e(x,y)$ are defined by the following equation:

$P_d(x,y) = (\mathbf{n}_x - \mathbf{n}_y) / (\mathbf{n}_F - \mathbf{n}_C)$ (6)

$P_e(x,y) = (\mathbf{n}_x - \mathbf{n}_y) / (\mathbf{n}_{F'} - \mathbf{n}_{C'})$ (7)

Where subscripts x and y denote the standard spectral line assignments associated with specific refractive index values.

The dispersive characteristics of various glasses may be compared by plotting the relative partial dispersion $P_d(x,y)$ versus the Abbe-number v_d (or, alternatively, $P_e(x,y)$ versus v_e). These quantities share a linear correspondence for most optical glasses and therefore plot along a single straight line.

The Relative Partial Dispersion alternate Relative Partial Dispersion are listed glass data of each optical glass type and are indicated in the glass data sheet as followings:

Figure 5. Relative Partial Dispersions and Alternative Relative Partial Dispersions

Relative Partial Dispersions							
$P_d(h,g)$	$P_d(g,F')$	$P_d(F',e)$	$P_d(e,d)$	$P_d(d,C')$	$P_d(e,C')$	$P_d(C',r)$	$P_d(r,s)$

Alternative Relative Partial Dispersions							
$P_e(h,g)$	$P_e(g,F')$	$P_e(F',e)$	$P_e(e,d)$	$P_e(d,C')$	$P_e(e,C')$	$P_e(C,r)$	$P_e(r,s)$

2.6. Deviation of Relative Partial Dispersions, $\Delta P_d(x,y)$

Glasses exhibiting this behavior are referred to as "normal dispersion glasses". The partial dispersion of these glasses can be approximately described by the following equation:

$$P_d(x,y) \sim \mathbf{a}_{x,y} + \mathbf{b}_{x,y} \cdot V_d \tag{8}$$

$$P_e(x,y) \sim \mathbf{c}_{x,y} + \mathbf{d}_{x,y} \cdot V_e \tag{9}$$

Where $\mathbf{a}_{x,y}$ and $\mathbf{b}_{x,y}$, $\mathbf{c}_{x,y}$ and $\mathbf{d}_{x,y}$ are constants. Glasses which deviate significantly from the line described by equation (8) and (9) are called "abnormal dispersion glasses".

For any glass, the deviation of the partial dispersion from the "normal line" can be represented by the quantity $\Delta P_d(x,y)$ and $\Delta P_e(x,y)$. A more general expression for $P_d(x,y)$ and $P_e(x,y)$ are then given by the following equation:

$$\Delta P_d(x,y) = P_d(x,y) - \mathbf{a}_{x,y} - \mathbf{b}_{x,y} \cdot V_d \tag{10}$$

$$\Delta P_e(x,y) = P_e(x,y) - \mathbf{c}_{x,y} - \mathbf{d}_{x,y} \cdot V_e \tag{11}$$

Delta $P_e(x,y)$ values listed in this catalog are referenced to a straight line defined by the $P_e(x,y)$ values found for the glass types K8 and F13.

Table 3. Normal Line

Glass Type	V_e	$P_e(i,F')$	$P_e(g,F')$	$P_e(F',e)$	$P_e(F',r)$
K8	63,87	1,6525	0,4754	0,5070	1,2261
F13	36,09	1,9209	0,5168	0,5223	1,2056

And:

$$\Delta P_e(i,F') = P_e(i,F') - 2{,}25801 + 0{,}0093272 \cdot V_e \tag{12}$$

$$\Delta P_e(g,F') = P_e(g,F') - 0{,}57035 + 0{,}0014832 \cdot V_e \tag{13}$$

$$\Delta P_e(F',e) = P_e(F',e) - 0{,}54290 + 0{,}0005702 \cdot V_e \tag{14}$$

$$\Delta P_e(F',r) = P_e(F',r) - 1{,}17926 + 0{,}0007208 \cdot V_e \tag{15}$$

The Deviation of Relative Partial Dispersion are listed glass data of each optical glass type and are indicated in the glass data sheet as followings:

Figure 6. Deviation of Relative Partial Dispersions

Deviation of Relative Partial Dispersions			
$\Delta P_e(i,F')$	$\Delta P_e(g,F')$	$\Delta P_e(F',e)$	$\Delta P_e(F',r)$

2.8. Internal Transmittance, τ_x

The transmittance characteristics of optical glasses in this catalog are expressed by two terms. One is "Internal Transmittance" and the other is "Farbcode".

Internal transmittance (τ_x) refers to transmittance obtained by excluding reflection losses at the entrance and exit surfaces of the glass. Internal transmittance values over the wavelength range 365 nm, 400 nm, 440 nm, 550 nm, 640 nm and value τ_a for standard light A (T = 2856º K) are calculated from transmittance measurements on a pair of specimens with different thicknesses.

Internal transmittance values obtained for 10 mm thick glasses are given.

The internal transmittance τ_x for glass with arbitrary thickness d can be obtained from these values by using:

$$\tau_x = \tau_0^{\,d/d_o} \tag{16}$$

Where τ_0 refers, to the internal transmittance given in the tables for glass with thickness d_0 equal to either 10 mm.

The Internal Transmittance listed glass data of each optical glass type and are indicated in the glass data sheet as followings:

Figure 7. Internal Transmittance

Internal Transmittance					
τ_{365}	τ_{400}	τ_{440}	τ_{550}	τ_{640}	τ_a

3. THERMAL PROPERTIES

3.1. Transformation Temperature, **T**g

The glass transformation temperature **T**g refers to the temperature at which the glass transforms from a lower temperature glassy state to a higher temperature super-cooled liquid state.

A differential thermal dilatometer is used for the measurement as it maintains a uniform temperature distribution within the furnace to ± 1 °C. The glass viscosity at **T**g corresponds to about $10^{13.3}$ dPa • s. Transformation temperature (**T**g) serves as a useful benchmark for annealing.

Note 2:

- 1 dPa • s = 1 poise

3.2. Coefficient of Thermal Expansion, CTE

The expansion coefficient from + 20 °C to + 120 °C, CTE, is obtained by using the interference-dilatometer and expressed in 10^{-7} / ºC.

CTE = L / Δ L · ΔT (17)

Where L and Δ L denote the values length and differential of length associated with differential of temperatures for optical glass type.

2.7. Temperature Coefficient of Refractive Index, **NT**abs

The refractive index of optical glass changes with the temperature. The temperature coefficient of the refractive index (**NT** abs = Δ**n** abs / ΔT) is measured at 20 °C intervals between -60 ~ 20 °C and 20 ~ 120 °C in a vacuum, using an interference-dilatometer to detect changes in both optical path length and dilation of the specimen. The light source used is a C'-line (643,85 nm).

For calculation of the temperature coefficient of the relative refractive index (NT relative = Δ**n** relative / ΔT) in air at 101,325 kPa, the following equation is given:

NT abs = NT relative + **n** · NT air (18)

Where NT air = Δ**n** air /ΔT is the temperature coefficient of the refractive index of air. Reference should be made to Table 4.

Note 3:

- 101,325 kPa = 1 atm

Table 4. Temperature Coefficient of the Air Refractive Index

Temperature (°C)	NT air (10^{-6}/ºK)
- 40 ~ - 20	-1.35
- 20 ~ 0	-1.15
0 ~ + 20	-1.00
+ 20 ~ + 40	-0.87
+ 40 ~ + 60	-0.76
+ 60 ~ + 80	-0.68

The Transformation Temperature, Expansion Coefficient and Temperature Coefficient of Refractive Index are listed glass data of each optical glass type and are indicated in the glass data sheet as followings:

Figure 8. Thermal Properties

Thermal Properties		
Tg	CTE	**NT**abs

4. MECHANICAL PROPERTIES

4.1. Specific Gravity, SG

Specific gravity is defined as by the ratio of weight (g) of each glass type to his volume (cm^3) and expressed as g/cm^3. Specific gravity is measured by weighing sample 20 · 20 · 10 mm in air and toluene with accuracy of 0,001 g/cm^3. Specific gravity are approximated to the second decimal sign. Specific gravity is measured using GOST method.

The specific gravity is the important parameter of an optical glass. However only with the help of empirical formulas based on experimental data it is possible to establish correlation of specific gravity and a refraction index, mechanical and thermal properties.

Constant and steady dependence which could be named natural, does not exist, but for the majority of types of an optical glass such dependence is in the most simple dependence and frequently this dependence appears linear.

Basically with increase of specific gravity the refraction index, durability and hardness of an optical glass increases too.

Apply property of specific gravity in your designs.

$$SG \sim (\mathbf{n}^2 - 1) / (\mathbf{n}^2 + 2) \qquad (19)$$

4.2. Grindability, HG

The Grindability, HG, is a relative measure for lapping. A glass specimen with a surface area of 9 cm^2 is placed at 80 mm from the center of a cast iron circular plate. The plate is then rotated horizontally at 60 r.p.m., and a 9,807 N lapping weight is vertically loaded on the specimen. Lapping is continued for 5 minutes, with a continuous supply of a lapping compound composed of 10 g aluminum oxide (grain size 20 μm) in 20 ml of water.

The mass loss of the specimen, m, is then measured and compared to that of the standard reference material (GOST K8 and SCHOTT N-BK7), m_0. The abrasion factor is then determined by the following equation:

$$HG = (m / d) / (m_0 / d_0) \cdot 100 \qquad (20)$$

Where d is the specific gravity of the test specimen and d_0 is the specific gravity of the standard reference material (GOST K8 and SCHOTT N-BK7).

Table 5. Grindability

Grindability, Limit Value	GOST 13659	ISO FDIS 12844
30	0,3 · 100	HG1
60	0,6 · 100	HG2
90	0,9 · 100	HG3
120	1,2 · 100	HG4
150	1,5 · 100	HG5
200	2,0 · 100	HG6

4.3. Knoop Hardness, HK

Knoop hardnes is used to characterize the hardness of the surface of optical glass against penetration.

For this measurement a pyramidal diamond indenter with vertex angles 172°30' and 130°00' and with a rhombic base is applied to the polished specimen surface. Indentation loads of up to 0,9807 N are applied for 15 seconds. The size of the resulting indentation is then measured.

Knoop hardness HK is calculated using:

$$HK = 1{,}451 \cdot F / L^2 \qquad (21)$$

Where F (N) denotes the applied load and L (mm) is the length of the longer diagonal of the resulting indentation.

Note 4:

- The knoop hardness is expressed in terms of MPa or N / mm^2 which is omitted herein according to the usage.
- The HK value obtained by the above equation using SI units is equal to that which is obtained by the calculation equation using kgf units.
- 1N = 1,01972 x 10^{-1} kgf

4.4. Stress-Optical Coefficient, Beta

Ideally, the optical properties of glass are isotropic through fine annealing. Birefringence may be observed, however, when external forces are applied or when residual stresses are present (commonly the result of rapid cooling).

The optical path difference Δ **n** (nm) associated with birefringence is linearly proportional to both the applied tensile or compressive stress, Δ σ (10^5 Pa) and the thickness d (cm) of the specimen and is given by the following equation:

$$\text{Beta} = \Delta \mathbf{n} / d / \Delta \sigma, \ (\text{nm/cm} \cdot 10^{-5}\ \text{Pa}) \qquad (22)$$

The proportionality constant, Beta (10^{-12} / Pa), in this equation is proper constant of each glass type and referred to as the stress-optical coefficient.

Note 5:

- 1 x 10^{-12} / Pa = 0,9807 (nm/cm) / (kgf/cm^2)
- 10^5 Pa = 1,0197 kgf/cm^2 = 1 bar
- 1 x 10^{-12} Pa = 1,0000197 nm/cm 10^{-5} Pa)

Stress-optical coefficients are obtained by measuring the optical path difference caused at the center of a glass disk with light 550 nm and temperature 20 ºC, when the disk is subject to a compressive load in a diametrical direction.

The Specific Gravity, Grindability, Knoop Hardness and Stress-Optical Coefficient are listed glass data of each optical glass type and are indicated in the glass data sheet as followings:

Figure 9. Mechanical Properties

Mechanical Properties			
SG	HG	HK	Beta

5. CHEMICAL PROPERTIES

5.1. GOST Method. Climatic Resistance, CR*

Sample of optical glass type are varnished by partial cover. This varnish is steady against reagents of the acid environment for a solution (pH = 2,8) of acetic acid at temperature 50 ºC and time 0,25 ~ 5 hours. After etching this sample for the mentioned above conditions are found defects on the surface between the protected and unprotected surface. These found defects was formed as a result of destruction of optical glass type by an acid. Then defects are testing by imposing on the defective sample of the special control sample and testing in the daylight. The irregularity of light strips caused by defect and exceeding 0,3 width of a strip is equivalent to reduction in factor of reflection on 0,4 %. Optical glass type classify to corresponding class.

Table 6. Classes of Climatic Resistance

Climatic test time, hours	GOST 13917	ISO WD 13384
5	1	CR1
1	2	CR2
0,25	3	CR3
0,12	4	CR4

5.2. GOST Method. Stain Resistance, FR*

Test of water resistance orders to sustain fine polished sample of optical glass type instantly after polishing in the air environment of humidity of 80 % at temperature 50 ºC for silicate glass (60 ºC for un-silicate glass) and time 2 ~ 20 hours. As a result of test under conditions declared above on the defective sample are found out dense microscopic stains of a water solution of products of destruction or layers of firm reaction products or cracks. These defects are tested by a microscope 25 multiple. Optical glass type classify to corresponding class.

Table 7. Class silicate and un-silicate glass of Stain Resistance

Stain test time, hours	GOST 13917	GOST 13917	ISO
20	A	c	FR1
10	B	u	FR2
5	C	d	FR3
2	D	dd	FR4

The Water Resistance and Acid Resistance are listed glass data of each optical glass type and are indicated in the glass data sheet as followings:

Figure 10. Chemical Properties

Chemical Properties	
CR*	FR*

6. OTHER PROPERTIES

6.1. Bubbles and Inclusions

Bubbles and inclusions in our glasses, though not entirely absent, are very scarce owing to our development of melting methods. The size and number of bubbles varies with the glass composition and melting conditions.

Bubbles are counted to obtain the total cross sectional area (mm^2) of bubbles present in every 100 ml of glass. Inclusions such as small stones or crystals are treated together with bubbles. The total cross-sectional area of bubbles and inclusions with diameter greater than 0,05 mm is measured. The permissible number of bubbles and inclusions with diameter or maximum dimension less than 0,05 mm is described per unit volume or mass by our class. This measurement is used to classify the glass according to Table 15 and 16.

6.2. Transmittance and Farbcode, FC

Optical glasses exhibit almost no light absorption over a wavelength range extending through the visible to the near infra-red. The spectral transmittance characteristics of optical glasses can be simply summarized with the coloration code

The coloration code is determined in the following way. The internal transmittance of a specimen with thickness 10 ± 0,1 mm is measured from 280 nm to 700 nm. Wavelengths are rounded off to the nearest 10 nm and expressed in units of 10 nm. $\lambda_{0,8}$ is the wavelength for which the glass exhibits 80% transmittance while $\lambda_{0,5}$ is the wavelength at which the glass exhibits 5% transmittance.

$$FC = La\ \lambda_{0,8}/\lambda_{0,5} \qquad (23)$$

For example, a glass with 80% transmittance at 398 nm and 5% transmittance at 362 nm has a coloration code 40 / 36, as shown:

FC = Lambda 39/36 or La 39/36

The coloration code is generally applied for transmittance control of optical glasses.

The Bubble, Farbcode are listed glass data of each optical glass type and are indicated in the glass data sheet as followings:

Figure 11. Other Properties

Other Properties	
Bubble	FC

7. STANDARD QUALITY

7.1. Index Tolerance

Since the listed refractive indices and Abbe-numbers are the mean of several melts, those for an individual melt will differ from the mean.

The tolerances are generally as follows:

Refractive index $\mathbf{n}_d$: $\pm 1 \cdot 10^{-3}$ (Class 4).

When you order, please specify the tolerance with respect to against our nominal values given in this catalog.

Table 8. Classes of Refractive Index

Index Tolerance	GOST 23136 Part 2.1	ISO 10110
$\pm 2 \cdot 10^{-4}$	1	1
$\pm 3 \cdot 10^{-4}$	2	2
$\pm 5 \cdot 10^{-4}$	3	3
$\pm 1 \cdot 10^{-3}$	4	4
$\pm 2 \cdot 10^{-3}$	5	5

Upon delivery of the ordered materials, melt data will be attached to report the specific refractive indices.

7.2. Abbe-number Tolerance

Since the listed refractive indices and Abbe-numbers are the mean of several melts, those for an individual melt will differ from the mean.

The tolerances are generally as follows:

Abbe-number V_d: ± 0,8% (Class 4).

When you order, please specify the tolerance with respect to against our nominal values given in this catalog.

Table 9. Classes of Abbe-number

Abbe-number Tolerance	GOST 23136 Part 2.2	ISO 10110
$\pm 0{,}2 \cdot 10^{-2}$	1	0,2 %
$\pm 0{,}3 \cdot 10^{-2}$	2	0,3 %
$\pm 0{,}5 \cdot 10^{-2}$	3	0,5 %
$\pm 0{,}8 \cdot 10^{-2}$	4	0,8 %
$\pm 1{,}6 \cdot 10^{-2}$	5	1,6 %

Upon delivery of the ordered materials, melt data will be attached to report the specific Abbe-number.

7.3. Transmittance, HT

Transmittance tolerance of the ordered materials will be followings.

Table 10. Transmittance Tolerance (improved internal transmittance)

Transmittance Tolerance	GOST 23136 Part 2.3	ISO 10110
0,991	1	HT 1%
0,980	2	HT 2%
0,962	3	HT 4%
0,944	4	HT 6%
0,925	5	HT 7%
0,902	6	HT 10%
0,861	7	HT 15%
0,741	8	HT 26%

The extent of coloration varies slightly from one melt to another, and therefore the coloration code listed in the catalog is the mean of several melts. Coloration between lots is controlled within ± 10 nm of the listed nominal values.

7.4. Homogeneity, H

The glass blanks with tight index control, or with very high homogeneity control, are manufactured by special manufacturing processes followed by interferometric inspection.

Homogeneity as index control can be supplied and are listed as follows:

Table 11. Classes of Homogeneity as index control

Homogeneity	GOST 23136 Part 2.4	ISO 10110	
$\pm 0,5 \cdot 10^{-6}$	-	H5	
$\pm 0,1 \cdot 10^{-5}$	-	H4	
$\pm 0,2 \cdot 10^{-5}$	-	H3	
$\pm 0,5 \cdot 10^{-5}$	-	H2	
$\pm 0,2 \cdot 10^{-4}$	A	S1	-
$\pm 0,5 \cdot 10^{-4}$	B	S0	LH2
$\pm 1,0 \cdot 10^{-4}$	C	SN	LH1
$\pm 2,0 \cdot 10^{-4}$	-	-	LN
No Test	D	No Test	No Test

The more detailed analysis of optical homogeneity gradients, focus, astigmatisms, coma, or spherical aberrations are an important part of our measurement. We are using interferometers types by ZYGO USA.

The glass blank in diameter or the greatest side no more than 150 mm characterize the aperture at design wavelength 550 nm and is classed by the glasses aperture (φ) attitude to interferometer aperture (φ_0).

Optical Homogeneity as aperture control can be supplied and are listed as follows:

Table 12. Classes of Optical Homogeneity as aperture control

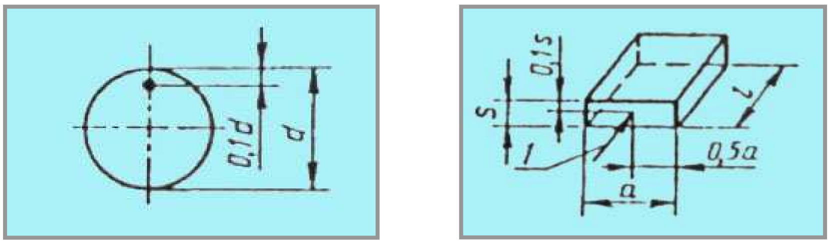
Optical Homogeneity, φ/φ_0	GOST 23136 Part 2.7.1	ISO 10110
1,00	1	via interferogram
1,05	2	via interferogram
1,10	3	via interferogram
1,20	4	via interferogram
1,50	5	via interferogram

7.5. Stress Birefringence, SB

Optical glass retains slight residual stresses even after being well annealed. Internal stresses cause birefringence, which is represented in terms of differences in the optical path in nm / cm.

For disc-shaped products, the stress birefringence is measured at a distance 0,1 d of the diameter from the circumference, and for rectangular plates, at a distance 0,1 s of its width from the edge in the middle of the longer side.

Figure 12. Measurement distance of stress birefringence



1 – Direct; a – Width; s – Thickness; l – Length.

Stress birefringence is graded as follows:

Table 13. Classes of Stress Birefringence

Stress Birefringence, nm/cm	GOST 23136 Part 2.8.1	ISO 10110
2	I	SSK
6	II	SK
10	III	Fine annealed
20	IV	Commercial annealed
50	V	Coarse annealed

7.6. Striae, VS

Striae are inspected by a striae-scope equipped with a point light source and an optical lens system. For inspection, striae are first identified in a selected direction which facilitates good viewing, then rated in one of GOST's own striae grades. With respect to standard references samples, the MIL-G-174B and ISO striae grade is compared to GOST's own grade, as shown in Table 14.

Table 14. Classes of Striae

Striae	GOST 23136 Part 2.9	MIL-G-174B	ISO 10110
No visible striae graduated by first sample	1	A	VS2
No visible striae graduated by second sample	2	B	VS2
Striae graduated as light and scattered	3	C	VS1
Striae graduated as heavier than light and scattered	4	D	VS1

7.7. Bubble, VB

Bubbles and inclusions in our glasses, though not entirely absent, are very scarce owing to our development of melting methods. The size and number of bubbles varies with the glass composition and melting conditions.

Bubbles are counted to obtain the total cross-sectional area (mm^2) of bubbles present in every 100 cm^3 of glass. Inclusions such as small stones or crystals are treated together with bubbles. The total cross-sectional area of bubbles and inclusions with diameter greater than 0,03 mm is measured. This measurement is used to classify the glass according to Table 15.

Table 15. Classes of bubbles as total cross-sectional

Bubbles, mm^2 per 100 cm^3	GOST 23136 Part 2.10.1	ISO 10110
0,029	1.1	EVB
0,125	1.2	VB
0,250	1.3	0,250
0,5	1.4	0,5
1	1.5	1
2	1.6	-
4	1.7	-

The permissible number of bubbles and inclusions with diameter or maximum dimension less than 0,03 mm is described per unit volume or mass by our class.

Table 16. Classes of bubbles as total number

Bubbles, number per 100 cm^3	GOST 23136 Part 2.10.2	ISO 10110
1	2.1	EVB
2,5	2.2	EVB
6,3	2.3	VB
16	2.4	VB
40	2.5	-
80	2.6	-
150	2.7	-
200	2.8	-

7.8. Polished, P

Surfaces quality, roughness, defects deposits, scratch or dig are subject to the effective machining and polishing.

Table 17. Classes Polished

Class Polished		Roughness	Scratch	Dig	Site	Machining
No class	Un-worked	Rz 320	No test	No test	No test	Fire-polished
		Rz 160	No test	No test	No test	Pressed
	Coarse	Rz 40	No test	No test	No test	Fine-molded
IX		Rz 20	0,3	3,0	No test	Cutting
VIII	Average	Rz 2,5	0,2	2,0	No test	Roughing
VII		Rz 1,2	0,1	1,0	50	Grinding
VI	Fine	Rz 0,6	0,06	0,7	25	Fine-grinding
V		Rz 0,32	0,04	0,5	10	
IV	Polished	Rz 0,1	0,02	0,3	5	Polishing
III		Rz 0,05	0,01	0,1	2	
II		Rz 0,025	0,006	0,05	1,2	

8. DELIVERY QUALITY

8.1. Standard Delivery, ST

Standard delivery has test certificate as listed the following.

Table 18. Standard delivery of optical glass blanks

Standard Quality, ST			
Quality Properties	Abbreviate	GOST	ISO
Index	$\mathbf{n}_d$	4	$\pm$ 1·10^{-3}
Abbe-number	V_d	4	± 0,8 %
Homogeneity	H	C/D	SN/LN
Stress Birefringence	SB	IV	Commercial
Transmittance	HT	6	10 %
Striae	VS	3	VS1
Bubble	VB	1.5	VB
Polished	P	Average	Average

8.2. Increased Quality, SE, PZ, SPZ

The increased quality classes cannot be completely ordered for all forms. Please see this table.

Table 19. Increased quality classes

Forms	Blocks		Pressings	Blanks	
Quality	Standard	Increased Standard	Standard	Precision	Super Precision
	ST	SE	ST	PZ	SPZ
Index	4	3	4	2	1
Abbe-number	0,8 %	0,5 %	0,8 %	0,3 %	0,2 %
Homogeneity	No Test	SN	LN	H2	H4
Stress Birefringence	Commercial	Fine	Commercial	SK	SSK
Transmittance	10 %	7 %	10 %		
Striae	VS1	VS1	No Test	VS1-VS2	VS2
Bubble	VB	VB	No Test	VB-EVB	EVB
Polished	Un-worked	Average	Un-worked	Fine	Polished

9. STANDARD FORMS

9.1. Block

Two opposite sides, though not polished, may permit visual internal inspection, and the remaining sides are fire-polished or as cast. Bevels at the edges may vary depending on the dimensions of block.

Table 20. Dimensional block, max mm

Format	L	± L	W	± W	T	± T	V, cm^3
1	500	± 10	500	± 10	100	± 10	25000
2	400	± 10	200	± 10	130	± 10	10400
3	400	± 10	200	± 10	100	± 10	8000
4	400	± 10	200	± 10	75	± 4	6000
5	150	± 10	100	± 10	75	± 4	1125

Blocks are ordered by:

glass code, glass type, block L x W x T or drawing.

9.2. Blank

Discs, rectangles, plates and prisms are blanks that are cut or core drilled from blocks. These forms are generally specified when delivery is urgent and quantities are small.

Table 21. Dimensional Disc blank, max mm

Format	Dia	± Dia	CT	± CT	V, cm^3
1	150	± 2,0	60	± 2,0	1350
2	100	± 2,0	50	± 2,0	500
3	50	± 2,0	20	± 2,0	50

Blanks are ordered by:

glass code, glass type, Disc/Plate/Rectangle Dia x CT or drawing.

9.3. Pressed Blank

Pressed blanks refer to glass articles already formed in lens blanks or prism blanks. Pressings are blanks formed by manually pressing softened glass.

Table 22. Dimensional pressings, min (1) and max (2) mm

Format	Dia	± Dia	CT	± CT	R1	R2	V, cm^3
1	10	± 0,2	4	± 0,3	PL	PL	0,4
2	120	± 1,0	20	± 0,3	Rcx/Rcv	Rcx/Rcv	288

Pressings are ordered by:

glass code, glass type, pressed blank Dia x CT x ET x R1 (Rcx/Rcv) x R2 (Rcx/Rcv).

On request tighter tolerance is acceptable with condition that customers furnish the final dimensions or drawings indicating the thickness of glass removal by grinding and polishing.

Special orders for sliced discs, large molded blanks, window or mirror blanks and other miscellaneous shapes with various dimensions for special applications are acceptable on request.

9.4. Index Glass Lens Blank

The pressed ophthalmologic lens blanks 525-580 index glass for eyeglasses which specially designed for correctional glasses are delivering in the standard form.

Table 23. Dimensional ophthalmologic lens blank

Format	Designation										Power
1	DIA	65	CT	3,2	ET	3,2	RCX	140	RCV	137	+ 0,0
2	DIA	65	CT	3,5	ET	3,0	RCX	112	RCV	121	+ 0,5
3	DIA	65	CT	4,0	ET	2,9	RCX	112	RCV	137	+ 1,0
4	DIA	65	CT	4,2	ET	2,8	RCX	93	RCV	121	+ 1,5
5	DIA	65	CT	4,8	ET	2,8	RCX	93	RCV	137	+ 2,0
6	DIA	65	CT	4,9	ET	2,5	RCX	81	RCV	121	+ 2,5
7	DIA	65	CT	2,7	ET	3,9	RCX	150	RCV	114	- 1,0
8	DIA	65	CT	2,5	ET	4,2	RCX	175	RCV	114	- 1,5
9	DIA	65	CT	2,5	ET	4,9	RCX	150	RCV	93	- 2,0
10	DIA	65	CT	2,5	ET	5,4	RCX	175	RCV	93	- 2,5

Index glass lens blanks are ordered by:

525-580 BKC(U) lens blank Dia x CT x ET x Rcx x Rcv or drawing.

9.5. Droplet

Glass droplet are supplied in a fire-polished form in a given weight specified by the customer and are available only for selected glass types.

We supply small diameter pre-formed glass droplet suitable for mould pressing into commercial lenses. Glass droplet is produced by direct molding of molten glasses with low softening properties. Shape of standard glass droplet is convex on both sides as shown on the figure below.

Figure 13. Glass droplets

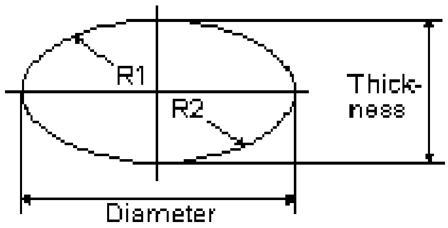


Table 24. Dimensional droplet

Format	Dia	CT	R1	R2	V, cm^3
1	6,0	4,5	3,0	3,0	0,1
2	8,5	6,5	7,0	8,0	0,2
3	10,0	7,0	7,5	8,5	0,3
4	12,5	8,0	11,0	10,0	0,4
5	14,5	8,5	17,5	12,0	0,5

Droplet are ordered by:

glass code, glass type, droplet Dia x CT x R1 x R2 or drawing.

9.6. Optical Element

Optical elements or finished components polished, coated and assembled various lenses objectives and lenses for correctional eyeglasses and lenses such as camera lenses are available on request.

Optical elements are ordered by:

glass code, glass type, lens Dia x CT x ET and drawing.

10. PREFERED PRODUCT LINE

10.1. Preferred Product

Practice shows, that the principal optical glass types have high stable selling.

Table 25. Preferred product line

POTAPENKO GLASS & FILTERS			**Principal Properties**					
Glass Type	Glass Code (d)	Glass Code (e)	n_d	V_d	$n_F - n_C$	n_e	V_e	$n_{F'} - n_{C'}$
LK6	470 668	472 666	1,47046	66,83	0,007040	1,47214	66,64	0,007085
LK5	478 655	479 654	1,47817	65,59	0,007290	1,47990	65,44	0,007334
K8	516 640	518 638	1,51637	64,07	0,008060	1,51829	63,87	0,008115
FK11	519 691	521 689	1,51997	69,14	0,007520	1,52176	68,92	0,007570
BK10	568 560	571 557	1,56889	56,05	0,010150	1,57131	55,76	0,010245
FK14	579 650	582 648	1,57998	65,09	0,008910	1,58211	64,83	0,008979
OF6	601 510	604 508	1,60121	51,04	0,011780	1,60401	50,84	0,011880
F1	612 369	616 366	1,61294	36,95	0,016590	1,61688	36,69	0,016814
TK16	612 583	615 580	1,61269	58,35	0,010500	1,61519	58,08	0,010592
TK14	613 605	615 603	1,61309	60,58	0,010120	1,61551	60,33	0,010203
TF1	647 338	652 336	1,64766	33,87	0,019120	1,65219	33,62	0,019397
OF4	650 434	654 432	1,65063	43,46	0,014970	1,65419	43,25	0,015127
CTK3	659 573	662 570	1,65950	57,35	0,011500	1,66224	57,09	0,011600
OF5	662 417	666 415	1,66264	41,78	0,015860	1,66640	41,56	0,016033
CTK7	687 535	690 533	1,68701	53,59	0,012820	1,69006	53,31	0,012944
TF8	689 311	694 309	1,68949	31,13	0,022150	1,69473	30,90	0,022486
CTK12	692 550	695 547	1,69201	55,01	0,012580	1,69501	54,79	0,012684
CTK8	703 496	706 494	1,70312	49,69	0,014150	1,70650	49,41	0,014298
TF3	717 295	723 292	1,71741	29,51	0,024310	1,72317	29,29	0,024691
TF7	728 283	734 281	1,72822	28,34	0,025700	1,73429	28,12	0,026111
TF4	740 275	761 273	1,75523	27,53	0,027430	1,76171	27,32	0,027879
CTK9	742 502	746 500	1,74253	50,24	0,014780	1,74605	50,01	0,014918
CTK19	744 504	747 501	1,74413	50,42	0,014760	1,74765	50,19	0,014895
TF5	755 281	746 279	1,74002	28,16	0,026280	1,74623	27,94	0,026705
TF13	784 263	791 261	1,78466	26,33	0,029800	1,79169	26,13	0,030299
TBF9	808 427	812 425	1,80846	42,78	0,018900	1,81296	42,52	0,019118
TBF10	814 334	820 331	1,81481	33,42	0,024380	1,82057	33,17	0,024740

11. REFERENCES

11.1. Formulas

Dispersion Formula

$\mathbf{n}_x^2 - 1 = A1 \cdot \lambda^2 + A2 \cdot \lambda^{-2} + A3 \cdot \lambda^{-4} + A4 \cdot \lambda^{-6} + A5 \cdot \lambda^{-8}$ (1)

Partial Dispersion

$(\mathbf{n}_x - \mathbf{n}_y)$ (2)

Main Partial Dispersion

$(\mathbf{n}_F - \mathbf{n}_C)$ and $(\mathbf{n}_{F'} - \mathbf{n}_{C'})$ (3)

Abbe-number

$V_d = (\mathbf{n}_d - 1) / (\mathbf{n}_F - \mathbf{n}_C)$ (4)

$V_e = (\mathbf{n}_e - 1) / (\mathbf{n}_{F'} - \mathbf{n}_{C'})$ (5)

Relative Partial Dispersion

$P_d(x,y) = (\mathbf{n}_x - \mathbf{n}_y) / (\mathbf{n}_F - \mathbf{n}_C)$ (6)

$P_e(x,y) = (\mathbf{n}_x - \mathbf{n}_y) / (\mathbf{n}_{F'} - \mathbf{n}_{C'})$ (7)

Deviation of Relative Partial Dispersions

$P_d(x,y) \sim \mathbf{a}_{x,y} + \mathbf{b}_{x,y} \cdot V_d$ (8)

$P_e(x,y) \sim \mathbf{c}_{x,y} + \mathbf{d}_{x,y} \cdot V_e$ (9)

$\Delta P_d(x,y) = P_d(x,y) - \mathbf{a}_{x,y} - \mathbf{b}_{x,y} \cdot V_d$ (10)

$\Delta P_e(x,y) = P_e(x,y) - \mathbf{c}_{x,y} - \mathbf{d}_{x,y} \cdot V_e$ (11)

$\Delta P_e(i,F') = P_e(i,F') - 2{,}25801 + 0{,}0093272 \cdot V_e$ (12)

$\Delta P_e(g,F') = P_e(g,F') - 0{,}57035 + 0{,}0014832 \cdot V_e$ (13)

$\Delta P_e(F',e) = P_e(F',e) - 0{,}54290 + 0{,}0005702 \cdot V_e$ (14)

$\Delta P_e(F',r) = P_e(F',r) - 1{,}17926 + 0{,}0007208 \cdot V_e$ (15)

Internal Transmittance

$\boldsymbol{\tau}_x = \boldsymbol{\tau}_0^{\,d/d_o}$ (16)

Coefficient of Thermal Expansion

$CTE = L / \Delta L \cdot \Delta T$ (17)

Temperature Coefficient of Refractive Index

$\mathbf{NT}$ abs = NT relative + $\mathbf{n}_x \cdot$ NT air (18)

Specific Gravity

SG ~ $(\mathbf{n}_x^2 - 1) / (\mathbf{n}_x^2 + 2)$ (19)

Grindability

HG = $(m / d) / (m_0 / d_0) \cdot 100$ (20)

Knoop Hardness

HK = $1{,}451 \cdot F / L^2$ (21)

Stress-Optical Coefficient

Beta = $\Delta\, \mathbf{n}_x / d / \Delta\, \sigma$, $(nm/cm \cdot 10^{-5}\ Pa)$ (22)

Farbcode (FC)

FC = La $\lambda_{0,8} / \lambda_{0,5}$ (23)

11.2. Abbreviates

$\mathbf{n}_x$	- Refractive Index
V_d	- Abbe-number
V_e	- Alternative Abbe-number
$P_d(x,y)$	- Relative Partial Dispersion
$P_e(x,y)$	- Alternative Relative Partial Dispersion
$\Delta P_d(x,y)$	- Deviation of Relative Partial Dispersions
$\Delta P_e(x,y)$	- Alternative Deviation of Relative Partial Dispersions
$\boldsymbol{\tau}_x$	- Internal Transmittance
CTE	- Coefficient of Thermal Expansion
NT abs	- Absolute Temperature Coefficient of Refractive Index
NT relative	- Relative Temperature Coefficient of Refractive Index
NT air	- Air Temperature Coefficient of Refractive Index
SG	- Specific Gravity
HG	- Grindability
HK	- Knoop Hardness
Beta	- Stress-Optical Coefficient
SB	- Stress Birefringence
H	- Homogeneity
VS	- Visible Striae
VB	- Visible Bubble
P	- Polished
FC	- Farbcode
HT	- Transmittance Tolerance
CR*	- Climatic Resistance. GOST Method
FR*	- Stain Resistance. GOST Method
ST	- Standard Quality
SE	- Increased Standard Quality
PZ	- Precision Quality
SPZ	- Super Precision Quality

11.3. Literature

1. GOST 3514. Optical glass. Specification.
2. GOST 13659. Optical glass. Physical and Chemical properties.
3. GOST 23136. Optical materials. Defects and classifications.
4. GOST 13917. Optical glass. Chemical test methods.
5. GOST 13240. Optical glass blanks. Technical conditions.
6. DIN 58925. Optical glass. Principal concepts.
7. ISO 10110. Issuing of drawings for optical elements.
8. ISO 12844. Optical raw glass. Test methods.
9. OPTOPROM. Optical materials. Catalogue. Moscow 2003.
10. SCHOTT GLASS. Catalogue. Version 1.1 E Status 02/2001.
11. HOYA GLASS. Catalogue. USA Divisions. Version 2002.
12. OHARA GLASS. Catalogue. FRG Divisions. Version 2002.

Note 6:

- Potapenko is the sole owner of the information collected into this technical catalogue and will not make express modifications this information to others in ways different from what is disclosed as this catalogue text. The above technical catalogue text is version of the our company. In the event of ambiguity or difference arising between the version of the catalogue text and his modified information, modern version of the catalogue text shall prevail.

- This catalogue text may contain inadvertent inaccuracies or typographical errors. These will be corrected at Potapenko's discretion, as they are found. The information on this catalogue text is updated regularly, but inaccuracies may occur where changes occur between updates.

- Potapenko has used and will use reasonable efforts to include accurate and up-to-date information on his catalogue. However, Potapenko makes no warranties or representations, express or implied, as to the timeliness, accuracy or completeness of the information contained or referenced in this version of the catalogue text.

- Please contact us for reception of modern version of the catalogue text and other exacter technical data.