Optical Glass

1 Classification and Designation of Optical Glass Types

1.1 Classification of Optical Glass Types

Optical glass can be classified into 16 groups according to its different refractive index (n_d) and Abbe-number (ν_d) positions in the n_d - ν_d diagram and their chemical composition (Table 1).

Table 1

Group	CDGM	Group	CDGM
Fluoria Crown	Fk	Light Flint	QF
Light Crown	QK	Flint	F
Crown	K	Barium Flint	BaF
Phosphate Crown	PK	Dense Barium Flint	ZBaF
Barium Crown	BaK	Dense Flint	ZF
Dense Crown	ZK	Lanthanum Flint	LaF
Lanthanum Crown	LaK	Dense Lanthanum Flint	ZLaF
Crown Flint	KF	Special Flint	TF

1.2 Designation of Optical Glass Types

Each optical glass type within a group is designated by an abbreviated group symbol and a number. In addition to our glass type designation, a six -digital code is listed in this catalogue. The first three digitals indicate the three numbers after the decimal point of the glass refractive index and the last three digitals indicate the Abbe-number , for example H-K9L n_d =1.$\underline{516}$80, ν_d=$\underline{64.2}$, its code comes to be 517642.

1.3 Designation of the Optical Glass without Lead , Arsenic and Cadmium

The optical glass without Lead, Arsenic and Cadmium and other radioactive elements is expressed by a prefix “H-” indicating its environment-friendly characteristics.

1.4 Designation of Low Softening Point Glass Types

Low softening point glass type without Lead, Arsenic and Cadmium and other radioactive elements is prefixed by an alphabet “D-”, for example, D-K9L.

1.5 Designation of UV High Transmittance Glass Types

The type of UV high transmittance is prefixed by an alphabet “U” which means ultraviolet, for example, UQF50. High transmittance glass type is expressed by a suffix “-HT” indicating high transmittance, for example, ZF7LHT.

2 Optical Properties

2.1 Refractive Index

Refractive indices are accurate to 5-decimal and are given for the following 12 lines of the spectrum in Table 2. The precise measurement methods of those spectrum lines are specified in GB/T 7962.11,P.R.China,and its measurement accuracy is $\pm 1 \times 10^{-5}$.

Table 2

Wavelengths(nm)	Spectral Line	Element
760.52	r	He
656.27	C	H
643.85	C'	Cd
632.80	He-Ne	He-Ne Laser
589.29	D	Na
587.56	d	He
546.07	e	Hg
486.13	F	H
479.99	F'	Cd

2.2 Refractive and Abbe number

The main dispersion: $n_F - n_C$ or $n_{F'} - n_{C'}$

Abbe number υ_d: $\upsilon_d = (n_d - 1)/(n_F - n_C)$……………………………...(1)

While υ_e: $\upsilon_e = (n_e - 1)/(n_{F'} - n_{C'})$…………………………… ..(2)

2.3 Dispersion Formula

In the spectral range of 365nm~706.5nm, the refractive index at other wavelength can be calculated according to the following dispersion formula:

$$n^2 = A_0 + A_1^2 + A_2 \lambda^{-2} + A_3 \lambda^{-4} + A_4 \lambda^{-6} + A_5 \lambda^{-8} \quad \text{……………………..(3)}$$

Where: A_0~A_5——calculating constants;

λ——wave length, μm;

n——the calculated refractive index , the calculating accuracy of n : $\pm 3 \times 10^{-6}$ at the wavelength range of 400nm~706.5nm ; $\pm 5 \times 10^{-6}$ at a wavelength between the range of 365nm~400nm.

2.4 Relative Part Dispersion

At the wavelength of X and Y, the relative part dispersion $P_{x,y}$ can be expressed by the following formula:

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

$$P'_{x,y} = (n_x - n_y)/(n_{F'} - n_{C'}) \quad \text{…………………………………….(4)}$$

The value of $P_{d,c}$,$P_{e,d}$,$P_{g,F}$ and $P'_{d,c'}$, $P'_{e,d}$, $P'_{g,F'}$ for each glass type are listed in the data sheets. According to the Abber's formula, the following linear correspondence is correct for most "normal dispersion glass":

$$P_{x,y} = m_{x,y} \nu_d + b_{x,y} \quad \text{……………………………………………….(5)}$$

The linear correspondence can be plotted along a straight line , in which $P_{x,y}$ is the Y-coordinate according to Abbe's formula. The deviated value is indicated as $\Delta P_{x,y}$,thus each $P_{x,y}$- υ_d point moves parallel $\Delta P_{x,y}$ from those "normal lines" which are suitable to formula (5). So $\Delta P_{x,y}$ for each glass type can be calculated according to the following formula:

$$P_{x,y} = m_{x,y} \quad \nu_d + b_{x,y} + \Delta P_{x,y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Therefore, the $\Delta P_{x,y}$ can express quantificationally the deviation property of special chromatic dispersion when compared with the "normal glass ". For example, we choose H-K6 and F4 as the "normal glass", and its relative part dispersion and Abbe -number is suitable for Abbe-number formula (5). $\Delta P_{g,F}$, $\Delta P_{F,e}$ are given in data table , their calculating formula as follows:

$$\Delta P_{F,e} = P_{F,e} - 0.4894 + 0.000541 \quad \upsilon_d$$

$$\Delta P_{g,F} = P_{g,F} - 0.6457 + 0.001703 \quad \upsilon_d \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

2.5 Stress-Optical Coefficient B

The birefringence may result from the chemical stress in optical glass. Stress-optical coefficient expresses the relationship between the effective stress and the optical path difference caused by stress birefringence:

$$\delta = B \cdot d \cdot F \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Where: δ——optical path difference , nm;

B——Stress-optical coefficient, /p_a;

d——the distance of light through the glass ,cm;

F——applied stress ,p_a

2.6 Internal Transmittance

Internal transmittance is the transmittance exclusive of surface reflection losses at both sides . The measurement method is specified in GB/T 7962.12,P.R.China. The data sheets show the internal transmittances of different wavelength for 5mm and 10mm thick glass.

2.7 Color Code (λ_{80}/λ_{5})

Performance of optical glass transmittance can also be indicated by color code. A 10mm±0.1mm thick glass sample is tested for the wavelengths when the glass transmittance reaches 80% and 5%. For example ,if at the wavelength of 368 nm and 313nm, the transmittance is respectively 80% and 5%, then the color code λ_{80}/λ_{5} is indicated as 37/31.See details in Figure 1.

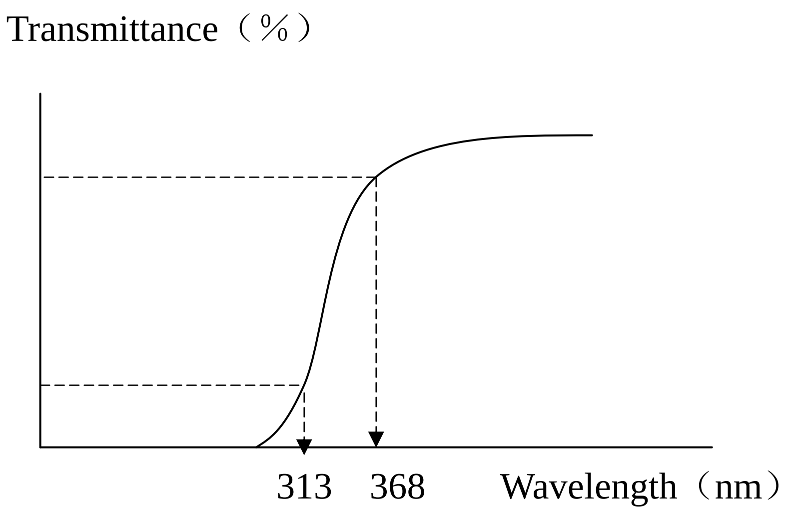

Fig 1

3 Chemical Properties

The chemical stability is the ability of polished surface to resist erosive substance of sorts during the glass component is being processed and afterwards being applied.

3.1 Humidity Resistance RC(S) (Surface Method)

According to the resistance of the polished glass surface to humidity, the RC(S) are classified into 3 grades:

Grade 1——At 50℃ and the relative humidity of 80%, the hydrolysis “spot” is not formed on the polished glass surface till more than 20 hours later.

Grade 2——Under the same testing condition , the “spot” is found 5 to 20 hours later.

Grade 3——Under the same testing condition , the “spot” appears within 5 hours.

3.2 Acid Resistance RA(S) (Surface Method)

According to resistance of the polished glass surface to acid, the RA(S) are classified into 3 grades:

Grade 1——After erosion by the 0.1N Vinegar acid resolution at 50℃, the polished glass surface is eroded a layer with a thickness of 135nm, and the whole erosive process lasts more than 5 hours.

Grade 2——Under the same testing condition, a layer with same thickness is dissolved in the time period of 1 hour to 5 hours.

Grade 3——Under the same testing condition, a layer with same thickness is dissolved less than 1 hour.

3.3 Durability of Water D_w (Powder Method)

The water durability can be measured by the method specified in GB/T 17129, P.R. China, the D_w is calculated by the following formula:

$$D_w=(B-C)/B-A)\times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

Where: D_w——soaking-out percentage,%;

B——mass of filter and sample, g;

C——mass of filter and soaked sample, g;

A——mass of filter, g;

With the calculation results, the D_w are classified into 6 grades (Table 3)

Table 3

Grades	**1**	**2**	**3**	**4**	**5**	**6**
soakingout percentage D_w	<0.04	0.04~0.10	>0.10~0.25	>0.25~0.60	>0.60~1.10	>1.10

3.4 Durability of Acid D_A (Powder Method)

The acid durability can be measured by the method specified in GB/T 17129,P.R. China, the D_A is calculated by the following formula:

$$D_A=(B-C)/B-A)\times 100\% \qquad \ldots\ldots(10)$$

Where: D_A---soaking-out percentage, %

B---- mass of filter and sample, g

C---- mass of filter and soaked sample, g;

A--- mass of filter, g;

With the calculation results, the D_A are classified into 6 grades (Table 4)

Table 4

Grades	1	2	3	4	5	6
soakingout percentage D_A	<0.20	0.20~0.35	>0.35~0.65	>0.65~1.20	>1.20~2.20	>2.20

4 Thermal Properties

4.1 Mean Coefficient of Linear Thermal Expansion (α)

It refers to the elongation of the unit length of glass when heated per 1℃ in a certain temperature range .The thermal expansion coefficient listed in the catalogue is the mean thermal expansion coefficient, measured by the method specified in GB/T 7962.16 P.R. China, at a temperature ranges from +20℃ to 120℃and from +100℃ to 300℃(Fig.2)

4.2 Transformation Temperature Tg

When heating up the glass to a certain temperature range, the optical glass will be transformed from its solid state into a plastic state. Tg represents the temperature at the intersecting point of the straight line extended from the curve of the sample's thermal expansion in the low temperature range and high temperature range when it heats up from room temperature to sag temperature (Ts), measured by the method specified in GB/T 7962.16, P.R. China. (Fig.2).

4.3 Sag Temperature Ts

Sag temperature, Ts, is the temperature at which the sample stops expanding in the process being heated up, measured by the method specified in GB/T 7962.16, P.R. China. (Fig.2).

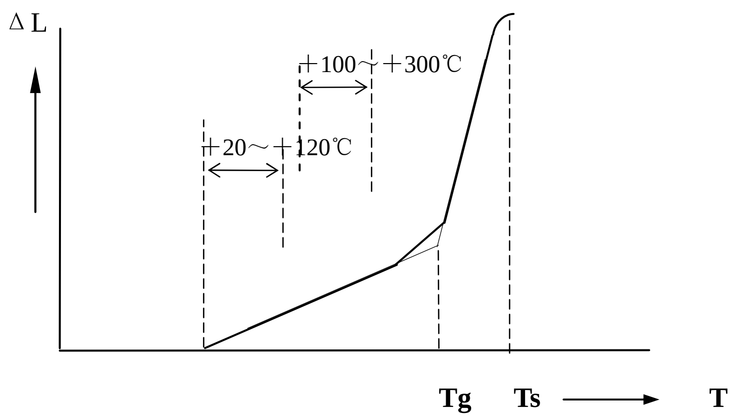

Fig 2

4.4 Strain Point $T_{10^{14.5}}$

Strain point, $T_{10^{14.5}}$, is the temperature at which inner stresses in a glass are eliminated within a few hours. The viscosity of the glass at that temperature corresponds to about $10^{14.5}$ dpa • s or $10^{13.5}$ pa • s.

4.5 Annealing Point $T_{10^{13}}$

Annealing point, $T_{10^{13}}$, is a temperature at which inner stresses in a glass are eliminated within a few minutes. The viscosity of the glass at that temperature corresponds to about 10^{13} dpa • s or 10^{12} pa • s.

5 Mechanical Properties

5.1 Young' s Modulus (E), Shear Modulus (G) and Poisson' s Ratio (μ)

The glass Young' s Modulus ,Shear Modulus G and Poisson' s Ratio μ are given by the following formulas:

$E=(4G^2-3G \cdot V_\ell^2 \cdot \rho)/(G-V_\ell^2 \cdot \rho)$……………………….............. ….(11)

$G=V_s^2 \cdot \rho$ ………………………...(12)

$\mu=E^2/2G-1$…………………………...(13)

Where: E ——Young's Modulus ,$p_{a;}$

G —— Shear Modulus , $p_{a;}$

V_ℓ ——Velocity of longitudinal wave;

V_s ——Velocity of transverse wave;

ρ ——glass density ,g/cm^3

5.2 Knoop Hardness H_k

Knoop hardness is measured by the method specified in GB/T7962.21, P.R. China. A pyramid-shaped diamond indenter with vertex angles of 172° 30′ and 130° and with a rhombic base is loaded on a glass specimen surface for a certain time, and then the length of the longer diagonal of the indentation is observed with the microscope .H_k is calculated by the following formula:

$$H_k=F/(0.07028 \cdot L^2) \qquad (14)$$

Where :F——load ,N;

L——the length of the longer diagonal of the indentation, m;

H_k——knoop hardness, Pa.

5.3 Abrasion Hardness F_A

Impacting the tested sample on the revolving plate while grinding it with the grinding materials under the same grinding condition, people define the abrasion hardness as the value of ratio of the weight loss of tested sample in grinding to the standard sample multiplying 100. The abrasion hardness can be calculated by the following formula:

$$F_A = \frac{W/\rho}{W_0/\rho_0} \times 100 \qquad (15)$$

Where: F_A——the abrasion hardness

W: ——the weight loss of the tested sample, g;

W_0——the weight loss of the standard sample, g;

ρ_0——the density of tested sample, g/cm^3.

ρ——the density of standard sample, g/cm^3

5.4 Density

The density of glass is defined as the mass per unit volume at the temperature 20℃,and is measured by the method specified in GB/T 7962.20, (g/cm^3).

6 Quality Definition

6.1 Allowable Tolerance of Refractive Index (n_d)and Abbe-number（υ_d）

The tolerance of refractive index and Abbe-number to standard value is classified into 3 grades,(Table 5) .

Table 5

Grade	The allowed tolerance of n_d,(Δn_d)		Grade	The allowed tolerance of ν_d（$\Delta \upsilon_d$%）
1	$\pm 30\times 10^{-5}$		1	± 0.5
2	$\pm 50\times 10^{-5}$		2	± 0.8
3	$\pm 100\times 10^{-5}$		3	± 1.0
Notice: For tight tolerance, please inquire.				

n_d and υ_d are measured by the method specified in GB/T 7962.1, P.R. China, the measured accuracy for: n_d $\pm 3\times 10^{-5}$, and for main dispersion $n_F - n_C$: $\pm 2\times 10^{-5}$.

6.2 Optical Homogeneity

6.2.1 Glass Blank Smaller Than 150 mm

The homogeneity of glass blank of this size is measured by the method specified in GB/T 7962.2, P.R.China. The glass sample is placed in the beam in collimator, and the changing of resolution of collimator caused by the sample is observed. Given the theoretical resolution of the collimator is α_0 , increased resolution is α after glass sample being put in , then refractive index variation in the blank can be reflected by the ratio of α / α_0 . The optical homogeneity are classified into 4 grades (Table 6):

Table 6

Grade	α / α_0	Image characters
1	1.0	A bright spot in the center surrounded by concentric circles, and all the circles bearing no deformation such as breakage, tail tilting and oblateness etc.
2	1.0	A bright spot in the center surrounded by deformed circles and all the circles bearing no deformation such as breakage, deformed angle, tail tilting and oblateness etc.
3	1.1	/
4	1.2	/

6.2.2 Glass Blank Larger Than 150mm

The optical homogeneity is defined as the maximum variation of the refraction index Δn_{max} within a piece of glass. Δn_{max} is measured by the method specified in GB/T 7962.4, P.R. China, and classified into 4 grades (Table 7):

Table 7

Grade	Δn_{max}
H1	$\pm 2 \times 10^{-6}$
H2	$\pm 5 \times 10^{-6}$
H3	$\pm 10 \times 10^{-6}$
H4	$\pm 20 \times 10^{-6}$

6.3 Stress Birefringence

6.3.1 Middle Stress

The middle stress existing in the glass blank is measured by the method specified in GB/T 7962.5, P.R. China. Optical path difference δ in nm/cm is measured along the longest direction of glass blank, and the middle stress reflects optical path difference per unit in the middle section. It is classified into 5 grades (Table 8):

Table 8

Grade	Middle optical path difference δ (nm/cm)
1	2
1a	4
2	6
3	10
4	40 (strips, coarse annealed) 60 (slabs, coarse annealed)

6.3.2 Edge Stress

It is measured by the method specified in GB/T 7962.6, P.R. China, i. e , measuring the optical path difference at a distance of 5% of the diameter or from the longer side of glass blank. Edge stress (nm/cm) is defined by maximum optical path difference δ_{max} per unit thickness and is classified into 5 grades (Table 9):

Table 9

Grade	The maximum optical path difference at the edge of glass δ_{max}(nm/cm)
S1	3
S2	5
S3	10
S4	20
S5	80

6.4 Striae

With the striae-scope, striae is viewed in the direction of maximum visibility, by comparing with a standard sample. The striae is classified into 3 grades. (Table 10):

Table 10

Grade	Striate feature
A	invisible to the naked eye
B	Fine and scattering striate
C	slight parallel striate

6.5 Bubble

Bubbles are inspected by the method specified in GB/T 7962.8, P.R. China, and counted to obtain the total cross sectional area (mm^2)of bubbles of 100 cm^3 glass volume(bubbles dia Φ ≥0.05~2mm).The bubble quality of glass is classified into 7 grade (Table 11):

Table 11

Grade	Total cross sectional area per 100 cm^3 of glass bubbles dia Φ ≥ 0.05mm (mm^2 / 100 cm^3)
A_{00}	≤0.003~0.03
A_0	>0.03~0.10
A	>0.10~0.25
B	>0.25~0.50
C	>0.50~1.00
D	>1.00~2.00
E	>2.00~4.00

Inclusions such as small stone or crystal are treated like bubbles and counted in the same manner. The cross section area of non-spherical bubbles is counted by arithmetical mean value of the longest shaft and the shortest shaft as the diameter.

6.6 Optical Absorption Coefficient

It is measured by the method specified in GB/T 7962.9 , P. R. China , with spherical photometer . It is represented by the ratio between the luminous flux absorbed and the initial luminous flux when the incandescence passes the path per cm. According to the ratio, the quality is divided into 8 grades (Table 12).

Table 12

Grade	Max. Coefficient. for. Optical glass		Grade	Max. Coefficient for Optical glass
00	0.001		3	0.008
0	0.002		4	0.010
1	0.004		5	0.015
2	0.006		6	0.30

7 Radio-resistant Optical Glass and Radio-resistant Properties

The radio-resistant glass is a kind of optical glass , the color of which do not change when exposed under $\gamma-$ ray. The glass composition is added a small amount of other oxides to the normal optical glass formula. So their optical constants are the same. The order of type is that adding 500 to the corresponding normal optical glass order, i.e., K9 glass, the corresponding radio-resistant glass type is K509.

The radio-resistant properties is represented by the increase in optical density (Δ D)when γ - ray ,whose radiation dosage is 10^5 R (25.8c/kg) ,passes per cm thickness, or by the increase in optical density (ΔD_1) when other rays being equivalent to 10^5 R X ray passes per cm thickness (Table 13) :

Table 13

Type	Radio-resistant properties		Type	Radio-resistant properties		Type	Radio-resistant properties	
	ΔD1	ΔD		ΔD1	ΔD		ΔD1	ΔD
K502	0. 035	0. 035	ZK507	0. 025	0. 025	BaF503	0. 045	0. 070
K505	0. 030	0. 035	ZK508	0. 025	0. 025	BaF504	0. 045	0. 040
K507	0. 035	0. 045	ZK509	0. 035	0. 040	BaF506	0. 065	0. 060
K509	0. 030	0. 015	ZK510	0. 025	0. 020	BaF508	0. 055	0. 045
K510	0. 060	0. 060	ZK511	0. 065	0. 065	ZBaF501	0. 055	0. 060
BaK501	0. 025	0. 015	KF501	0. 065	0. 070	ZBaF502	0. 090	0. 200
BaK502	0. 020	0. 015	KF502	0. 110	0. 090	ZBaF503	0. 055	0. 065
BaK503	0. 025	0. 020	QF502	0. 110	0. 080	ZBaF504	0. 200	0. 200
BaK506	0. 025	0. 025	QF503	0. 110	0. 110	ZBaF505	0. 200	0. 200
BaK507	0. 040	0. 040	F502	0. 080	0. 070	ZF501	0. 080	0. 080
BaK508	0. 020	0. 025	F503	0. 065	0. 070	ZF502	0. 060	0. 080
ZK501	0. 030	0. 025	F504	0. 060	0. 070	ZF503	0. 080	0. 120
ZK503	0. 025	0. 025	F505	0. 050	0. 070	ZF504	0. 120	0. 200
ZK505	0. 025	0. 025	F506	0. 060	0. 070	ZF505	0. 120	0. 120
ZK506	0. 020	0. 025	BaF502	0. 060	0. 090	ZF506	0. 080	0. 120

8 Forms of Supply

We can supply glass as follows, mainly.

8.1 Blocks

The two larger surfaces are fine ground with the other surfaces being coarse ground. All the edges and angles are chamfered and the blocks are fine annealed.

8.2 Strips

A strip has two cut ends and four surfaces which are naturally formed. The glass is coarse or fine annealed.

8.3 Blank

8.3.1 Direct-press blank

Direct –press blank is directly formed from melted glass, not fine annealed.

8.3.2 Reheated -Press Blank

Reheated-press blank is formed by reheated –press process, and is fine annealed. （Table 14）

Table 14

Unit: mm

Outer diameter of pressed blanks	DP products		RP products	
	Tolerance of outer diameter	Thickness tolerance	Tolerance of outer diameter	Thickness tolerance
Φ<15	±0. 10	±0. 20	±0. 10	±0. 50
15≤Φ<29	±0. 10	±0. 20	±0. 15	±0. 35
29≤Φ<40	±0. 15	±0. 20	±0. 20	±0. 30
40≤Φ<60	±0. 20	±0. 20	±0. 30	±0. 30
60≤Φ<90	±0. 30	±0. 40	±0. 35	±0. 35
90≤Φ<150	±0. 40	±0. 40	±0. 40	±0. 40
Φ≥150	±0. 50	±0. 50	±0. 50	±0. 50

8.4 Gobs

It refers to the blank which cross section is nearly round, and not fine annealed .On request, we can supply Gobs having the required weight or volume.

8.5 Others

The glass meets customers' special specification.

9 Index catalog

In this mutual Index table, the equality of glass type refers to the same code of glass, but the glass composition is different between **CDGM** and **HOYA,OHARA, SCHOTT.**

10 Data Sheets