OHARA
OHARA CORPORATION

Western Office: CA
PH 949-858-5700 - FAX 949-858-5455

Eastern Office: NJ
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www.oharacorp.com

Ohara Glass	Ohara Code	Melt Frequency	Relative Price to S-BSL7
S-BAH10	670473	5	3.5
S-BAH11	667483	4	2.0
S-BAH27	702412	1	2.0
S-BAH28	723380	1	2.0
S-BAL2	571508	5	2.5
S-BAL3	571530	2	2.0
S-BAL12	540595	3	2.0
S-BAL14	569563	1	2.0
BAL15Y	557587	5	6.0
S-BAL35	589612	1	2.0
S-BAL35R	589610	5	10.0
BAL35Y	589612	5	9.0
S-BAL41	564607	X	2.0
S-BAL42	583594	2	2.0
S-BAM4	606437	1	2.5
S-BAM12	639449	3	4.0
S-BSL7	516641	1	1.0
S-BSL7R	516641	5	19.0
BSL7Y	516643	2	6.0
S-BSM2	607568	3	3.0
S-BSM10	623570	1	3.5
S-BSM14	603607	1	2.0
S-BSM15	623582	1	1.5
S-BSM16	620603	2	1.5
S-BSM18	639554	2	2.0
S-BSM22R	622532	5	20.0
S-BSM25	658509	1	2.0
S-BSM28	618498	3	3.0
BSM51Y	603606	3	15.5
S-BSM71	649530	2	3.0
S-BSM81	640601	3	3.5
ClearCeramZ (CCZ)	546555	1	3.5
S-FPL51	497816	1	7.5
S-FPL51Y	497811	3	28.5
S-FPL53	439950	1	12.0
S-FPL55	439948	1	10.5
S-FPM2	595677	1	7.0
S-FPM3	538747	1	8.0
S-FPM4	528765	2	8.0
S-FPM5	552708	2	7.5
S-FSL5	487702	1	2.0
S-FSL5Y	487703	1	11.0
S-FTM16	593353	1	3.0
S-LAH51	786442	1	4.5
S-LAH52	800422	1	4.5
S-LAH52Q	800422	3	4.5
S-LAH53	806409	1	5.0
S-LAH53V	806409	3	3.5
S-LAH55V	835427	5	9.0
S-LAH55VS	835427	1	4.5
S-LAH58	883408	1	16.5
S-LAH59	816466	2	12.5
S-LAH60	834372	1	4.5
S-LAH60MQ	834372	2	3.5
S-LAH60V	834372	1	4.0
S-LAH63	804396	5	4.5
S-LAH63Q	804396	5	7.5
S-LAH64	788474	1	8.0
S-LAH65V	804466	5	10.0

Ohara Glass	Ohara Code	Melt Frequency	Relative Price to S-BSL7
S-LAH65VS	804465	1	4.5
S-LAH66	773496	1	6.0
S-LAH71	850323	3	6.0
S-LAH79	2003283	5	46.5
S-LAH88	917316	2	4.5
S-LAH89	852408	1	4.5
S-LAH92	892371	3	4.0
S-LAH93	905350	2	4.0
S-LAH95	904313	1	3.5
S-LAH96	764485	1	4.5
S-LAH97	755523	2	4.5
S-LAH98	954323	2	5.0
S-LAH99	2001291	3	5.0
S-LAH99W	2001291	2	8.0
S-LAL7Q	652585	2	3.0
S-LAL8	713539	1	3.5
S-LAL9	691548	2	3.0
S-LAL10	720502	1	3.5
S-LAL12	678553	3	2.5
S-LAL12Q	678553	2	3.0
S-LAL13	694532	5	4.0
S-LAL14	697555	1	3.5
S-LAL18	729547	1	8.0
S-LAL19	729541	2	3.0
S-LAL20	699511	1	5.0
S-LAL21	703524	2	5.5
S-LAL54Q	651562	2	5.5
S-LAL58	694508	2	2.5
S-LAL59	734515	2	5.0
S-LAL61	741527	2	5.5
S-LAL61Q	741527	2	6.0
S-LAM2	744448	1	3.0
S-LAM3	717479	2	3.0
S-LAM7	750353	3	3.0
S-LAM54	757478	5	4.5
S-LAM55	762401	1	3.0
S-LAM60	743493	1	3.5
S-LAM66	801350	1	3.5
S-LAM73	794371	3	3.5
NANOCERAM™	539523	3	5.0
S-NBH5	654397	1	4.0
S-NBH8	720347	1	4.5
S-NBH51	750353	1	4.0
S-NBH52V	673383	1	11.0
S-NBH53V	738323	1	11.0
S-NBH55	800299	2	3.0
S-NBH56	855248	1	5.0
S-NBH57	850300	2	4.0
S-NBH58	789284	2	6.5
S-NBH59	766358	2	8.0
S-NBM51	613443	1	4.5
S-NPH1	808228	2	8.0
S-NPH1W	808228	1	8.5
S-NPH2	923189	1	9.5
S-NPH3	959175	1	8.5
S-NPH4	893204	2	8.5
S-NPH5	859227	3	7.5
S-NPH7	778239	2	7.0
S-NSL3	518590	2	2.5

Ohara Glass	Ohara Code	Melt Frequency	Relative Price to S-BSL7
S-NSL5	522598	X	2.0
S-NSL36	517524	2	2.5
PBL1Y	548458	3	6.0
PBL6Y	532490	3	6.5
PBL25Y	581408	3	6.0
PBL26Y	567428	5	6.5
PBL35Y	581409	2	6.5
PBM2Y	620363	4	6.0
PBM2R	620365	5	18.5
PBM8Y	596393	5	6.0
PBM8R	596394	5	19.5
PBM18Y	596387	5	6.5
S-PHM52	618634	1	4.0
S-PHM52Q	618633	2	4.0
S-PHM53	603655	3	4.0
S-TIH1	717295	2	2.5
S-TIH3	740283	4	3.0
S-TIH4	755275	2	3.0
S-TIH6	805254	1	3.0
S-TIH10	728285	1	2.5
S-TIH11	785257	1	3.0
S-TIH13	741278	3	2.5
S-TIH14	762265	2	3.0
S-TIH18	722292	3	2.5
S-TIH23	785263	5	3.0
S-TIH53	847238	1	3.0
S-TIH53W	847238	1	3.5
S-TIH57	963241	3	3.5
S-TIL1	548458	3	3.0
S-TIL2	541472	2	3.0
S-TIL6	532489	3	3.0
S-TIL25	581407	3	3.0
S-TIL26	567428	3	3.0
S-TIL27	575415	2	3.0
S-TIM1	626357	X	2.5
S-TIM2	620363	1	2.5
S-TIM5	603380	2	2.5
S-TIM8	596392	3	3.0
S-TIM22	648338	5	2.0
S-TIM25	673321	1	2.0
S-TIM27	640345	2	2.5
S-TIM28	689311	1	2.5
S-TIM35	699301	2	3.0

Melt Frequency:

1 - Highest   4 - Low
2 - High   5 - Lowest
3 - Medium   N - New
X - Discontinued
(Not melting, but some stock remains)

This list is intended as a cross reference guide beween similar glass types.
Because optical properties of similar glass types may vary slightly, please consult our catalog before making glass type substitutions.

- Recommended glasses
- i-Line glasses (improved XMT at 365nm)
- Improved XMT at near UV (370 - 390nm)
- Radiation resistant glass

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Ohara Code	Ohara Type	Schott Type	Schott Code
439948	S-FPL55	-	-
439950	S-FPL53	-	-
487702	S-FSL5	N-FK5	487704
487703	S-FSL5Y	-	-
497811	S-FPL51Y	-	-
497816	S-FPL51	N-PK52A	497816
516641	S-BSL7	N-BK7	517642
516641	S-BSL7R	BK7G18	520636
516643	BSL7Y	-	-
517524	S-NSL36	KF6	517522
518590	S-NSL3	K3	518590
522598	S-NSL5	N-K5	522595
528765	S-FPM4	N-PK51	529770
532489	S-TIL6	N-LLF6	532488
532490	PBL6Y	-	-
538747	S-FPM3	-	-
540595	S-BAL12	N-BAK2	540597
541472	S-TIL2	-	-
548458	S-TIL1	LLF1	548458
548458	PBL1Y	-	-
552708	S-FPM5	-	-
557587	BAL15Y	-	-
564607	S-BAL41	N-SK11	564608
567428	S-TIL26	-	-
567428	PBL26Y	-	-
569563	S-BAL14	N-BAK4	569560
571508	S-BAL2	-	-
571530	S-BAL3	-	-
575415	S-TIL27	LF7	575414
581407	S-TIL25	LF5	581409
581408	PBL25Y	-	-
581409	PBL35Y	-	-
583594	S-BAL42	SK12	583595
589612	S-BAL35	N-SK5	589613
589612	S-BAL35R	-	-
589612	BAL35Y	-	-
593353	S-FTM16	TiFN5	594355
595677	S-FPM2	-	-
596387	PBM18Y	-	-
596392	S-TIM8	-	-
596393	PBM8Y	-	-
596394	PBM8R	LF5G19	597399
603380	S-TIM5	F5	603380
603606	BSM51Y	-	-
603607	S-BSM14	N-SK14	603606
603655	S-PHM53	PSK52	603654
606437	S-BAM4	N-BaF4	606437
607568	S-BSM2	N-SK2	607567
613443	S-NBM51	N-KZFS4/HT	613445
618498	S-BSM28	N-SSK8	618498
618633	S-PHM52Q	-	-
618634	S-PHM52	N-PSK53A	620635
620363	PBM2Y	F2/F2HT	620364
620363	S-TIM2	N-F2	620364
620365	PBM2R	F2G12	621366
620603	S-BSM16	N-SK16	620603
622532	S-BSM22R	-	-
623570	S-BSM10	N-SK10	623570
623582	S-BSM15	N-SK15	623580
626357	S-TIM1	-	-

Ohara Code	Ohara Type	Schott Type	Schott Code
639449	S-BAM12	N-KZFS11	638424
639554	S-BSM18	N-SK18	639554
640345	S-TIM27	-	-
640601	S-BSM81	N-LAK21	640601
648338	S-TIM22	N-SF2	648338
649530	S-BSM71	-	-
651562	S-LAL54Q	-	-
652585	S-LAL7Q	-	-
654397	S-NBH5	N-KZFS5	654396
658509	S-BSM25	N-SSK5	658509
667483	S-BAH11	BaFN11	667484
670473	S-BAH10	N-BAF10	670471
673321	S-TIM25	N-SF5	673323
673383	S-NBH52V	-	-
678553	S-LAL12	N-LAK12	678552
678553	S-LAL12Q	-	-
689311	S-TIM28	N-SF8	689313
691548	S-LAL9	N-LAK9	691547
694508	S-LAL58	-	-
694532	S-LAL13	LaKN13	694533
697555	S-LAL14	N-LAK14	697554
699301	S-TIM35	N-SF15	699302
699511	S-LAL20	-	-
702412	S-BAH27	N-BASF52	702412
703542	S-LAL21	-	-
713539	S-LAL8	N-LAK8	713538
717295	S-TIH1	N-SF1	717296
717479	S-LAM3	N-LAF3	717480
720347	S-NBH8	N-KZFS8	720347
720502	S-LAL10	N-LAK10	720506
722292	S-TIH18	-	-
723380	S-BAH28	BaSF51	724381
728285	S-TIH10	N-SF10	728285
729541	S-LAL19	-	-
729547	S-LAL18	N-LAK34	729545
734515	S-LAL59	LaK16A	734510
738323	S-NBH53V	-	-
740283	S-TIH3	-	-
741278	S-TIH13	-	-
741527	S-LAL61	-	-
741527	S-LAL61Q	-	-
743493	S-LAM60	N-LAF35	743494
744448	S-LAM2	N-LAF2	744449
750353	S-LAM7	N-LAF7	750348
750353	S-NBH51	LAFN7	750350
755275	S-TIH4	N-SF4	755274
755523	S-LAH97	N-LAK33A/B	755523
757478	S-LAM54	LaFN24	757478
762265	S-TIH14	N-SF14	762265
762401	S-LAM55	-	-
764485	S-LAH96	-	-
766358	S-NBH59	-	-
773496	S-LAH66	N-LAF34	773496
778239	S-NPH7	-	-
785257	S-TIH11	N-SF11	785258
785263	S-TIH23	N-SF56A	785261
786442	S-LAH51	N-LAF33	784441
788474	S-LAH64	N-LAF21	788475
789284	S-NBH58	-	-
794371	S-LAM73	-	-

Ohara Code	Ohara Type	Schott Type	Schott Code
800229	S-NBH55	-	-
800422	S-LAH52	N-LAF36	800424
800422	S-LAH52Q	-	-
801350	S-LAM66	N-LASF45	801350
804396	S-LAH63	-	-
804396	S-LAH63Q	-	-
804465	S-LAH65VS	N-LASF44	804465
804466	S-LAH65V	N-LASF44	804465
805254	S-TIH6	N-SF6	805254
806409	S-LAH53	N-LASF43	806406
806409	S-LAH53V	N-LASF43	806406
808228	S-NPH1	-	-
808228	S-NPH1W	-	-
816466	S-LAH59	-	-
834372	S-LAH60	N-LASF40	834373
834372	S-LAH60MQ	-	-
834372	S-LAH60V	N-LASF40	834373
835427	S-LAH55V	N-LASF41	835431
835427	S-LAH55VS	N-LASF41	835431
847238	S-TIH53	N-SF57	847238
847238	S-TIH53W	N-SF57HT ultra	847238
850300	S-NBH57	-	-
850323	S-LAH71	N-LASF9	850322
852408	S-LAH89	-	-
855248	S-NBH56	-	-
859227	S-NPH5	-	-
883408	S-LAH58	N-LASF31A	881408
892371	S-LAH92	-	-
893204	S-NPH4	-	-
904313	S-LAH95	N-LASF46A/46B	904313
905350	S-LAH93	-	-
917316	S-LAH88	-	-
923189	S-NPH2	N-SF66	923209
954323	S-LAH98	-	-
959175	S-NPH3	-	-
963241	S-TIH57	-	-
2001291	S-LAH99	-	-
2001291	S-LAH99W	-	-
2003283	S-LAH79	-	-
539523	NANOCERAM™	Ultra-Strong Glass	

Zero Expansion Glass Ceramic

546555 ClearCeramZ (CCZ) Zerodur

*Available: IR/UV • Fused Silica • CaF2

• Glass types starting with the prefix of "S-" are environmentally friendly, REACH compliant, and meet the requirements as outlined in the RoHS – Directive 2011/65/EU and (EU) 2015/863.

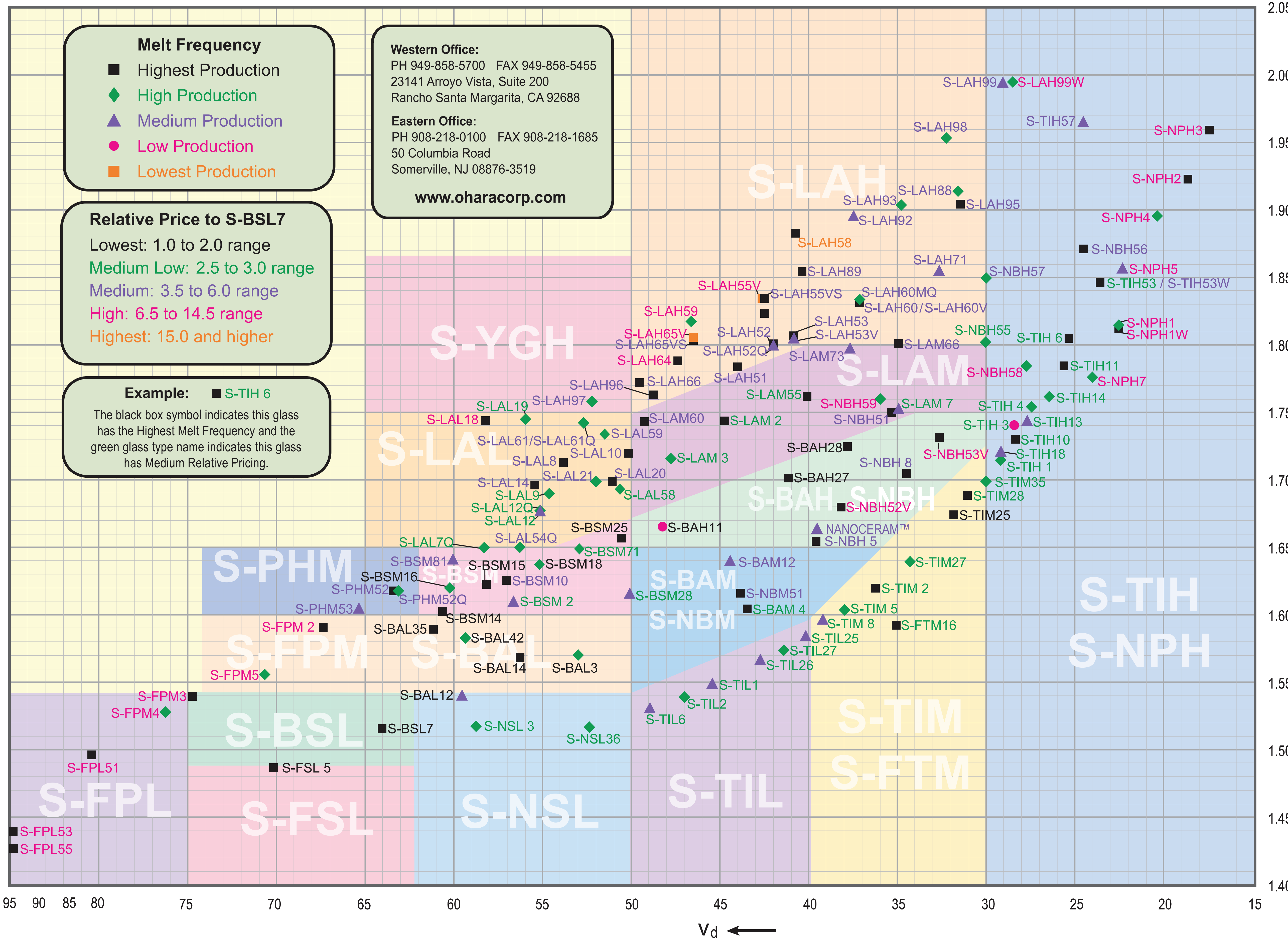
• 2 – 3 days delivery on most glass types!!!

This list is intended as a cross reference guide between similar glass types.

Because optical properties of similar glass types may vary slightly, please consult our catalog before making glass type substitutions.

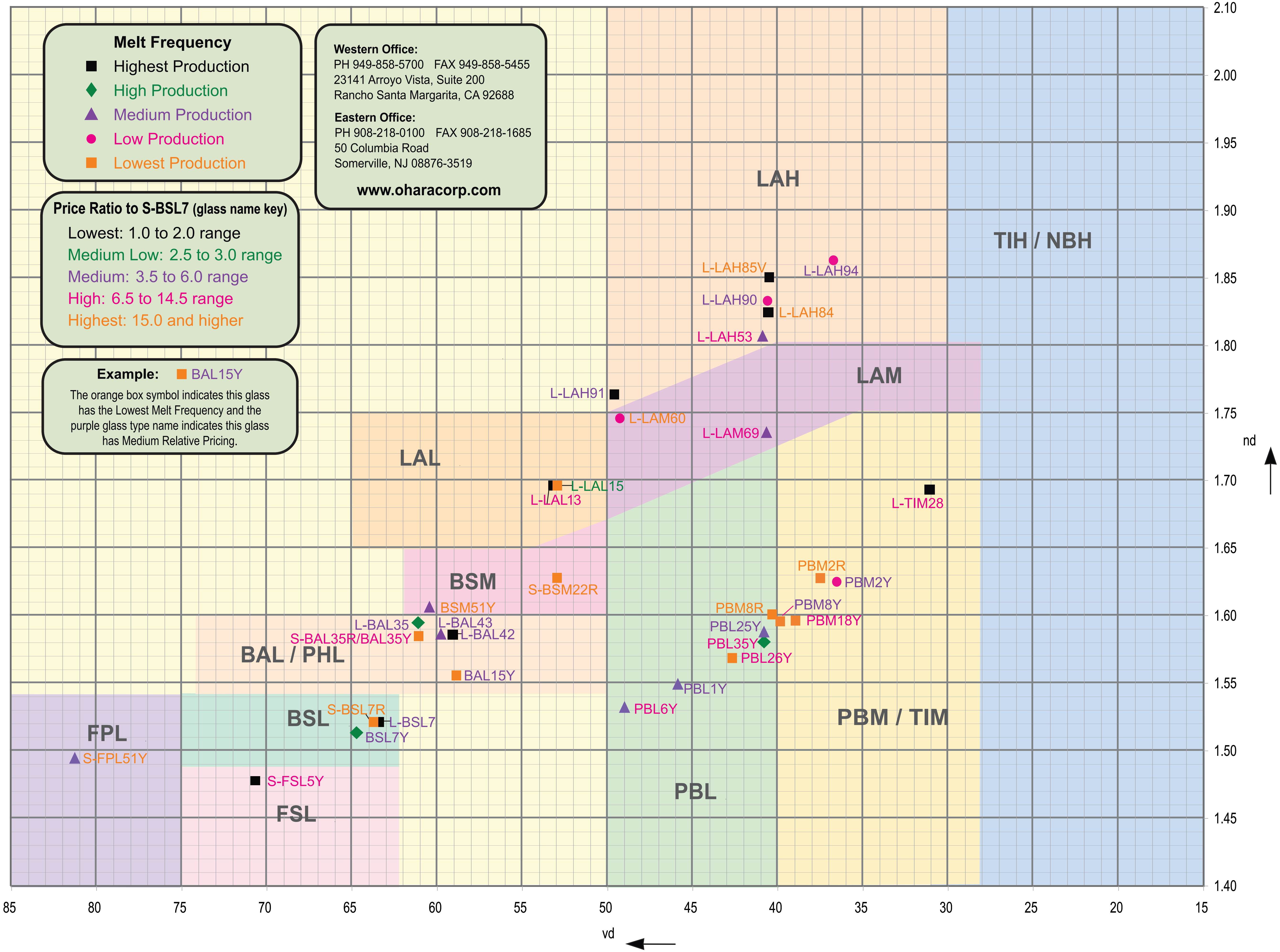
- Recommended glasses
- i-Line glasses (improved XMT at 365nm)
- Improved XMT at near UV (370 - 390nm)
- Radiation resistant glass

Optical Glass Chart



Ohara Type	Ohara Code	Ohara Type	Ohara Code
S-BAH11	667483	S-LAL19	729541
S-BAH27	702412	S-LAL20	699511
S-BAH28	723380	S-LAL21	703524
S-BAL3	571530	S-LAL54Q	651562
S-BAL12	540595	S-LAL58	694508
S-BAL14	569563	S-LAL59	734515
S-BAL35	589612	S-LAL61	741527
S-BAL42	583594	S-LAL61Q	741527
S-BAM4	606437	S-LAM2	744448
S-BAM12	639449	S-LAM3	717479
S-BSL7	516641	S-LAM7	750353
S-BSM2	607568	S-LAM55	762401
S-BSM10	623570	S-LAM60	743493
S-BSM14	603607	S-LAM66	801350
S-BSM15	623582	S-LAM73	794371
S-BSM16	620603	NANOCERAM™	539523
S-BSM18	639554	S-NBH5	654397
S-BSM25	658509	S-NBH8	720347
S-BSM28	618498	S-NBH51	750353
S-BSM71	649530	S-NBH52V	673383
S-BSM81	640601	S-NBH53V	738323
S-FPL51	497816	S-NBH55	800299
S-FPL53	439950	S-NBH56	855248
S-FPL55	439948	S-NBH57	850300
S-FPM2	595677	S-NBH58	789284
S-FPM3	538747	S-NBH59	766358
S-FPM4	528765	S-NBM51	613443
S-FPM5	552708	S-NPH1	808228
S-FSL5	487702	S-NPH1W	808228
S-FTM16	593353	S-NPH2	923189
S-LAH51	786442	S-NPH3	959175
S-LAH52	800422	S-NPH4	893204
S-LAH52Q	800422	S-NPH5	859227
S-LAH53	806409	S-NPH7	778239
S-LAH53V	806409	S-NSL3	518590
S-LAH55V	835427	S-NSL36	517524
S-LAH55VS	835427	S-PHM52	618634
S-LAH58	883408	S-PHM52Q	618633
S-LAH59	816466	S-PHM53	603655
S-LAH60	834372	S-TIH1	717295
S-LAH60MQ	834372	S-TIH3	740283
S-LAH60V	834372	S-TIH4	755275
S-LAH64	788474	S-TIH6	805254
S-LAH65V	804466	S-TIH10	728285
S-LAH65VS	804465	S-TIH11	785257
S-LAH66	773496	S-TIH13	741278
S-LAH71	850323	S-TIH14	762265
S-LAH88	917316	S-TIH18	722292
S-LAH89	852408	S-TIH53	847238
S-LAH92	892371	S-TIH53W	847238
S-LAH93	905350	S-TIH57	963241
S-LAH95	904313	S-TIL1	548458
S-LAH96	764485	S-TIL2	541472
S-LAH97	755523	S-TIL6	532489
S-LAH98	954323	S-TIL25	581407
S-LAH99	2001291	S-TIL26	567428
S-LAH99W	2001291	S-TIL27	575415
S-LAL7Q	652585	S-TIM2	620363
S-LAL8	713539	S-TIM5	603380
S-LAL9	691548	S-TIM8	596392
S-LAL10	720502	S-TIM25	673321
S-LAL12	678553	S-TIM27	640345
S-LAL12Q	678553	S-TIM28	689311
S-LAL14	697555	S-TIM35	699301
S-LAL18	729547		

L-type, i-Line, and Radiation Resistant Glass Chart



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1. Designation of optical glass types

In the course of Ohara's long history, many types of optical glasses have been developed. In this catalog, you will find over 130 glasses which we have selected as our "recommended glass types". Each optical glass has its own properties which are closely connected with the key chemical element it contains.

With this in mind, we have developed a new glass type designation system and the new names are used in this catalog. On the nd/vd diagram, located on the Optical Catalog webpage, you will see we have divided our glasses into groups. For each glass type, we have selected on or two chemical elements contained which are considered the most important and have used the atomic 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 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 group
7 indicates this is the 7th glass within this glass family

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 the first three digits represent the refractive index at the helium line (nd) and the last three digits represent the Abbe number (vd). These six-digit codes are internationally recognized within the optical community.

2. Optical Properties

2.1 Refractive Index

The refractive indices listed in this catalog 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.

Table 1

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

On the catalog pages, the wavelengths of each line are given in um units in parentheses under each spectrum line symbol.

2.2 Dispersion

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

$\nu_d = (n_d - 1)/(n_F - n_C)$ $\nu_e = (n_e - 1)/(n_{F'} - n_{C'})$

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 favorable 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:

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

2.3 Dispersion Formula

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

$$n^2 - 1 = \{A^1 \Lambda^2 / (\Lambda^2 - B^1)\} + \{A^2 \Lambda^2 / (\Lambda^2 - B^2)\} + \{A^3 \Lambda^2 / (\Lambda^2 - B^3)\}$$

The constants A1 ,A2 , A3 , B1 , B2 , B3 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 and 2325nm can be calculated to have an accuracy of around $\pm 5 \times 10^6$. These constants A1 ,A2 , A3 , B1 , B2 , B3 are listed on the left side of the individual catalog pages. However in 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 scope where refractive indices are given. 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. 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).

In this catalog, figures of the relative coefficients are listed. The temperature coefficients of refractive index dn/dt were determined by measuring the refractive index from - 40C to + 80C at wavelengths of 1,013.98nm (t), 643.85nm (C'), 632.8nm (He-Ne laser), 589.29nm (D), 546.07nm (e), 479.99nm (F') and 435.835nm (g).

These measurements are shown in the temperature range from - 40C to + 80C in 20C intervals, and are listed in the lower part of each catalog page. The absolute temperature coefficient of refractive index (dn/dt absolute) can be calculated by the following formula:

dn/dt absolute = dn/dt relative + n ·(dn air /dt)

dn air /dt is the temperature coefficient of refractive index of air listed in Table 2.

Table 2

Temperature range (degC)	dnair/dt (10-6/K)						
	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	-1	-1	-1	-1.01	-1.01
+20~+40	-0.86	-0.87	-0.87	-0.87	-0.87	-0.88	-0.88
+40~+60	-0.763	-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

2.5 The refractive indices in Ultraviolet and the Infrared Range

The refractive indices in the ultraviolet and the 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

Most types of Ohara optical glass are transparent and colorless because they are made 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 catalog the internal transmittance is given - i.e., reflection losses are eliminated. Glass varies slightly from melt to melt and, therefore, listed are typical values of internal transmittance obtained on 10 mm thick samples chosen from many melts, measured from 280 nm to 2400 nm.

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3. Thermal Properties

Thermal properties are essential to processing optical glass for annealing, heat treatment and coating. We have listed 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 by the Fiber EIongation 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 by the Fiber EIongation Method prescribed in ASTM-C336.

3.3 Softening Point (SP)

T he 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 by the Fiber EIongation Method prescribed in JIS-R3104 and ASTM-C338. 6

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. This region of transformation is defined as the transformation temperature (Tg). The transformation temperature can be determined from the thermal expansion curve (Fig. 1). Viscosity coefficient at this temperature is approximately 10^{13} poise. Yield point (At) is the deformation point temperature on the thermal expansion curve, or the point at which elongation becomes zero.

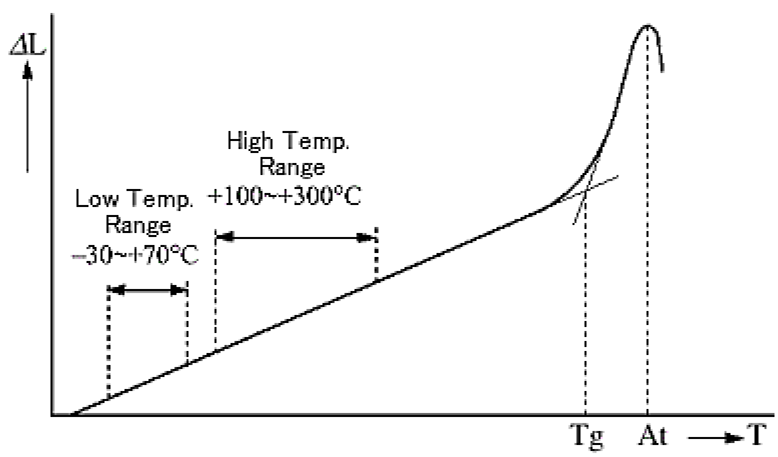


Fig1

3.5 Linear Coefficient of Thermal Expansion (a)

The thermal expansion curve is obtained by measuring a well-annealed glass sample 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 respectively up to 10^{-7} /K is determined and is given in the catalog.

3.6 Thermal Conductivity (k)

The thermal conductivity of most optical glasses at room temperature is located between 1.126W/(m.K) which is that of S-BSL 7 and 0.546W/(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 a temperature of 35 °C is listed in the catalog. Accuracy is ±5%.

4. Chemical Properties

There are some glasses that lack durability d ue to the chemical behavior of the constituents utilized in the composition. These glasses are influenced by water vapor, acid, gasses, etc., as well as ions in the polishing slurry. Consequently, dimming and staining will occur 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 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, following the test method of ISO8424 and 9689.

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

The glass to be tested is crushed to 425μm ~ 600μm grains. A sample of this powder equivalent to the specific gravity in grams is placed on a platinum basket. This is put in a flask of silica glass containing the reagent and boiled for 60 minutes. The sample is then carefully dried and re-weighed to determine the loss of weight (percent) and classified as per Tables 1 and 2. The reagent used for the water resistance test is distilled water (pH 6.5 ~ 7.5). 1/100N nitric acid is used for the acid resistance test.

Table1 Water Resistance

Class	1	2	3	4	5	6
Loss of wt%	<0.05	≥0.05 <0.10	≥0.01 <0.25	≥0.25 <0.60	≥0.60 <1.10	≥1.10

Table2 Acid Resistance

Class	1	2	3	4	5	6
Loss of wt%	<0.20	≥0.20 <0.35	≥0.35 <0.65	0.65≥ 1.2<	1.20≥ 2.20<	2.20>

4.2 Weathering Resistance [W(s)] (Surface Method)

This test is carried out by putting freshly polished glass plates in a chamber at +50°C, 85% humidity for 24 hours. If the glass surface is severely attacked, another 6 hour test is carried out with new pieces. The classification into four groups is then obtained by inspecting the treated surface through a 50x microscope as per Table 3.

Table 3

Class	Classification
1	When there is no fading on the glass exposed in the chamber for 24 hours and observed 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 when inspected at 1500 luxes.
4	When fading is observed on the glass exposed in the chamber for 6 hours when inspected at 1500 luxes.

4.3 ISO Method

4.3.1 Acid Resistance (SR)

Glass samples with dimensions of 30 x 30 x 2 mm are prepared. The surface of these samples are polished to the specified polishing conditions. They are hung by platinum wire into nitric acid solution (pH 0.3) or acetic acid buffer solution (pH 4.6) at 25degC 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 0.1μm is done using the following formula:

$t_{0.1} = (t_e dS) / \{(m_1 - m_2)100\}$

$_{0.1}$: the time (h) necessary to etch a surface layer to a depth of0.1μm.

t_e :the time (h) for attack in the experiment

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 use of the value of the loss of mass which is ob-served 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 1mg / 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 0.1μm (h) with time scales given in the classification Table 4.

Table 4

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 0.1μm （h)	>100	100 ~10	10 ~1	1 ~0.1	<0.1	>10	10 ~1	1 ~0.1	<0.1

In addition, changes in the surface of the sample following the treatment are qualitatively evaluated with the naked eye. Additional classification numbers are given ac-cording to Table 5.

Table 5

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

4.3.2 Phosphate Resistance (PR)

Glass samples with dimensions of 30 x 30 x 2 mm are prepared and all surfaces are polished to given specifications. They are hung by platinum wire into aqueous solution containing 0.01 mol / l purified tripolyphosphate at 50degC 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 t0.1 necessary to etch a surface layer to a depth of 0.1μm is made using the same formula which is used for obtaining the acid resistance (SR) in the previous section. In this case, however, the time units are minutes. The calculation is carried out, as a rule, using the value of the loss of mass which 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 0.1μm (min) with time scales given in classification Table 6.

Table 6

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

Next, changes in the surface of the sample following the treatment are qualitatively evaluated with the naked eye. Additional classification numbers are given in addition to the class number according to Table 5used for obtaining the acid resistance (SR) in the previous section. For example, it is indicated that the phosphate resistance class is PR 2.0 for optical glass which needs 120 minutes for attack to a depth of 0.1μm , with no visible changes in the surface after the attack.

5. Mechanical Properties

5.1 Modulus of Elasticity

Young's modulus, Modulus of rigidity and Poisson's ratio are determined by measuring the velocities of the longitudinal and transverse elastic waves in a well annealed rod of size 100 ~ 150 x 10 x 10 mm at room temperature. Young's modulus (E), Modulus of rigidity (G) and Poisson's ratio (s) are calculated using the following equations. Accuracy is ±1%.

Modulus of rigidity $G = v_t p$

Young's Modulus $E=(9KG)/(3K+G)$ vl : Velocity of longitudinal waves

Bulk Modulus $K = v_t p - (4/3)G$ vt : Velocity of transverse waves n: Density

Poisson's ratio $s=(E/2G)-1$ p: Density

5.2 Knoop Hardness (Hk)

The indentation hardness of optical glass is determined with the aid of the 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 ° respectively. The load time is 15 seconds, the load is 0.98 N. The glass specimen is indented at 5 places. Knoop hardness can be computed with the following equation:

Knoop Hardness =1.45l F/l^2
F : Load (N) : l Length of longer diagonal line (mm)

Table 1 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. value of 158 is shown as 160.)

Table 1

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

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 center of the flat and is under a 9.8N load. 20 ml of water containing 10 g of aluminous abrasive as the lapping material, with mean grain size 20μm(#800), is supplied evenly to the test piece for 5 minutes. The weight loss of the test piece is then measured. The known weight loss of the standard glass is compared according to the following equation:

Abrasion = {(Weight loss of sample / Specific gravity)/(Weight loss of standard sample / Specific gravity)} X 100

Glasses showing a higher value are less resistant to abrasion.

5.4 Photoelastic Constant (ß)

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 d (nm) and thickness of glass d(cm) have the follow-ing relationship:

$d = ß d F$

In this case, proportional constant ß is called the photoelastic constant. It is listed in this catalog at a unit of ($nm/cm/10^5$ Pa). The photoelastic constant is the material constant which 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 Bubble & Inclusion

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. The classification of bubble content is established by specifying in mm^2 the total bubble cross sections existing in 100ml of glass volume. Inclusions such as small stones or crystals are treated as bubbles. The bubble classes are shown in Table 1. The classification includes all bubbles and inclusions measuring larger than 0.03mm.

Table 1

Class	1	2	3	4	5
The total cross section of bubbles (mm^2 /$100cm^3$)	<0.03	> 0.03 <0.1	> 0.1 <0.25	> 0.25 < 0.5	> 0.5

6.2 Coloring

Internal transmittance (t) of optical glass is listed for each glass type. To express absorption, a column labeled "Coloring" is provided in the catalog page. Coloring can be determined by measuring spectral transmission including reflection losses with 10 mm thick test pieces. The wavelengths corresponding to 80% transmission and 5% transmission are given. For glass types of S-TIH 53 , PBH 71 and LAH78 reflection losses are so large that we used the wavelength corresponding to 70% 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, with the value shown to the second decimal place.

7. Guarantee of Quality

7.1 Refractive Index and Abbe

Refractive index and Abbe number values of our fine annealed products vary from catalog value by:

Refractive index (nd): +/-0.0003
Abbe number (vd): +/-0.5%

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

Refractive index (nd): +/-0.0002
Abbe number (vd): +/-0.3%

When special demand exists for specifications with other optical constants than the above, please consult us. 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. We normally send certification (melt data) of refractive indices measured at the spectral lines: C, d, F, g and vd . On special request, we can supply refractive indices measured 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:

Refractive index = ±0.00001 Dispersion = ±0.000003

We will report the environmental temperature, humidity and atmospheric pressure of the room where the precision measurement was undertaken. For, "ultra-precision measurements" and measurements at spectral lines not described in this catalog, please contact us.

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 high homogeneity (Low Δn) optical glasses. Our Grade Special A glasses are available in the following homogeneity levels:

Table

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

Please note that the Grade Special A number indicates n in the sixth decimal place. The anneal required must also be specified in terms of birefringence (nm/cm). Generally, low and also implies low birefringence from precision annealing. Using phase measuring interferometers, we measure transmitted wave front of each test piece. Interferograms can be supplied for high homogeneity blanks upon customer request.

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, 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% from the edge of the diameter. 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:

Table 2

Class	1 (Precision)	2 (Fine)	3 (Course)	4 (Very Course)
Birefringence (nm/cm)	<5	<10	<20	>20

Birefringence Measurement Chart (BMC) can be supplied upon customer request.

7.4 Striae

Striae are thread-like veins or cords which are visual indications of abruptly varying density. Striae can also be considered to be 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 parallel striae appear. Striae in glass are detected by means of a striaescope, which consists 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.

7.5 Bubbles

> Bubble content is determined by taking a sample of glass from each melt. The total bubble cross-section per 100ml of glass volume is measured. Please refer to 6.1 . On request, we shall undertake bubble examination with the method and procedures of MIL-G-174B or the customer's own specifications.

7.6 Coloring

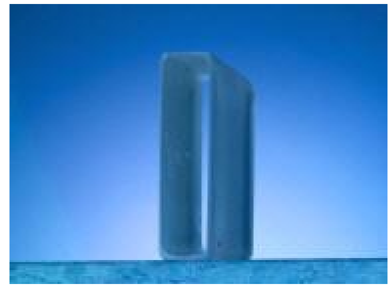
Variation of coloring between melts is generally within ±10 nm. On special request, we shall report the coloring or the transmission, including reflection losses, of the melt to be supplied by measuring spectral transmission.

7.7 Other

We showed each properties as representative value except for 7.1~7.6. Please contact us when you want to know the other value. In addition, please let us know your preferred specification when you place the orders.

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, (unworked) and are flame cut to required lengths. The corners are radiused. Strips are coarse or fine annealed. This is the least expensive form of supply.

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 sides for inspection. Generally, slabs are fine annealed.

Thickness 15 ~ 40mm   Width and Length 50 ~200mm

8.2 Pressings (Reheat Pressings (RP))

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

1) Diameter (including grinding stock)
2) Center Thickness (including grinding stock)
3) Radii of curvature
4) Glass quality (striae, bubble, etc.)
>5) Bevel
6) First processing side

Dimensional tolerances are given in Table 1.

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

Table1

Diameter	Thickness	Diameter
Φ18mm	±0.5mm	±0.10mm
Φ18~30	±0.4	±0.15
Φ30~50	±0.4	±0.20
Φ50~100	±0.3	±0.30
Φ100~150	±0.3	±0.40
≥Φ150	±0.4	±0.50

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8.3 Saw cut Centerless Ground Cylindrical Blanks

These blanks are cut from a precisely ground rod formed on a centerless grinding machine.

This process is very useful for making lenses that:

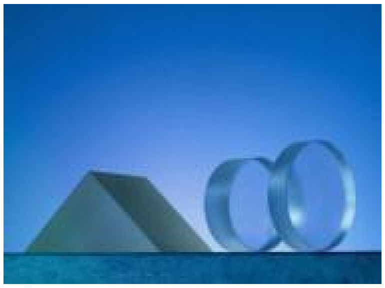
1) Are small in diameter but quite thick.
2) Are small in diameter with shallow radii.
3) Are such that the precise blank dimension can eliminate lens centering operations.
4) Can utilize precision spot blocks.

Diameter range of these blanks is 3 mm to 20 mm and the dimensional tolerances are given

Table 2

Product Size	Thickness	Diameter
Φ3~20mm	>±0.15mm	±0.015mm

8.4 Cut Blanks, Polished Blanks and the other



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.

Polished Ball

Polished Balls have a broad range of uses from telecommunications to imaging. We respond to our customer’s demands with low cost, excellent quality, and high-volume production. The out diameters can range from less than 1mm to greater than 10mm. Typical diameter tolerance is +/-5um. Read More...

9. Additional Notes on Catalog Data

Ohara optical glass catalog data in Excel file format can be downloaded from this website. Please use the link on the Optical Catalog webpage.

Notice for Special Order Glasses

The data for Special Order Glasses are from our previous catalog issued in 1990. Some glasses have slightly better coloring than the catalog values thanks to some minor modification of our process. We have not re-measured the internal transmittance of those glass types. Therefore, please take the internal transmittance of the Special-Order Glasses just as references.

Notice for Refractive Indices

The Refractive Indices in the data were determined by calculation of Dispersion Formula and the 8th decimal numbers on each glass types were omitted. In order to obtain Refractive indices at 5th decimal, please round up the 6th decimal if it is 5 or more and round off if it is 4 or less.

Notice for Thermal Properties

Please note some glass types show no values on Strain Points (Stp), Annealing Point (AP) and Softening Point (SP) due to the difficulties of measurements (Marked "-").