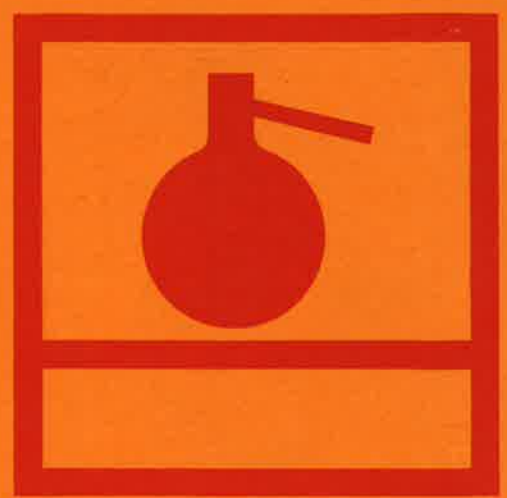
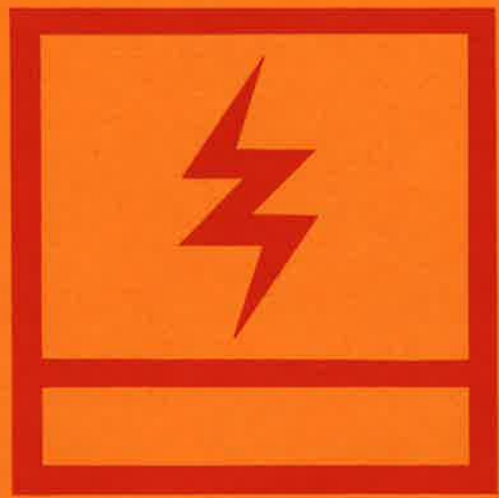


*D.A. Roney*

# PROPERTIES OF SELECTED COMMERCIAL GLASSES



**B-83**

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CORNING GLASS WORKS  
Corning, N. Y. 14830

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# Introduction

Glass is a noncrystalline material that has no regular internal structure. It is rigid at ordinary temperatures and soft or almost fluid at high temperatures. It has no definite freezing point, but becomes solid because its viscosity increases progressively to values which, for all practical purposes, are infinitely great.

Although silica sand ( $\text{SiO}_2$ ) is a principal ingredient of most glasses, melting economy and flexibility of properties require the addition of other melting agents and modifiers. Thus, depending on the choice of these additional constituents, glasses can be classified into several groups with characteristic properties.

Soda lime glasses (or lime glasses) used for lamp envelopes, bottles, and window glass are melted from silica that has been fluxed with lime ( $\text{CaO}$ ), and soda ( $\text{Na}_2\text{O}$ ) plus small quantities of other oxides. A typical lime glass composition is approximately as follows:

Silica— $\text{SiO}_2$ .....	72%
Soda— $\text{Na}_2\text{O}$ .....	15%
Lime— $\text{CaO}$ .....	9%
Magnesia— $\text{MgO}$ .....	3%
Alumina— $\text{Al}_2\text{O}_3$ .....	1%

Lime glasses are low in cost, easily hot-worked and are usually specified for service where high heat resistance and chemical stability are not required.

Lead glasses are used for electric light bulb stems, neon sign tubing, crystal tableware and certain optical components. A typical composition is given below:

Silica— $\text{SiO}_2$ .....	68%
Lead Oxide— $\text{PbO}$ .....	15%
Soda— $\text{Na}_2\text{O}$ .....	10%
Potash— $\text{K}_2\text{O}$ .....	6%
Lime— $\text{CaO}$ .....	1%

Lead glasses are useful because of their good hot workability, high electrical resistivity and high re-

fractive indices. Dense lead glasses serve as shields to cut off X-rays and gamma radiations.

Borosilicate glasses are used for baking and cooking dishes, chemical laboratory glassware, boiler gauge glasses, glass pipe, etc. Their compositions are usually similar to the following:

Silica— $\text{SiO}_2$ .....	80%
Boric Oxide— $\text{B}_2\text{O}_3$ .....	14%
Soda— $\text{Na}_2\text{O}$ .....	4%
Alumina— $\text{Al}_2\text{O}_3$ .....	2%

Reasonable manufacturing cost coupled with high chemical stability, low coefficients of thermal expansion, high heat shock resistance and excellent electrical resistivity make borosilicate glasses the best choice for most industrial applications.

Glasses composed almost entirely of silica are made by chemically removing the flux from a borosilicate glass after it has been melted and formed to the desired shape. Since removal of the flux leaves voids in the glass it is necessary to consolidate each piece by an additional firing operation. Considerably more expensive than the other three types of glass, its principal applications are at high temperatures since it does not begin to soften until it reaches  $1000^\circ\text{C}$ . and can be regularly used at temperatures as high as  $800^\circ\text{C}$ . The low thermal expansion coefficient of such high silica glass enables it to easily withstand the most severe thermal shocks. Its chemical composition is:

Silica .....	96% at least
Boric Oxide .....	3% at most
Other oxides .....	1% at most

## COLORED GLASSES

All glasses can be colored by the addition of metallic oxides that become suspended or dissolved in the parent glass usually without substantially changing its chemical composition or physical properties unless substantial amounts of chemical compounds are needed.

Glasses are so different from metals that some discussion of their physical properties is necessary before the engineer can properly appreciate the data given in Table 2 (pages 8 and 9). For example, shear strength means much when associated with metals but it has little or no significance in glasses.

Similarly, hardness of glasses must be measured and reported in terms that rarely apply to ductile materials. These notes discuss the specific properties of glass that require explanation before they can be correctly evaluated from tabulated data.

## Mechanical Properties

### STRENGTH

Glass, like other ceramics, is a brittle material. Thus, it does not plastically deform before failure and it fractures only from tensile stresses, never from shear or compression. The stress-strain curve for glasses is a straight line up to the breaking point.

The intrinsic strength of all glasses is extremely high, possibly as much as 3,000,000 p.s.i. Glass fibers have supported tensile stresses of over 1,000,000 p.s.i. The useful or everyday strength of glass is but a small fraction of the above figures because of stress concentrations due to surface imperfections. A rod of glass with perfect surfaces may be as strong as steel, but normal handling introduces surface imperfections that limit its ultimate strength to about 10,000 p.s.i. Another consequence of surface faults is the introduction of a time factor, so that glass is stronger under momentary loading than under prolonged stresses.

When an adequate safety factor is provided, the prolonged working stress for annealed glass is taken as 1,000 p.s.i. and for tempered, or thermally strengthened glass as 2,000 to 4,000 p.s.i., depending on the piece in question. It should be noted that the composition of glass has no practical effect on its strength although most borosilicate glasses resist scratching and therefore usually give better mechanical service. The above figures can be used for all commercial glasses.

### ELASTICITY

For all ordinary purposes it can be assumed that glass is perfectly elastic up to the point of fracture. The Young's Modulus of elasticity varies from 6,000,000 to 13,000,000 p.s.i. but most commercial

glasses have values between 8,000,000 and 10,000,000 p.s.i. Values are listed in Table 2.

Poisson's ratio can be taken as 0.20, since it is seldom less than 0.18 or more than 0.22.

### HARDNESS

Hardness is not a basic physical property of a body, but one which combines a number of physical properties in some complex manner and in different degrees depending upon the conditions under which the particular test is made. Hardness numbers are empirical. Many hardness tests have been devised for glasses, the most common of which are as follows:

1. Scratch hardness tests
2. Grinding or abrasion hardness tests
3. Penetration hardness tests.

The method to be used depends on the application.

The hardness of glass cannot be measured by the Brinell or Rockwell machines as the high contact pressures fracture the specimens. Knoop, Vickers, scratch, and abrasion tests are usually used to evaluate the hardness of glass.

On the Mohs scale of scratch hardness glasses lie between apatite (5) and quartz (7). Some common materials that are hard enough to scratch glass include agate, sand, silicon carbide, hard steel and emery. Glasses are harder than mica, mild steel, copper, aluminum and marble.

Impact abrasion resistance of glasses is evaluated by measuring their resistance to sandblasting under standard conditions. Values recorded are relative only, showing resistance as compared to soda lime plate glass which is arbitrarily given a value of unity.

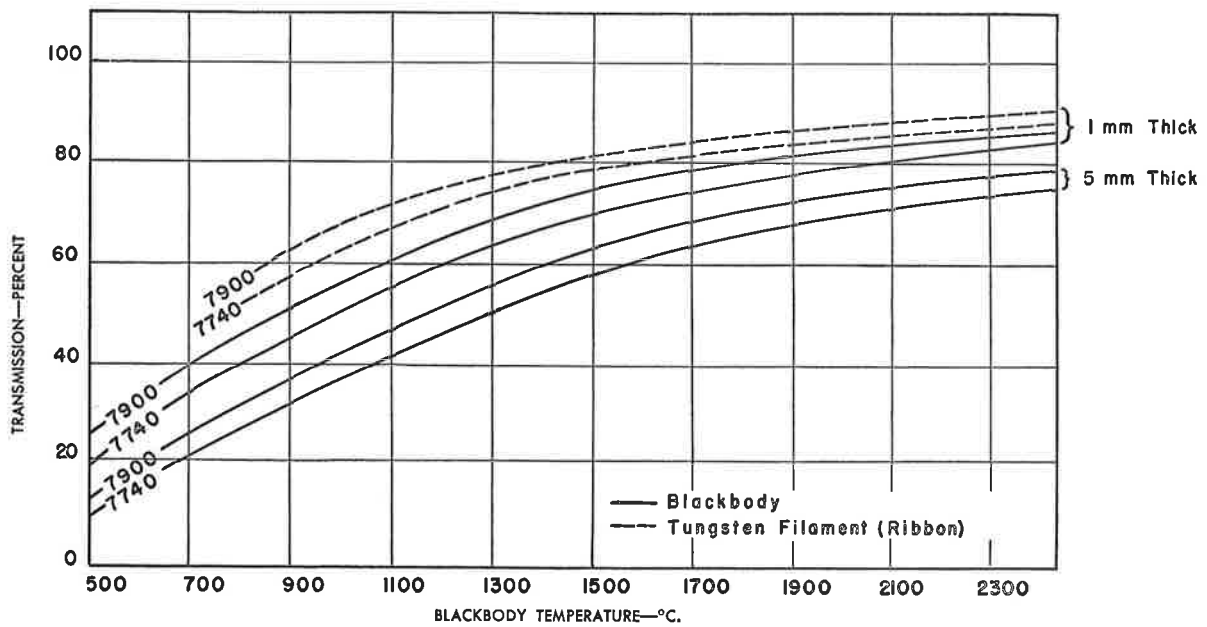


Fig. 1—Transmission of Radiant Energy—Glasses 7740 and 7900

## Electrical Properties

Glasses are widely used in the electrical industry for insulators, incandescent lamp and electronic tube components, neon sign tubing, sealing beads, fuse bodies, etc. The desirable properties of electrical glasses include the following:

- (a) High dielectric strength
- (b) High volume resistivity
- (c) High surface resistivity and hard smooth surfaces that do not carbonize or become conducting under the action of arcs.
- (d) Low power factor and loss factor.

Table 3, (page 4) compares some of the electrical properties of glasses with those of other frequently used insulating materials. It should be noted that the data given for dielectric strength are intrinsic only and apply where failure of the surrounding medium, (air, oil, vacuum, etc.) can be avoided.

The important properties of electrical glasses are given in Table 2. Some of these properties are discussed in detail below.

### DIELECTRIC STRENGTH

The dielectric strength of glass is very high indeed. Thus, in applications, this property is rela-

tively unimportant compared with the problem of design to prevent flashover and, in laboratory testing, to the necessity of employing rather unusual dimensions or conditions to insure true breakdown. One such expedient is the use of thin sections. Another is testing under oil.

Figure 2, (page 4), shows the range of breakdown voltages in various thicknesses of glass 7740. Both of the above mentioned methods were employed in determining these data.

It should be noted that dielectric breakdown voltage decreases with increase in frequency and temperature. At elevated temperatures, breakdown is governed mainly by the resistivity of the glass at those temperatures. Dielectric breakdown voltages for lime glass plates tested under oil are about 75% of those for borosilicate glass 7740.

The subject of dielectric strength is treated in detail in "Electrical Properties of Glass" by Littleton and Morey, John Wiley and Sons, N.Y. (1933), page 149; and an article "Puncture Tests Affected by Strength of Oil," by Littleton and Shaver, *Electrical World*, 91, 759 (1928).

# electrical properties—continued

**TABLE 3—Comparison of Electrical Properties of Insulating Materials at Room Temperature**

Material	Intrinsic Dielectric Strength		Dielectric Constant	Volume Resistivity (ohm-cm)
	Thickness (mm)	(Kv/cm)		
1. Cellulose Acetate	.025-.12	2300**	5.5	10 <sup>12</sup>
2. Glass				
Borosilicate No. 7740	.10	4800*	4.8	10 <sup>16</sup>
Soda Lime	.10	4500*	7.0	10 <sup>12</sup>
Soda Lead	.10	3100*	8.2	10 <sup>14</sup>
3. Mica, Muscovite Clear Ruby	.020-.10	3000-8200**	7.3	10 <sup>17</sup>
4. Phenolic Resin	.012-.04	2600-3300**	7.5	10 <sup>11</sup>
5. Porcelain, Electrical	.....	380**	4.4-6.8	10 <sup>14</sup>
6. Silica, Fused	.....	5000*	3.5	10 <sup>18</sup>
7. Rubber, Hard	.10-.30	2150**	2.8	10 <sup>13</sup>
8. Porcelain, Steatite—Low Loss	.....	500**	6.0-6.5	10 <sup>15</sup>

Intrinsic dielectric strength can be realized only under special test conditions and is very much higher than the working dielectric strength attainable in ordinary service. These data are listed for purposes of comparison.

\* Values of P. H. Moon and A. S. Norcross. Trans. A.I.E.E. 49, 755, (1930).

\*\* Values of S. Whitehead. World Power, Pg. 72, Sept. 1936.

Table from "Glass, the Miracle Maker," by C. J. Phillips (Pitman Publishing Co., New York, N. Y.).

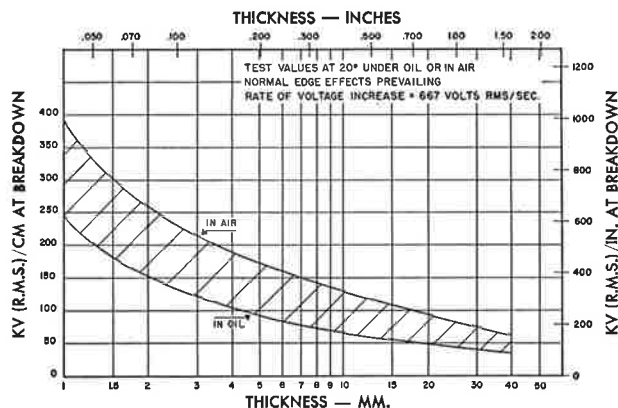


Fig. 2—Range of Values of 60 Cycles RMS Voltages at Dielectric Breakdown for Glass 7740

## VOLUME RESISTIVITY

Measurements of volume resistivity are made at temperatures of 250° and 350°C. Data for other temperatures, especially in the lower ranges, are obtained by extrapolation of the straight line relationship between log resistivity and reciprocal of the absolute temperatures. Figure 5 shows log of resistivity plotted against temperatures in degrees C.

## SURFACE RESISTIVITY

Surface resistivity depends more upon the surface films than on the composition of the glass itself although the borosilicate glasses are better than lime glasses in this regard. A film of moisture, particularly in the presence of dirt or dissolved gases, seriously lowers the surface resistivity. This effect is substantially reduced by treating the glass surface with water repellent silicones so that the moisture forms into discrete droplets rather than a continuous film. These effects are shown in Figure 3.

## POWER FACTOR

Several glasses with exceptionally low power factors have been developed in recent years. These glasses, numbers 7070, 7761, 7900, 7910 and 8870 all have power factors of less than .1% at room temperature and 1 megacycle. Figure 6 shows variation of power factor with glass temperature. It should be noted that there is relatively little increase until temperature exceeds 100°C.

# electrical properties—continued

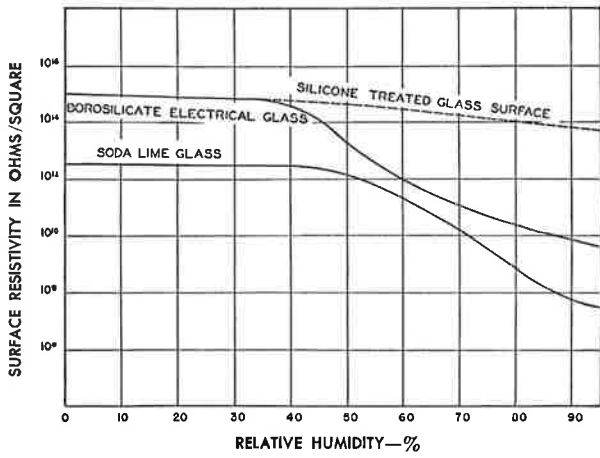


Fig. 3—Surface Resistivity of Glasses vs. Relative Humidity. Values given are Markedly Affected by any Contamination on the Surface of the Sample

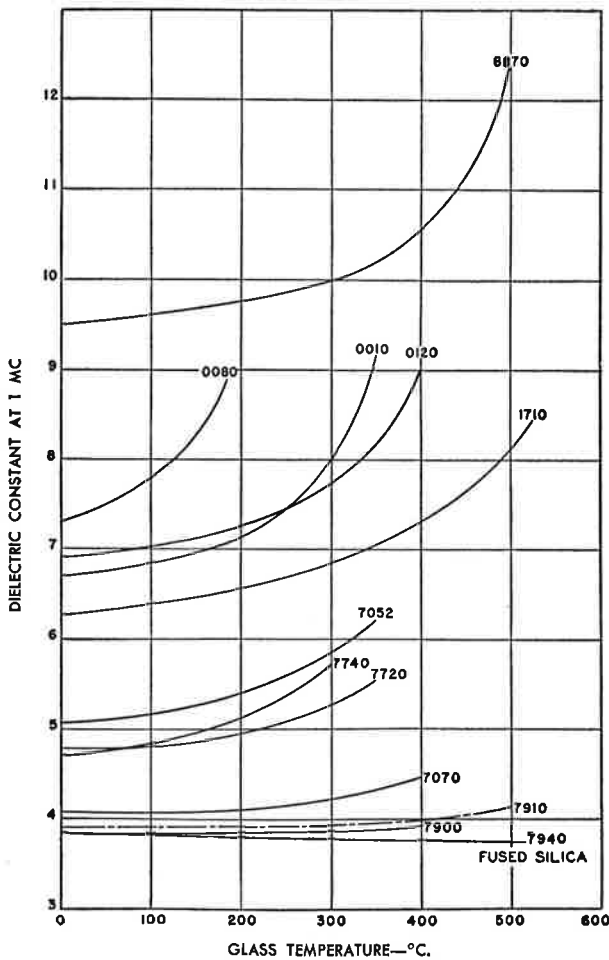


Fig. 4—Variation of Dielectric Constant with Glass Temperature. Curves marked 1710 apply as well for Glass 1720

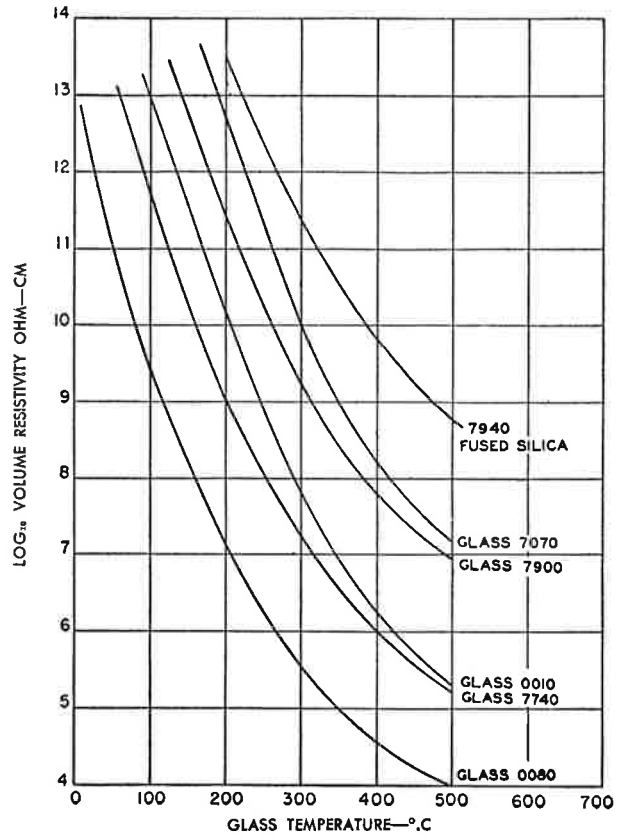


Fig. 5—Volume Resistivity

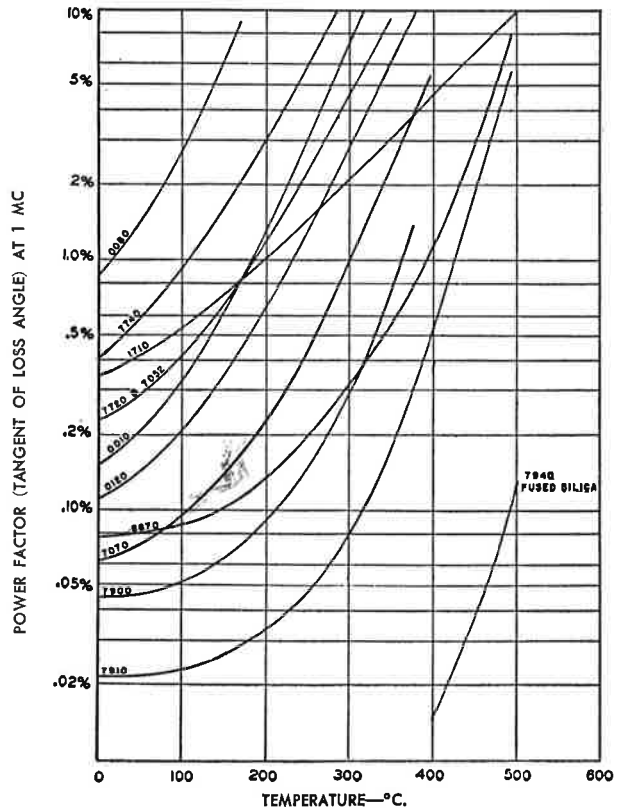


Fig. 6—Power Factor

# Thermal Stresses

## STEADY STATE THERMAL STRESSES

Stresses due to steady state thermal gradients can be either innocuous or dangerous, depending entirely on the degree of constraint imposed by some parts of the item upon others or by the external mounting. Thus under minimum constraint and maximum uniformity of gradient through the thickness, very large temperature differences can be tolerated. Under complete constraint, the tensile stress on the cool side depends only on the temperature difference and on the glass properties (expansion, elastic and thermal) and can be calculated. The formula is:

$$S = \frac{\alpha E \Delta T}{2(1 - \mu)}$$

where

S = maximum stress (tension on cooler surface, compression on hotter surface)

$\alpha$  = coefficient of linear thermal expansion

E = Young's Modulus of elasticity

$\mu$  = Poisson's ratio, and

$\Delta T$  = temperature differential between the two surfaces.

When complete constraint is imposed, it is important to know the temperature difference that approaches the danger point of  $S = 1,000$  p.s.i.

This is 
$$\Delta T_{1000} = \frac{2000(1 - \mu)}{E\alpha}$$

Column 10, Table 2, lists for tubes and constrained plates, the face to face temperature differentials that will cause a tensile stress of 1,000 p.s.i. on the cooler face.

For glass 7740 the listed figure is 48°C. Therefore a furnace sight glass in a fully constraining frame with an inner surface temperature of 148°C. and an outside face temperature of 100°C. will be under a tensile stress of 1,000 p.s.i. at the outside surface.

It must be remembered that temperature differen-

tial means temperature difference between the two glass surfaces, exclusive of gradients across the surface itself. In air, particularly, an appreciable difference exists between surface temperature of the glass and of the air moving past it.

## TRANSIENT THERMAL STRESSES

When glass is suddenly cooled, such as by removal from a hot oven, tensile stresses are introduced in the surfaces and compensating compressional stresses in the interior. Conversely, sudden heating leads to surface compression and internal tension. In either case the stresses are temporary (transient) and disappear on attainment of temperature uniformity. Since the strength of glass is greater under momentary stress than under prolonged load, thermal shock endurance cannot be directly calculated but is generally determined by empirical testing.

Since glass fails only in tension, and usually at the surface, the temporary stresses from sudden cooling are much more damaging than those resulting from sudden heating, assuming of course, that all surfaces are heated or cooled at the same time.

The transient thermal stresses increase directly with expansion coefficient and in a complex way with glass thickness. They also depend upon the shape of the article and on the method of chilling or heating. Thus, a complicated shape would be more severely stressed than a simple one. Sudden chilling by immersion in cold water is more rigorous than by blowing with cold air.

Column 9 of Table 2 illustrates the most extreme case: direct plunging into cold water. Cooling into less severe media, such as air, permits much higher temperatures than those listed. When special applications lead to problems in which these data are not useful, the technical services of Corning Glass Works should be employed.

# Heat Transmission

## THERMAL CONDUCTIVITY

At room temperature the thermal conductivity of glasses ranges from .0016 to .0029 cal./cm./sec./°C., with the most common compositions near the upper end of the range. At a mean temperature of 200°C. the values are greater by 20 to 25%.

For glass 7740, used frequently in heat-transfer applications, the thermal constants are listed below:

- Thermal conductivity at 25°C. = 0.0023 cal./[sec. (cm.<sup>2</sup>) (°C./cm.)  
= 6.7 B.T.U./[hr. (ft.<sup>2</sup>) (°F./in.)]  
= 0.025 watts/[in.<sup>2</sup>] (°C./in.)
- Mean specific heat (25°-175°C.) = 0.20 cal./[gm. (°C.) or B.T.U./(lb.) (°F.)]
- Thermal diffusivity ..... = 0.0056 cm.<sup>2</sup>/sec.
- Emissivity coefficient,  
radiant energy ..... = 0.94

## GLASS IN HEAT EXCHANGERS

Although the thermal conductivity of glass is only a small fraction of that of metals, the overall heat transfer is frequently determined largely by film coefficients of heat transfer at the surfaces. This is particularly true where the heat is carried away

only by natural air convection. Consequently, where film resistance is high, the thermal efficiency of a heat exchanger equipped with glass tubes may approach that of a similar unit equipped with metal tubes. In addition, the glass surfaces remain free of oxide, and generally of other adhering material, so that its effectiveness does not deteriorate.

In specific cases, the conditions may be analyzed and the overall heat transfer calculated in accordance with accepted methods, such as are given by W. H. McAdams, ("Heat Transmission," McGraw-Hill Book Co., Inc.). Table 1 gives data for several commonly encountered conditions in heat exchangers equipped with jacketed tubes and special .030" wall tubes made of glass 7740. Sizes listed refer to inside diameter. Wall thickness is .030" for ¾", .060" for 1", 1½" and 2" tubes, .090" for 3" tubes, and .125" for 4" tubes.

## TRANSMISSION OF RADIANT HEAT

Many glasses effectively transmit heat radiation from incandescent Tungsten filaments and similar sources. Transmission of heat energy increases with source temperature so that most of the energy from high temperature sources is transmitted through the glass by radiation rather than by conduction. Data for glasses 7740 and 7900 are shown in Figure 1.

TABLE 1—Typical Overall Heat Transfer Coefficients for Various Size Jacketed Tubes of Glass 7740

Process	Fluid Inside Glass 7740 Tube	Mass Velocity G Inside lb./[hr. (sq. ft.)]	Average Inside Temp. ° F.	Fluid Outside Tube (In Jacket)	Mass Velocity G Outside lb./[hr. (sq. ft.)]	Average Outside Temp. ° F.	Approx. Overall "U" B.T.U./[hr. (sq. ft.)] (° F.)				
							¾"*	1"	1½"	2"	3"
Liquid Cooling	Saturated Aqueous Chlorine Soln.	5 x 10 <sup>5</sup>	150° F.	Water	5 x 10 <sup>5</sup>	100° F.	150	94	94	94	68
Liquid Heating	5% HCl Soln.	5 x 10 <sup>5</sup>	150° F.	Steam	.....	250° F.	165	114	114	114	89
Condensing Pure Vapor	Benzene	.....	176° F.	Water	5 x 10 <sup>5</sup>	100° F.	137	86	86	86	64
Gas Cooling	Dry Diatomic Gas	8 x 10 <sup>3</sup>	200° F.	Water	5 x 10 <sup>5</sup>	100° F.	4.9	4.4	4.4	4.4	3.6

\*Type tubing (.030" wall) in shell and tube heat exchangers.

1 Glass Code	2 Type	3 Color	4 Principal Use	5 Forms Usually Available	6 Corrosion Resistance			7 Thermal Expansion 10 <sup>-7</sup> in./in./°C.		8 UPPER WORKING TEMPERATURES (Mechanical Considerations Only)				Thermal Plate	
					Weathering	Water	Acid	0-300°C	Room Temp.-Setting Point	Annealed		Tempered		1/8" Thk. °C.	1/4"
										Normal Service °C.	Extreme Limit °C.	Normal Service °C.	Extreme Limit °C.		
0010	Potash Soda Lead.....	Clear	Lamp Tubing	T	2	2	2	93.5	101	110	380	—	—	65	
0080	Soda Lime.....	Clear	Lamp Bulbs	B M T	3	2	2	93.5	105	110	460	220	250	65	
0120	Potash Soda Lead.....	Clear	Lamp Tubing	T M	2	2	2	89.5	97	110	380	—	—	65	
1720 <sup>4</sup>	Aluminosilicate.....	Clear	Ignition Tube	B T	1	1	3	42	52	200	650	400	450	135	
1723	Aluminosilicate.....	Clear	Electron Tube	B T	1	1	3	46	54	200	650	400	450	125	
1990	Potash Soda Lead.....	Clear	Iron Sealing	—	3	3	4	124	136	100	310	—	—	45	
2405	Borosilicate.....	Red	General	B P U	—	—	—	43	53	200	480	—	—	135	
2473	Soda Zinc.....	Red	Lamp Bulbs	B	2	2	2	91	—	110	460	—	—	65	
3320	Borosilicate.....	Canary	Tungsten Sealing	—	<sup>3</sup> 1	<sup>3</sup> 1	<sup>3</sup> 2	40	43	200	480	—	—	145	
6720	Soda Zinc.....	Opal	General	P	<sup>2</sup> —	1	2	78.5	90	110	480	220	275	70	
6750	Soda Barium.....	Opal	Lighting Wave	B P R	<sup>2</sup> —	2	2	88	—	110	420	220	220	65	
7040	Borosilicate.....	Clear	Kovar Sealing	B T	<sup>3</sup> 3	<sup>3</sup> 3	<sup>3</sup> 4	47.5	54	200	430	—	—	—	
7050	Borosilicate.....	Clear	Series Sealing	T	<sup>3</sup> 3	<sup>3</sup> 3	<sup>3</sup> 4	46	51	200	440	235	235	125	
7052	Borosilicate.....	Clear	Kovar Sealing	B M P T	<sup>3</sup> 2	<sup>3</sup> 2	<sup>3</sup> 4	46	53	200	420	210	210	125	
7056	Borosilicate.....	Clear	Kovar Sealing	B T P	2	2	4	51.5	56	200	460	—	—	—	
7070	Borosilicate.....	Clear	Low Loss Electrical	B M P T	<sup>3</sup> 2	<sup>3</sup> 2	<sup>3</sup> 2	32	39	230	430	230	230	180	
7251	Borosilicate.....	Clear	Seal Beam Lamps	P	<sup>3</sup> 1	<sup>3</sup> 2	<sup>3</sup> 2	36.7	38.1	230	460	260	260	160	
7570	High Lead.....	Clear	Solder Sealing	—	1	1	4	84	92	100	300	—	—	—	
7720	Borosilicate.....	Clear	Tungsten Sealing	B P T	<sup>3</sup> 2	<sup>3</sup> 2	<sup>3</sup> 2	36	43	230	460	260	260	160	
7740	Borosilicate.....	Clear	General	B P S T U	<sup>3</sup> 1	<sup>3</sup> 1	<sup>3</sup> 1	32.5	35	230	490	260	290	180	
7760 <sup>5</sup>	Borosilicate.....	Clear	General	B P	2	2	2	34	37	230	450	250	250	160	
7900 <sup>1</sup>	96% Silica.....	Clear	High Temp.	B P T U M	1	1	1	8	5.0*	800	1100	—	—	1250	10
7913 <sup>1</sup>	96% Silica.....	Clear	High Temp.	B P R S T	1	1	1	7.5	5.5*	900	1200	—	—	—	
7940	Fused Silica.....	Clear	Ultrasonic	U	1	1	1	5.5	3.5*	900	1100	—	—	1250	10
8160	Potash Soda Lead.....	Clear	Electron Tubes	P T	2	2	3	91	100	110	380	—	—	65	
8161	Potash Lead.....	Clear	Electron Tubes	P T	2	1	4	90	99	110	390	—	—	—	
8463	High Lead.....	Clear	Radiation Shielding	LC	3	1	4	104	112	100	200	—	—	—	
8871	Potash Lead.....	Clear	Capacitors	—	2	1	4	102	112	125	300	—	—	55	
9010	Potash Soda Barium....	Grey	TV Bulbs	P	2	2	2	89	100	110	380	—	—	—	
9741	Borosilicate.....	Clear	u v Transmission	B U T	<sup>3</sup> 3	<sup>3</sup> 3	<sup>3</sup> 4	39.5	50	200	390	—	—	150	

## COLUMN 1

<sup>1</sup>Glasses 7905, 7910, 7911, 7912, 7913 and 7917 for special ultraviolet and infrared applications.

<sup>4</sup>Glass 1720 is available with improved ultraviolet transmittance (designated glass 9730).

<sup>5</sup>Glass 7760 also available with special transmission suitable for sun lamps.

## COLUMN 5

B—Blown Ware  
M—Multiform  
U—Panels

P—Pressed Ware  
R—Rolled Sheet  
LC—Large Castings

S—Plate Glass  
T—Tubing and Rod

## COLUMN 6

<sup>2</sup>Since weathering is determined primarily by clouding which changes transmission, a rating for the opal glasses is omitted.

<sup>3</sup>These borosilicate glasses may rate differently if subjected to excessive heat treatment.

See page 10 for a full discussion of corrosion resistance.

## COLUMN 7

See Text Page 13.

\*Extrapolated Values

		10	11				12	13	14		15			16			17	18
Shock Res. 5 x 6" sized		Thermal Stress Resistance °C.	Viscosity Data				Knoop Hardness KHN <sub>100</sub>	Density grams per cc	Young's Modulus (10 <sup>6</sup> lb./sq. in.)	Poisson's Ratio	Log <sub>10</sub> of Volume Resistivity			Dielectric Properties at 1 MHz and 20°C.			Refractive Index Sod. D Line (589.3 nm)	Glass Code
Thk.	1/2" Thk. °C.		Strain Point °C.	Annealing Point °C.	Softening Point °C.	Working Point °C.					25°C.	250°C.	350°C.	Power Factor %	Dielectric Const.	Loss Factor %		
50	35	19	392	432	626	983	363	2.86	8.9	.21	17.+	8.9	7.0	.16	6.7	1.	1.539	0010
50	35	16	473	514	696	1005	465	2.47	10.2	.22	12.4	6.4	5.1	.9	7.2	6.5	1.512	0080
50	35	20	395	435	630	985	382	3.05	8.6	.22	17.+	10.1	8.0	.12	6.7	.8	1.560	0120
5	75	28	667	712	915	1202	513	2.52	12.7	.24	17.+	11.4	9.5	.38	7.2	2.7	1.530	1720 <sup>4</sup>
10	70	26	665	710	908	1168	514	2.64	12.5	.24	17.+	13.5	11.3	.16	6.3	1.0	1.547	1723
35	25	14	340	370	500	756	—	3.50	8.4	.25	17.+	10.1	7.7	.04	8.3	.33	—	1990
5	75	37	501	537	765	1083	—	2.48	9.9	.21	—	—	—	—	—	—	1.507	2405
50	35	19	466	509	697	—	—	2.65	9.5	.22	—	—	—	—	—	—	1.52	2473
10	80	43	493	540	780	1171	—	2.27	9.4	.19	—	8.6	7.1	.30	4.9	1.5	1.481	3320
50	40	20	505	540	780	1023	—	2.58	10.2	.21	—	—	—	—	—	—	1.507	6720
50	35	18	447	485	676	1040	—	2.59	—	—	—	—	—	—	—	—	1.513	6750
—	—	37	449	490	702	1080	—	2.24	8.6	.23	—	9.6	7.8	.20	4.8	1.0	1.480	7040
10	70	39	461	501	703	1027	—	2.24	8.7	.22	16.	8.8	7.2	.33	4.9	1.6	1.479	7050
10	70	41	436	480	712	1128	375	2.27	8.2	.22	17.	9.2	7.4	.26	4.9	1.3	1.484	7052
—	—	33	472	512	718	1058	—	2.29	9.2	.21	—	10.2	8.3	.27	5.7	1.5	1.487	7056
50	100	66	456	496	—	1068	—	2.13	7.4	.22	17.+	11.2	9.1	.06	4.1	.25	1.469	7070
10	90	48	500	544	780	1167	—	2.25	9.3	.19	18.	8.1	6.6	.45	4.85	2.18	1.476	7251
—	—	21	342	363	440	558	—	5.42	8.0	.28	17.+	10.6	8.7	.22	15.	3.3	1.86	7570
10	90	49	484	523	755	1146	—	2.35	9.1	.20	16.	8.8	7.2	.27	4.7	1.3	1.487	7720
10	100	54	510	560	821	1252	418	2.23	9.1	.20	15.	8.1	6.6	.50	4.6	2.6	1.474	7740
10	90	52	478	523	780	1198	442	2.24	9.0	.20	17.	9.4	7.7	.18	4.5	.79	1.473	7760 <sup>5</sup>
10	750	207	820	910	1500	—	463	2.18	9.8	.19	17.	9.7	8.1	.05	3.8	.19	1.458	7900 <sup>1</sup>
—	—	220	890	1020	1530	—	487	2.18	9.8	.19	17.+	9.7	8.1	.04	3.8	.15	1.458	7913 <sup>1</sup>
10	750	286	956	1084	1580	—	489	2.20	10.5	.16	17.+	11.8	10.2	.001	3.8	.0038	1.459	7940
10	35	18	397	438	632	973	—	2.98	—	—	17.+	10.6	8.4	.09	7.0	.63	1.553	8160
—	—	22	400	435	600	862	—	3.99	7.8	.24	17.+	12.0	9.9	.06	8.3	.50	1.659	8161
—	—	18	300	316	377	460	—	6.22	7.5	.29	—	9.2	7.5	.19	17.0	3.2	1.97	8463
5	35	17	350	384	527	783	—	3.84	8.4	.26	17.+	11.1	8.8	.05	8.4	.42	1.656	8871
—	—	18	408	446	646	1004	—	2.64	9.8	.21	17.+	8.9	7.0	.17	6.3	1.1	1.507	9010
10	80	54	408	450	705	1161	—	2.16	7.2	.23	17.+	9.4	7.6	.32	4.7	1.5	1.468	9741

**COLUMN 8**

Normal Service: No breakage from excessive thermal shock is assumed. Extreme Limits: Glass will be very vulnerable to thermal shock. Recommendations in this range are based on mechanical stability considerations only. Tests should be made before adopting final designs. These data approximate only.

**COLUMN 9**

These data approximate only. Based on plunging sample into cold water after oven heating. Resistance of 100°C means no breakage if heated to 110°C and plunged into water at 10°C. Tempered samples have over twice the resistance of annealed glass.

**COLUMN 10**

Resistance in °C is the temperature differential between the two surfaces of a tube or a constrained plate that will cause a tensile stress of 1000 p.s.i. on the cooler surface.

**COLUMN 11**

See page 12. These data subject to normal manufacturing variations.

**COLUMN 12**

Data show relative resistance to sandblasting.

**COLUMN 15**

Data at 25° extrapolated from high temperature readings and are approximate only.

# Corrosion Resistance

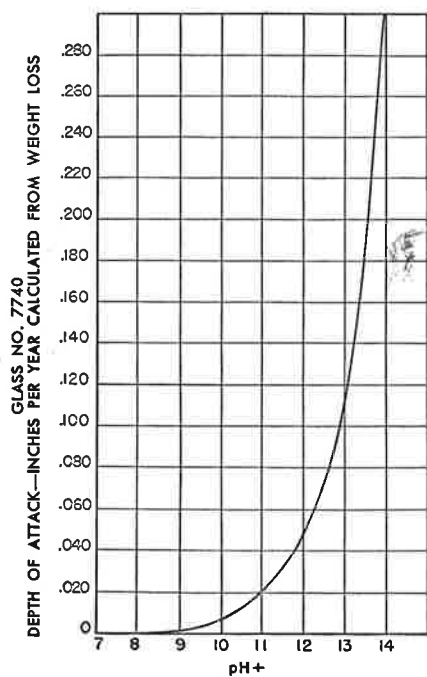


Fig. 7

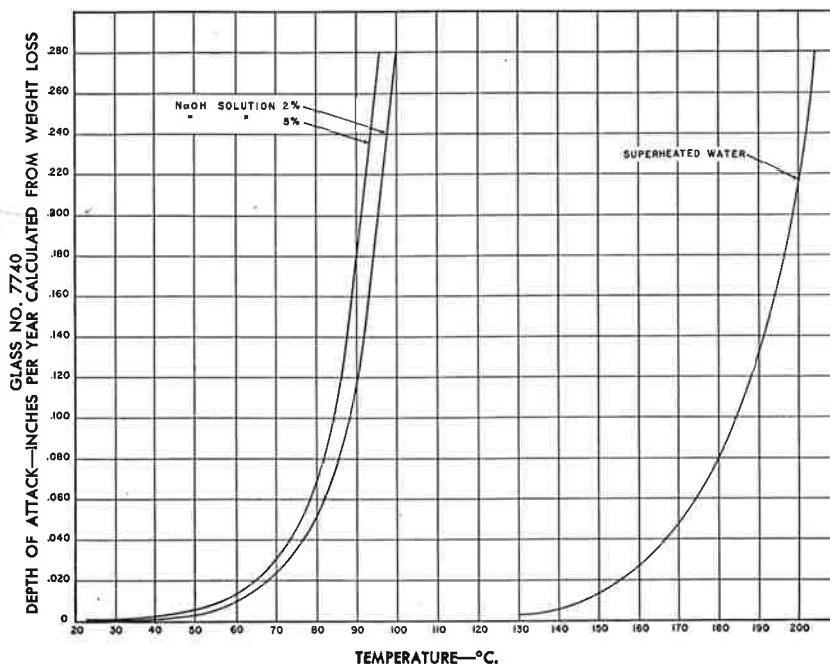


Fig. 8

The excellent corrosion resistance of most commercial glasses is an important reason to prefer them over other materials for many applications. The slight corrosion that does occur varies with the glass composition. Borosilicate glass 7740 and high silica glass 7900 are extremely corrosion resistant, particularly in acid or neutral solutions.

Factors affecting the rate of corrosion for a given glass are type and concentration of corroding liquid, temperature, contamination of the liquid by the glass and the degree of agitation of the liquid. Agitation removes the products of decomposition from the vicinity of the glass surface and permits more corrosive liquid to contact the glass.

Corrosion may be evidenced in many ways. Most common are clouding of the surface and contamination of solutions in contact. A few other less common effects include increase of electrical surface leakage, surface hydration, loss of strength and surface discoloration. Loss in weight may also occur and is frequently the basis for testing. However, it cannot always be correlated to the above effects. For example, many silicate glasses remain clear even after severe corrosion.

The corrosion of a silicate glass by the following aqueous solutions generally decreases in the order listed: HF, NaOH,  $\text{Na}_2\text{CO}_3$ ,  $\text{NH}_4\text{OH}$ , chelates, sea salt, dilute  $\text{H}_3\text{PO}_4$ , HCl and  $\text{H}_2\text{SO}_4$ ,  $\text{HNO}_3$ , organic acids,  $\text{H}_2\text{O}$  and neutral salts. Organic solutions are generally less corrosive than water.

## RESISTANCE TO WATER

The resistance of most commercial glasses to corrosion by water is very high. The corrosion that does occur is seldom a matter of simple solution of the glass. It involves ion exchange, hydration and selective attack. Column 6, Table 2 classifies the various glasses as to their resistance to water. Glasses rated 1 will rarely give trouble at temperatures below  $100^\circ\text{C}$ . For instance, 7740 loses only about  $5 \times 10^{-7}$  inches per day when exposed to boiling water. Those rated 2 may show corrosion under adverse conditions. Those rated 3 may require special consideration in their use.

Corrosion increases with temperature and this factor can be significant when dealing with superheated water. Figure 8 shows the effect of corrosion on glass 7740. Glasses 7740 and 7331 are standard glasses for boiler gauges.

## RESISTANCE TO WEATHERING

Weathering of glass is defined as its corrosion by atmospheric gases such as water, carbon dioxide and other gases. The effect is usually evidenced by clouding of the surface or electrical surface leakage. Weathering resistance closely follows the ratings in Column 6, Table 2. Glasses rated 1 will virtually never show weathering effects; those rated 2 may occasionally be troublesome, particularly if weathering products cannot be removed; those rated 3 require more careful consideration.

## RESISTANCE TO ACIDS

Most silicate glasses are highly resistant to all acids, except hydrofluoric. The rate of corrosion decreases with time. Column 6, Table 2 classifies various glasses as to their resistance to acids. Glasses rated 1 will lose less than  $1 \times 10^{-6}$  inches for one day when exposed to 5% hydrochloric acid at 95°C; those rated 2 between  $1 \times 10^{-6}$  and  $1 \times 10^{-5}$ ; those rated 3 between  $1 \times 10^{-5}$  and  $1 \times 10^{-4}$ , and those

rated 4 greater than  $1 \times 10^{-4}$ . In general the rate at which other acids attack these glasses will be comparable.

## RESISTANCE TO ALKALI

There are countless applications for glass in contact with alkali, although the corrosion by strong alkalies is relatively high. The mechanism of attack differs from water or acid in that the entire structure of a silicate glass is dissolved. The effects of alkalinity and concentration are shown in Figure 7. Cold alkaline solutions attack glasses slowly. The rate increases with the temperature as shown for two concentrations of NaOH in Figure 8. Both these figures apply to borosilicate glass 7740.

Corrosion by a given alkali solution will not vary over wide ranges with respect to different glasses as in the case of acid attack. The vast majority of glasses will lose between 3 and  $13 \times 10^{-4}$  inches per day in 5% NaOH at 95°C. Glass 7280 is the most alkali resistant glass and will lose only about  $5 \times 10^{-5}$  inches per day in 5% NaOH at 95°C.

---

# Optical Properties

Absence of physical imperfections and availability of more than one glass type are basic requirements of optical glass. Optical glasses are made of a variety of compositions, including soda-lime, lead, borosilicate as well as some that do not contain silica. Some 100 different types are melted each year.

Corning optical glass possesses high purity, is virtually free from defects, and is tightly controlled for index of refraction and dispersion.

The optical properties of glass are important in applications where transmission, refraction, or absorption of light rays is essential. Today, glasses are available which transmit and control radiation through a broad portion of the spectrum.

More investigation and research has been directed to the optical properties than to any other single characteristic of glass. There are hundreds of different optical glasses which have varying character-

istics and varying relationships between characteristics. Some of the optical properties of glass which can be controlled are: refraction, the bending of light rays passing through a piece of glass; dispersion, differences in the refraction of various wavelengths; reflection, the amount of light returned from a glass surface; and absorption and transmission, controlling the amount of light which passes through glass.

Optical glasses are used for lenses, prisms, and mirrors in microscopes, cameras, binoculars, and range-finders. They are also used in a wide range of scientific and photographic equipment, including infrared-detecting missile domes.

For details on physical and optical properties of Corning optical glasses, write Optical Sales Department, Corning Glass Works, Corning, N.Y. for Bulletin 038-OP-9.

# Viscosity Data

At ordinary temperatures the viscosity of glass is so high that it can be considered to be infinite. As the temperature is raised, however, the viscosity decreases and the glass gradually assumes the character of a liquid. Four points on the viscosity temperature curve have been arbitrarily chosen to represent the softness of the glass at important points in its change from solid to liquid. These points, or reference temperatures, are listed in Table 2, Column 11.

The following definitions for strain, annealing and softening points are taken from those tentatively adopted by the American Society for Testing Materials; that for Working Point is employed by Corning Glass Works and corresponds to the upper end of the working range as defined by A.S.T.M.

**Strain Point.** The temperature, at the lower end of the annealing range, at which the internal stress is

substantially relieved in a matter of hours. The strain point corresponds to a viscosity of approximately  $10^{14.50}$  poises when measured by the Tentative Method of Test for Annealing Point and Strain Point of Glass (A.S.T.M. Designation: C. 336).

In general the strain point represents the extreme upper limit of servcability for annealed\* glass.

**Annealing Point.** The temperature, at the upper end of the annealing range, at which the internal stress is substantially relieved in a matter of minutes. The annealing point corresponds to a viscosity of approximately  $10^{13.00}$  poises when measured by the Tentative Method of Test for Annealing Point and Strain Point of Glass (A.S.T.M. Designation: C. 336).

In an annealing operation the glass is heated somewhat above the annealing point and slowly cooled to somewhat below the strain point. Distortion of the glass becomes a problem above the annealing point.

**Softening Point.** The temperature at which a uniform fiber, 0.55 to 0.75 mm. in diameter and 23.5 cm. in length, elongates under its own weight at a rate of 1 mm. per min. when the upper 10 cm. of its length is heated in the manner prescribed in the Tentative Method of Test for Softening Point of Glass (A.S.T.M. Designation: C. 338) at a rate of approximately 5° C. per min. For glass of density near 2.5 gm./cm.<sup>3</sup> this temperature corresponds to a viscosity of  $10^{7.6}$  poises.

At the softening point the glass deforms very rapidly and starts to adhere to other bodies.

**Working Point.** The temperature where the glass is soft enough for hot working by most of the common methods. Viscosity at the working point is approximately  $10^4$  poises.

Figure 9 shows viscosity curves for some representative glasses.

\* Tempered glasses are limited to a considerably lower absolute maximum temperature because they begin to lose their temper in the region below the strain point. See Table 2, Column 8.

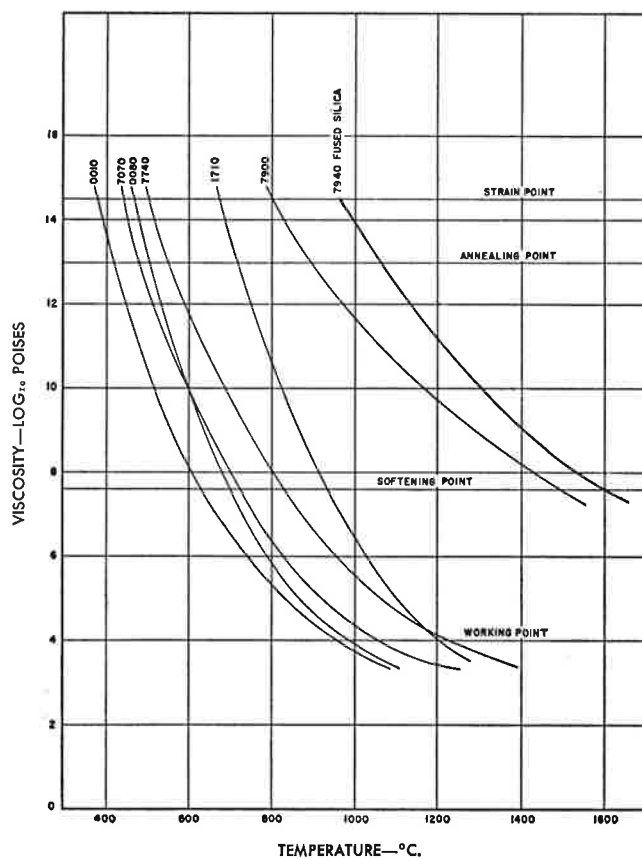
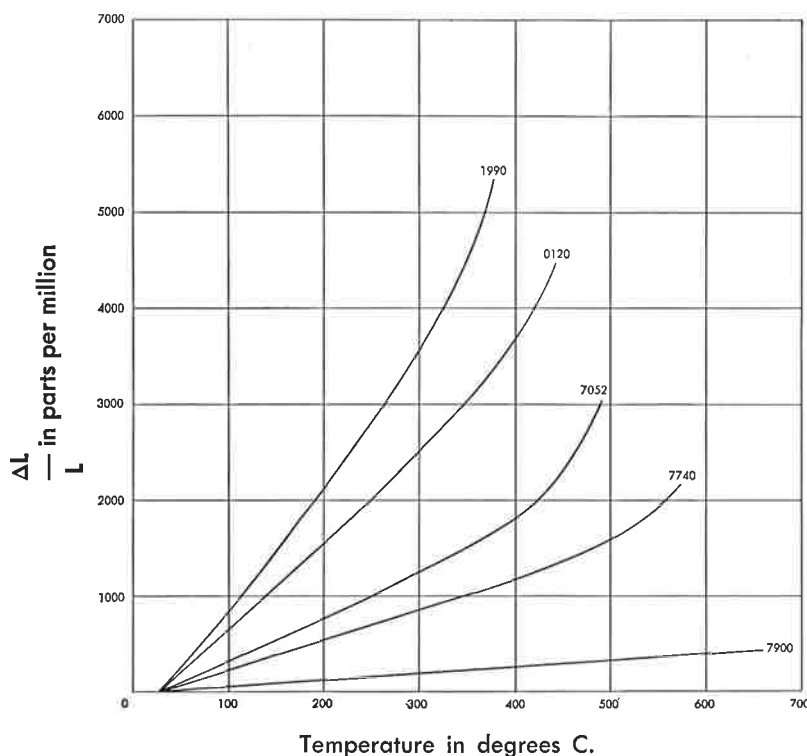


Fig. 9—Viscosity—Temperature Curves

# Thermal Expansion

Fig. 10—Expansion—Temperature Curves.



As the temperature is raised, glasses tend to expand. In general the change is smaller than with most ordinary substances, but because of the brittle nature of glass the expansion is often quite important both in connection with heat shock resistance and in connection with rigid seals to other materials such as metals, ceramics and other glasses.

Fig. 10 shows some typical glass "expansion curves" in which the change in length per unit length  $\left(\frac{\Delta L}{L}\right)$  is plotted against the temperature (T) in degrees centigrade. It will be noted that the curves are initially linear but that they swing upward, indicating a higher rate of expansion, as we approach the annealing zone. The quantity which we usually refer to by the term "expansion" and which we list in Table 2 as "Thermal Expansion Coefficient", is the slope of the initial, linear portion of this curve. To be more precise it is the average change of length per unit length per °C between

0°C and 300°C. This figure gives a good indication of the ability of the glass to withstand heat shock. For sealing applications, values are given in Table 2 for the average expansion coefficient from room temperature to the setting point—arbitrarily defined as 5°C. above the strain point. A comparison of the expansion coefficients to the setting point between a material of known expansion and a particular glass will give a good estimate of sealing compatibility. However, for precise predictions of stresses due to expansion differences, complete expansion curves for the sealing materials should be consulted. Complete expansion curves have been determined for most of the glasses that are of interest for sealing applications and are available upon request.

The expansion of glass is affected to some extent by its thermal history and for this reason our measurements of this property are always made on well annealed samples.

# Chemically Strengthened Glasses

By applying chemical treatments to a series of special glass compositions, Corning has developed a wide range of ultra-high-strength glasses. Articles made from these glasses can be classed as chemically strengthened in contrast to thermally strengthened glasses made by traditional tempering techniques. Corning calls this glassmaking method Chemcor.

Strength achieved for specific products is dependent on the particular chemical treatment applied and the glass composition used.

Some chemically strengthened glasses have shown extremely high flexural strength. Using a one-fourth inch diameter rod as a laboratory standard of comparison, the strengths tabulated here were achieved for several characteristic conditions of glass. Each sample was abraded by a standard process.

<i>Type of Glass</i>	<i>Flexural Strength</i>
Annealed . . . . .	7,000 psi
Thermally Tempered . . . . .	20,000 psi
Chemically Tempered . . . . . (One Type)	100,000 psi

Sheets of the chemically strengthened glasses have been bent repeatedly into relative short radius arcs without failure.

Corning's Chemcor approach permits fabrication of lighter weight articles without loss of strength. At the same weight these glasses can be more resistant to breakage than ordinary glass products.

Chemical treatment given the glass article in no way affects the basic properties characteristic of glassy materials: durability, and hardness and smoothness of the surface.

Chemically strengthened glasses can be made optically clear and highly transparent. They also can be made translucent or opaque. The glasses have dimensional stability. They do not discolor with age or in any way deteriorate.

These glasses are made from non-strategic, readily available raw materials. The materials are mixed, melted and shaped by standard glassmaking methods. The strengthening treatment is applied after the glass object has been fabricated and finished.

First chemically strengthened products include tableware with unprecedented strength, rear windows for convertible automobiles, laboratory pipets and lenses for safety goggles.

## PYROCERAM<sup>®</sup> brand Glass-Ceramics

PYROCERAM is the registered trademark of Corning Glass Works for a family of materials that have been converted into crystalline ceramics from their original glassy state by the use of nucleating agents and heat treatment. A glass batch containing a suitable nucleating agent is melted and formed into a transparent glass article by conventional glassmaking techniques. The product is cooled to temperatures inducing precipitation of the nucleating agents. Then, the nucleated article is heated to a temperature range in which growth of the nucleated crystals takes place. Composition of glass and degree of heat treatment determine the type of crystallization and final properties.

The resultant PYROCERAM brand material is an opaque ceramic substantially the same shape and size as the original glass article (minute volume changes occur due to altered density and expansion

coefficient of the crystalline material). It is generally characterized by greater strength and hardness than the parent glass; has greater abrasion resistance, and improved electrical properties.

Increased strength may be produced in some glass-ceramic compositions by chemical strengthening processes. Thus Code 9608 with a modulus of rupture of 16,000 psi becomes on chemically strengthening Code 0326 with a modulus of rupture of 45,000 psi. Similar increases are achieved in going from unstrengthened Code 0335 or Code 0336 (12,000 psi) to their strengthened counterparts: Codes 0330 and 0333 (65,000 psi).

To date, thousands of different types of glass-ceramics have been experimentally melted. Many of these are being tested in Corning's laboratories. Like glasses, these glass-ceramics are not definite chemical compounds so that, within limits, an in-

finite variety of compositions can be produced with many desirable commercial properties.

Glass-ceramics can be formed by conventional high speed glass-forming methods, as well as by special manufacturing techniques developed to fit the processing qualities of the material.

These glass-ceramics are made from non-strategic, readily available raw materials, such as glass sand, limestone, soda ash and borax.

Glass-ceramics, currently in production, are approximately 40 per cent harder than borosilicate glass, as measured by indentation tests. In their initial glassy state, they can be ground and polished by standard glass finishing methods. Precision grinding can be done in their final crystalline state. Dimensional changes during heat treatment are less than 1 per cent, minimizing finishing for precision contours after conversion to ceramic form.

Unlike other crystalline ceramic materials the glass-ceramics are transparent in the initial stages. This permits visual inspection for internal defects before final finishing. Special glass melting techniques can be used to assure uniform composition, constant density, freedom from bubbles and striations and uniform electrical properties.

Due to the homogeneous nature of PYROCERAM® brand glass-ceramics, they will not delaminate at elevated temperatures. Equal thermal expansion of the glass-ceramic in all directions is assured by the nature of the material, which is isotropic in its glassy state. PYROCERAM brand glass-ceramics will not deteriorate or change under normal storage conditions.

## POLICY

In view of the critical heat cycles involved in the final stage of manufacturing PYROCERAM brand glass-ceramics, all processing is done by Corning. The material will not be sold in its glassy state, either as an end product or as a component.

## GLASS-CERAMIC PROPERTIES

	Code 9606	Code 9608	Code 0326
Specific Gravity (25°).....	2.61	2.50	2.50
Water Absorption (%).....	0.00	0.00	0.00
Porosity (gas permeability)...	gas tight	gas tight	gas tight
<b>THERMAL</b>			
Softening Temp. (°C)*.....	1350	1250	1250
Specific Heat (25°C).....	0.185	0.190	0.190
Mean (25-400°C).....	0.230	0.235	0.235
Thermal Conductivity (cgs)			
25°C mean temp. ....	0.0087	0.0047	0.0047
Linear Coef. of Thermal Expansion			
(25-300°C) (10 <sup>-7</sup> /°C).....	57	4-20**	4-20**
(77-570°F) (10 <sup>-7</sup> /°F).....	32	2-11	2-11
<b>MECHANICAL</b>			
Modulus of Elasticity (10 <sup>9</sup> psi)	17.3	12.5	12.5
Poisson's Ratio.....	0.245	0.25	0.25
Modulus of Rupture (abraded) (10 <sup>8</sup> psi).....	20	16	45
Hardness			
Knoop 100 gm.....	698	703	—
500 gm.....	619	588	—
<b>ELECTRICAL</b>			
<i>Dielectric Constant</i>			
Freq. 10 <sup>9</sup> 25°C.....	5.58	6.78	—
300°C.....	5.60	—	—
500°C.....	8.80	—	—
Freq. 10 <sup>10</sup> 25°C.....	5.45	6.54	—
300°C.....	5.51	6.65	—
500°C.....	5.53	6.78	—
<i>Dissipation Factor</i>			
Freq. 10 <sup>9</sup> 25°C.....	0.0015	0.0030	—
300°C.....	0.0154	—	—
500°C.....	—	—	—
Freq. 10 <sup>10</sup> 25°C.....	0.00033	.0068	—
300°C.....	0.00075	.0115	—
500°C.....	0.00152	.040	—
<i>Loss Factor</i>			
Freq. 10 <sup>6</sup> 25°C.....	0.008	.02	—
300°C.....	0.086	—	—
500°C.....	—	—	—
Freq. 10 <sup>10</sup> 25°C.....	0.002	.045	—
300°C.....	0.004	.077	—
500°C.....	0.008	.27	—
<i>Volume Resistivity Log 10 (ohm-cm)</i>			
250°C.....	10	8.1	—
350°C.....	8.6	6.8	—

\* Measurements are on different bases  
\*\* Depending on heat treatment

# Temperature Conversion Table

By **ALBERT SAUVEUR**

0 to 100		100 to 1000		1000 to 2000		2000 to 3000	
-17.8	0	38	260	538	816	1500	1093
-17.2	1	43	266	543	821	1510	1099
-16.7	2	49	271	549	827	1520	1104
-16.1	3	54	277	554	832	1530	1110
-15.6	4	60	282	560	838	1540	1116
-15.0	5	66	288	566	843	1550	1121
-14.4	6	71	293	571	849	1560	1127
-13.9	7	77	299	577	854	1570	1132
-13.3	8	82	304	582	860	1580	1138
-12.8	9	88	310	588	866	1590	1143
-12.2	10	93	316	593	871	1600	1149
-11.7	11	99	321	599	877	1610	1154
-11.1	12	104	327	604	882	1620	1160
-10.6	13	110	332	610	888	1630	1166
-10.0	14	116	338	616	893	1640	1171
-9.44	15	121	343	621	899	1650	1177
-8.89	16	127	349	627	904	1660	1182
-8.33	17	132	354	632	909	1670	1188
-7.78	18	138	360	638	916	1680	1193
-7.22	19	143	366	643	921	1690	1199
-6.67	20	149	371	649	927	1700	1204
-6.11	21	154	377	654	932	1710	1210
-5.56	22	160	382	660	938	1720	1216
-5.00	23	166	388	666	943	1730	1221
-4.44	24	171	393	671	949	1740	1227
-3.89	25	177	399	677	954	1750	1232
-3.33	26	182	404	682	960	1760	1238
-2.78	27	188	410	688	966	1770	1243
-2.22	28	193	416	693	971	1780	1249
-1.67	29	199	421	699	977	1790	1254
-1.11	30	204	427	704	982	1800	1260
-0.56	31	209	432	709	988	1810	1266
0	32	214	438	714	993	1820	1271
0.56	33	219	443	719	999	1830	1277
1.11	34	224	449	724	1004	1840	1282
1.67	35	229	454	729	1010	1850	1288
2.22	36	234	460	734	1016	1860	1293
2.78	37	239	466	739	1021	1870	1299
3.33	38	243	471	744	1027	1880	1304
3.89	39	249	477	749	1032	1890	1310
4.44	40	254	482	754	1038	1900	1316
5.00	41	259	488	759	1043	1910	1321
5.56	42	264	493	764	1049	1920	1327
6.11	43	269	499	769	1054	1930	1332
6.67	44	274	504	774	1060	1940	1338
7.22	45	279	510	779	1066	1950	1343
7.78	46	284	516	784	1071	1960	1349
8.33	47	289	521	789	1077	1970	1354
8.89	48	294	527	794	1082	1980	1360
9.44	49	299	532	799	1088	1990	1366
	50	304	538	804	1093	2000	1371
	51	309	543	809	1099	2010	1377
	52	314	549	814	1104	2020	1382
	53	319	554	819	1110	2030	1388
	54	324	560	824	1116	2040	1393
	55	329	566	829	1121	2050	1399
	56	334	571	834	1127	2060	1404
	57	339	577	839	1132	2070	1410
	58	344	582	844	1138	2080	1416
	59	349	588	849	1143	2090	1421
	60	354	593	854	1149	2100	1427
	61	359	599	859	1154	2110	1432
	62	364	604	864	1160	2120	1438
	63	369	610	869	1166	2130	1443
	64	374	616	874	1171	2140	1449
	65	379	621	879	1177	2150	1454
	66	384	627	884	1182	2160	1460
	67	389	632	889	1188	2170	1466
	68	394	638	894	1193	2180	1471
	69	399	643	899	1199	2190	1477
	70	404	649	904	1204	2200	1482
	71	409	654	909	1210	2210	1488
	72	414	660	914	1216	2220	1493
	73	419	666	919	1221	2230	1499
	74	424	671	924	1227	2240	1504
	75	429	677	929	1232	2250	1510
	76	434	682	934	1238	2260	1516
	77	439	688	939	1243	2270	1521
	78	444	693	944	1249	2280	1527
	79	449	699	949	1254	2290	1532
	80	454	704	954	1260	2300	1538
	81	459	709	959	1266	2310	1543
	82	464	714	964	1271	2320	1549
	83	469	719	969	1277	2330	1554
	84	474	724	974	1282	2340	1560
	85	479	729	979	1288	2350	1566
	86	484	734	984	1293	2360	1571
	87	489	739	989	1299	2370	1577
	88	494	744	994	1304	2380	1582
	89	499	749	999	1310	2390	1588
	90	504	754	1004	1316	2400	1593
	91	509	759	1009	1321	2410	1599
	92	514	764	1014	1327	2420	1604
	93	519	769	1019	1332	2430	1610
	94	524	774	1024	1338	2440	1616
	95	529	779	1029	1343	2450	1621
	96	534	784	1034	1349	2460	1627
	97	539	789	1039	1354	2470	1632
	98	544	794	1044	1360	2480	1638
	99	549	799	1049	1366	2490	1643
	100	554	804	1054	1371	2500	1649
	101	559	809	1059	1377	2510	1654
	102	564	814	1064	1382	2520	1660
	103	569	819	1069	1388	2530	1666
	104	574	824	1074	1393	2540	1671
	105	579	829	1079	1399	2550	1677
	106	584	834	1084	1404	2560	1682
	107	589	839	1089	1410	2570	1688
	108	594	844	1094	1416	2580	1693
	109	599	849	1099	1421	2590	1699
	110	604	854	1104	1427	2600	1704
	111	609	859	1109	1432	2610	1710
	112	614	864	1114	1438	2620	1716
	113	619	869	1119	1443	2630	1721
	114	624	874	1124	1449	2640	1727
	115	629	879	1129	1454	2650	1732
	116	634	884	1134	1460	2660	1738
	117	639	889	1139	1466	2670	1743
	118	644	894	1144	1471	2680	1749
	119	649	899	1149	1477	2690	1754
	120	654	904	1154	1482	2700	1760
	121	659	909	1159	1488	2710	1766
	122	664	914	1164	1493	2720	1771
	123	669	919	1169	1499	2730	1777
	124	674	924	1174	1504	2740	1782
	125	679	929	1179	1510	2750	1788
	126	684	934	1184	1516	2760	1793
	127	689	939	1189	1521	2770	1799
	128	694	944	1194	1527	2780	1804
	129	699	949	1199	1532	2790	1810
	130	704	954	1204	1538	2800	1816
	131	709	959	1209	1543	2810	1821
	132	714	964	1214	1549	2820	1827
	133	719	969	1219	1554	2830	1832
	134	724	974	1224	1560	2840	1838
	135	729	979	1229	1566	2850	1843
	136	734	984	1234	1571	2860	1849
	137	739	989	1239	1577	2870	1854
	138	744	994	1244	1582	2880	1860
	139	749	999	1249	1588	2890	1866
	140	754	1004	1254	1593	2900	1871
	141	759	1009	1259	1599	2910	1877
	142	764	1014	1264	1604	2920	1882
	143	769	1019	1269	1610	2930	1888
	144	774	1024	1274	1616	2940	1893
	145	779	1029	1279	1621	2950	1899
	146	784	1034	1284	1627	2960	1904
	147	789	1039	1289	1632	2970	1910
	148	794	1044	1294	1638	2980	1916
	149	799	1049	1299	1643	2990	1921
	150	804	1054	1304	1649	3000	1927

NOTE: The numbers in bold face type refer to the temperature either in degrees Centigrade or Fahrenheit which it is desired to convert into the other scale. If converting from Fahrenheit degrees to Centigrade the equivalent temperature will be found in the left column, while if converting from degrees Centigrade to degrees Fahrenheit, the answer will be found in the column on the right. Reprinted from Chemical & Metallurgical Engineering with permission of copyright owners, McGraw-Hill Publishing Co. Inc., New York, N. Y.

## Bibliography

A.S.T.M. Standards of Glass and Glass Products  
April, 1955, Page 74

"PROPERTIES OF GLASS," G. W. Morey  
Reinhold Pub. Corp., 1938

"GLASS ENGINEERING HANDBOOK,"  
E. B. Shand  
McGraw-Hill, 1958

"HANDBOOK OF PHYSICS"  
E. U. Condon and Hugh Odishaw  
Chapter 7, Part 8,  
"GLASS" by H. R. Lillie  
McGraw-Hill, 1958

Encyclopedia of Chemical Technology  
2nd Edition, Volume 10  
"GLASS" by J. R. Hutchins and R. V. Harrington  
John Wiley & Sons, 1966

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