U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20235

National Bureau of Standards

Certificate of Viscosity Values

Standard Sample No. 711

Lead-Silica Glass

TABLE 1. *Comparison of viscosity vs temperature data from each participating laboratory*

Log_{10} viscosity poise	Temperature, °C								Combined equation
	Laboratories								
	A	B	C	D	E	F	G	H	
1.90	1361.8	1355.4	--------	1360.8	1359.3	--------	--------	--------	1360.5
2.00	1328.5	1323.0	--------	1326.8	1324.9	1330.0	1361.8	--------	1327.1
2.25	1252.9	1249.2	1243.6	1249.7	1247.2	1253.0	1283.9	--------	1251.2
2.50	1186.3	1184.0	1178.0	1182.2	1179.5	1185.4	1214.9	--------	1184.5
2.75	1127.3	1126.0	1119.9	1122.6	1119.9	1125.7	1153.5	--------	1125.5
3.00	1074.7	1074.1	1068.0	1069.5	1067.1	1072.4	1098.5	--------	1072.8
3.25	1027.4	1027.5	1021.3	1022.0	1019.9	1024.6	1048.9	--------	1025.6
3.50	984.7	985.2	979.3	979.3	977.5	981.6	1003.9	--------	982.9
3.75	945.9	946.8	941.0	940.6	939.3	942.5	963.0	--------	944.3
4.00	910.6	911.8	906.2	905.3	904.6	907.0	925.5	--------	909.0
4.50	848.5	850.1	845.0	843.7	844.0	--------	--------	--------	847.2
5.00	795.8	797.5	793.1	791.5	792.9	--------	--------	--------	794.7
5.50	750.5	752.2	748.3	746.7	749.2	--------	--------	--------	749.6
6.00	711.1	712.7	709.5	707.9	--------	--------	--------	--------	710.4
6.50	676.5	678.0	675.3	673.9	--------	--------	--------	--------	676.0
7.00	645.9	647.2	645.2	643.9	--------	--------	--------	--------	645.6
8.00	594.2	595.2	594.2	593.3	--------	--------	--------	591.8	594.3
9.00	552.2	552.9	552.8	552.4	--------	--------	--------	552.7	552.7
10.00	517.5	517.8	518.4	518.5	--------	--------	--------	518.7	518.2
11.00	488.2	488.1	489.5	490.1	--------	--------	--------	488.8	489.2
12.00	463.2	462.8	464.9	465.9	--------	--------	--------	462.4	464.5

Viscosity of the Glass

The data received from each participating [a] laboratory was analyzed by the method of least squares to determine the parameters for the Fulcher equation [1]. Using these equations, a comparison of the temperatures obtained by each participating laboratory at nominal values of log_{10} viscosity are shown above in table 1.

To arrive at the best equation to represent the data from all the participating laboratories, a plot of the difference between observed viscosities and calculated viscosities from the general equation (using all data points) was made. Using this plot and a number of statistical tests, it was obvious that the determinations submitted by Lab. G were inconsistent with the rest of the data. The data points from Lab. G were not used in calculating the temperature values shown in the last column of table 1. The equation for the combined data is

$$\log_{10}\eta = -1.621 + \frac{4254.649}{T\,°C - 152.1}$$

Standard error of $\log_{10}\eta = 0.035$

[a] List of Participating Laboratories:
Bausch & Lomb, Inc., Rochester, N.Y.
Brockway Glass Co., Inc., Brockway, Pa.
Corning Glass Works, Corning, N.Y.
Emhart Manufacturing Co., Hartford, Conn.
General Electric Co., Cleveland, Ohio
National Bureau of Standards, Washington, D.C., 20234 (Lab. A)
Owens-Corning Fiberglas Corp., Granville, Ohio
Owens-Illinois, Toledo, Ohio
Thatcher Glass Manufacturing Co., Inc., Elmira, N.Y.

Softening, Annealing and Strain Points of the Glass

These empirical points, as defined in the ASTM STANDARDS, were determined by five of the participating laboratories and are shown below in table 2.

TABLE 2. *Softening, annealing and strain points of standard glass No. 711 by participating labs.*

Log_{10} viscosity poise	Temperature, °C					Average
	Laboratories					
	A	D	E	F	I	
Softening point [1] 7.6	603	602	599	603	603	602
Annealing point [2] 13.00	433	431	429	432	435	432
Strain point [2] 14.50	393	393	389	387	396	392

[1] Littleton softening point.
[2] The glass viscosity at the annealing temperature, as found by the ASTM test, is an apparent viscosity and not an equilibrium viscosity. This is also true for the strain point which is an extrapolation of the annealing point test.

Type of Glass

The sample is a lead-silica glass having an index of refraction, after fine annealing, of $N_D=1.61822 \pm 0.00020$, and a dispersion of $\nu=36.6\pm0.3$.

Composition of the Glass

The composition of the glass as analyzed [b] by one of the participating laboratories is as follows:

SiO_2 —46.0%
PbO —45.32
K_2O — 5.62
Na_2O— 2.50
R_2O_3 — 0.56

Methods of Measuring Viscosity of Glass

The rotating concentric cylinder (Margules technique) was used by seven of the participating laboratories at high temperatures, i.e., above the softening point or in the viscosity range $\log_{10}2.0$ to $\log_{10}6.0$. At the lower temperatures, in the viscosity range $\log_{10}9.0$ to $\log_{10}15.0$, the fiber elongation method of measuring viscosities at equilibrium temperatures was employed by four of the laboratories and a beam bending method by the fifth laboratory.

The test methods used by five laboratories in determining the softening, annealing and strain points are given in the ASTM Standards.

Listed below are references, which appear at the end of this certificate, pertaining to the apparatus and methods used by each participating laboratory in making their measurements.

Laboratory	*References*
A	2, 3, 4, 5, 9
B	2, 4, 8
C	2, 6
D	2, 9, 10
E	2, 4, 9
F	7, 9
G	7
H	4
I	9

[b] Chemical analysis—This glass is not intended as a standard for chemical analysis. The above analysis is offered only for information purposes.

List of References

1. G. S. Fulcher, Analysis of recent measurements of viscosity of glasses, J. Am. Ceram. Soc. **8,** No. 6, 339 (1925); **8,** No. 12, 789 (1925).
2. a. H. R. Lillie, Viscosity measurements in glass, J. Am. Ceram. Soc. **12,** No. 8, 516 (1929).
   b. H. R. Lillie, Measurements of absolute viscosity by use of concentric cylinders, J. Am. Ceram. Soc. **12,** No. 8, 505 (1929).
   c. H. R. Lillie, High-temperature viscosities of soda-silica glasses, J. Am. Ceram. Soc. **22,** No. 11, 367 (1939).
   d. H. R. Lillie, Viscosity of glass between strain point and melting temperature, J. Am. Ceram. Soc. **14,** No. 7, 502 (1931).
3. J. O. M. Bockris and D. C. Lowe, An electromagnetic viscometer for molten silicates at temperatures up to 1800° C., J. Sci. Instr. **30,** 403 (1953).
4. H. A. Robinson and C. A. Peterson, Viscosity of recent container glass, J. Am. Ceram. Soc. **27,** No. 5, 129 (1944).
5. J. Boow and W. E. S. Turner, Viscosity and working characteristics of glasses; I. Viscosity of some commercial glasses at temperatures between 500° C–1400° C, J. Soc. Glass Tech. **26,** No. 117, 215 (1942).
6. J. P. Poole, Improved apparatus for measuring viscosity of glasses in annealing range of temperature, J. Am. Ceram. Soc. **32,** No. 7, 215 (1949).
7. R. L. Tiede, Improved apparatus for rapid measurement of viscosity of glass at high temperatures, J. Am. Ceram. Soc. **42,** No. 11, 537 (1959).
8. C. L. Babcock, Viscosity and electrical conductivity of molten silicates, J. Am. Ceram. Soc. **17,** No. 11, 329 (1934).
9. a. ASTM Standard, Annealing point and strain point of glass, ASTM Designation C 336, 1961.
   b. ASTM Standard, Softening point of glass, ASTM Designation C 338, 1961.
10. H. E. Hagy, Experimental evaluation of beam-bending method of determining glass viscosities in the range 10^8 to 10^{15} poises, J. Am. Ceram. Soc. **46,** No. 2, 93 (1963).

WASHINGTON, D.C., 20234, July 1, 1964.

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