THE STATE UNIVERSITY OF NEW JERSEY RUTGERS

# Overview of Glass Properties

## Glass Engineering 150:312

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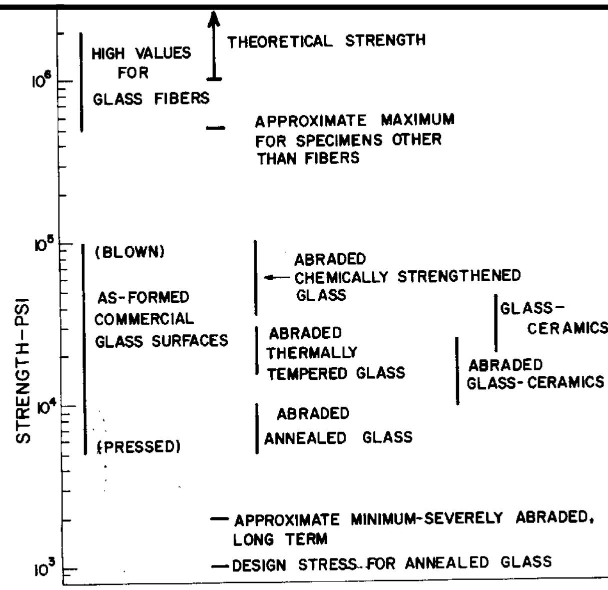
## Overview of Physical Properties of Glass

- **Optical Properties**
- **Overview of Other Properties**
- **Strength Introduction**
- **Elastic Modulus**
- **Thermal Expansion**
- **Surface Tension**
- **Thermal Conductivity**
- **Stress-Optical Coefficient**
- **Heat Capacity (Specific Heat)**
- **Knoop Hardness**
- **Electrical Resistivity**
- **Chemical Durability**

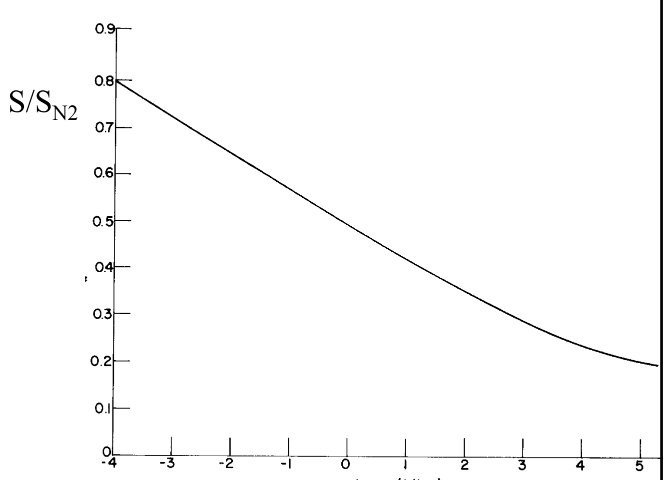
- **Separate Lectures**
  - → Viscosity
  - → Mechanical Behavior

## From Theoretical Strength to Design Strength - - A Wide Range!



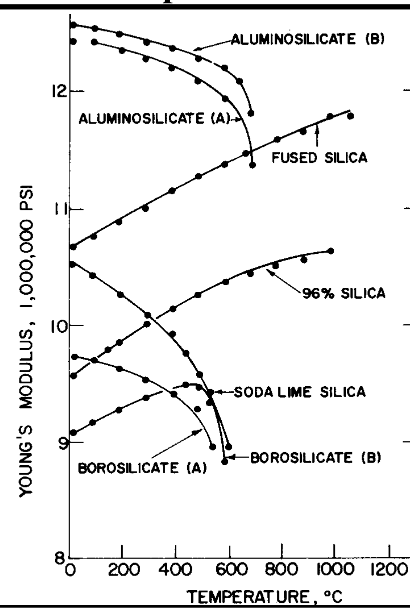

## Universal Fatigue Curve

- **Strength of glass after loading for time t.**
- **To make ALL data fit this line: normalize strength with liquid nitrogen strength, and time with time to reach 50%**



## Elastic Modulus of A Range of Glass Compositions as a Function of Temperature

- **Elastic modulus is the stiffness of the glass, an important engineering property.**
- **Generally, the stiffness decreases with temperature.**
- **Silicate glasses are an exception**



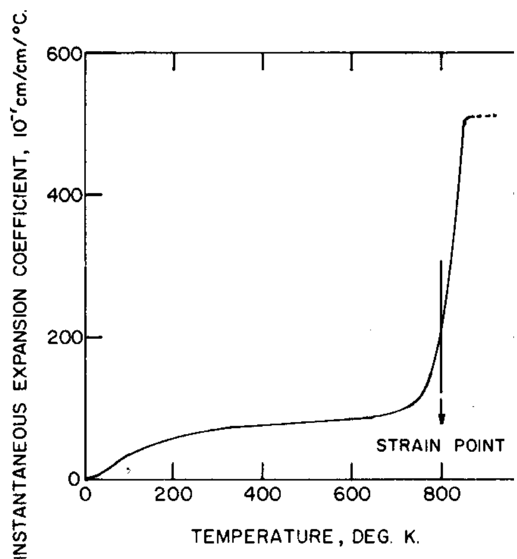

## Elastic Constants for Glasses and Glass Ceramics

| Code | Type | E GPa | G GPa |
|---|---|---|---|
| 9606 | Glass Ceramic | 17.2 | 6.9 |
| 1723 | Aluminosilicate | 12.5 | 5.1 |
| 9608 | Glass Ceramic | 12.5 | 5.0 |
| 7940 | Fused Silica | 10.4 | 4.5 |
| 0080 | Soda Lime Silicate | 10.2 | 4.2 |
| 7900 | 96% Silica | 10 | 4.2 |
| 7740 | Borosilicate, Low Expansion | 9.1 | 3.8 |
| 7070 | Borosilicate, Low Loss | 7.4 | 3 |

- **E = Young's Modulus**
- **G = Shear Modulus (modulus of rigidity)**

## Thermal Expansion of Glass

- Instantaneous Expansion of Borosilicate Crown Glass




## Thermal Expansion of Commercial Glass

- Units are $10^{-7}/^{o}$ C

| Corning Code | Type | 25 to −190°C | at 25°C | 0 to 300°C | 25°C to Setting Point |
|---|---|---|---|---|---|
| 0080 | Soda-Lime | 66 | 86 | 93.5 | 103 |
| 0120 | Potash Soda Lead | 70 | 81 | 89.5 | 98 |
| 1720 | Aluminosilicate | 22 | 37.5 | 42 | 52 |
| 7052 | Borosilicate | 35 | 43 | 46 | 53 |
| 7720 | Borosilicate | 29 | 35 | 36 | 43 |
| 7740 | Borosilicate | 25.5 | 32.5 | 32.5 | 35 |
| 7900 | 96% Silica | 4 | 8 | 8 | 7 |
| 7940 | Fused Silica | 2.5 | 5.5 | 5.0 | 2 |
| 8871 | Potash Lead | 75 | 86 | 102 | 113 |
| 9010 | Potash Soda Barium | 66 | 78 | 89 | 102 |

## Thermal Expansion of Glass

- **Linear factors for calculation of glass expansion from oxide weight percent**
- **Sodium in highest contributor**
- **Boric oxide is lowest [applies only from 0 - 12% $B_2O_3$]**
- **From English and Turner**
- **Valid from 25° to 90° C**

| Oxide | Factor |
|---|---|
| $SiO_2$ | 0.05 |
| $B_2O_3$ | -0.66* |
| $Na_2O$ | 4.32 |
| $K_2O$ | 3.90 |
| $Al_2O_3$ | 0.14 |
| CaO | 1.63 |
| MgO | 0.45 |
| ZnO | 0.70 |
| BaO | 1.40 |
| PbO | 1.06 |
| $ZrO_2$ | 0.23 |

## Factors for Calculating Surface Tension

| | Soda-Lime-Silica Type Glasses (Ratio $SiO_2$ : $Na_2O$ > 3.25) Temp., 1200°C. (after Lyon[87]) | Enamel-Type Glasses Temp., 900°C. (after Dietzel[88]) |
|---|---|---|
| $Li_2O$ | . . . | 4.6 |
| $Na_2O$ | 1.27 | 1.5 |
| $K_2O$ | 0.0 ca. | 0.1 |
| MgO | 5.77 | 6.6 |
| CaO | 4.92 | 4.8 |
| BaO | 3.7 ca. | 3.7 |
| PbO | . . . | 1.2 |
| ZnO | . . . | 4.7 |
| $B_2O_3$ | 0.23 | 0.8 |
| $Al_2O_3$ | 5.98 | 6.2 |
| $SiO_2$ | 3.25 | 3.4 |
| $TiO_2$ | . . . | 3.0 |
| $V_2O_5$ | . . . | −6.1 |
| $ZrO_2$ | . . . | 4.1 |
| $CaF_2$ | . . . | 3.7 |
| $Fe_2O_3$ | 4.5ca. | 4.5 |
| CoO | . . . | 4.5 |
| NiO | . . . | 4.5 |
| MnO | . . . | 4.5 |

## Thermal Conductivity of Glass

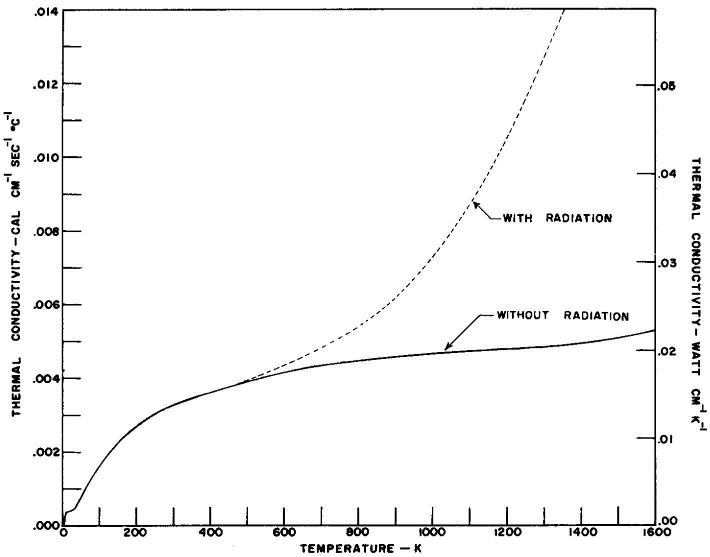
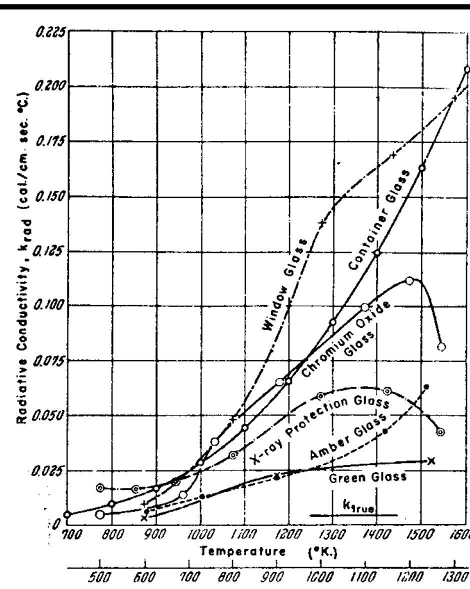



Figure 8. Thermal conductivity of vitreous silica.

## Thermal Conductivity of Glass

- **Major contributor to conductivity at high temperature is radiation**
- **Colored glasses absorb radiation.**



## Stress-Optical Coefficient for Glasses

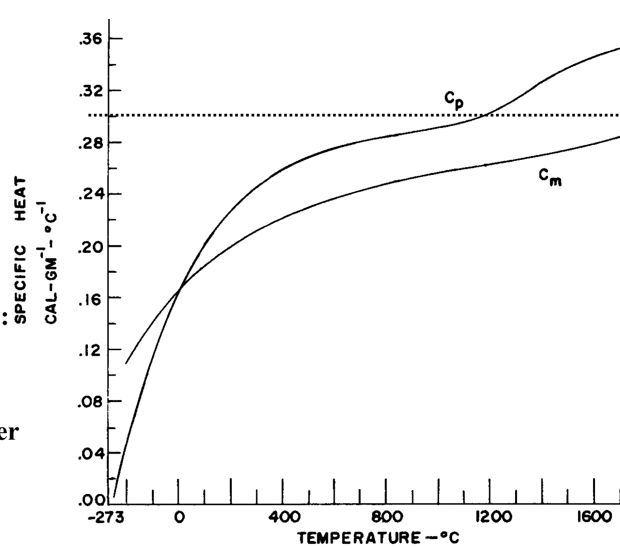
- **Stress generates birefringence in glass**
- **The larger the photoelastic constant, C, the more birefringence is generated by a given stress.**

$$Stress_{MPa} = \frac{\partial_{nm}}{t_{mm}\, C_{Brewster}}$$

| Glass | Type | Photoelastic Constant in Brewsters |
|---|---|---|
| Corning 0080<br>Owens-Illinois R-6 | Soda-Lime | 2.83 |
| Corning 0120<br>Owens-Illinois KG-12 | Lead | 3.23 |
| Corning 1723 | Aluminosilicate | 2.77 |
| PPG 6695 | Aluminosilicate | 2.65 |
| Corning 7052<br>Owens-Illinois EN-1 | Kovar sealing | 3.65 |
| Corning 7570 | High lead | 0.25 |
| Corning 7740 | Borosilicate, Low Expansion | 4.01 |
| Corning 7900 | 96% Silica | 3.65 |
| Corning 7940 | Fused Silica<br>Plate glass<br>Sheet glass | 3.52<br>2.65<br>2.45 |
| F 5795 / 410 | Light Flint | 3.18 |
| F 689 / 309 | Dense Flint | 2.18 |
| BaC 5725 / 574 | Light Barium Crown | 2.56 |
| BaC 611 / 588 | Dense Barium Crown | 1.83 |
| BSC 517 / 645 | Borosilicate Crown | 2.81 |

## Specific Heat of Vitreous Silica as a Function of Temperature

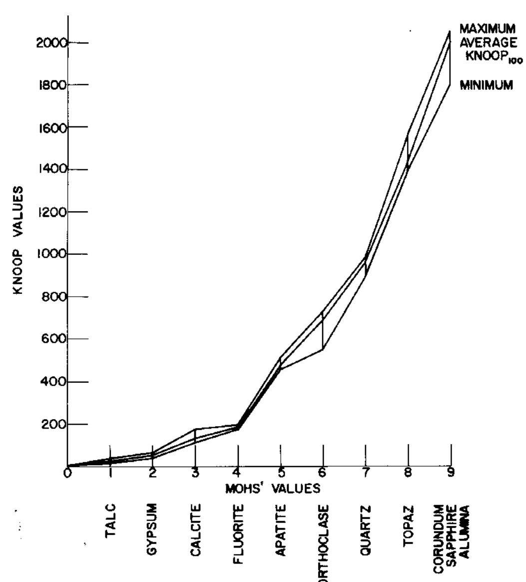
- **Most glasses and ceramics follow, approximately, the rule:**
- **$C_p$ = 3R per mole atom**
- **= 6 kcal/mole atom**
- **$SiO_2$ contains 3 atoms per mole, so:**
- **$C_p(SiO_2)$ = 18 kcal/mole**
  **= 0.3 kcal/g**



## Knoop Hardness of Commercial Glasses

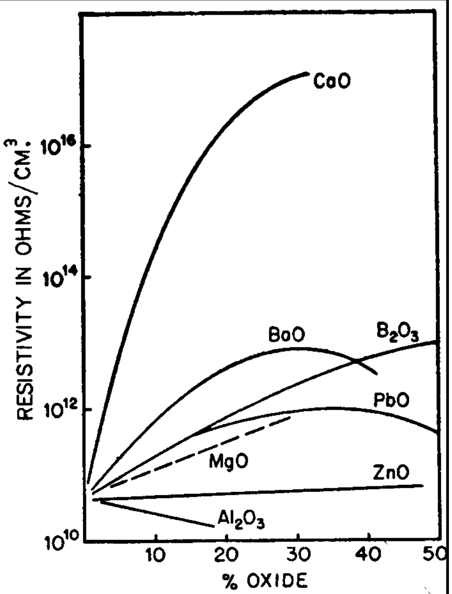
| Code | Type | Indentation Hardness Kg per sq. mm. $KHN_{100}$ |
|---|---|---|
| Corning 7940 | Fused Silica | 489 |
| " 7900 | 96% Silica | 463 |
| " 0800 | Soda-lime | 465 |
| " 0010 | Potash Soda Lead | 363 |
| " 7740 | Borosilicate, Low Expansion | 418 |
| " 1723 | Aluminosilicate | 514 |
| " 9606 | Glass-Ceramic | 657 |
| " 9608 | Glass-Ceramic | 593 |
| PPG | Soda-Lime (Float process) | 443 |
| NBS 710 | Soda-Lime | 486 |
| NBS 711 | Lead Silicate | 388 |
| NBS 715 | Aluminosilicate | 540 |

## Relationship Between MOH Hardness and Knoop Values



## Electrical Resistivity of Silicate Glasses

- **Conductivity in silicate glass is by charged ions.**
- **Monovalent ions, such as sodium, move easily in silicate glasses and promote conductivity**
- **Resistive glasses usually contain little or no monovalent content**




## Chemical Durability Summary

| Type of reagent | Temperature | Degree of attack | Remarks |
|---|---|---|---|
| water | boil | negligible | no absorption or swelling |
| | 100–260°C | 0.001 to 0.01 mg/cm², in 6 hr | depends on glass |
| seawater, 5% sea salt | boil | 0.03–0.08 mg/cm², 24 hr | 1 yr in ocean, no visible effect |
| acids | | | |
| HF | all | severe | not recommended |
| 21% $H_3PO_4$ | 100°C | 0.005 mg/cm², 24 hr | glass satisfactory except at high concentrations or raw acid with fluorides |
| 85% $H_3PO_4$ | 100°C | 0.014 mg/cm², 24 hr | |
| other inorganic | boil | negligible | |
| organic | boil | negligible | |
| bases | | | |
| strong, 5% NaOH | 80°C | 0.3 mg/cm², 6 hr | |
| 6.9% KOH | 80°C | 0.2 mg/cm², 6 hr | |
| weak. 3% $NH_4OH$ | 80°C | 0.33 mg/cm², 100 hr | |

**1 mg/cm² = 10 µm**

## Chemical Durability Summary

| | | | |
|---|---|---|---|
| halogens | to 150°C | negligible | dry fluorine questionable |
| metal salts | | | |
| acid | to 150°C | negligible | |
| neutral | to 150°C | negligible | |
| basic 0.5$N$ $Na_2CO_3$ | 100°C | 0.18 $mg/cm^2$, 6 hr | |
| 5% $Na_2CO_3$ | 150°C | 10 $mg/cm^2$, 6 hr | |
| inorganic nonmetallic halides | to 150°C | negligible | fluorides excepted |
| sulfur dioxide | to 150°C | negligible | slight bloom may appear |
| ammonia (dry) | to 150°C | negligible | see bases for $NH_4OH$ |
| oxidizing chemicals | to 150°C | negligible | |
| reducing chemicals | to 150°C | negligible | |
| hydrocarbons | to 150°C | negligible | includes chlorinated compounds |
| amines | to 150°C | negligible | those with pronounced basic reaction questioned |
| polyhydroxyl aliphatics | to 150°C | negligible | |
| mercaptans | to 150°C | negligible | |
| oils and fats | to 150°C | negligible | |

NOTE: A weight loss of 1 $mg/cm^2$ is equivalent to a depth loss of 0.01 mm/(specific gravity of glass) for those cases where the attack is not selective.

**$1\ mg/cm^2 = 10\ \mu m$**