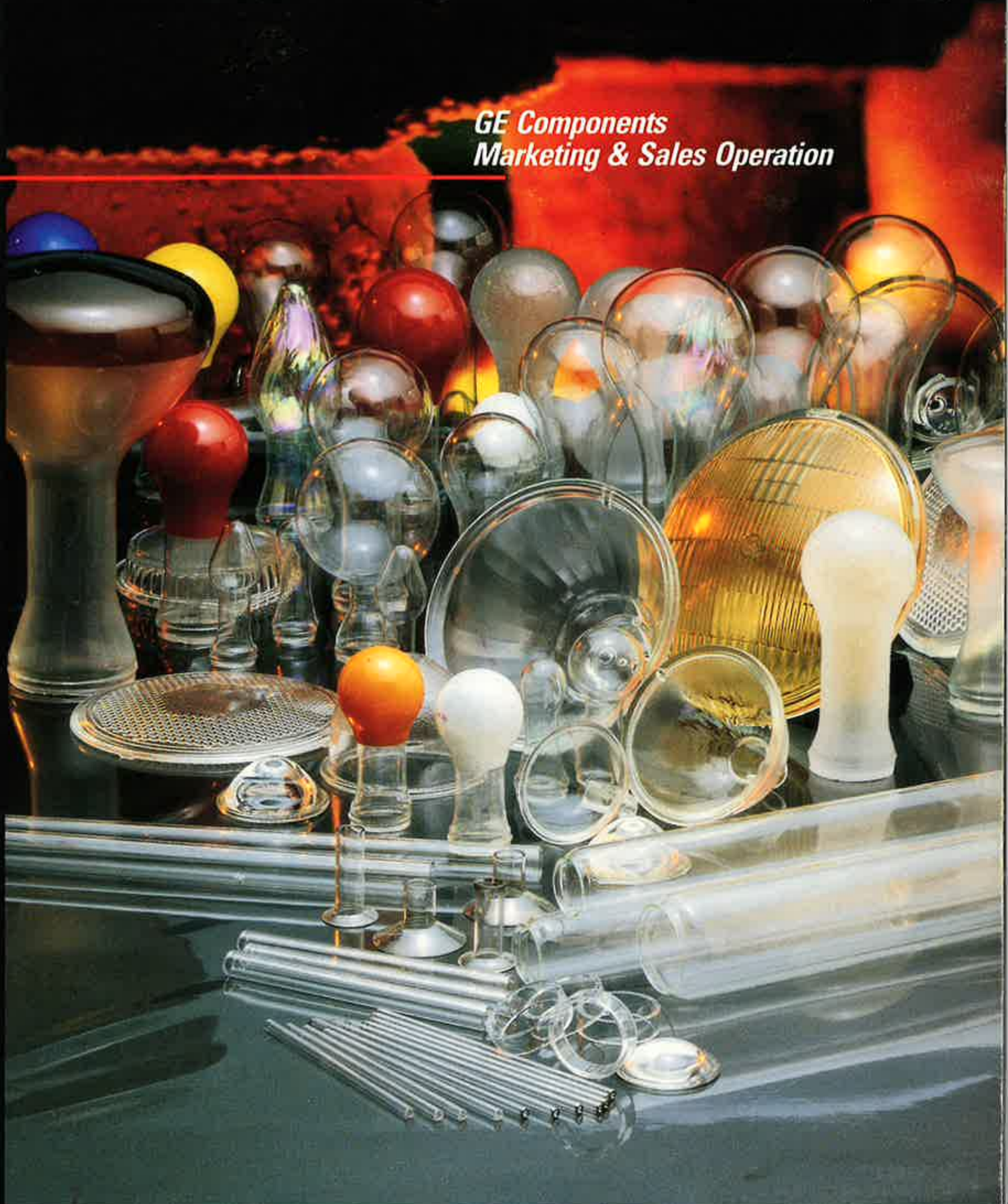
GE Components
Marketing & Sales Operation



Glass Products




Discover The Possibilities

GE Glass Products

Glass has been evolving as a design material since the dawn of time. The pace has quickened in recent years as the material finds new and exciting roles in today's engineering environment.

Because glass is essential in all forms of lighting, GE has been among the leaders in developing higher performance and specialized varieties of the material. And not all of these achievements have been in the past. Some of the most promising of these discoveries are just now making their impact on design, both inside and outside the lighting industry.

The surprising thing about glass is how readily it can be engineered to meet specific needs.

By altering its chemical makeup and choosing the appropriate method to produce it, glass shows tremendous versatility. For instance:

- Glass with a high lead content can be drawn down so small that 3 million tiny diameters can be combined to make microchannel plates for night vision systems.
- High temperature aluminosilicate glasses are expanding the benefits of halogen lamps from automotive applications to a much broader range of lighting.
- Glass that is chemically formulated to pass energy at specific points on the ultraviolet/infrared spectrum is providing a low cost means to dry paint, accelerate weathering of materials, cure adhesives and remove insects and bacteria from water.

Even when chemical additions are significant, as in the case of 50% lead glass, the material can retain its crystal clear transparency.

Glass can be easily formed and worked into intricate shapes and utilized in demanding environments of heat and chemical exposure. It often combines properties that are either costly or impossible to put together in other materials.

And since it is derived from one of the world's most plentiful resources—common sand—glass can be a very cost competitive option when compared to other materials.

But glass is different than other materials. Once these differences are taken into account, engineers are finding that one of the world's oldest materials can meet the challenge of many modern day applications.

GE's achievements in glass technology are partially responsible for the wide variety of lighting products we enjoy today.

Types of Glass

GE manufactures a variety of glass products primarily for the lamp industry. But our capabilities are also widely used in other industries. We produce and market bulb blanks in a wide range of sizes and shapes, tubing of various diameters, and glass parts that are machine pressed to specific shapes.

The major constituent of glass is silicon dioxide. At GE, this raw material is combined with oxides of sodium, potassium, calcium, barium, lead, aluminum or boron to produce different types of glass, each with specific engineering properties.

Soda Lime Glasses

Soda lime glasses are the most common type and are composed primarily of silica, soda and calcia, with relatively small additions of other constituents. Most lamp envelopes, and for that matter, most applications of glass, are this most common grade of the material. These "soft" glasses have moderate chemical durability and relatively poor resistance to thermal shock, but they are low in cost and easily worked.

When higher performance is required, various chemical additions are made to upgrade the material or give it special properties.

Lead Glasses

By replacing the lime of the soda lime glass with 20, 30, even 50% lead oxide, a very special breed of glasses is created.

Adding lead creates a fluxing action that lowers the softening point below that of the soda lime glasses, making the glass much more formable at lower temperatures. As the lead oxide content is increased, electrical resistivity, density, refractive index, and x-ray absorption also increase.

One of the best known uses for lead glass is in the neon sign industry where the low temperature workability of the material enables craftsmen to turn out interesting, carefully detailed designs without repeated reheating.

Another application which demonstrates the workability of lead glass are microchannel plates for night vision systems. These wafer thin light filters contain as many as three million microscopic openings, each one provided by an individual piece of lead glass tubing. The lens is produced by progressively drawing down the tubes, packaging them in clusters, and slicing off wafers from the cross section of the final assembly.

Lead glasses are moderately priced and have a good resistance to weathering, but they are sensitive to thermal shock.

Lenses for night vision systems have as many as three million openings that are created by drawing down clusters of lead glass tubes to microscopic sizes. Because of the excellent formability of lead glass, each tube retains its through hole integrity.

Glass tubing containing 20 to 30% lead is workable at low temperatures, permitting neon sign artisans to form the material into intricate shapes.

The high strength of borosilicate glasses, along with the excellent design details that the machine pressing process imparts, makes this the ideal material for automotive headlights.

Borosilicate Glasses

For parts that call for greater thermal shock resistance and service temperatures above 300°C, glasses containing boric acid and smaller amounts of other additives represent the next step up the engineering ladder.

Borosilicates also have a much lower alkali content than other glasses and therefore are ideally suited for hot pressing to shape in permanent molds, a method referred to as "machine pressing."

Borosilicate glasses are widely used for lamp lenses, reflectors and refractors, as well as automotive headlight lenses and reflectors.

The fluted lines and tiny prisms on the surface of these parts are formed in the mold and no secondary operations are required.

Strength, vibration resistance and good surface quality are also major parameters for these applications.

The thermal properties of these glasses are also useful in applications where parts are exposed to direct flame or used in extremely hot atmospheres. Inside self cleaning ovens, for instance, borosilicate glass lens covers and antenna shields withstand temperatures in excess of 900°F.

Aluminosilicate Glass

For parts that must withstand even higher temperatures, engineers turn to glasses that have substantial additions of alumina and other constituents. The aluminosilicates provide lower thermal expansion and better thermal shock resistance than the borosilicates. Their softening point is approximately 930°C, permitting exposure to rather high temperatures. But high working temperatures are also required in fabricating parts with these glasses.

One application that has focused major attention on the aluminosilicates is the tungsten/halogen lamp. Although smaller in size than incandescent lamps of the same wattage,

A chemical reaction that occurs at approximately 500°C keeps halogen lamps brighter for much longer periods than ordinary incandescents. But those high temperatures require a very superior grade of aluminosilicate glass.

they last significantly longer and stay brighter throughout their life.

In these lamps, halogen combines with tungsten vapor that burns off the filament and, through a chemical reaction, redeposits the tungsten atoms back on the filament. This process continually cleans the lamp wall and avoids the bulb darkening that usually occurs when the tungsten vapor deposits on the bulb wall. But this exchange of gases occurs at temperatures in excess of 500°C.

To meet these high temperature requirements, GE developed 180 aluminosilicate glass. It is less costly than the quartz and 96% silica used previously, has superior sealing characteristics, and more than enough hot strength. And its thermal contraction characteristics are suitable for sealing directly with the lamp's molybdenum lead wires rather than using a foil lead.

Type 180 is also virtually free of impurities, especially alkalis. If sodium, lithium and other alkalis which occur naturally in most glasses escape in high operating temperatures, reaction with the halogen gas could disrupt the regenerative cycle. Type 180 avoids this.

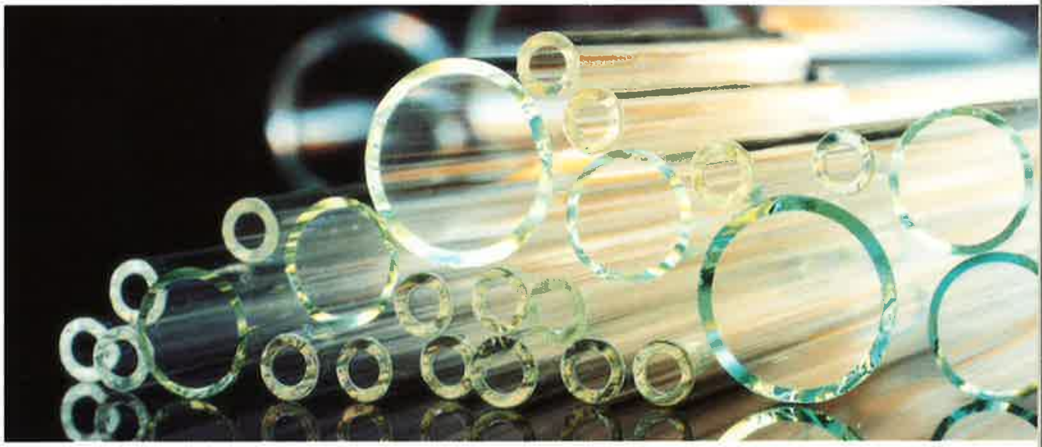
Glass Tubing

In the lamp industry, glass tubing is used for fluorescent lighting, exhaust and flare tubes, and tubing blown bulbs.

But this versatile shape has just as many uses outside lighting, including neon signage, diode and resistor encapsulation, trimmer capacitor housings, and many others.

GE produces tubing in a range of standard diameters from .085″ to 2.50″. Wall thicknesses are held to tolerances of ±.002″ to ±.010″ depending on size and type of glass, and the forming method used.

Glass tubing is one of the basic shapes GE produces for several phases of lamp making and a number of non-lamp applications.



Fluorescent tubes are used in lighting as well as in accelerated weathering, drying and herbicidal equipment.

Tubing is the starting material for a number of small bulb blanks, including the halogen lamps seen here. GE developed a special grade, Type 180, for this application.

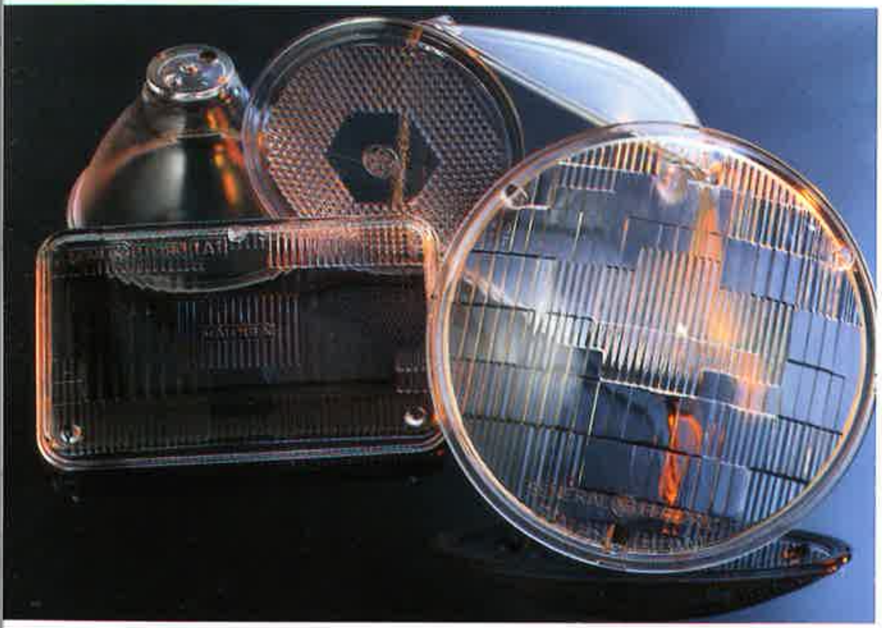
Exhaust and flare tubing used in the manufacture of lamps.

Pressed Glass

Reflectors, refractors, lamp covers and lenses need a glass that can accommodate intricate design details and also withstand demanding operating conditions. For these parts, machine pressing, a process akin to casting, provides the best results.

In addition to lighting products, this process is used to make automotive lamp covers and reflectors, interior light covers and terminal insulators in electric ovens, and many other high temperature, high strength parts.

Almost any glass composition can be hot pressed, but the need for heat resistance in most of these parts has made borosilicate glass the most widely used.



Headlamps for automobiles are made by machine pressing because the process can reproduce the detailed reflector and lens surfaces required for accurate beam control. Glass reflectors are shown in the background.

Pressed glass lamp covers for highway lighting.

The high temperature properties of pressed glass are put to work in lens covers and terminal blocks in electrical ranges.

Pressed glass reflectors are made with a variety of interior patterns and are often aluminized or dichroic coated to optimize reflectivity.

Hard glass envelopes are used for high performance lighting applications.

Bulb Blanks

The glass shape that is most readily associated with lamp making is the familiar lamp envelope. GE produces these by the billions every year, covering a wide variety of sizes and shapes.

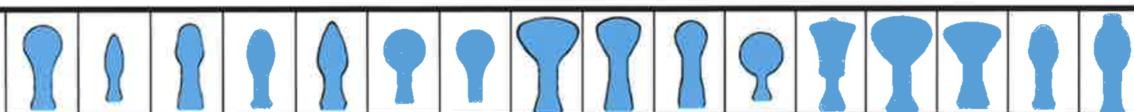
In addition to lighting, bulb blanks are used as breakaway molds in molding plastic parts, chimneys for lanterns, blanks for Christmas ornaments, and other applications. Some of the more popular sizes and shapes are shown in the table below, but there are literally hundreds of other types available from GE.

Blown bulbs come in a large variety of sizes and shapes.

GE's bulb manufacturing facilities are versatile enough to produce chimneys for the well known Coleman Lantern®.

Photo courtesy of Coleman Company.

Table I—Bulb Shapes and Description



Bulb Shape																
Designation	A	B	C	E	F	G	PS	R	RP	S	GEX	RBX	RD	RL	ED	BT
Available Nominal Diameters (Eighths of an inch)	15 19 21 23	6 9½ 10 11 12 13 17 21	7 7½ 9½	17 18 25	10 15	16½ 19 25 30 40	25 30 35 40 52	12 14 20 30 40 52	11	8 11 14	Ornaments 14 16 18 21 26	Bell Shape 16	40 52 80	38	18 23½ 28 37	25 28 37 56

Working With Glass

Glass is not a difficult material to use in fabricating parts, but it presents its own list of requirements. Engineering precepts associated with metals or plastics simply don't apply.

Although it has high compressive strength, glass has little resistance to tensile stresses. Unlike metals, there are no stress accommodating mechanisms such as grain boundaries or slip planes. Glass will deform elastically under stress, but plastic flow takes place so slowly that the net effect is to transfer, undiminished, all stresses imposed on the part to its surface.

The forms of glass supplied by GE—tubing, blown bulbs and pressed parts—are heated above their softening point in the fabrication process. Since thermal stresses are created each time glass is heated and cooled, proper conditioning must precede and follow each of these operations in order to maintain the required strength in the part.

When glass is placed under load, two factors determine how much force is required to exceed the elastic limit, causing the part to fracture: stresses and surface flaws. Controlling these two elements can result in much stronger glass parts.

Mechanical Stresses

There are actually four types of stress that occur in glass parts. The first two are classified as mechanical stresses, and are either temporary or permanent.

A hard impact on a glass surface is a **temporary mechanical stress.** This could occur in transferring a part from one machine to another, fixturing it too tightly, or handling it too roughly. Simple bending of the glass is another common cause of this stress.

The second type, **permanent mechanical stress,** is caused when glass parts are heated and cooled unevenly. It occurs when one section is heated beyond its plastic range while another stays much cooler, setting up tension on the outside of the part. This is called a "crossover" or "stress reversal." Another form of this stress can occur when joining glass parts that have different expansion coefficients, or in joining glass to metals.

Thermal Stresses

Thermal stresses are also classified as **temporary** and **permanent.** Both occur because of the temperature gradient in the glass; temporary stresses **below** the strain range, permanent stresses if the glass cools **through** the strain range with a temperature gradient.

Many high expansion glasses are particularly vulnerable to **temporary** thermal stresses. When glass is heated or cooled, tensile stresses develop in sections of the glass that are relatively cooler than other sections. In a typical part, heat will be applied from the outside, so inside surfaces will be cooler and will generally be in tension. But in cooling, ambient air reaches the outside first, so it will be cooler than inside surfaces and will be the site of greatest tension. This explains why slow heating and cooling is recommended for glass parts, and why they are so vulnerable to damage during the heating and cooling cycles.

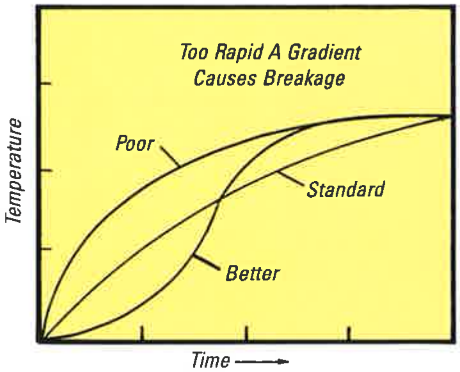
Hold At Plateau

Given the expansion rate and thickness of the glass, the thermal gradient must be tightly controlled to achieve success. The best procedure is to heat the glass very slowly at first. Since thermal conductivity increases with temperature, the heating rate can be raised after the initial heating. As the glass reaches the temperature where it will be formed or sealed, it is desirable to hold it at this plateau to permit the inside and outside of the glass to arrive at a temperature equilibrium. This promotes good sealing. If the thermal gradient is too steep, or there isn't sufficient soak time, it could lead to glass sticking to the tooling or tearing away, inconsistent forming or sealing, shrinkage or sharp edges instead of the desired contours. All these defects can lead to stress, flaws and failures.

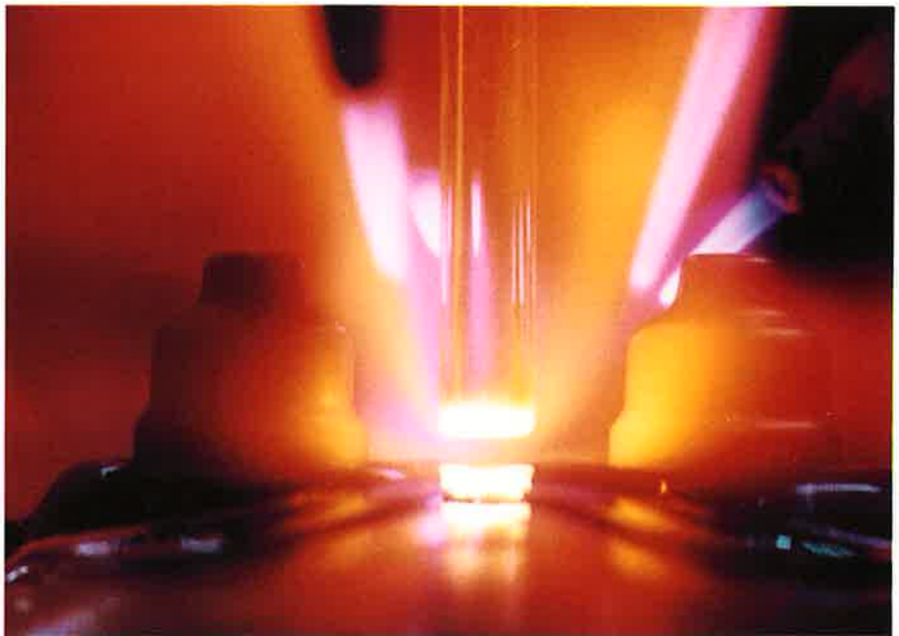
The fourth type of stress, **permanent** thermal stress, also occurs as glass is heated and cooled. For many applications, this is the most potentially damaging type of stress.

The magnitude of these cooling stresses depends on three factors: the rate of cooling, the expansion characteristics of the glass, and the thickness of the part.

Glass Heating Rate



Heat gradients must be carefully monitored in sealing glass parts (right) in order to avoid cooling stresses.



Thicker sections of glass can generate steeper temperature gradients, while thinner sections require less gradual heat gradients in processing.

However, both thickness and expansion rate are usually beyond the control of the user. Only by careful control of the cooling rate can the desired results be attained.

The Cooling Rate

Avoiding high stresses in the glass at this point demands maximum attention to the cooling rate. If the glass is cooled with a temperature gradient through the critical strain range, residual stresses are trapped within the part. To lower the chance of creating stress, the usual step is to slow the temperature change as much as possible.

When slow cooling isn't practical or desirable, the glass should be "conditioned" so that it develops a specific pattern and intensity of surface stress.

All stresses within a glass part must balance, so a high level of compressive stress in one area can result in a high level of tensile stress in other regions of the part.

If the compressive stress is too high, the glass will be difficult to score and cut. If residual tension is too high, the glass may shatter or crack later during service.

Balanced Heat

Ideally, the temperature of the inside and outside of the part should be uniform. As the glass cools through the strain range, a slight compressive stress will be created on the outside of the part, balanced by a slight tensile stress on the inside. Having this layer of compression around the outside provides the strength that will enable the part to withstand the effects of further processing or service loads, as well as to resist scratching, abrasion and breakage. It also helps counteract the effects of thermally or externally induced tensile stresses.

Surface Defects

The condition of a glass surface is also very important. Imperfections can act as stress risers and crack initiation sites. In the presence of high tensile stresses, this will lead to fracture of the part.

The theoretical strength of glasses is considerably higher than is normally measured. Surface imperfections limit the ultimate strength to around 10,000 p.s.i. with practical tensile strength that is even less, about 5,000 p.s.i. Between 70 and 80% of the failures in commercial glass occur near this value.

Surface defects range from easily identified cracks to the less obvious small checks and scratches that result from mild abrasion. Internal defects are also important because they present a boundary between differing materials within the glass. This boundary is technically a "surface" and a potential failure site.

The best defense against defects of this kind is to understand what they are, how they develop, and how they can be prevented.

Flaws

Flaws come from many places such as abrasion on the surface of the part, joining metal or glass to the part at sharp angles, sharp angles in molding, etc. These types of defects can be avoided by proper design and careful handling of glass parts during and after processing.

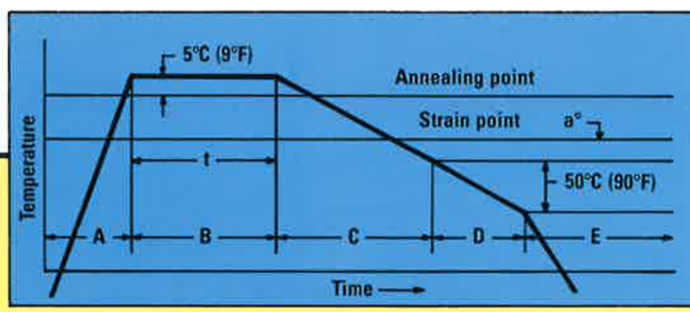
With surface flaws, the shape is more significant than the size. In the sketch shown above, all four defects are the same depth. Flaw #1 is relatively wide, so stresses will be evenly distributed around it. At the other end of the scale, flaw #4 represents a sharp reentrant angle where the stresses will be concentrated.

Using the formula $K = 1 + 2\,(A/B)$, the vast difference in the flaws can be illustrated mathematically.

A is the depth of the flaw, B, the width of the flaw.

(1) $K = 1 + 2\,(2/2) = 3$
(2) $K = 1 + 2\,(2/.250) = 17$
(3) $K = 1 + 2\,(2/.0312) = 129$
(4) $K = 1 + 2\,(2/.001) = 4000$

Table II—Schedule For Commercial Annealing



Annealing Periods:
A - Heating to 5°C above annealing point.
B - Hold temperature for time t.
C - Initial cooling to a° below strain point.
D - Cooling, next 50°C.
E - Final cooling.

Expansion coefficient of glass per °C	Thickness of glass mm (in.)	Cooling on one-side						Cooling on two sides					
		Heat rate, °C/min.	Time t, min.	Temp. a, °C	Cool rate, °C/min.			Heat rate, °C/min.	Time t, min.	Temp. a, °C	Cool rate, °C/min.		
		A	B	C	C	D	E	A	B	C	C	D	E
$33\text{-}37 \times 10^{-7}$	3 (1/8)	130	5	5	12	24	130	400	5	5	39	78	400
725, 772, 776, 777 Glass	6 (1/4)	30	15	10	3	6	30	130	15	10	12	24	130
$45\text{-}50 \times 10^{-7}$	3 (1/8)	85	5	5	8	16	85	260	5	5	26	52	260
706, 180 Glass	6 (1/4)	21	15	10	2	4	21	85	15	10	8	16	85
$89\text{-}95 \times 10^{-7}$	3 (1/8)	50	5	5	4	8	50	140	5	5	14	28	140
001, 008, 012, 137, 355, 539, 980, 982 Glass	6 (1/4)	11	15	10	1	2	11	50	15	10	4	8	50

Reference: Glass Engineering Handbook, McLellan & Shand.

In applications involving high levels of stress, these defects can be detrimental because they provide a site where stresses can concentrate.

But all glass imperfections are not necessarily causes of failure. Severity levels are more critical than the presence of an imperfection.

Scuffs and **scratches** are relatively mild surface abrasions characterized by a scraping out of surface material. They can be avoided or minimized by keeping glass away from abrasive materials during reworking and using suitable external lubricants.

Checks and **fractures** are similar in that they are separations in the glass that form a sharp re-entrant angle, such as #4 above.

Fractures are usually easy to see because they extend completely through the part and usually render the part unserviceable.

Checks, small, shallow cracks that penetrate only partially through the glass section, are the most insidious because they are hard to detect and yet present very potent stress risers.

Checks can be seen by rotating the part under a non-diffusing incandescent light and looking for a tell-tale sparkle. But even under light, checks will not always sparkle. If the opening of the check is less than one-quarter of the wavelength of the light used, it is completely invisible.

Surface defects of this kind can be controlled by utilizing the appropriate glass—borosilicate grades are the most scratch resistant—and taking care to keep the surface away from abrasive materials.

Internal defects that can create stress problems include:

- **Cord,** an optical defect caused by inhomogeniety in the glass
- **Stones** and other nonvitreous inclusions
- **Bubbles**
- **Chill marks,** a wrinkled surface condition caused by uneven cooling of pressed glass parts
- **Shear marks,** left by the cooling action of a cutting blade
- **Laps,** surface folds due to incorrect forming
- **Fins,** flash at the parting line of pressed ware

The strength of glass is determined by the type and amount of flaws. The greater the density and sharper the flaws, the lower the strength. Stresses are in many cases additive, and if the sum total of the stresses exceeds the strength of the glass, the glass breaks.

Like other materials, glass is subject to fatigue. A stress that won't affect glass if applied for only a second or two might break it if applied over longer periods. Glass can also be adversely affected by chemicals in the air—most notably water.

Surface Contamination

Surface contamination of glass during working and final forming can also be a source of defects. Care must be taken to keep glass away from materials that can leave debris on its surface, such as hard rubber, asbestos or plastics. Fingerprints may also be a common source of foreign material on glass. Soft cotton gloves should be worn when handling the material.

There are five basic guidelines for the design and manufacture of glass parts:

1. Utilize the glass with the appropriate properties for each application.
2. Design for a condition of mild surface compressive strength because it counteracts the effects of thermally or externally induced tensile stresses. But keep compressive stresses to a minimum so as not to create counterbalancing tensile stresses in other areas of the part.
3. Design glass parts with gently rounded corners to reduce or minimize stress problems.
4. Reduce residual stresses by slow cooling after high temperature exposure.
5. Avoid scratching or abrading the surface during manufacture. This is one of the most common causes of problems in glass parts.

Optical Quality

It is often tempting to try to eliminate defects by specifying "optical quality" or defect-free glass. But this is not recommended because optical-quality glass requires special production and inspection techniques and could result in an expensive over design.

Because of the complexity of glass characteristics, designers are advised to discuss their requirements with their supplier before the design is formalized.

Glass Sealing

One of the most important aspects of glass is its ability to create an effective seal with a variety of metals and other glasses. Glass-to-metal sealing is a critical operation in the manufacture of lamps, cathode ray tubes and many electronic devices.

For sealing applications, glass must expand and contract at the same rate as the metal to which it is joined. This should occur over a temperature range from approximately the anneal point to room temperature. Conventional sealing temperatures for most common glasses is in the 800-900°C range.

Depending on the application, such properties as low dielectric constant, low loss factor, high electrical resistivity and high dielectric strength may also be required in sealing glasses.

Glass expands as it warms and contracts as it cools, just like metals. But unlike metals, glass is an insulator rather than a conductor of heat, and this can create a sizable temperature gradient within a single piece of glass.

The result can be nonuniform expansion and contraction which could cause thermal stresses. The mean coefficient of expansion is usually given over a temperature range of 0-300°C. But above 300°C glass expands more rapidly with increasing temperature and may have a coefficient two or three times larger than measured below 300°C. For proper seal design, complete contraction curves provide the best information, rather than simply using the 0-300°C data.

In making a seal, a metal oxide must be developed on the surface of the metal and it must adhere tightly. When glass and metal are joined, some of the metal oxide will be dissolved in the glass. Certain combinations of metal and glass will have undesirable chemical reactions and necessitate a change in materials.

Fire Chemistry

Achieving the desired metal oxide condition depends on how well the flame chemistry is controlled.

A reducing flame, which results from the presence of unburned fuel in the flame, causes heavy metals such as lead or antimony to be reduced from their oxides to a metallic state. This metallic condition increases the thermal absorption of the glass and therefore promotes a better seal.

But there are also problems. It may turn the glass black, and if the reducing atmosphere is excessive, the metallic content could cause an electrical short. Although darkening may be of no consequence, appearance or transmission requirements may demand that it be avoided. Many operators prefer seeing clear glass.

The reducing condition can be reversed by increasing oxygen. The metals will reform oxides and the glass will return to its clear condition. However, if the shift is too far on the oxidizing side, it's possible to reboil the glass. This leaves bubbles and froth in the glass, a condition that cannot be tolerated in lamp or electronic parts manufacture.

For best results in sealing, operators should strive for just the right balance between reducing and oxidizing flames.

Lead Glasses

When electrical resistivity is required, a change to lower alkali glasses or lead glasses may be indicated. Low alkali glasses usually seal at higher temperatures, however, so using lead glass may be preferable.

Lead glasses provide a long working range. During sealing, oxidizing and reducing fires can be used to advantage to achieve certain goals. For example, reducing fires can be used during the initial stages of sealing to reduce the lead, and promote heat absorption. This will blacken the glass, but later in the process, oxygen can be added to the flame to clear the glass.

Sealing Metal

The metal being sealed can also have a profound effect on the glass-metal interface. Because of the tendency of lead oxide to be reduced by ferrous metals, it may be necessary to coat the metal with copper or platinum to prevent this reaction.

In sealing, it is also important that both the glass and metal be free of lubricants, corrosion products, residue of cleaning compounds, organic material, or other foreign matter. In most cases, standard cleaning procedures will provide good results.

Encapsulation

Encapsulation of diodes, capacitors and other electronic devices also come under the heading of glass sealing.

Because of the miniaturization of many electronic parts, much more is now expected from encapsulation materials.

In addition to providing a good coefficient of expansion match to the metal to which it is sealed, the glass must be very workable in its viscous state and cool and harden to form a hermetic seal.

Encapsulation is done with tiny glass sleeves that are perfectly round and have very uniform wall thicknesses. The dimensional requirements are so stringent that special drawdown procedures have been developed just for this application.

Glass is available with compositions that are compatible with all the common metals used to create vacuum tight seals in electronic devices. Glasses with low alkali compositions are preferred. Alkalis tend to migrate into resistive films and alter their resistance value, and they could also cause leakage currents through the glass, especially at high temperatures.

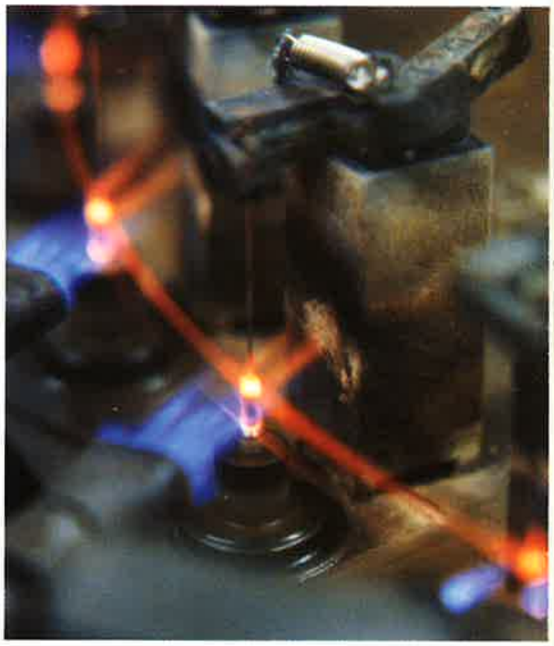
Heavy Walls

Because the devices being encapsulated are very sensitive to temperature, it is desirable to accomplish the encapsulation at as low a temperature as possible. Since lead glasses are the lowest melting types, they are the most commonly used. They also possess high electrical resistivity and low dielectric loss, two properties that permit procedures to achieve small size and thin sections without inducing current leakage through the glass. For solid state devices, lead glass also protects the component from external sources of radiation because of its good absorption properties.

Because glass is a poor conductor of heat, it is necessary to start with heavy walled glass tubes in drawing sleeves required for encapsulation. The heavy wall is needed to keep enough heat in the glass to maintain the desired workability. A typical size range for redraw tubes supplied by GE is 1″ to 1½″ outside diameter, and up to 33% of the OD in thickness.

The glass is heated to approximately 1000°C, controlled to its ideal viscosity, and then drawn in one pass down to a wall section of .010″ or smaller.

Heavy walled lead glass tubing, drawn down to tiny sleeves as small as .010″ in OD, is used for encapsulating diodes, capacitors, and other electronic parts.



In encapsulating devices, glass sleeves are flame sealed to metal leads at high production rates.

Photo courtesy of GTI Corporation.

Viscosity

Unlike metals, glass does not have a specified melting point at which it exists as both solid and liquid masses. Rather, it gradually softens into a plastic state and finally a liquid as temperatures increase.

At temperatures above its softening point the material can be formed or worked into intricate shapes.

Glasses that soften at relatively low temperatures (up to approximately 700°C) are called "soft," while glasses that soften at higher temperatures are called "hard." Soda lime and lead are considered "soft," borosilicate and aluminosilicate are "hard." These terms apply exclusively to the workability of the glass and not to mechanical hardness.

Working Regions

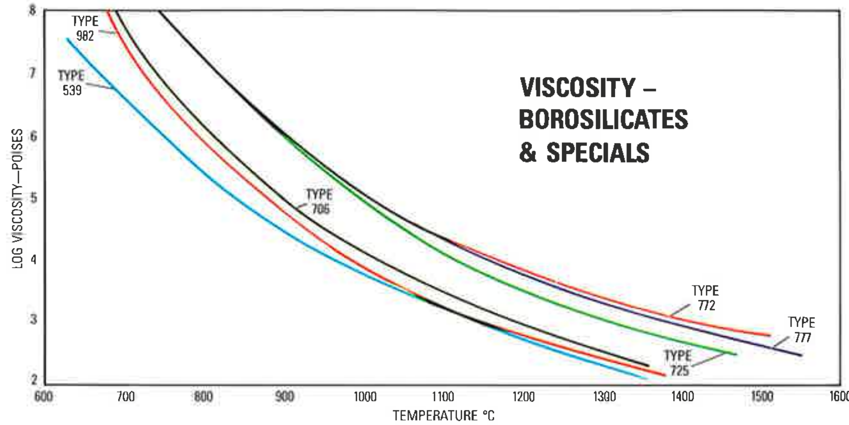
There are actually three temperature ranges which must be considered in both the design and manufacture of glass parts. At room temperature, the material is in the elastic range. It will return to its original shape after bending just like any other elastic material. Since glass is also brittle, built-in stresses and surface defects can make it break easily in the elastic range.

As glass is heated, it passes through the strain range, crossing its softening point to reach the plastic range.

In the plastic range, glass flows easily and relieves any stresses that are present.

The ideal temperature for sealing or pressing is just above the softening point. Here it is hot enough to avoid being torn by the tooling, cool enough so its flow can be controlled through sealing or forming.

The degree of flowability that molten glass exhibits at this point is measured by its viscosity. This is the resistance to flow of the material when exposed to a shear stress. Since the range in flowability in glass is extremely wide, the viscosity scale is logarithmic and measured in the "poise" expressed as powers of 10.



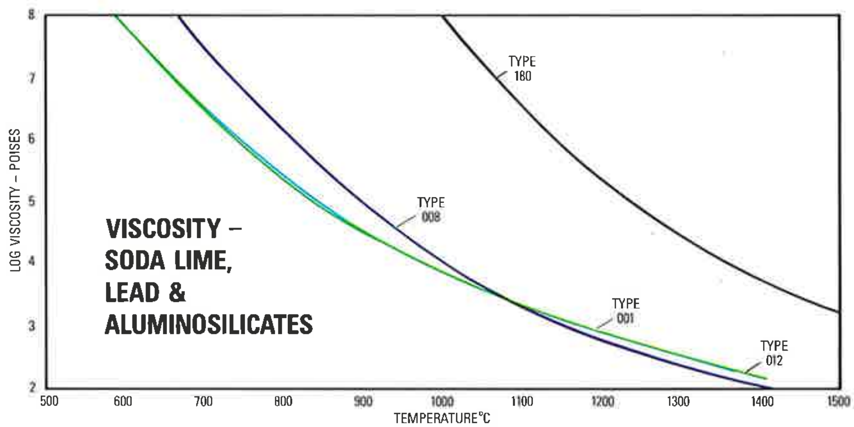


Table III—Viscosity Data

	Temperature	Viscosity of Glass (Poises)	Comments
	Room Temperature	$10^{22}+$	
	Maximum Service Temperature	$10^{15}+$	Below this point, the glass is thoroughly rigid.
Annealing Range	Strain Point	$10^{14.5}$	The temperature at which the internal stress in a glass is substantially relieved in four hours.
	Tranformation Point	$10^{13.3}$	The boundary above which glass is plastic, below which glass is elastic. It is also the breaking point of the curves of thermal expansion and electrical conductivity.
	Annealing Point	$10^{13.0}$	The temperature at which the internal stress in a glass is substantially relieved in 15 minutes.
Working Range	Softening Point	$10^{7.6}$	The temperature at which a glass will deform under its own weight and start to adhere to other bodies.
	Working Point	$10^{4.0}$	The temperature at which the glass is soft enough for hot working by most conventional methods.

Viscosity data for glass is given at three (and sometimes four) points on the temperature curve: strain point, annealing point, softening point, and occasionally the working point.

Strain point is the temperature at which the internal stress in a glass is substantially relieved in four hours; the annealing point is the temperature at which the internal stress is substantially relieved in 15 minutes. The softening point is the temperature at which a glass will deform under its own weight and start to adhere to other bodies.

Viscosity of glass is measured by a fiber elongation method (at low temperatures) and by rotating cylinder methods (at high temperatures).

Properties Of Glass

Glass is not one material but many. Each type is designed to meet specific requirements in terms of product shape and physical and mechanical properties.

The properties of glass should not be compared to those of metal. For instance, shear strength means a great deal with metals, but has little or no significance in glass. Hardness of glass must be measured and reported in terms that rarely, if ever, apply to ductile materials.

In addition to the usual mechanical, electrical, and thermal properties of glass, there is considerable interest in the optical characteristics, chemical durability, viscosity-temperature relationship, and the composition and density of glass.

Mechanical Properties

Ductility

Glass does not plastically deform before failure and therefore breaks in a brittle fashion.

In practice, it can be considered to break only from tensile stresses. Failure due to pure shear or compressive stresses is rare.

Strength

The intrinsic or theoretical strength of glasses is considerably higher than is normally measured, but stress concentrations caused by surface imperfections resulting from manufacturing or handling limit the ultimate strength to around 10,000 p.s.i.

Laboratory tests have shown glass fibers with tensile strengths of up to one million p.s.i. The practical tensile strength of glass however, is about 5000 p.s.i. Between 70 and 80% of the failures occur in commercial glass near this value. To preserve a safety factor, a prolonged working stress of 1000 p.s.i. is the maximum that should be used. Rate of loading is also important. Glass fatigues under constant load and the faster the loading rate, the higher the apparent strength.

These values can be used for current commercial glasses since the composition of glass has little practical effect on its strength. Most borosilicate glasses, though, tend to resist scratching and therefore usually give better mechanical service.

Young's Modulus (Modulus of Elasticity)

Young's Modulus is the ratio between stress and strain, and is determined by measuring the sonic or ultrasonic frequencies of a simple beam at room temperature. Most commercial glasses have values between 9 and 10 million p.s.i. By comparison, steel is 30 million, copper 17 and aluminum 10.

Poisson's Ratio

The longitudinal stretching of any elastic material is accompanied by a lateral contraction, and the ratio of the contraction to the proportional stretching is known as Poisson's Ratio. It is measured by a similar method to that used to measure Young's Modulus. A Poisson's Ratio of 0.20 is usually given for glass since the actual value is very seldom less than 0.18 or greater than 0.22.

Hardness and Impact Abrasion Resistance

Glass hardness cannot be measured by the methods and scales (Brinnel or Rockwell) used for metals. One of three other scales is usually used:

MOHS—scratch hardness. Glasses lie between apatite (5) and quartz (7). On this scale glasses are softer than (i.e., can be scratched by) sand, hard steel, agate, emery; and are harder than mica, aluminum and copper.

KNOOP (AND VICKERS)—penetration hardness. Typical values for commercial glasses range from 300-600 Kg/mm (Knoop Scale) when a load of 50 grams is used.

ZEISS—grinding or impact abrasion. Impact abrasion resistance is evaluated by measuring the glass' resistance to sandblasting under standard conditions. All values are relative. Unity is assigned to soda lime plate glass (standard window glass) and all other values are assigned relative to this standard.

Generally accepted values on the impact abrasion resistance of glasses are as follows:

Soda Lime Plate	1.0
Soda Lime (ribbon and tubing)	1.2
Lead	0.6-0.8
Borosilicate	3.0-4.0
Aluminosilicate	2.0

Density

Density is defined as the mass per unit volume. For glass, density depends upon its composition (primarily) and its thermal treatment (density for a particular glass composition will be greatest when the glass has been stabilized at the lowest practical temperatures). It is measured by one of several buoyancy methods, usually a hydrostatic weighing procedure.

Weathering

While the effects of weathering can be minimized by washing the surface in dilute hydrofluoric acid, or warm water, the treatment does not afford lasting protection from future weathering. The best protection for glasses subject to weathering is to store them in dry places, keep them from contact with moisture absorbing materials (i.e. paper), and control the turnover of stored products.

Weight Formula

This calculation for weighing glass tubing is based on pieces-per-pound. For calculating cane, use half the diameter as the wall thickness value.

$$P = \frac{224}{LW(D-W)d}$$

Where P = pieces/pound
L = length in millimeters
W = wall thickness in inches
D = outside diameter in inches
d = density gm/cc.

Table IV—Properties of Glass

1	2	3	4	5	6	7	8	9	10	11
					Mechanical Properties			**Thermal Properties**		
Glass Type	Description/Use	Color	Forms Usually Available	Density (g/cc)	Youngs Modulus (10^6 psi)	Poisson's Ratio	Impact Abrasion Resistance	Expansion (10^7cm/cm°C) 0–300°C	Thermal Endurance Ratio	Conductivity
Soda Line:										See
008	General	Clear	T.F.	2.47	10	.24	1.2	92	1	Footnote
008			B.	2.49	10	.24	1.2	93	1	For Data
Lead:										
001*	Lamp, Electronic	Clear	T.F.	2.81	9	.21	—	92	1	
012*	Lamp, Electronic	Clear	T.	3.04	8.6	.22	06-08	89	1	
Borosilicate										
706	Kovar Sealing	Clear	T.	2.24	8	.22	3-4	48	2.2	
725	General	Clear	P.	2.26	9	.21	3-4	37	2.5	
772	Lead Borosilicate	Clear	T.	2.35	9	.20	3-4	34	—	
772	Lead Borosilicate	Clear	B.	2.33	9	.20	3-4	34	—	
776	Lamp	Clear	B.	2.23	9	—	3-4	33	2.5	
776	General	Clear	D.	2.23	9	—	3-4	33	2.5	
777*	Lead Borosilicate	Clear	T.	2.30	9	—	3-4	37	—	
Aluminosilicate	Alkali Free									
180	Molybdenum Sealing	Clear	T.	2.77	—	—	—	45	—	
Special:										
009	UV Transmission	Clear	T.	2.495	10	.24	1.2	92	1	
250	Encapsulation for Capacitors	Clear	Ft.	2.94	—	—	—	60	—	
310	Antimony Borate Sealing Glass	Dark	T.	3.10	—	—	—	150	—	
355	Automotive Signal	Amber	T.	2.57	—	—	—	92	—	
539	UV Transmission	Dk. Blue	T.F.	2.91	—	—	—	91	—	
980	General	Clear	T.	2.71	10	.20	—	92	—	
982	UV Transmission	Clear	T.F.	2.71	10	.20	—	92	—	

Column	Item	Comments
1 & 2	Glass Type, Description, Use	All forms not always available nor in all sizes
3 & 4	Color, Forms usually available	T = Tubing & cane. B = Blown. Ft = Frit or Powder. P = Pressed. F = Formed.
5	Density	
6	Young's Modulus	Data shown in table are estimates to show relative values. They are to be used for reference only.
7	Poisson's Ratio	Data shown in table are estimates to show relative value. They are to be used for reference only.
8	Impact Abrasion Resistance	Using soda lime plate glass as a base of unity, relative values for other glasses are shown.
9	Thermal Expansion	
10	Thermal Endurance	Using soda lime as a base of unity, relative values for other glasses are shown.
11	Thermal Conductivity	Most glasses are between .002 and .003 cal per sec x cm x C.
12	Viscosity	
13	Electrical Resistivity	

***CAUTION: FABRICATION OF LEAD-CONTAINING GLASSES**

On March 1, 1979, an OSHA standard regulation, "Occupational Exposure to Lead", went into effect. This rule, and appendices to it published in October of 1979 contain stringent requirements for compliance with very low exposure levels, specified air sampling, blood-analysis, and medical programs, respiratory protection, engineering and work practice controls, employee notification of exposures and employee education.

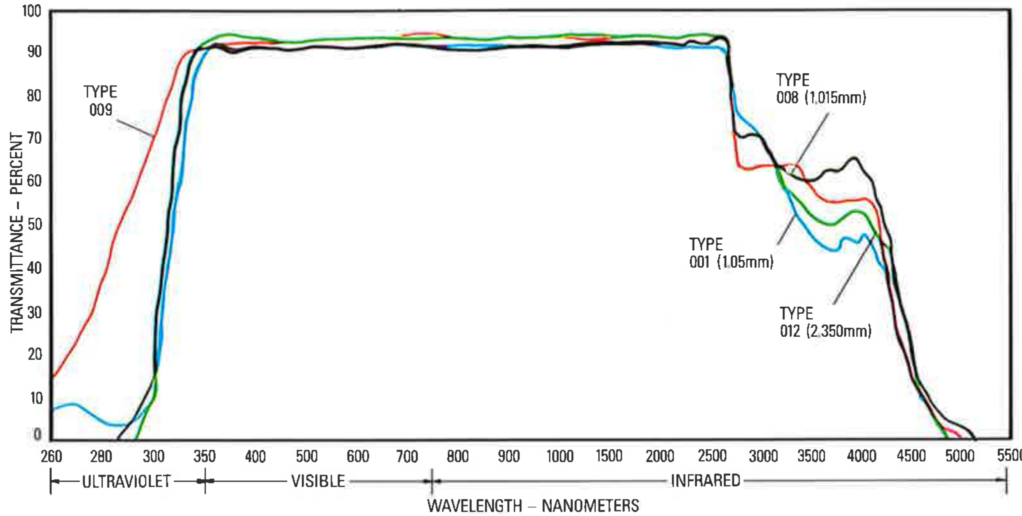
12			13			14	15	16	17	18	19	20	21
Viscosity			Electrical Properties						Optical Properties				
Strain Point °C	Anneal Point °C	Softening Point °C	Electrical Resistivity (Log_{10} ohm-cm) 250°C	300°C	350°C	Dielectric Constant At 1 MHz and 20°C	Loss Tangent At 1 MHz and 20°C	Loss Factor At 1 MHz and 20°C	Refractive Index n_d	Dispersion	Stress Optical Coefficient	Useful Transmittance Nanometers	Resistance To Weathering
472	515	700	6.3	5.8	5.3	7.2	.009	.065	1.512	.0089	2.4	290-4600	C
482	524	705	6.4	5.8	5.3	7.2	.009	.065	1.512	.0089	2.4	380-4600	C
385	430	630	8.7	7.6	6.7	6.7	.0015	.010	1.534	—	2.8	300-4700	B
390	435	630	9.9	8.8	7.8	6.7	.0014	.009	1.559	.0083	2.8	300-4600	B
440	485	705	9.9	8.8	8.0	—	—	—	1.480	—	3.7	300-2800	B
505	550	780	7.9	7.1	6.5	4.7	.003	.013	1.476	.0069	3.5	290-2700	A
487	529	760	8.6	7.8	7.1	4.7	.003	.013	1.484	.0076	2.9	340-2700	B
481	526	760	8.7	7.9	7.2	—	—	—	1.484	—	2.9	325-2700	
489	536	785	8.6	7.7	7.0	—	—	—	1.471	—		290-3500	
490	538	790	8.3	7.5	6.8	4.5	.002	.008	1.471	.0073		290-3500	B
485	530	765	8.6	7.8	7.1	—	—	—	1.480	.0074		300-2700	A
735	785	1015	12.9	11.9	11.1	—	—	—	1.536	—	2.4	280-4800	A
492	532	700	—	—	—	—	—	—	—	—		258-4600	—
510	545	680	12.3	11.4	10.6	—	—	—	1.568	.0093		—	—
		380	—	—	—	—	—	—	—	—		—	—
430	475	690	7.5	6.6	5.9	—	—	—	1.511	—		520-4600	—
395	435	625	8.9	7.8	6.9	—	—	—	—	—		See Note 19a	—
470	515	700	9.8	8.7	7.8	—	—	—	1.522	—			—
470	515	695	9.8	8.7	7.8	—	—	—	1.522	—		220-4400	—

Column	Item	Comments
14	Dielectric Constant	
15	Loss Tangent	This is sometimes expressed as a percent (.009 = 0.9%)
16	Loss Factor	This is sometimes expressed as a percent (.065 = 6.5%). Of the standard glasses, lead and borosilicate are the better insulators.
17	Refractive Index	Values at 589.3 nm.
18	Dispersion	Dispersion is shown at $n_f - n_c$.
19	Stress Optical Coefficients	
20	Useful Transmittance	Useful transmittance (exceeding 10%) range is shown in nanometers for 1 mm thickness. 22a. Type 539 has selective transmittance bands. Its useful transmittance is: 310-450 690-1100 1100-4600
21	Resistance To Weathering	A. Seldom affected by weathering. B. Could occasionally show weathering effects. C. Weathering can be a problem.

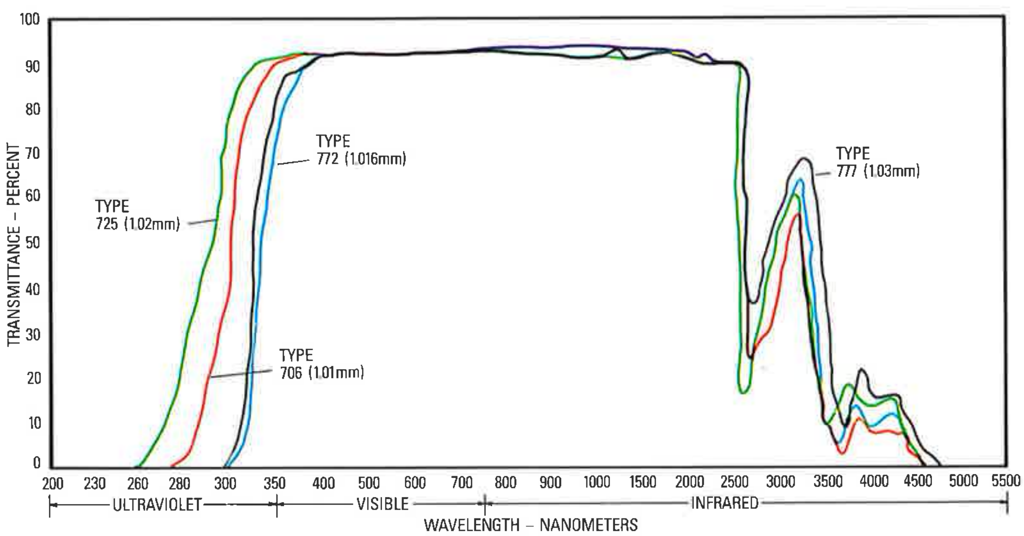
There is evidence that the heating of sufficient quantities of *any* lead glass to working temperatures (regardless of manufacturer) may result in the release of some lead fumes into the working environment in concentrations subject to one or more of the requirements briefly outlined above. You should avail yourself of the final rule and appendices available from your local OSHA office to determine if any of these requirements would be applicable to your process.

Glass thickness shown in parentheses on graphs.

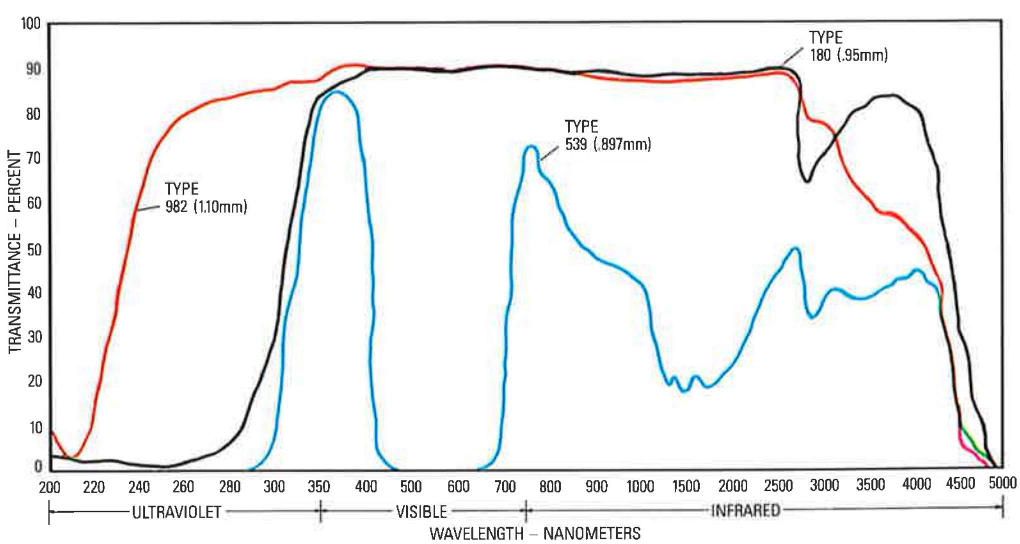
SODA LIME & LEAD



BOROSILICATES



ALUMINOSILICATES & SPECIALS



Glass is usually transparent whether it is clear or colored. The optical transmission and absorption characteristics of the material can be controlled to make glass serve special needs.

In general, the optical capabilities of a glass are defined in terms of the following properties:

Transmittance, the fraction of incident energy transmitted through a thickness of material.

Absorptance, the fraction of incident energy absorbed by the material.

Reflectance, the fraction reflected.

All three values are calculated from or measured on a spectrophotometer. In glass, if X is the total amount of energy directed (at any given wavelength) toward a glass sample, some is transmitted (T), some absorbed (A), some reflected (R). Thus the formula:

$$T + A + R = X$$

Transmittance is measured (and plotted) by the spectrometer by calculating the amount of energy lost due to the reflection at the glass surface (from Fresnel's Law) for glass in air.

At the sodium D line (589.3 nanometers) the reflectance as a function of the refractive index is shown in Table V below:

Table V—Reflectance

n	Loss by reflection at one surface
1.0	0 %
1.2	0.8
1.4	2.8
1.478 (725 glass)	3.7
1.5	4.0
1.513 (008 glass)	4.1
1.539 (001 glass)	4.5
1.560 (012 glass)	4.8
1.6	5.3
1.651	6.0

The third value, absorptance, accounts for the remainder of the incident energy.

Refractive Index

The index of refraction is the ratio of the velocity of light through a vacuum to the velocity of light through the material. The light used for glass is generally monochromatic light with a wavelength of 589.3 nanometers (the sodium D line). The greater the index, measured on an Abbe Refractometer, the slower the velocity of light.

Stress Optical Coefficients

The stress optical coefficient is a unique number associated with a particular glass. It is used to relate the birefringence per unit length to the stress present in the glass.

Electrical Properties

As with thermal properties, metals are electrical conductors while glasses are insulators. Because of exacting requirements, industry identifies glasses in terms of property specifications rather than by types of compositions. The electrical behavior of glass that makes it desirable for specific electrical applications can be described in terms of the following properties.

Resistivity

Volume resistivity is the resistance of a cube of material to the flow of current through its interior when placed between two electrodes which differ in DC potential. Volume resistivity is drastically affected by temperature. High volume resistivity is a desirable property of electrical glass.

Dielectric Constant

This is the ratio of the capacity of a condenser whose plates are separated by a specific dielectric to the capacity of the same system whose plates are separated by a vacuum. This property determines the energy storage in a polarized dielectric. ASTM D150 is the standard testing procedure.

Loss Tangent

Also called the dissipation factor, this represents the irrecoverable portion of the electrical energy through a material which shows up as heat. A low loss tangent is desired for glasses used in electrical applications. ASTM D150 is the standard testing procedure.

Loss Factor

This is the product of the loss tangent and dielectric constant. It is a measure of the actual loss in the insulator since the loss tangent is the fraction of energy lost during a cycle and the dielectric constant is proportional to the energy stored in the dielectric.

Thermal Properties

Thermal Expansion

Like most materials, glass expands as it is heated. The linear coefficient of thermal expansion defines the fractional change in length for a unit change in temperature. For general purposes and ease of recording data, the mean coefficient of expansion is usually given for glass over a temperature range of 0-300°C. Above 300°C glass expands more rapidly with increasing temperature and may have a coefficient two or three times larger than that measured below 300°C. Thermal expansion of glass is measured on a dilatometer or interferometer.

Thermal Endurance

Thermal endurance is the ability to undergo a change in temperature without breaking and is expressed as the temperature difference that can be endured. Also defined as resistance to thermal shock, thermal endurance is sometimes referred to as thermal stress resistance.

The ability of glass to withstand temperature changes depends upon the surface condition of the glass, the glass thickness, the thermal expansion, and the rate and amount of heating or cooling.

With this wide range of variables and possibilities, a test should be designed to duplicate the customer's requirements if this is of critical importance. However, some basic understanding of the mode of thermal endurance will be helpful to designers. There are several major points to be considered.

Although glass retains its mechanical strength to temperatures approaching its strain point, useful operating temperatures are more frequently determined by stresses set up by temperature differentials within the glass part itself.

If one surface of an unrestrained relatively thin glass part is maintained at a higher temperature than the other surface, the expansion of the heated surface will cause the part to bend slightly, allowing for some relaxation of the thermal stresses which would otherwise develop. If, however, the part is restrained so that it cannot bend (either by clamping or by the shape of the part) internal stresses develop which are compressive on the warmer side and tensile on the cooler side, and failure may result.

When the temperature of the glass part is changed rapidly, a tensile stress is developed on the cooler surface and a compensating compressive stress on the warmer surface. When a part is cooled rapidly (quenched), tensile stresses develop on the surfaces and the interior is under compression. On rapid heating, the outer surfaces will be in compression and the interior under tension.

The magnitude of the stress developed by a given thermal shock depends upon many factors, including: the thermal conductivity, thermal expansion, elasticity and thickness of the glass, and the thermal conductivity of the medium applying the thermal shock. High values of the glass thermal conductivity will increase the thermal endurance while high values of the other four factors will decrease this endurance.

Of the factors relating to the properties of the glass, the expansion can be varied over the widest range through composition change. Elasticity and thermal properties change only slightly. As a result, it is a general rule that the thermal endurance of a glass is inversely proportional to its coefficient of thermal expansion.

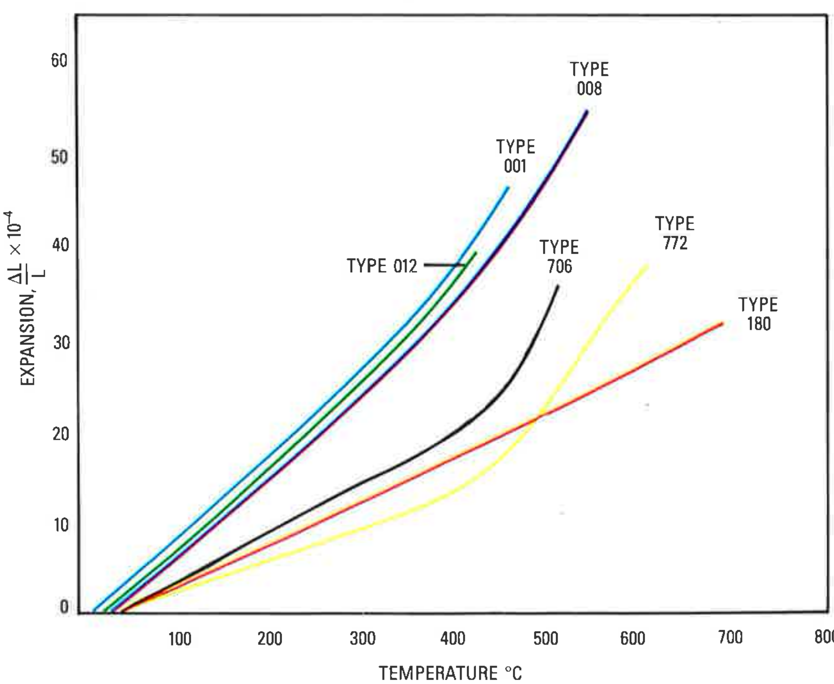
Thermal Conductivity

The thermal conductivity of a material is the measure of the transfer of heat through the material during a time interval. In general, most metals are heat conductors while glass is an insulator. Thermal conductivity is measured on a thermal conductometer.

Table VI

Material	Thermal Conductivity (cal per sec × cm × °C)
Copper	0.91
Lead	0.09
Molybdenum	0.35
Tungsten	0.38
Glass	0.002—.003

EXPANSION VS. TEMPERATURE



Manufacturing & Quality Control

To meet the needs of lamp makers and the other industries it serves, GE produces glass in three distinctly different forms.

Glass Tubing

One of these forms, glass tubing, is available in a range of diameters from .085″ to 3½″.

GE uses two different methods for tubing production.

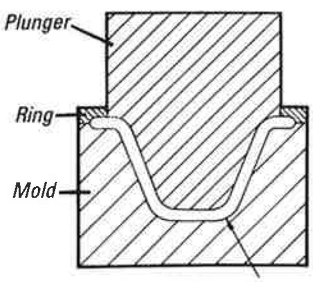
In the Danner process, a continuous stream of molten glass is flowed onto the surface of a downwardly sloping, rotating hollow mandrel. Centrifugal force creates a sleeve of molten glass, and air is blown through the center to form and expand the tubular shape.

The modified down draw (MDD) process consists of flowing molten glass through an annular orifice at the bottom of a bowl shaped chamber and blowing air through the interior of the mass to create the tubing.

In both processes, glass temperature, viscosity, drawing speed and air pressure are tightly controlled to produce a continuous length of tubing to precise diameters and wall thicknesses.

Pressed Glass

Machine pressing is an efficient mass production process that provides a net or near net shape, eliminating expensive grinding and polishing in many instances. It is also very economical because molds can be reused thousands of times.



The tendency of the glass to expand and contract at different rates is studied on the dilatometer in our materials characterization laboratory. Machined samples are placed in vacuum or atmosphere, and dimensional changes are recorded automatically as the temperature is increased to the material's softening point.

In this process, a gob of molten glass is removed from a furnace in a highly viscous consistency. It is placed in the mold, and a plunger is forced down to flow the molten glass into the shape of the cavity. After a few milliseconds, the exact time depending on the thickness of the part, the plunger is withdrawn. The glass is cooled until it can be removed and conveyed to a lehr for annealing. This process can accommodate glass parts weighing from less than an ounce to sixteen pounds.

Bulb Blanks

Lamp envelopes are made by the age old process of glass blowing. Today it is a highly automated operation referred to as the ribbon process. A stream of molten glass is poured from a furnace and channelled between two rolls to form a continuous ribbon. Indentations are made to form evenly spaced "biscuits" on one side of the ribbon as it advances on a conveyor. The molten glass sags through an orifice hole located below each biscuit. A blow tip is centered over the hole and pressed down on the globule, elongating it. Two-sided molds then come on line and close around the globule and the glass is blown into the mold. After cooling, the complete envelope is knocked off the ribbon and is ready for subsequent operations (frosting, staining, enameling). A ribbon machine can turn out many more than 1000 bulb blanks a minute. The machine is surprisingly flexible; a change to different shape molds can be made with less than one hour loss of production.

Soda lime glass is used as the envelope material for most incandescent lamps, particularly for the general service applications. Where higher wattages, smaller bulbs, or outdoor applications are involved, low expansion, heat-resistant glasses such as borosilicate are used.

Every step in the preparation of glass for sealing is controlled from this batch mixing panel, from receipt of the cullet and other constituents to delivery of the molten glass.

Technical Staff

Because of the complexity of these operations, GE maintains a full staff of technicians to develop and improve glass products, to keep operating equipment in peak running order, and to make certain that the quality of the product meets or exceeds our specifications.

Glass: Another Of GE's Specialized Engineering Materials

Lamp making is the common denominator for all the specialized materials and parts marketed through the GE Components Marketing & Sales Operation. Many of them are also playing key roles in other industries. These include semiconductor processing, EDM and tungsten carbide cutting tools, laser optics, electronic packaging and testing, vacuum metallizing and others.

In addition to glass, GE produces a number of specialized wire products, including tungsten and molybdenum lamp filaments, metallizing wire and coils; Dumet and Cumet copper clad wires; lead wires and lead wire assemblies. Lamp bases, tungsten carbide powder and formed and fabricated parts are also part of our metalworking capability.

To other markets, we supply Lucalox® ceramics, luminescent phosphors and inorganic chemicals.

Because of the special nature of many of these parts and materials, GE is always willing to assist in adapting them to your manufacturing operations, or to work with you in product development or application engineering.

If you want more information or wish to initiate an order for glass products, contact your regional GE Components sales office listed below, or the headquarters operation in Cleveland. Data sheets and specification information are available on all products covered in this publication.

Sales Offices

Domestic

Cleveland
21800 Tungsten Road
Cleveland, Ohio 44117
(216) 266-2451
FAX: (216) 266-3372

Mt. Arlington
111 Howard Blvd., Suite 107
Mt. Arlington, NJ 07856
(201) 770-3150
FAX: (201) 770-3103

Boston
P.O. Box 348
Westwood, MA 02909
(617) 762-6662
FAX: (617) 762-6622

International

Headquarters International Sales
21800 Tungsten Road
Cleveland, Ohio 44117
(216) 266-3295
FAX: (216) 266-3702
Telex: 256616

Japan
Soei Tsusho Company, Ltd.
27-4 Bakuro-machi
5 chome, Higashi-Ku
Osaka, Japan 541
Phone: 011-816-241-0900
FAX: 011-816-241-0571
Telex: J65156 (SOEICOJ)

Taiwan
Alexander & Associates
Room 819, No. 121
Chung King, South Road,
Section 1
Taipei, Taiwan R.O.C.
Phone: 011-886-2-381-2456
Telex: 20052 (LEXASSO)
FAX: 011-886-2-233-16034

EUROPE
G.E. Lighting
Components Marketing & Sales
Melton Road
Leicester LE4 7PD England
Tel: 0116 261 1754
Fax: 0116 261 1499

Korea
Won Ik Corporation
13th Fl., Seo Woo Bldg.
837-12, Yeok Sam-Dong,
Kang Nam-Ku, C.P.O. Box 7825
Seoul, Korea
Phone: 011-82-2-555-4939
FAX: 011-82-2-554-5324
Telex: K22836 (WICORP)

India
Moly Colloids Private, Ltd.
9 Gulistan
M.L. Dahanukar Marg.
Bombay 400026, India
Phone: 011-91-22-492-7434
Telex: 011-4254 (IGCCIN)

GE Components Marketing & Sales Operation

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