Report

Glass—Sand + Imagination

by Kenneth E. Kolb and Doris K. Kolb

Glass is older than recorded history, and yet it is as new as tomorrow! How, when, or where man first learned to make glass is not known, but we do know that the ancient Egyptians were making glass articles as early as 2,600 B.C.E. (The making of glass beads may have begun as much as 3000 years earlier.) They used it to make jewelry and luxury items, such as decorative bowls and perfume bottles, available only to the wealthy.

Today, everyone uses glass. It is the stuff used to make jars, bottles, windows, light bulbs, and any number of other everyday objects. But it is also the material used to make television tubes, computer monitors, telescope lenses, spectrometer prisms, and all kinds of laboratory ware, as well as the optical fibers that are revolutionizing modern communication. Glass has even become a popular medium for artists, on a scale that is unprecedented.

Glass is really a physical state rather than a particular composition. It is a rigid material with the extrinsic properties of a solid but with a less ordered structure, more similar to that found in a liquid. When a liquid cools and hardens without forming crystals, it becomes a glass. For example, when sugar is melted with other ingredients and then allowed to cool, it solidifies as glassy "hard candies". Many different substances can form glasses, but what most people have in mind when they talk about glass is the stuff used to make windows and bottles, the common glassy material that is made from sand.

Natural glass was being used to make knives and arrowheads as long ago as 75,000 years B.C.E., long before man learned how to make glass. There are four different kinds of natural glass:

> **Obsidian** is a dark-colored volcanic glass, mostly granite that melted during volcanic activity and then failed to recrystallize on cooling.
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> **Pumice** is another glassy material found around volcanoes. It is a solid foam formed from hot lava, and it is so full of gas bubbles that it floats on water. In powder form, it is an abrasive used for scouring, scrubbing, and polishing. Lumps are used as "pumice stone".
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> **Fulgerites** are thin glassy tubes sometimes found along beaches or on the surface of sand dunes. They are formed when sand is hit by lightning.
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> **Tektites** are more difficult to explain. They are small glassy beads found in many different places around the world, but especially in the Pacific area from Japan to Australia. Their unusual composition suggests that their origin might have involved some kind of extraterrestrial impact.

Glass composition can vary widely. There are hundreds of different glasses produced commercially, but most of them belong to one of four major classes.

Photo by National Liberty Museum

Figure 1. "The Flame of Liberty", a 20-foot tall pillar of crimson glass tendrils created by world-renowned artist Dale Chihuly spans two floors of the National Liberty Museum to serve as a stunning reminder of the universal quest for freedom. "Glass is the perfect imagery for liberty," says Museum President Carole Haas Gravagno. "It reminds us that our freedom is precious and that it will shatter if we don't protect it." The National Liberty Museum in Philadelphia is the first gallery in the world to correlate freedom with glass for the purpose of protecting our society from violence. Its many glass sculptures serve to represent the fragile nature of liberty.

Classes of Glass

Soda-Lime Glass

Soda-lime glass is the most widely used glass in the world. It was the glass that the ancient Egyptians and Romans used, but it also accounts for more than 90% of all modern glass. It is inexpensive, comparatively easy to melt and fabricate, and suitable for many uses. It is made by melting together a mixture of about 66% sand (SiO_2, silica), about 15% soda (Na_2O or Na_2CO_3), and about 10% lime (CaO or $CaCO_3$), plus a few percent of other oxides. The proportions have changed remarkably little over the last 4,000 years. This is the familiar glass used to make windows, bottles, jars, and light bulbs. It is chemically inert enough for most ordinary purposes, but it has only limited resistance to thermal shock. Sudden wide changes in temperature will cause it to crack.

Lead Glass

Lead glass, made by replacing the lime and soda in ordinary glass with litharge (PbO), is more expensive than common glass, but it is easier to melt and to work, and it has some unique physical properties. It has a very high refractive index—giving it clarity and sparkle—and it is softer than other glass, so that it is easier to cut, engrave, and polish. Lead glass is used to make fine crystal and cut-glass objects as well as glittering pieces of art glass. Lead glass also has excellent electrical resistance, so it finds use in electrical devices (e.g., the cylinder at the end of the TV tube where the electronics are mounted).

Heat-Resistant Glass

Heat-resistant glass can be made by using boron oxide to replace the lime and most of the soda. This *borosilicate* glass has such a low coefficient of thermal expansion that it can be used to make oven bakeware. It is also used to make most laboratory glassware. Replacing the lime with aluminum oxide (alumina) instead of boron oxide produces an *aluminosilicate* glass that has even greater heat resistance, such that the glass can be used to make glass pans for top-of-the-stove use. However, the glass is also harder to melt and to work. Borosilicate and aluminosilicate glasses are not only resistant to thermal shock, but they also have unusual chemical resistance, and both have exceptional durability. They are sold under such tradenames as Pyrex and Kimax.

High-Purity Silica

High-purity silica is the highest quality and most durable of all glasses. There are three different processes used to make it: melting pure quartz, making 96% silica, and using flame hydrolysis to produce fused silica.

Quartz is crystalline SiO_2. **Fused quartz** is made by melting pure quartz crystals at about 1900 °C under vacuum. (The vacuum is needed to remove bubbles from the extremely viscous melt.) Objects made from fused quartz tend to be simple in shape and rather expensive.

Glass sold under the Vycor trademark is **96% silica**. It is made by heating articles made from a special borosilicate glass in order to grow channels of crystalline sodium borate, which are then leached out by treatment with hot nitric acid. The remaining porous glass items are shrunk (about 14%) by heating to 1200 °C. The products are only 96% silica, but their properties closely resemble those of fused quartz, and borosilicate glass is much easier to form into useful shapes.

Fused silica is made by flame hydrolysis of silicon tetrachloride ($SiCl_4$). Very pure $SiCl_4$ is fed into a methane–oxygen flame (above 1500 °C) to produce an extremely pure, high-surface silica "soot", which thermally sinters into pure silica glass (without having to be heated to 1723 °C, the melting point of SiO_2).

Special Glasses

Special glasses are made by adding various ingredients to the glass melt or sometimes by simply treating the glass surface.

Colored glass is usually obtained by adding a transition metal oxide. For example, manganese dioxide gives glass a violet color; cobalt oxide makes it blue; and chromium oxide makes it green. The type of glass can affect the color (nickel oxide makes soda-lime glass yellow, but it makes potash-lime glass purple). The charge on the metal ion can be important, too. Iron(II) oxide gives a blue-green color and iron(III) oxide a brown-yellow color. The kind of heat treatment can also make a big difference.

Opal glass, sometimes called "milk glass", is transparent when molten. Upon cooling, added solids (usually CaF_2 or NaF) separate from the melt and make the glass cloudy. "Alabaster" glass (often made by adding NaCl) is similar to opal but is more opaque.

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Figure 2. Glass artist Greg Fidler reheats a molten glass sample in the “glory hole” of a glass furnace.

Figure 3. John Miller, a glass artist at the University of Illinois at Urbana-Champaign, is shown blowing into a blowpipe, at the other end of which is a gob of hot glass being formed into a bubble.

Photos by Doris K. Kolb

Phototropic glass darkens on exposure to light but then turns colorless again when the light dims. It is used in some sunglasses and contains AgCl or AgBr, which will precipitate silver atoms when exposed to light.

Frosted glass is obtained when glass is exposed to hydrofluoric acid (HF), etching the glass and giving it a satiny look. Sandblasting has a similar effect, but it tends to give a rougher finish.

Methods of Forming Glass

Glass-forming is a difficult operation, involving an intensely hot, sticky, and corrosive material. Basic glass-shaping processes that have been used for centuries are listed.

- **Casting:** pouring hot, melted glass into a mold
- **Pressing:** pouring molten glass into a mold and then pressing a second mold on top of it
- **Core-forming:** dipping a clay core into molten glass, letting it cool, and then scraping out the core; this gives the glass its shape
- **Fusing:** softening glass rods by heating and then fusing them together around a mold
- **Blowing:** picking up a gob of molten glass on the end of a long hollow pipe and then blowing gently into the other end to form a hot glass bubble

Whereas the methods of casting, pressing, core-forming, and fusing had already been in use for several thousand years, the blowing process was not discovered until about the first century B.C.E. It marked an important milestone in glass-forming technique because blowing made it possible to form symmetrical objects with thin walls. Glassworkers were now able to make much larger glass objects and to work at a much faster pace than had been possible earlier.

A few special industrial glass-forming procedures are worth mentioning.

The **ribbon machine** (developed in the 1920s at Corning Glass) is an automatic glass-blowing machine for making light bulbs. Puffs of air blow glass bubbles from a moving ribbon of hot glass into molds, producing glass globes for light bulbs at an amazing rate of speed. Small light bulb blanks can be made at the phenomenal rate of 2,000 per minute (faster than a machine gun)!

The **centrifugal casting** process (developed during the 1950s at Corning Glass) is used to make television tubes. A gob of hot glass is dropped into a funnel-shaped mold, which spins around, causing the molten glass to climb up the inside walls of the mold. A pressed glass faceplate is later sealed onto the open end of the glass funnel. Centrifugal casting on a much larger scale is used to make telescope mirrors (at the University of Arizona and at Schott Glass). In this case, tons of hot glass on a giant, heated mold is spun around so that the molten glass is forced to move toward the outer edges of the mold.

The **float process** (developed in 1959 at the Pilkington Company in Great Britain) is based on the fact that there is no surface smoother than that of a quiet liquid. The float process makes high-quality flat glass (for windows and mirrors) by casting molten glass onto a pool of stabilized molten tin. The liquid tin provides a smooth underside, and the liquid glass gives a smooth top surface, so that the plate glass produced needs no further grinding or polishing.

Fiber Optics

The most important new development in the field of commercial glass is surely the manufacture of *optical wave guides* or *fiber optics*. Made from ultra-pure glass fibers, as fine as human hair, they can carry telephone messages much more efficiently than the copper wires previously used. The fibers have an inner core of pure fused silica (made by flame hydrolysis), are clad with a modified outer layer to act as a light-refraction barrier, and are coated with plastic to give the fibers exceptional strength. With these fibers, using lasers, sound waves are converted to electrical impulses and trans-

The British Museum has granted permission to use the image of the Portland Vase in the printed publication only.

Photo by The British Museum

Figure 4. “The Portland Vase”, a Roman cameo vase from about 70 C.E. This is perhaps the most valuable piece of glass in the world. (Copyright © The British Museum)

Photo by National Liberty Museum

Figure 5. “Golden Egg of Opportunity”, a flawless solid glass sculpture carved from a block of the purest glass by artist Christopher Ries. It is on display at the National Liberty Museum in Philadelphia, PA, which characterizes it as a symbol of the golden opportunities that can be achieved in a democracy.

mitted as light signals. A 1/4-inch bundle of glass fibers can carry as many messages as a 4-inch bundle of copper wires. The glass fibers are also unaffected by temperature changes, dampness, vibrations, or electrical fields. Last year alone over 40 million miles of optical fibers were produced in the United States.

Art Glass

Another noteworthy development in the field of glass production is the burgeoning interest in art glass. Ever since man first learned to make glass, perhaps 5,000 or more years ago, there has been glass art. In fact, most of the early glass artifacts from ancient civilizations belong in that category. Glassmaking reached a zenith during the Roman empire, when many outstanding pieces of glass art were created. It was probably around 70 C.E. when the famous Portland Vase was made. This exquisite amphora of cameo glass is probably the most valuable single piece of glass in the world. Owned by the British Museum, it is on display in spite of the fact that it was once smashed into pieces and then put back together and carefully repaired (three different times).

Over the centuries there have been many skillful glass artists from Egypt, Syria, Greece, Italy, Germany, France, and other places. We can admire their work, but we often cannot identify the artists. During the 20th century, a number of names became famous because of their connection with art glass. Some of these (Tiffany, Lalique, etc.) were names of individual artists, but many (Steuben, Waterford, Orrefors, Baccarat, Murano, etc.) were names of glass factories where art glass was created by various, often unnamed, artists. Up until the latter part of the 20th century, most glass artists had to be associated with a glass-making factory because that was where the furnaces were. But today there are many glass artists who maintain their own hot-glass studios. Never before have there ever been so many private glass studios or so many hot-glass artists.

Much of the credit for this phenomenal popularity of art glass is due to Harvey Littleton and Dominick Labino, who, in 1962, developed a small glass furnace suitable for use in a private studio. Together they presented the first hot-glass workshop at the Toledo Museum of Art. It was also in 1962, at the University of Wisconsin–Madison, that Harvey Littleton taught the first college course in glassworking ever to be offered. (Harvey’s father, Jesse Littleton, had been a director of research at Corning Glass and was a pioneer in the production of glass cooking ware.)

For many centuries, the practice of glassworking had been a highly restrictive trade to which one had to become apprenticed. Not only were there no glassworking schools, but the techniques of the trade were often zealously guarded secrets. The recent open availability of courses in handling hot glass represents a complete break with tradition and a new freedom in the world of glassmaking.

During the decades of the 1970s and 1980s, many other college-level glass studio courses began appearing, thanks mainly to Littleton’s former students. Special mention might be made of the Pilchuck Glass School, near Seattle, Washington, founded in 1971 by Littleton’s student Dale Chihuly. It has since become a mecca for glass artists and students all over the world.

Glass schools and private hot-glass studios can now be found all over the United States, as well as in other countries. Many courses are being offered in areas such as glassblowing, flameworking, and hot-glass sculpting. Perhaps we are entering a new golden age of glass art!

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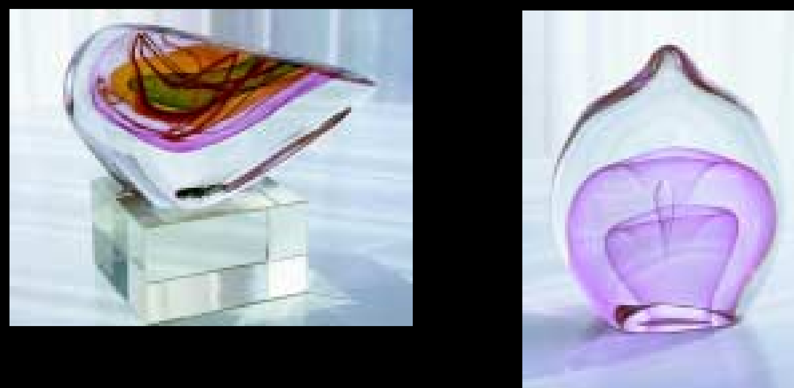

Figure 6. Two samples of glass art from pioneers in the modern hot-glass movement—"Curvilinear Form" by Harvey Littleton (left) and "Emergence Series" by Dominick Labino (right). (Collection of Dr. and Mrs. George Kottemann.)

Photos by Duane R. Zehr

Figure 7. Examples of contemporary art glass. "K/S Construction" by Bill Carlson (left) and "Fresh Chaos" by Toots Zynsky (right). (Collection of Dr. and Mrs. George Kottemann.)

Further Reading

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Editor's Note: This article uses the notation C.E. and B.C.E. ("of the common era" and "before the common era"). These designations are equivalent to A.D. and B.C.