Leaded Glass

The tools, materials and techniques of this craft haven't changed much in 500 years

by Doug Hechter

It wasn't easy to find a large sheet of glass in the Middle Ages, but you could get small, bubble-filled glass discs called crowns. To make them, a glassmaker would gather a blob of molten glass on the end of a blowpipe, and spin it until it formed a circular plate, sometimes as big as 5 ft. in diameter. The resulting glass might be colored or clear, but it was always very expensive.

Once it hardened, the glass was ready to be cut into pieces and assembled by artisans into windows. These craftsmen used lead channels called cames to tie the pieces of glass together into a large panel.

Making windows this way was an expensive, time-consuming process, and the Church was just about the only customer who could afford them. Church windows often depicted Biblical events, thereby teaching the illiterate as well as letting in the light.

The beginning of the 15th century brought change. Church windows were becoming wider and taller, and a burgeoning middle class wanted more comfortable, better lit houses. Simple rectilinear windows, using square and diamond-shaped panes linked by lead cames, were made to satisfy both markets. These are called quarry windows (after the individual panes of glass, which are called quarrels), and building one is the topic of this article. Quarry windows remained the standard glazing for centuries, and there is a revived interest in them today. I think it's a reaction to the textureless modern goods that we see everywhere. The individual panes in a leaded-glass window are almost in the same plane, but not quite. The tiny differences in angle between them fracture the reflected light. This random quality is the human touch, a valued commodity in the late 20th century.

Designing the window—A good leaded window is a window first, and an object of art second. A sound window must withstand a reasonable wind load, as well as the sometimes grueling fluctuations of temperature and movement within the building. To achieve this, steel-reinforcement braces are soldered to the inside of the lead frame. Without them the window would eventually sag and fall apart. A well-designed leaded window has lead lines wide enough to hide the braces.

When a building is designed, the architect gives considerable thought to its proportions, its visual mass and the textures and values of the materials. The leaded-glass maker should tune in to these choices. A successful window design reflects the scale of the structure, and if it has colored glass, it should have light and dark areas, just as the building's mass presents highlights and shadows. Like the glazing bars in French doors, the lead lines afford some patterned continuity in the plane of the wall. The larger the window is, the heavier the lines should be.

Strong outdoor light tends to minimize the lead lines once the window is in place. It's especially noticeable in skylights. Colors that might look strong and expressive on the workbench can easily become anemic and indistinct under the glare of natural light.

The cartoon—The cartoon is where construction begins. It is a plan containing all the information pertinent to the building of the window, such as the lead widths, decorative details, the panel size and the client's name. It stays with the window throughout assembly. The cartoon for the window you see on these pages is on 70-weight kraft paper (photo facing page), but any heavyweight paper that will take pencil lines can be used.

I begin a cartoon by marking it with the lines that define the full size of the panel. I get these dimensions by measuring the window opening from the inside of the rabbets, and subtracting ⅛ in. I note them on the cartoon next to the client's name, width first. This is when the window opening has to be checked for square, and any deviations noted.

After the full-size perimeter lines are drawn, I decide how wide the border lead should be. This is a function of how deep the rabbet is at the sash. I like about ¼ in. of lead line around the window, so I add that to the depth of the rabbet for the width of the border lead. For instance, if the rabbet is ⅜ in. deep, the border lead should be ⅝ in. wide. The dimension of the window from the inside edges of the border leads is called the daylight panel size.

Once I've marked the inside edge of the border lead on the cartoon, I draw in the positions of any other lead lines. These are all done at full size, and they are followed by more lines that mark the center, or heart, of the leads.

Patterns—Next, I sandwich a large piece of carbon paper between the cartoon and another piece of kraft paper. Tacks or tape hold both sheets securely to the table. I use a ballpoint pen to transfer the lead centerlines to the lower sheet. These become cutlines for glass patterns. During the copying, I occasionally lift a corner of the cartoon to see if I missed any passages. Each shape represents a separate piece of glass, and each one is designated by location with a letter, as shown in the drawing at right. In a more complicated window, I designate the shapes with numbers. If there are colors in the window, they are also noted on the patterns.

I cut the lower sheet into a pile of patterns with a special pair of shears. Unlike a normal pair of scissors, this tool has two blades opposed by a third in the middle. The pattern shears remove a small fillet of paper as they cut, which compensates for the heart of the lead. There are different shears for different sizes of lead. The cut should be made with the portion of the blade closest to the rivet. The shears should be slid into the cut and only closed completely at the end of a line. Closing them in the middle of a cut will cause a nick that may snag the glass cutter later. The patterns have to be cut accurately, because they will reproduce exactly on the glass. Slight flat spots along a curve can be corrected, but in general the cut should split the carbon line. When the cutting is done, sort the patterns into piles by color and shape.

Cutting glass—Glass can be cut into simple or complex shapes by scoring one side and then applying concentrated pressure opposite the score marks. Glaziers use two types of tools to score glass for a cut: the diamond-tipped cutter and the steel wheel. The steel wheel is the more accessible tool and it's the one I used on this window. Steel wheels are inexpensive, and if they are cared for, they can handle the most complex of cuts. If the wheel is nicked, however, it will make a discontinuous score mark, which will make the break in the glass run wild.

The steel-wheel cutter should be stored in a container with some tissue at the bottom. This tissue should be soaked with a lubricant—mineral spirits, kerosene or any light machine oil. The lubricant is necessary for a successful cut. The oil not only helps the wheel spin freely during the cut, but also seems to affect how long the score mark remains open and breakable. A score is likely to heal over if the glass isn't broken within about 30 seconds.

When I make a cut against a straightedge, I first paint oil along the path of the cutter. This makes for a very clean break. Sometimes cranky old salvaged glass or the more brittle antiques and opals (see the sidebar at right) need this extra help.

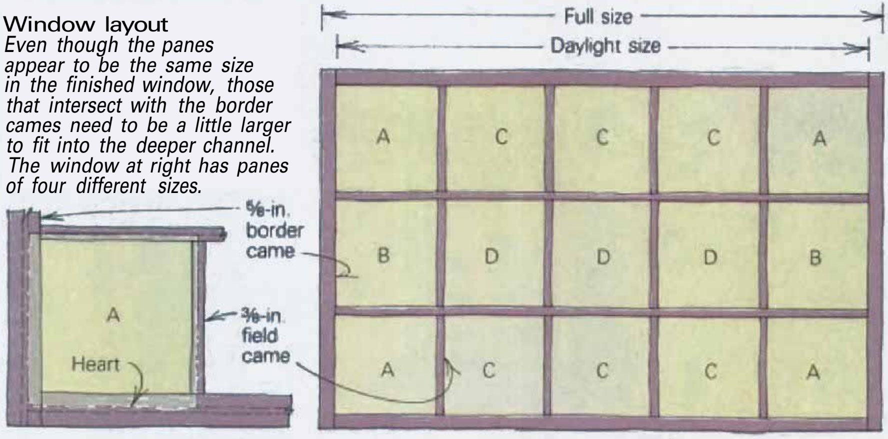
The steel wheel feels quite awkward at first. Most beginners either push too hard or are indecisive. The score should be made on the smoother side of the glass. Hold the cutter plumb. The cut should be heard but not easily seen. If the cut is a fuzzy, sputtering line, too much pressure has been applied. Speed is not important but evenness is, so don't stop in mid-cut. You can let the wheel roll off the edge of the sheet to complete the cut without worrying about breaking the glass.

To make the break, hold the glass with a thumb on each side of the score at one end, and your index fingers bent and touching

The Cartoon is a full-size drawing of the window with all the information pertinent to its construction. For this window, the border cames will be ⅝ in. wide, and the field cames ⅜ in. The lead lines are transferred, via carbon paper, to the bottom sheet. The shapes inside these lines represent the glass, and they are labeled, cut out and used as patterns.

Window layout

Even though the panes appear to be the same size in the finished window, those that intersect with the border cames need to be a little larger to fit into the deeper channel. The window at right has panes of four different sizes.



Art glass

Three basic kinds of colored glass are used most often in leaded windows. Antique glass is hand-blown in the form of a cigar-shaped bubble, which is then split and flattened in a kiln. It was dubbed antique by the 19th-century Gothic revivalists who are credited with developing the technique. Antique glass is watery, full of bubbles and surface imperfections, and it comes in more colors than any other kind of art glass. This is important in an art form where the pallet cannot be mixed. Blenko Glass in West Virginia makes this country's only antique glass. It is blown into wood molds, producing square bubbles with the imprint of charred logs on its surface. These small sheets, roughly 20 ill. by 30 in., are usually easy to cut but they run very thick in places. They are available in a wide range of good colors from stained-glass supply houses.

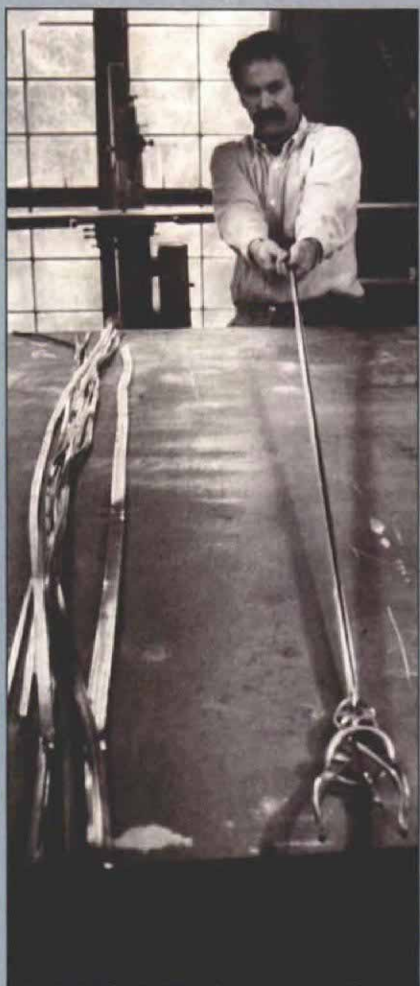
Most antique glass is made in Europe. The English make small sheets of antique with many good medium and dark colors. They also cut well. French antique has a lot of internal tension and it can be brittle and unpredictable, but it comes in colors that are unavailable anywhere else, and the sheets are larger than most. German glass also comes in many good colors, and most of it is even-tempered. But some cuts erratically. As in most other types of glass, antique reds, pinks, yellows and oranges are more brittle than the other colors.

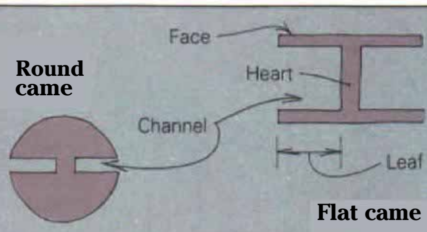
Flash glass is a type of antique with a clear or tinted base and a thin veneer of stronger color. It has to be cut on the side opposite the veneer. Most antique reds are flashed. Some machine-made glass goes by the title of semi-antique. It has some surface character but is generally flat and consistent in color. The best antiques will usually have uneven shading.

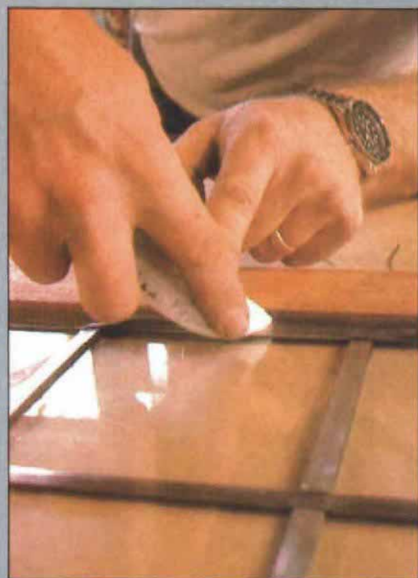
Opalescent glass was developed in America toward the end of the 19th century. The studios of Tiffany and La Farge used this variety widely, sprinkling their complex landscapes and plant motifs with the crucible-bred swirls, mottles, variegations and textures characteristic of this glass. Good opalescent glass is made in limited lots by small factories scattered around the U.S. At its best, it is lively and spontaneous. At its worst, it looks like colored plywood.

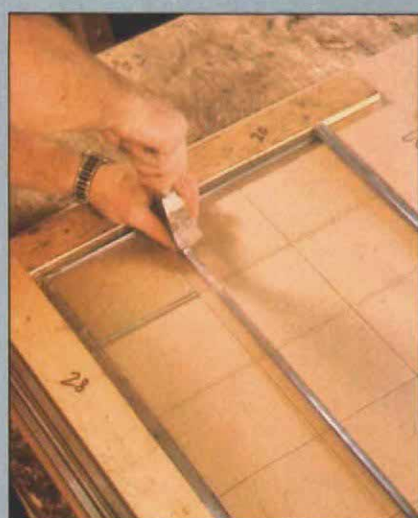
Cathedral glass, a machine-rolled commercial product, has a limited range of colors, a gravelly texture and a consistent thickness. It is inexpensive and boring. *—D. H.*

Illustrations: Frances Ashforth









Working with cames. **Pure lead has to be straightened by stretching before it can be used in windows. Hechter uses a bench-mounted ring and a pair of pliers to secure one end, above, while he pulls the other. The tapered tip of the lathkin, above right, is used to open and close the came leaves. Here it presses a leaf flat against the glass in preparation for soldering. Hechter uses a sharpened putty knife, right, to cut the cames to length. Here, the cartoon has been secured to the bench with wooden stops, and the first two border leads are in place. Although the panes appear to be the same dimension, there are actually four different sizes in this panel.**

each other at both knuckles beneath the glass. As the thumbs press down, the index fingers become a fulcrum, and the glass will break along the weakened score line. On a stubborn piece or a tight curve, you can tap the score from beneath to start a crack. Use either the handle of the cutter or the grozing teeth found on the back side of the cutting end. This crack can then be chased along the whole cut, or used only to encourage a break. Breaking pliers can also be used to assist a stubborn cut. They have jaws up to 1 in. wide that meet only at the end of the tool. They are used to provide more leverage. But a tool-assisted break is never as clean as one done by hand.

Grozing is the term for nibbling away at a piece of glass. A notch on the cutter handle slips over the edge of the glass, and when the handle is levered upward, a bit of glass breaks off. This is how glass was shaped during the Middle Ages. Most grozing is done with a pair of grozing pliers. This blunt-nosed, untempered, parallel-jawed tool can be very useful at the cutting bench. It has jaws that meet only at the business end, and it is used as the name implies—when a cut can't be completed by hand. There is no inside curve that cannot be shaped by patient grozing, and I have won beer proving this.

To cut glass with the pattern, hold the pattern against the glass with one hand, and follow the edge of the paper with the cutter wheel. This method works for both curved and straight-sided shapes. If I'm going to make repetitive 90° cuts, such as the ones for the glass in this window, I set up a jig using a T-square and a stop, and I occasionally check the cuts against the pattern.

Working with cames—I'm often asked how I pour the lead between the panes. The lead is not, and never was, poured around the glass. It starts out cold as H-shaped strips called cames. They are about 6 ft. long, bend easily by hand, and can be cut with a knife. Cames may be less than ⅛ in. wide, or exceed 1 in. in width. The faces are usually round or flat (drawing, above left). Flat lead has a flexible leaf that closes down snug against the glass. The round style is usually heavier in section, with a stiff leaf not intended to be closed down. Round lead looks more delicate than flat lead, and it can be bent into tight, intricate curves. Most Victorian work uses round came.

Not all brands of came are pure lead. Antimony and other metals are being used more and more. These mixes are economical, and are not as prone to tarnish as pure lead. Many craftsmen prefer this new product because it solders so well, but its drawbacks make me hesitant to use it. It is harder and more brittle than pure lead, which makes it more difficult to cut and shortens its lifespan.

Lead cames must be stretched before they're used (photo far left). This hardens the lead, so I'm careful to pull just enough to straighten the came. Over-stretching also gives the surface a scaly texture. Alloy leads usually don't need stretching.

I used flat lead in this window, and the channels had to be opened with a lathkin. It looks like a fat knife blade (photo top center), and 1 use it constantly. Mine is 2 in. by 6 in. by ⅜ in. thick, and it's made of Teflon. Traditional lathkins are made of waxed hardwood.

Once the came is prepared for glazing, it should be set carefully aside. Its pliability causes it to kink readily, and if it's bent more than once through careless handling, it will lose its crisp look in the finished window.

In addition to the lathkin, I use a small hammer, a lead knife, a stopping knife and horseshoe nails. The lead knife I use is a hand-forged, high-carbon steel putty knife made in England under the brand name of Footprint. I have shortened the blade a bit and honed a sharp edge onto it. Many window makers use the German-style lead knife. It has a rounded cutting edge that ends in a hook. Its point is also useful for lifting the leads and poking around in tight places. I make a cut by setting the knife on the face of the lead, applying light pressure and rocking the knife back and forth (photo bottom left). After the blade penetrates the top leaves, the lead can be quickly chopped without crushing it. If many leads of a single length are needed, you can use a bandsaw or a radial-arm saw. Still, my everyday cutting is done by hand. The tools used in glazing have worked well for centuries, and there's little room for improvement.

Partner to my lead knife is my stopping

knife. Made from a wood-handled oyster knife, it is used for probing tight corners, lifting came leaves and prying. I cast a lead plug into its handle for tacking nails or tapping glass into place.

Glazing—This is the term used for the assembly of glass and lead into a window panel, and it takes place on a sturdy, flat workspace. The top of my glazing bench is a series of tightly fitting 2x planks, and it's 36 in. high. The cartoon is placed at one end, with ½-in. by 2-in. stops nailed along the bottom and the left-side lines (photo right). Check the stops with a framing square. If they're too long for the square, use the 3-4-5 method. After cutting and placing the border leads, I insert the first glass into the channels. The open edges of the glass should align precisely with the inside edge of the penline that transferred the design to the pattern. These lines will be the references throughout the glazing stage. If the glass is allowed to deviate from this line, the result will be distortions that will multiply as the panel progresses.

Flat came is tucked wherever it intersects. The flexible leaf is gently pried up to accept the intersecting lead. The hump that results is then carefully hammered flat. This tucking strengthens the window and enables the glazier to adjust the leadwork without recutting any of it. The tucked end should not extend all the way to the heart but should be held back slightly to prevent the panel from glazing full (expanding beyond the reference lines).

I tack horseshoe nails into the bench alongside each piece of glass as it goes into place. They pin the loose pieces against the stops until the cames are soldered, which happens when the entire panel is in place. As the window grows, I pull them up and stick them around the working perimeter.

Round-faced lead can not be tucked. It is always butted or mitered, and for it to be done right, the cuts have to be straight. If any undercutting occurs, what looks tight on one side will have gaps on the other.

Working from left to right, the quarry pattern is glazed one course at a time with one long lead capping each course. These leads can be kept straight by placing a stop alongside and tapping it with a hammer.

***Glazing.* A window builds from left to right, with a long lead came capping each course. The short leads are tucked under the leaves of the intersecting cames, strengthening the panel. At the top of each course, the leads are adjusted with a few taps from a hammer against a stop. Note how the leads and the panes align with the cartoon.**

Occasionally, handmade glass runs too thick to fit into the channel. Many people avoid using it for precisely this reason. Seen from the outside, leaded glass has a certain faceted quality, and glass of random thickness contributes to this effect. Thicker glass also bends the light as it passes through the window, casting wavy patterns of sunlight around the room. Much new leaded glass is flat and inanimate because the craftsman holds flawless lead as the highest priority, using only glass that cuts and fits easily.

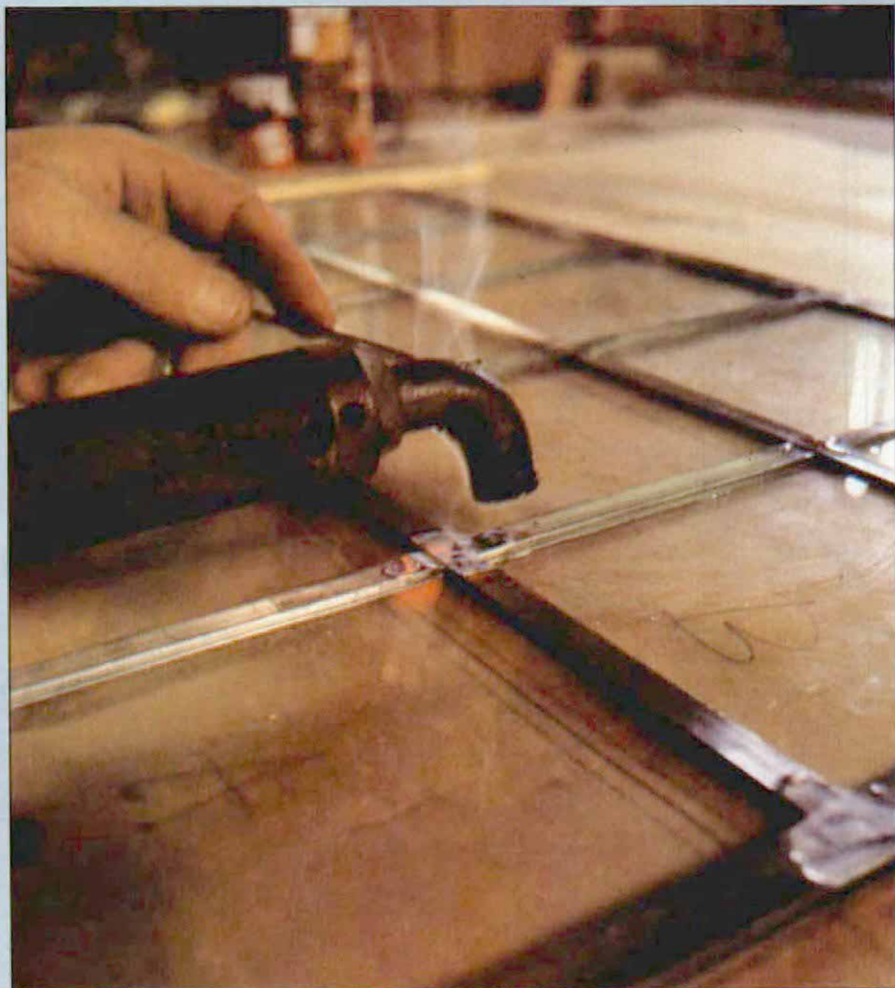
To modify the channel to accommodate thick glass, I sever the leaf from the heart with a pair of front-cutting nippers, the type that carpenters use for clipping nails. The leaf should be cut only on the side where the glass is uneven, leaving the other half intact. If necessary, I make several cuts ⅛ in. apart. This segmented leaf yields to the glass. It is then pressed flat against the glass and reconnected with solder. The soldering iron should be on the cool side. A scar remains, but the overall product is improved.

One further note on glazing: a neat, uncluttered bench shows up in the finished product. It is better to have unbroken leads wherever possible, for this reason. Leads partially woven into the unfinished panel will trail out onto the bench. They scratch easily, so don't let them mingle with tools, and can your lead scraps frequently.

Placing the last two border leads along the upper and right-hand edges completes the panel. Nail two more wooden stops to the bench, recheck your full-size dimensions and adjust the border leads accordingly. With the flat came there is a bit of give and take, and I slide the tucked leads in and out to adjust the size of the panel.

Once all of the joints have been hammered flat, the leads can be pressed down against the glass with the lathkin. The tool rides over the heart of the cames, and you have to be careful not to stress the glass. Individual leads can be straightened or aligned by placing the tip of the lead knife on the came at about a 45° angle, and then tapping its handle with a hammer.

Leads down and aligned, I affix a small pa-



Soldering. A special tip solders the cames, but before it can be used it must be heated, filed and tinned. Hechter's tinning tray is an old coffee can, above, and it contains a small amount of solder and powdered rosin or flux. The hot soldering tip is held slightly above the joint and a piece of wire solder placed between the two. The three are brought together for a few seconds, and the heat transferred through the solder to the came. When the solder melts, the tip is lifted and the finished joint looks like the one at right.

Finishing. Pigmented cement is forced into the cracks on the weather side of the window using a stiff bristle brush, left. In addition to sealing the window, the pigment tones down the brightness of the fresh lead. Excess cement is removed with brushes, rags and sawdust. Steel braces keep a leaded window from sagging or giving in to the wind. They are soldered to the interior side of the window. The ends of the braces are pounded flat into 'paddles' and soldered to the came with a chisel-tipped iron, above.

per label to the glass in the upper right-hand corner. This identifies the panel, and marks the interior side.

Soldering—A glazed panel should be soldered as soon as possible. If you wait, you get oxidation, which hampers the soldering. Minor oxidation can be cleaned away with steel wool or a wire brush. When the lead is badly oxidized, as is often the case with pure lead came exposed to moisture, brush the panel with flux and allow it to sit awhile before you scrub it. Be sure the panel is free of dust and debris before soldering. Any bits of lead or loose solder caught under a leaf will break the glass during cementing.

Oleic acid, a derivative of sheep fat, is the best flux for lead. With a brush, I coat each joint with flux just before soldering. Use the flux sparingly, because any excess will seep into the panel, form a puddle and then ooze out after the window is finished.

A soldering gun is of little use for all but the smallest of lead. The tool worth owning is a 250-watt American Beauty soldering iron with a ⅝-in. tip. Hexicon also makes a good iron.

The iron doesn't need a thermostat. Its temperature can be controlled by switching the power on and off. My iron is connected to a switched socket, and I know it's on when I see the red light out of the corner of my eye. The temperature demands for soldering leaded glass differ greatly from moment to moment, and the switch gives me the most flexibility.

For soldering the leads, I use a homemade tip made from a ⅝-in. piece of copper rod. It's bent at a 90° angle, and it has a blunt end. As soon as the iron starts to heat up, I file the tip smooth of the burrs and pits caused by the acid in the flux. I then tin the clean tip (coat it with a thin layer of solder) on the lid of an ordinary can (photo facing page, top left) on which is placed a little flux or powdered rosin and some solder. The tinning tray will draw excess heat off the iron, which makes it another means of temperature control. Before I start in on the panel, I test the iron on a piece of scrap lead.

Soldering done well requires a light touch, proper temperature and pacing. The tip hovers above the joint as a piece of 50/50 wire solder is placed between the two (photo facing page, top right). The solder transmits the heat as the tip is rolled slightly. When the lead has taken on sufficient heat, it will accept the solder and the joint will flatten. If the iron is too hot, the lead (which melts at a slightly higher temperature than the solder) will mingle with the puddled solder and make a lumpy joint. These can be flattened, but messing with them doesn't help them to look their best. When every joint has been soldered, I go back and check the panel for the joint that has inevitably been passed over. Then I wipe off the flux with a rag, pull the stops and dress down the unused channels on the outside of the border lead with the lathkin. The panel is now ready to turn over.

A half-soldered panel is still flimsy, and must be turned carefully. I pull it halfway off the bench and pivot it to vertical using the bench edge as a support. Then I lay it back down using the same technique in reverse. After truing any misaligned leads, I hammer the joints flat. This is the exterior side of the window, and the leads will not be closed down until the panel is cemented (explained below). Once the soldering is finished, I let the panel stand for a few days. This allows the flux to dry out. It should be tilted slightly, backed by boards for support. Larger panels should be stacked with a board in front as well to prevent them from folding over on themselves under their own weight.

Cementing—At this stage, the panel still rattles when it is moved, and it would leak on a dewy morning. It becomes a solid, impermeable unit when a waterproofing compound called cement is forced into the spaces between lead and glass on the outside of the panel. Cement is pigmented, and it turns the new metal shine of the panel to a dull grey. Quick cement can be had by mixing white gas and lampblack into a portion of steel-sash glazing putty. Stirred with an electric drill and paint-mixing attachment, it will flow freely, yet support a popsicle stick upright when its consistency is right. The best cement takes longer to concoct, but it is tenacious. The formula, in volume measurement, is: 12 units powdered whiting (powdered calcium carbonate), ½ unit powdered lampblack, 1½ units Japan or cobalt drier, ½ unit grey floor and deck enamel (alkyd resin type), 1¼ units boiled linseed oil, ½ unit turpentine. This compound is best when it's fresh, but it can be stirred up and used for a week if it's kept covered.

Gloves and an apron are a good idea for messy jobs like mixing and applying cement. The tools I use for cementing include one large and one small natural-bristle scrub brush, two good rags, sawdust, a stiff bent putty knife and a sharpened bamboo stick.

I ladle some cement to the open-lead side of the window, and work it into the cracks with the small brush (photo facing page, bottom left). Only one side is cemented because air pockets deep in the window will heat up under sun and blow out the seal of one side or the other if both are cemented. The one-sided approach works only with flat lead.

I brush the cement under the leads in a circular motion. Every space, every corner must be filled. A heavy stroke discharges cement from the brush, a light stroke pulls it off the window. After the entire side is covered, I lift excess cement off the panel with light strokes and scrape the brush on the side of the can. Then I lay the leads down with the bent putty knife, trapping the cement under the leaf. Ride the heart of the lead to avoid cracking the glass.

When the leads are down, I rub a handful of sawdust over the surface with a clean rag. Ideally, the rag itself should not touch the panel—just the sawdust, if you can manage it. This cleans the panel nicely.

Though the interior side of the panel does not get cemented, it needs a little color to break the shine of the lead. I rub the cement brush over this side, then clean up with the sawdust. To further clean the panel, I scrub both sides with the clean brush, working in the direction of the lead. Then 1 polish the panel with sawdust, applied with the clean rag, and I finish by removing excess cement along the cames with the bamboo stick. A window with round-faced lead should be cleaned with whiting instead of sawdust, which would embed itself in the open channel.

The cement takes at least a week to cure, so I let the panels rest before installation. 1 lean them up, and brace them so they don't bow. Straightening a bowed panel after the cement has set up will break the seal.

Bracing—Horizontal braces should be used every 18 in. to 24 in. on panels that are 12 in. wide or wider. Bracing stock is usually ⅜-in. or ½-in. by ⅛-in. galvanized flat bar. It is soldered on edge along a lead line on the inside surface of the window. Both ends of the bar should fall on a solder joint along the edge of the panel. Braces are cut with a hacksaw or bench shear to a length ⅜ in. short of the full-size dimension. The ends should be gently tapered, then flared out into hammered paddles (photo facing page, bottom right). The paddles enable the bar to make contact with the sash; this braces the window without having to modify the rabbet. The bar can be bent to conform to a curved lead, but the greater the bend, the weaker the brace will be.

Sometimes passing a bar over a section of glass can't be avoided. But the bars, which can look obtrusive during construction, usually become a lot less obvious when the window is finally in place.

To secure a bar, I first center it over the lead line 1 want it to follow. Then I paint tinner's fluid (flux for galvanized metal) on each side of the bar over every solder joint the bar intersects. The soldering iron must be fitted with a flat chisel-tip, and it must be very hot. The tip is loaded with solder and held to one side of the bar without touching the lead. I hold a solder wire to the other side of the bar, which will conduct enough heat to melt it. At this point the iron is punched down onto the lead, pulling the solder down and around the bar with it. The iron is hot enough to fry the lead and should not be in contact with it for long. The bar is held still until the solder is completely cooled. Next, I tin the open cuts to keep them from corroding, and then solder the paddles and bring them flush with the border lead. I remove any residual flux, first with a rag and then with newspaper and window cleaner. If a lot of flux is left, I spray glass cleaner on the affected areas and scrub them with a brush and sawdust. A little gun bluing (sold at most sporting-goods stores) brushed on the brace bar will eliminate its shine.

The window is now ready to install. If you built it right and install it properly, it should last for 500 years. □

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