A Study in 14th century stained glass techniques and re-creation of a stained glass rose dated between the 1330 – 1340 A.D.

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Delftwood

INTRODUCTION

The goal of this entry was to re-create a portion of a stained glass panel currently on display at the Corning Museum of Glass (see photo A). My plan was to follow as closely as I could, the description of stained glass making found in the writings of the twelfth century Monk Theophilus in reproducing this panel (De Diuersis Artibus, book 2), so it wont be a surprise to see many references to his writing.

What I wanted to accomplish was to make a roundel that used silver staining as well as making and using my own black stain.

In the back of this paper are appendices devoted to my research in the areas of glass making, the construction of sheets of glass, stains, glass cutting, and lead and solder construction, along with my references.

Overview of the Project

The rose that I chose to reproduce was taken from The angel panel in Photo "A". The rose segment allows me to demonstrate many techniques used in the creation of a stained glass piece.

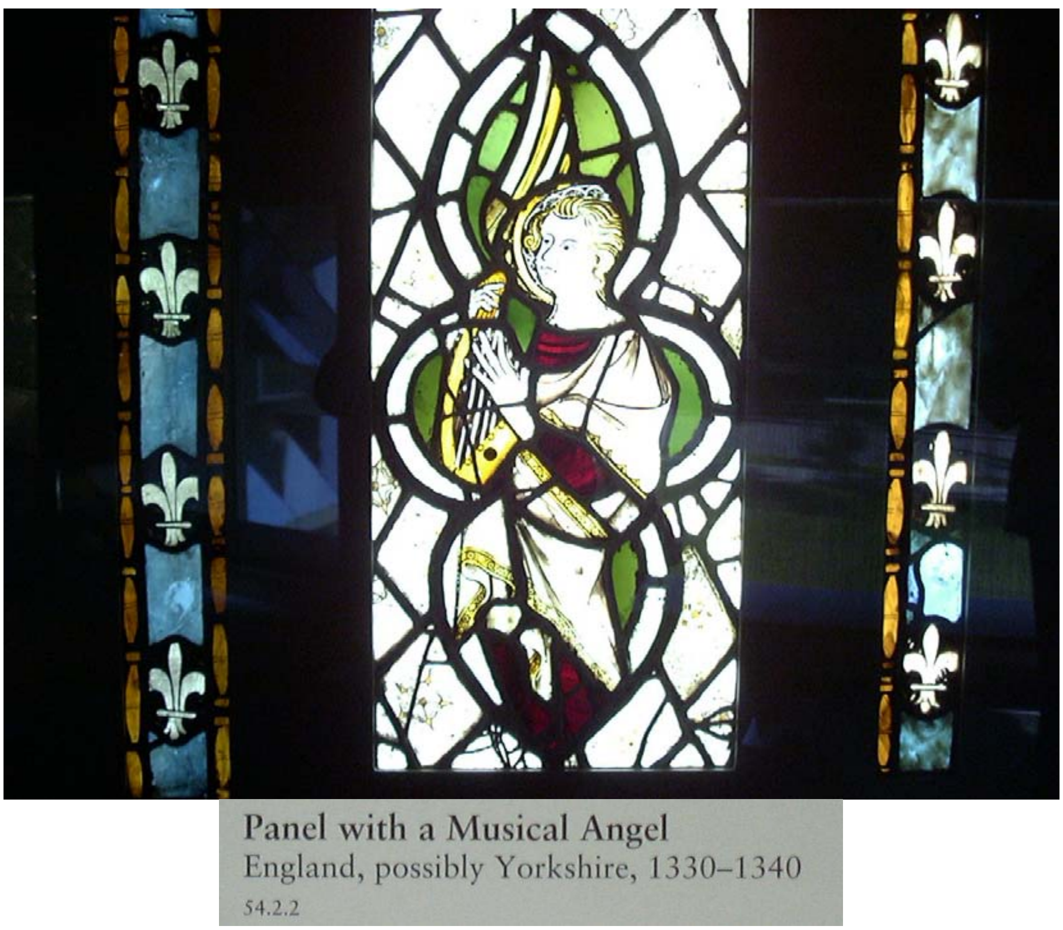


Photo A

The rose that I chose to use is located in the upper right hand corner of the Panel in the large diamond. Because of the lighting your really cant see the rose in Photo “A” , but shows up clearly in a close up shot in Photo “B”.

Photo B

The Panel (accession number 54.2.2), a rectangle, measures 26.5 inches by 12.75 inches. The rose measures about 2.5 inches. The panel itself was owned by Roy Grosevenor Thomas. In 1929 it was sold to Philip Hofer who served on the board of the Corning Museum of glass between 1952 and 1974. In 1954 Hofer gifted the angle to the museum (Lillich 2004).

While researching the angel, I found a book authored by Dr. Meredith Lillich, A professor at Syracuse University. In her book she cataloged all of the stained glass collections in upstate New York before the 1700. In this book she gives a detailed analysis of the panel. In short, she feels that over the years this piece has been reworked and incorporates aspects from several related designs. The support for the Yorkshire location is in the glass surrounding the angel and bears similarity to a design from St. Denis in York England.

Surrounding the angel are Heraldic roses. In Greek and Roman lore, the rose represents, love, beauty, purity, and passion. To the Christians it represented Mary and thus related to mother hood and Purity (Armorial Gold Heraldry Symbolism Library). The Angel and the rose can be religious symbols and religious symbols make up the subject matter of most stained glass in the middle ages (Brisac). The Rose is also the badge for Yorkshire and Lancaster, hence the War of the Roses (Davies).

Construction of the stained rose.
Choosing the glass

I decided to use a clear antique glass for this project. Antique glass has air bubbles and striations that would be found in the imperfections of period glass.

Creating the pattern

The pattern was created by measuring the chosen rose and printing it out to the correct size which was 2.5 inches. The rose I chose to reproduce is in Photo "B" above. The actual pattern used can be found in the appendices.

Cutting the glass

1) The first step in cutting glass is transferring the pattern you wish to cut onto the surface of the glass (see appendix – glass cutting). Conservation of the glass was important. The process to create sheets of glass is time consuming and involved, so planning how to cut the glass was important. Had this been a panel with many pieces, would have been done is to trace the glass pattern onto the glass. For this project all I had to do is place my glass over the rose and trace out a circle then rough cut the glass conserving as much glass as I could.

It is especially important to plan your cuttings with a clear glass. Clear glass was very difficult to make. The materials used to make the glass had many impurities (se appendix – construction of a stained glass panel). We know that it is these impurities that enabled Theophilus to get the range of colors he was able to get without adding any extra additives (see appendix – overview on Theophilus). So to get colorless glass required very careful control of the kiln (Royce-Roll Journal of glass studies, pp74-75). For this project all I needed was to cut a circle. So there were no intricate patterns to be traced.

In period glass was cut using a hot iron (see appendix – glass cutting) In past projects I have demonstrated that I could cut glass with a hot iron but for time considerations I decided to use a modern glass cutter.

Staining

I made the black stain (grisaille) mixing 1/3 part powdered green glass, 1/3 part powdered blue glass and 1/3 part copper oxide and a few drops of wine to make a paint (Theophilus pp 49.). Copper oxide is a black substance that forms on the surface of copper when it is heated to a high temperature. The resulting black material is removed then powdered. I heated my copper in a kiln to 1200 degrees for a few seconds. Due to different coefficients of expansion and contraction, when the copper cools it contracts faster than the black copper oxide causing the copper oxide to pop off of the copper sheet. The black stain or grisaille is used to create the shape of the heraldic roses.

1) To make the rose I placed the round piece of glass over the picture/ pattern of the rose and painted the lines with the stain. I used a thin paint brush for the. Photo “C and D” shows the original rose and my traced version. In a window the black stain would be painted on the inside of the glass because even though it is fused with the glass it is still subject to weathering (see appendix –glass stain).

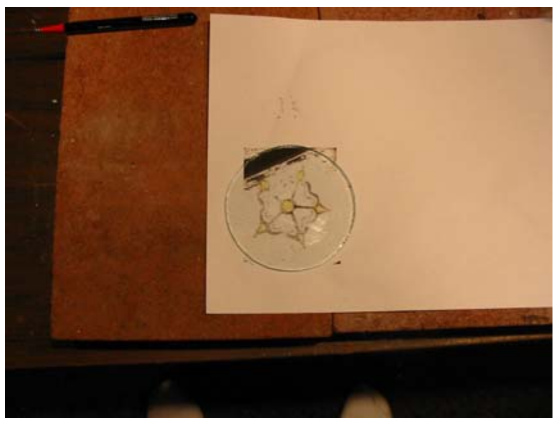


Photo “C”

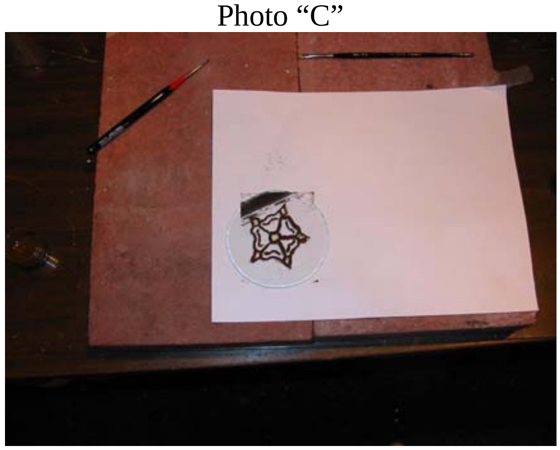


Photo D

2) When the stained dried (about an hour), I used an exacto knife to scrape away the excess stain even out and fine tune the lines (Photo E).

Photo E

3) My kiln is very small but the rose fit perfectly. The process starts with a room temperature kiln. The piece is placed in the kiln painted side up. I found that firing the kiln to about 1300-1400 degrees Fahrenheit and holding the temperature there for five minutes, was enough to fuse the stain to the glass (Liban & Mitchel, pp 19).

4) If you the glass is taken out of the kiln at this high of temperature, the glass will break due to stress fractures. To avoid this I cooled the kiln to 1000 degrees, then let the kiln cool on its own until it reaches room temperature. If you take the glass out before it completely cools it will devitrifie making the glass very brittle.

5) Once the piece was cooled I had to stain it again this time using a Silver stain. I am using Reach Companies deep amber H465. I have used this stain in other pieces at their suggestion. The stain comes in powder form so to prepare it I mixed a few drops of water and created a paste. A little bit of the powder goes a long way. The firing temperature per the manufacturer is 1050-1080 degrees F. I painted the paste on the reverse side of the glass over the area that I wanted stained (photo F). In a window the silver staining would be painted on the outside of the glass. When the silver stained is fired the silver ions migrate into the glass becoming part of the glass therefore not subject to weathering like its black stain counter part (see appendix glass stain)

Photo F

Once the stain was dried I scraped away what I didn’t want with an exacto knife as I did with the black stain then fired the piece in the kiln using the same precautions as before.

The lead came and solder

Again in past projects I have made my own lead came and solder (see appendix – lead came and solder) but for this project I used a commercial U lead came. I also used a commercial solder that was 50% lead and 50% tin. Seeing that the composition of the solder varied from glazier to glazier (Ran Busch) I chose the 50/50 percentage out of familiarity.

FINAL ASSEMBLY

The rose is a one piece project so I did not have to go through pinning pieces down, wrapping lead, pinning, and wrapping until the full project was done. Instead I simply wrapped a piece of U shaped lead around the glass (Photo G).

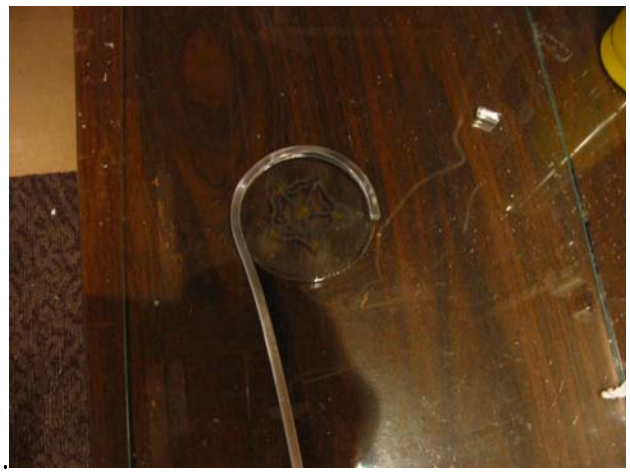
.

Photo G

The last step was to solder the ends of the lead came together and add a loop for suspending the rose (Photo H). In period a hot iron would be used but again for time considerations I used a commercial soldering iron.

Photo H

Once cleaned up, the piece is now ready for display (Photo I)
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Photo I

MAKING A SHEET OF GLASS:
Research

Theophilus described in his writings (I am summarizing in my own words here) that to make a sheet of glass: 1) Take 1 part sand (quartz) to 5 parts Beech wood ash, 2) place them into a Furnace until they fuse (stirring often) making a frit, 3) break the frit up and place it into a furnace till you have al glob of molten glass, 4) you take a glob of molten glass and place it on the end of a blowpipe. 5) You blow and rotate the glass until a bladder is created. 6) Remove the bladder from the blowpipe. 7) You remove both ends of the bladder to create a cylinder. 8) You then cut down the center of the cylinder lengthwise. 9) While still hot, you open up the cylinder until it lay as a flat sheet of glass (Theophilus pp 40,41).

I being the experimental type decided that I would attempt to make some frit. I got some sand from a local stream, cleaned it of organic material, and ordered some Beachwood. Photo "1" shows the parts. The sand has already been ground down in this picture.

Photo "1"

First you grind down the sand to a powder. Then reduce the Beachwood to an ash. Mix one part sand to five parts ash. The ash acts as flux. In northern Europe they used Beech wood (potash) and in southern Europe they used plants (soda). I then placed them in a pottery vessel and placed it in my kiln at about 2000 degrees F. I let it sit for a while occasionally stirring. After a while I gave up (couple of hours). What I got was in photo "2". It looked like it was trying to fuse but I either didn't have the right temperature or didn't wait long enough. I started with was a powder mixed with ash and what I ended up with was a granular material that was sticking together. Proto frit???

Photo “2”

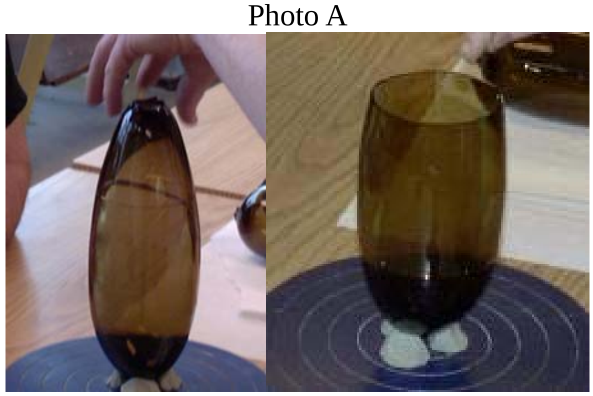
Ok that being done, on to making a glass sheet. My first problem here is I don’t have a blowpipe, or the furnaces to make glass. To solve these limitations, I contacted Harry Seaman who is the director of instructors for the Corning Museum of Glass Walk in Studio. I described what I wanted to do and we set up a meeting time at the museum’s walk in studio.

By the time I arrived Harry had already blown two bladders of glass. As the annealing process requires an overnight wait, he wanted to have something to work with the day we arrived.

Because the studio only works with certain colors on certain days I really didn’t have a choice of colors to work with, so we used what was already in furnaces. The color of the day was brown. To make this color, small amounts of nickel oxide was added to the molten glass. This is not one of the colors that were produced by Theophilus’s methods but still clearly illustrated the technique.

The first thing Harry did was to prop up one of the bladders that he had already made, and scored (scratch) it near the point where the curved top part meets the long portion of the glass. Then by heating and rotating the bladder we were able to create a crack running all the way around the top of the bladder. The left side of photo A shows where the top of the bladder had cracked and the right side shows the bladder with the top removed. We flipped over the bladder and repeated the process on the other side. When we were done we had a cylinder. We did this three times. Harry cut the first cylinder to instruct me in the technique, and then I cut the remainder.

Photo A



The next step was to create a crack going down the length of the cylinder without shattering the glass. We tried several methods. The first was to place a score down the entire length of the cylinder. Then heat the score until it cracked. This worked. Then we tried it by placing a score on each end of the cylinder. We applied heat again and still the crack traversed down the length of the cylinder. We noticed though that the crack did not match up with the scores on both ends of the cylinder. So we tried it again using one score. It worked just fine. Thinking back to the techniques described by Theophilus on cutting glass (see De Diuersis Artibus pp 48,49). We could have just as easily taken a hot iron, placed it on the lip of the cylinder, waited for a crack to form and dragged the iron down the length of the cylinder. I believe this would have accomplished the same thing and I would like to try this on another visit. Two of the conditions that could cause the crack not to form in a straight line would be defects in the glass such as air bubbles or impurities, or the varying thickness of the glass.

The next thing we did was go into the studio. Here we actually created a few more glass bladders (Photo B). Because of safety issues (I do not have any training in glass blowing), Harry did the actual forming of the bladder.

Photo B

For one of the bladders I was allowed to blow on the blow pipe to get an idea of how much (or little) pressure was needed to blow air into the glass. The bladders we made went into the annealing chamber and, once again, they had to stay there overnight.

After lunch we met back at the studio to complete making the sheets of glass. We tried the following varying techniques.

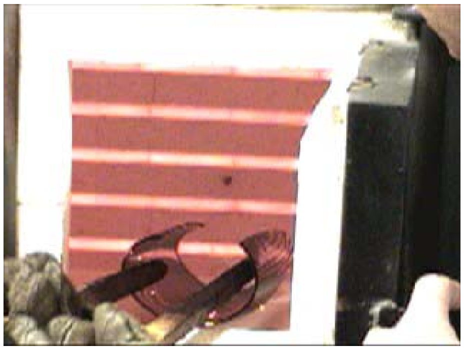
1) The first attempt was to find the correct temperature needed to work with the glass and to figure out the best way to spread the glass. We discovered that the glass first starts to slump or soften between 1250 and 1260 degrees Fahrenheit. If we held the temperature at 1300 degrees Fahrenheit the glass would begin to slump or flatten on its own. When we spread the glass on this attempt we applied pressure near the top of the cylinder closet to the seam. The idea was to pry it apart using a spreading motion and a downward motion. This worked but with a lot of effort. We used two wooden sticks to pry the glass apart.

2) By the time we were ready for the second attempt, we had the temperature down but not the technique. Again we tried spreading the glass from the top of the cylinder thinking that we didn’t have the temperature right causing the spreading to be difficult. We found that it was still difficult.

3) For the third attempt we tried spreading from the middle of the cylinder outward hoping that equal pressure on both sides of the glass would unfurl it (Photo C). This did in fact work

better than trying from the top. For all the attempts we knew that once we got the edge of the cylinder spread back far enough, the glass would slump flat to table and not back on it self.

Photo C



Some of the things we learned:

1) Wood burns nicely at this temperature. In order to reduce the time before the wood sticks burst into flame (which were seconds), and set off fire alarms, we got them damp.
2) If we apply too much pressure on the glass it will crack even though it is in a semi molten state.
3) If we let the glass fold in on itself then it is not possible to separate the two pieces.
4) If we were to get a good sample, we needed to work the glass in small increments at the proper temperature. Work the glass a bit, let heat up again, work it some more, heat it up again, and keep this cycle going until the glass lay flat.
5) We had to keep a close eye on the glass while it was in the kiln else it would slump too quickly and fold in on it self.

In Photo D you can see the bladder, the ends cut off and sliced down the center, and then the resulting sheet of glass.

Photo D

THE STAINED GLASS PATTERN

Research

In his book “Diverse arts”, Theophilus says to draw your pattern or cartoon, along with any painting that has to be done, on a whitewash board – a smooth board that was covered with chalk and wetted down (Theophilus, pp 47). The whitewash board could be repainted and used several times over. My research has shown that this process has not really changed much. Even in my own work I will start with drawing. Instead of using a whitewash board, create my pattern on a computer (I can’t draw a straight line with a ruler) or use a commercially printed pattern.

GLASS CUTTING

Research

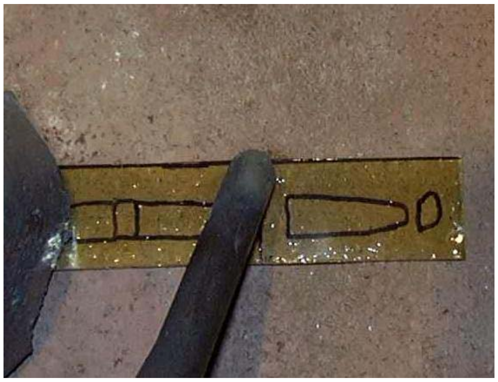
Theophilus tell us that to cut glass, all one needs to do is take your glass, place some spittle or water where you wish to start cutting. Then get a hot iron and hold it on that spot until a fissure in the glass begins to form. Then simply drag the iron along the line you wish to cut. When done, finish shaping it with a grozing or groseing iron (Theophilus pp 48, 49).

I tried three different rods in my research. The first rod I tried to cut glass with was a one quarter inch wood chisel. I chose it because it tapered off at the end providing a point for the heat to concentrate. I found that it did not retain heat long enough to heat the glass to crack it. The second rod I tried was a large punch. I filed the tip down to a point. This did the trick. It was large enough to store the heat and still be able to work with it. I did not have access to a forge to heat the first two rods so I used an acetylene torch.

I don’t mind telling you I was a bit apprehensive of this part. My experience has shown that when two temperature extremes meet, nasty things happen.

First I drew a line where I wanted the cut to go. I flipped the glass over so that the inked side of the glass was facing down. By working this way the heat of the iron would not burn off my tracing lines. Then I placed a drop of water on the edge of the glass where it is to be cut and then place a hot iron on that same spot (Theophilus, pp 48,49) (Photo A).

Photo A



The hot iron then caused a fissure to form in the glass. It is difficult to see where the fissure forms as it is a subtle crack (Photo B). I have learned from past experience the when a fissure forms from thermal contact, there is an almost bell like “tink” that can be heard.

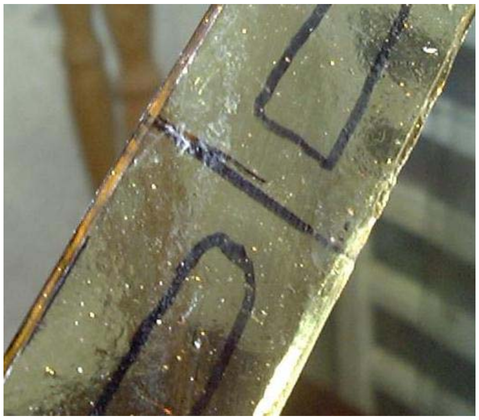


Photo B

Next I dragged the hot iron along the line I wanted cut. The fissure will follow the hot iron. As can be seed in Photo B, it is not always exact. It is however close. As I learned while experimenting with cutting glass, the glass doesn't always cut the way you want it to .I had two miss-haps where the fissure migrated into the glass that I did not want cut rendering those pieces useless. I ended up cutting additional glass. Photo C shows the cut piece of glass. I then used the same procedure on the remaining pieces of glass.

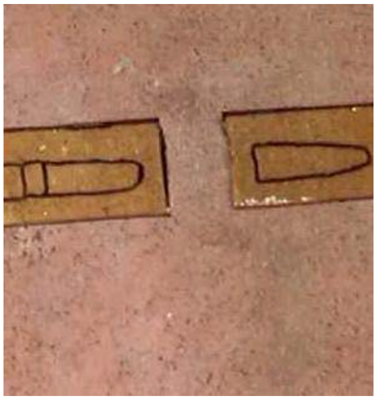


Photo C

Thinking that this was dumb luck, I tried another test piece. For this attempt I tried cutting a curved line. I paid closer attention to the sounds when I placed the iron on the glass. This time I heard the "tink" of the glass cracking. I dragged the iron across the glass in an S pattern and watched as the crack followed the iron.

It took a few attempts to figure out how fast to drag the iron. If I went too fast the fissure just stopped. If I went too slowly the defects in the glass would heat up and cause the crack to go in an unwanted direction. Lastly if I didn't follow my drawn line, neither did the crack.

If the glass did not cut the way it was intended but was still useable (i.e. the fissure went outside the line to be cut into spare glass), a grozing iron could be used to finish shaping the glass.

The glass can be smoothed down using another piece of glass or a stone (see Art History Final Project). Glass is predominantly quartz. According to the Mohs hardness scale quartz has a hardness of seven (see Cornelius p184). Also According to this scale the only material that can scratch or smooth quartz would be a material that has a hardness greater than seven. Seeing that the glass we are working with is not pure quartz, the impurities in the glass would make it either greater than seven or less. So it is possible to smooth glass with glass or a common rocks such as pumice (volcanic glass), granite (composite of quartz, mica, feldspar, hornblende), corundum (mineral hardness 9), or obsidian (volcanic glass). I smoothed down the edges with a piece of granite.

As of the time I tried the modified punch I was unable to find a picture or description of the rod that was used until the end of this project. Photo "D" shows a picture of what a dividing rod looked like.

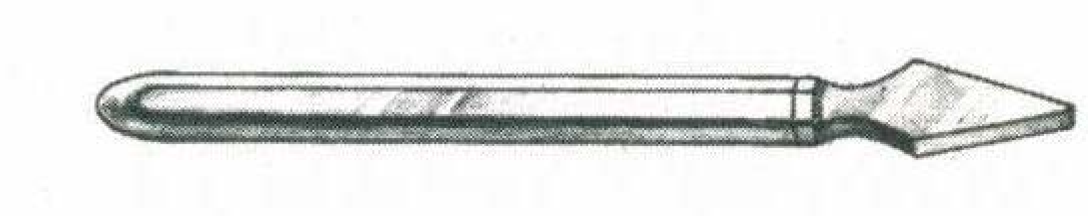


Photo D

This device looked like it would have worked well. The large flat diamond point could store the heat, and the point used to focus heat on the glass. Off I went to the Aethelmearc metal smiths guild meeting and they helped me forge a tool similar to what is pictured in Photo "A". Mind you this was my first time at a forge. Photo "E" shows the resulting tool along with the other two tools I tried. The ruler gives an idea of the size of each.

Photo E

Photo "F" shows me attempting to cut a piece of glass. I was successful but I found the new tool to be too heavy and too unwieldy. I think that a smaller version would have worked just fine.

Photo F

Photo “G” shows the resulting glass that was cut.

Photo G

GLASS STAIN
Research

To start this section of the project off I picked up an old cast iron pan, and a granite mortar and pestle. Theophilus used one third copper oxide, one third blue glass, and one third green glass, ground them to together to make a fine powder and added urine or wine as a binder (Theophilus pp 49). The first step is to make copper oxide, which is a black powder. The basic theory is to heat the copper and the oxide forms, and then just brush it off into a container. I tried several ways to make the copper oxide. My first attempt was to take copper shavings or filings and heat them up grind, re-heat, grind, until all the copper filings were reduced to copper oxide. It took me and hour to get enough filings to work with. I had to use a steel file because any other method (that I could think of) would introduce other materials into the collected filings. Steel is harder than copper. I had a very tired arm by the time I had enough filings to do anything with. I then put the filings in the pan and placed the pan on the stove on high heat. The reaction went quickly (more surface area the faster the reaction). Unfortunately it took a long time to reduce the filings to oxide (or what I thought was oxide). I then ground down blue and green glass to a fine powder.

I combined all the oxide I had with equal amounts of the blue and green glass. I ground them together and added some wine for a bonding agent (really couldn't bring myself to use urine which Theophilus suggested as an alternative to wine). On my first attempt I added too much wine because it painted on too watery, although I did have a dark enough "paint" to try the fusing. I painted a letter onto yellow glass noticing lumps in the paint, and placed it in the kiln. While I was mixing everything in the mortar, the grinding cleaned off the filings revealing that there was still a lot of copper that did not reduce to copper oxide. This explained the lumps in the paint. I fired it anyway. The temperature was not listed in Theophilus's manuscript so I went to two of my jewelry books that touched on enamel and decided to use the temperature outlined in the books. I set the temp for between 1300 and 1400 degrees Fahrenheit. My kiln does not have a reliable way to control the temperature accurately. The kiln relies on a rheostat that turns the kiln on and off to maintain temperature levels or to control the rate of heating. I let kept the temperature steady for 5 minutes then turned the kiln off. I let it cool slowly. When the kiln was cool I took the sample glass out. Per Theophilus, I did a scratch test on the stain and it did not come off.

I had a temperature to fire at, but I still did not have a good way to make the copper oxide. The next method was to put an entire sheet of copper in the pan and heat it instead of filings. I lightly sanded the sheet to reveal a bright copper. I then put the sheet in the same pan as before and heated it on my stove on high for 20 minutes. What resulted was a layer of copper oxide coating each sheet that I could then brush off into a container. This was a better method, as I knew that all I was getting pure copper oxide. I then cleaned off the sheet, sanded to reveal clean copper and heat it again.

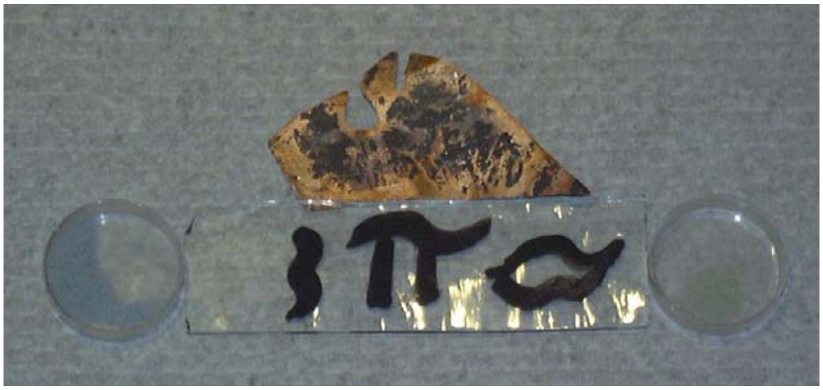
The yield was not that great but for the same amount of time I spent on the first method I found I was getting about the same amount of copper oxide without working as hard and knowing that I was getting pure copper oxide.

While the copper was cooking for my second method, I decided to play with the stain I had made with the previous batch of copper oxide. A few days had lapsed since I made this stain and the wine I had used evaporated. Instead of wasting what I had. I tried adding various amounts of wine to try and figure out a good consistency. I found that a thicker mixture worked better than a thinner. The stain held to the glass better and did not spread out.

I really wasn't satisfied with the way my copper oxide production was going. The next attempt was to use a propane torch instead of the stove. The torch had a higher heat and the reaction went quicker but it wasn't much better than the stove. Now Theophilus described how he made his copper oxide. Remembering Theophilus put thin sheets of copper in a fire and burned it, my third attempt at making copper oxide would be closer to his method. A fire was not feasible in my basement so I used the next best thing. I placed a thin sheet of copper in my kiln and fired it to about 1200 degrees and let it sit for about ten minutes. When the kiln cooled down some, I placed the copper sheet into a pan and covered it with a wire mesh screen. I learned and found that when the copper cools, the rate of contraction of the copper is faster than the rate of the copper oxide. What resulted was the copper oxide popping off the copper sheets sometimes making the copper sheet itself jump (see Chapter 3: Electrochemistry- make a solar cell in your kitchen). By placing the hot copper into the container and covering it, the copper won't jump all over the place and I can catch the copper oxide in my container instead of trying to clean it out of my kiln. This worked very nicely. What resulted were big thick flakes of copper oxide. I also found my copper oxide yield to be much higher than the other methods and didn't take anywhere as long.

I used the copper oxide that I made with kiln and once again grinding equal amounts of copper oxide, blue and green glass. I added a few drops of wine until I had the proper consistency and tried painting on piece of clear glass. This time the stain was smooth, covered the glass evenly, and there was no spreading. As last time, I fired the glass in the kiln at 1300-1400 degrees for about ten minutes. After the glass cooled in the kiln, I performed a scratch test on the paint and it held. Photo A shows some of the powdered blue and green glass, some copper oxide still on the copper (black residue), and my good stain sample.

Photo A



After this successful trial I attempted several other stains by varying the amount of blue and green glass. I found the one third method produced the best results.

SILVER STAIN

I also used a silver stain in this project. Silver stain is a silver compound mixed with a clay or ochre material. Now I say compound because in several sources I have seen the compound to be a silver nitrate (Frenzel pg 75), or a Silver oxide (Raguin pg 47). According to a study on the color differences on medieval silver stain there appears to be a number of different compounds such as silver chloride, silver phosphate, and silver sulfate as well as the silver nitrate and oxide (Caen pg 321).

Silver staining came during the 14^{th} century. It allowed the glass artists to expand their color schemes without the creation or use of additional glass. Depending on the silver stained used, the color can range from a yellow to deep amber depending on the amount of sodium or potassium is present in the glass, temperature of the kiln, and composition of the stain. Also when painted onto a blue surface the stain creates a green color. Silver stain was primarily used for coloring hair, halos, decorative details and the use of two colors in single pane such as blue glass plus silver stain yielding green (Rush).

Silver staining differs from black stain in the way it bonds to the glass. Black stain is fused to the glass and is prone to weathering and can break down. This is why black stain is on the inside of the window (Raguin pg 47). When heated, the silver ions migrate into the glass, replacing the alkali ions in the glass such as sodium (soda glass) and potassium (potash glass) becoming part of the glass network (Caen pg 321).

According to study by Caen, silver oxide, silver chloride, silver phosphate and silver sulphate, resulted in uneven or speckled coloring, whereas the silver nitrate formed a homogenous layer (Caen pg 323).

I thought about making my own silver nitrate until I read the formula. One of the by products is nitrogen dioxide (Silver nitrate manufacturing). So for health reasons I decided to purchase some from Reusche Co. Through emails they were very helpful in matching the color to my project but were less than helpful in a phone conversation as to what silver compound they used.

I did experiment with the silver stain prior to using it to see how it would react according to the literature. In Photo “B” I have four samples of silver staining using the Reusche h465 amber stain.

Photo B

Sample one was fired at the normal temperature of 1050 degrees F.
Sample three was fired twice with additional stain. It did come out darker.
Sample four was fired at 1100 degrees F and it came out dark as well.
Sample two was fired on blue glass and the resulting color was green.

LEAD CAME AND SOLDER

Research

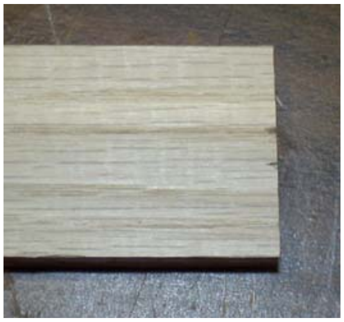
Lead came is used to hold the individual pieces of glass in place. There are two types. There is an “H” or “I” shape (channel) and a “U” channel. The “H” or “I” have two leaves and a heart forming two channels for glass to slide into. This used to keep the inside pieces of glass together. The “U” channel only has on channel for the glass to go into and is used for boarder pieces.

The Lead Came Mold:

To create a mold for the lead came and for the solder that I am using in this project, I am again, using the methods according to Theophilus’ writings. Theophilus gives to methods for making molds. The first is using iron (Theopilus pp 53,54), which is more durable or wood (Theophilus pp 55,56). Since I don’t have the means to make the iron version I chose wood.

1) I started off with two wooden blocks about 12 x 2 x 2 inches and sanded the surfaces smooth. This would end up being my mold. Theophilus does not state what kind of wood to use so I used a maple, which is proliferate in Europe. Maple is a hard wood and I believe, would survive multiple castings.
2) I marked the edge of one of the boards with two notches (Photo A). This represents the distance between the leaves of the came. I repeated the markings on the opposite end of the same board.

Photo A



3) I then soaked a string in some of my Lady’s Black Walnut ink (see Appendix C – Black walnut ink) made from some of seemingly thousands of black walnuts that rain on my house every year.
4) The string was slipped into the first set of notches at both ends of the board. I took the second board and placed it on top of the first and pressed. This created a line down the board representing where I needed to cut to create the first set of leaves. I then repeated this process with the other set of notches to make the line for the second set of leaves (Photo B). In retrospect, I probably could have used two threads and made both lines at the same time.
5) I also marked each board so that I knew how they went together when I actually got around to casting the lead.

Photo B

6) With the mold now marked, I used a series of knives and chisels, and files to cut the channels that would be leaves. Next I used a chisel to lower the middle section of both pieces of wood between the two channels to create the heart of the lead came.
7) In order to pour the lead into the mold I needed to cut a sprue. This is a funnel shaped cut so that the liquid lead can pour into the mold with out splashing around. I cut half a sprue on one end of both pieces of wood so when put together formed the full funnel (Photo C).
8) Once the wood was clean of dust and debris, I put both pieces together lining up the ends and clamped them together. The mold was ready to go.

Photo C

Casting the lead came itself in the handmade mold:

1) Theophilus is very clear on how to cast the lead (Theophilus pp 54,55). In a very well ventilated location, I placed raw lead into a cast iron pot. I melted the lead using a torch as I didn't have the means to make a fire, and poured it into the mold. After cooling I pried the two pieces of wood apart using a knife, and there I had my first piece of lead came (Photo D). Upon inspection I found gaps and holes in the lead in both the leaves and in the heart.

Photo D

NOTE: **Theophilus had left out one thing**! Obviously I had to modify the mold. I needed someplace for the air to go.

2) Adding more air vents: I built a second mold this time I added more sprues along the edges of the leaves to allow the air to escape (Photo E). This new mold worked much better and I used it to create the lead for this project.

Photo E

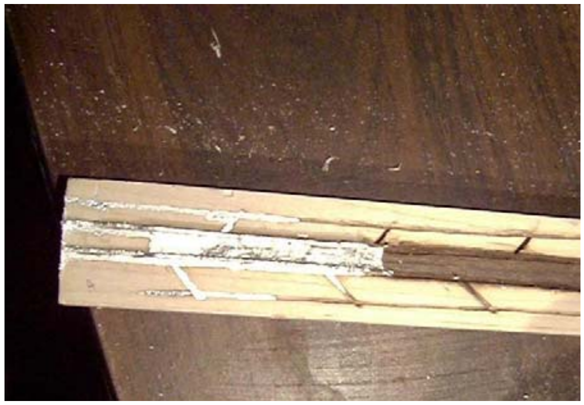
3) After I pulled the lead from the mold, I cut off all the lead from the sprues and cleaned up the edges.

4) Now as described in appendix A for lead, there are two shapes for the lead came. One is an H came (two leaves and a heart), of which we just finished making. Now we need to make the U came (one leaf and a heart). Theophilus does not describe how to make the U came or even mention the U came. To create the U came, I used intuition and simply turned one of the wood blocks around so that the uncut side faced the cut side of the other block. I then poured the lead following the above method (Photo F).

Photo F

For the solder, I took one part lead to five parts tin (Theophilus pp56). I melted them together and used the lead came mold to form the solder (Photo G). As Theophilus described there is no reason to make a mold when you already have one.

Photo G



STAINED GLASS CONSTRUCTION

In a book entitled *De Diuersis Artibus*, (De Diuersis Artibus , Theophilus, translated from the Latin by C.R.Dodwell) a 12th century Benedictine Monk by the name of Theophilus, penned what is considered to be the first "how to" book for the creation of stained glass.

How the glass was made

In northern Europe glass was made with two parts Beachwood ash and one part sand. This is known as potash glass due to its high concentration of potassium. This glass can produce stronger colors but is also more subject to deterioration as the potassium creates a softer more brittle glass and tends to discolor over time. This is why the works from this area now need heavy restoration. In southern Europe they used sand and a soda rich vegetable ash (marine or desert plants). Since these were rich in soda it is known as soda glass. Because the vegetable ash has fewer oxides than the Beachwood ash, the color ranges are not as good. However, the glass is more durable (Royce-Roll, Twelfth Century Stained Glass Technology, Avista Forum,p14). Theophilus used two parts wood ash to one part river sand (Theophilus p39). This combination came about by trial and error not by quantitative means.

There were two techniques to make a sheet of glass. The first is called the Muff Method. Here the glassmaker or glazier gathers a ball of molten glass called a parison, on the end of an iron rod called a pontil. He then molds the glass by rotating it. Then next step the glazier takes is to blow on the end the pontil, which is a hollow tube. What he creates is a hollow bottle shape known as a muff. He then cuts both ends of the bottle away to create a cylinder. While the muff is still hot, the glazier slices down the side of the muff length wise, and then flattens out the muff to create a flat sheet (Lee, Seddon, Stephens, pp 180,181).

The second method is called the sheet or crown method. Here the glazier gathers a parison onto a pontil and blows, shaping the glass as in the muff method. Once the desired shape is achieved, a second pipe is attached to the other end and the first pipe removed. The glass (crown) is rotated until it becomes flat and large. The crown is then removed from the second rod. The center of the crown forms an excrescence known as a bulls-eye. The resulting glass from both of these methods often had air bubbles and an uneven texture and thickness due to cooling and fabrication (Lee, Seddon, Stephens, pp 180,181).

Color of glass

The texts tell us that the color could be controlled by adding metal oxides to the glass. Red was made by adding iron oxide, green with copper, blue with cobalt, yellow with manganese (Brisac). Dr. Royce-Roll of the University of Alfred did research on this topic. His research was based on the methods of Theophilus to see if he could re-create the colors used in Theophilus' time. He went so far as to make a scaled down version of kiln who's design was based on an early 14th century furnace. What he found is that the colors may not have all been created by adding different oxides as the history texts imply. He found that the impurities in the materials that were used in the creation of the frit in concert with heating the glass in either a reduced (oxygen poor) environment, oxidized (oxygen rich) environment, or a combination (alternating) of reduced and oxidized environments caused the color differences in the glass. Beachwood ash contains a high concentration of manganese. It is these oxides of the manganese that produce the wide varieties in color. The manganese found in the ash can produce purple (oxidation), yellow (reduction), and pink (combination of oxidation and reduction). It was difficult to reproduce the colors the same from batch to batch because the concentration of manganese varied from tree to tree. With the addition of copper oxide you can produce red, green and blue glass. If you look through Theophilus' manuscript, the only oxide that is mentioned is copper oxide. Also because of these impurities in the raw materials, clear glass was very difficult to make (Royce-Roll, The Colors of Romanesque stained glass).

One of the problems with colored glass or pot glass is that it was not transparent enough to let much light in such as the color red. This problem was overcome by a method called flashing. Here a very thin layer of colored glass is fused on top of a clear piece of glass. It was also discovered that if several pieces of colored glass were layered, the top piece could be etched away to allow the underlying color to come through increasing the amount of detail an image in a piece of glass could have (Stained Glass msn Encarta p1).

CREATING A PATTERN

Now lets describe how Theophilus outlined how he made stained glass windows. Once the design of the window was decided upon, a cartoon or sketch was created of the window. whitewash board – a smooth board that was covered with chalk and wetted down (Theophilus, pp 47). This included the glass shapes and whatever images were to be painted on the glass. When the glaziers were done with the project they were working on, the board could be painted over for the next project.

CUTTING THE GLASS

The glazier then chose the glass in the colors that were available to him. Each piece of glass to be cut was placed over the cartoon and the needed shape was traced onto the glass with wet chalk. In order to cut the glass, the glazier took a glowing hot dividing rod and placed it upon the glass where it needed to be cut. When a small fissure appeared in the glass, the rod was drawn along the line, lengthening the fissure or crack until the piece was fully cut. To refine the shape of the cut glass, the glazier used a grozing rod to break away small bits of glass. A grozing rod is a piece of metal with slots cut into it matching the thickness of the glass. To smooth the edges the glazier used another piece of glass or a grindstone (Lee, Seddon, Stephens, pp 181).

STAINING THE GLASS

At this point any painting that was to be done on the glass was done then fired in a kiln to fuse the paint to the glass. Theophilus used a combination of one third copper oxide, one third powdered green glass, and one third powdered blue glass (Theophilus, pp 49). The glass we already have. The copper oxide was made by taking copper and placing it into a furnace, and then burn it. This yielded a black powder. All three ingredients are mixed together and bound by either urine or wine. For each level of detail several firings must be done. First a darker wash was used to create the details. The glass is fired to adhere the enamel to the glass. Next, lighter wash is used to create shadows. Lastly, the highlight lines are added and again the glass is fired. Depending on the effect that needs to be achieved, highlights can be created by taking a stick and dragging it through the enameling while it is still wet or sopping it up with a rag to create a texture (Valldeperez, pp 90-94).

Around 1300 A.D., silver staining came into use. The staining (silver nitrate, gamboge gum and diluted with water) created hues of yellow and was used for haloes and crowns. It was discovered that by using silver staining on different colored glass, the glazier could make different colors from a single colored piece of glass (Lee, Seddon, Stepens, pp 184). An example would be silver staining on blue glass to create green colors used for trees and grass. Once the painting was done, the glazier then placed the pieces of glass into a kiln (clay vessels that set on top of iron rods) for firing. The kiln used beech wood for heat. The glass was placed onto iron sheets and covered with plaster. The kilns temperature was raised to about 1250 degrees. This fused the paint to the glass. The glass was then cooled slowly so that stress cracks did not form breaking the glass (Lee, Seddon, Stepens, pp 184). If a silver staining was used, it was added after the main staining was done. The silver stain was added to the side of the glass that faces outside as the silver stain is not affected by the weather. The firing temperature was about 1050 degrees.

CREATING THE LEAD CAMES

Once the glass was cut, the paint for the images fused, and the glass cooled, pieces could be assembled. Each piece of glass is fitted with lead strips called kames or cames. The cames are “I” or “H” channeled shaped strips that wrap around the edge of the glass providing the means of connecting each piece of glass together. To hold the inside glass we will use “H” channels, and for the outside pieces we will use “U” channels. The “H” channel cames are made of a heart (the center piece) and two leaves. The “U” channel is basically half of a “H” channel.

Theophilus proposed two methods in making his molds for the lead. The first method is to cast iron molds that are hinged at the end with an opening in the top. Molten lead is poured in the opening at the top. When full, the two halves are separated and you have lead came. The second method called for taking a flat piece of wood and marking it where the ends of the came should be. Then take a string soaked in ink and lay it across the length of the wood where you made your markings. Take a second flat piece of wood and press it down on the first. When separated a line will be drawn on both pieces of wood where you need to cut. Repeat this step with the second set of markings. The next thing to do is to take a knife and cut into the wood to the desired depth of the came along the lines you just created, on both pieces of wood. Next match the two sides up and bind them. Heat your lead and pour it into the mold. Let it cool and separate the two pieces of wood (Theophilus pp 53-56). You now have your H came. To create the U came, flip one of the boards around so that its flat side matches up with a cut side. Bind them together, melt your lead, and pour. Let it cool, separate the boards and now you have the U channel.

ASSEMBLING THE GLASS PIECES

Theophilus started with a center figure and worked his way outwards. A piece of glass was fitted into the lead came. Pins were placed around each piece to keep it from moving during assembly. The next piece of glass was fit into place next to the first. Again, the exposed lines were encased in lead and pinned into place. When all the pieces of glass were set in their proper spots, lead was placed around the entire outer edge of the piece (Theophilus pp 56). Not much has changed since then. Modern glazers assemble the glass in a similar manner (Valldeperez, pp 58-65).

SOLDER

The next step was to permanently connect all the pieces together using solder. Solder is a low melting metal alloy composed of lead and tin, cast into sticks. Theophilus used one part lead to five parts of tin (Theophilus pp 56) . But it has been shown that this may have been a personal preference. Some artisans used a 50 percent mixture of tin to lead. This mixture is by percent weight (Pizano May). Theophilus notes that you may cast the solder in the same molds that were used to create the lead came. After each junction of the lead cames is cleaned, a hot iron is used to melt the solder into the joints between the cames, locking the glass into place. Then the assembled piece is carefully flipped over and, the other side is soldered in the same fashion (Theophilus pp56-57).

WHITIING

Once the soldering was complete, the last step was to cement the piece. This was done by creating a mixture of powdered whiting (calcium carbonate), and linseed oil then rubbing this mixture under the edges of the lead. After the excess was removed and the glass dried, the window became waterproof and had a bit more stability to it (Art History Final Project).

SUPPORT

At this point the window itself was complete. In order to install the window a little bit more work had to be done. The next step was to install the banding wires. These are copper strips about 4 to 5 inches in length, soldered onto the leading and are used to secure the window. There are two types. One is called a division tie and is used to connect adjacent panels of windows. The division tie had one long strip of copper that twisted around a division bar along with the tie from an adjacent panel, holding the panels together. The second type has two strips of copper called a middle tie and is used to connect the panel to a supporting bar. The copper strips wrapped around the supporting bar, almost like a twist tie, adding extra support to the panels (Lee, Seddon, Stepens, pp.188-189).

INSTALLATION

The last step was the installation. The window aperture was cut so that the window will fit into a L shaped channel. The bottom piece gets set into first. The next piece gets set into place on top of it. To ensure a watertight fit, the lead on the top edge of the first panel was bent over and the bottom edge of the upper piece got placed over the top edge of the bottom panel. The two windows were loosely tied together. To give more support, bars were embedded into the cement in the window frame and stretched across the window aperture. The middle ties were used to attach the window to these bars. Once the full window was in place, the ties were tightened down securing the window. The very last step was to cement the window in place to ensure weatherproofing, and securing up the window (Lee, Seddon, Stepens, pp 188-189).

THE HISTORY OF STAINED GLASS UP TO THOPHILUS

There is a story that was told by Pliny the Elder (23-79 AD) of a ship carrying a cargo of natural soda that made shore for the night. Having nothing to hold their pots and pans on for cooking, the crew took several blocks of the soda and placed them over the fire. The blocks, mixed with sand began to heat up and the crew saw a strange liquid begin to flow. This was the discovery of glass (History of Glass Engraving, pp 1). Who knows if it is true or not, but it is an interesting tale. What we do know is that glass has been around for a very long time.

Colored glass has its roots as far back as ancient Egypt around 3000 years ago. The Egyptians pressed glass for perfume bottles, beads, and a wide variety of other uses. Glass was preferred over pottery. They discovered that by heating silica (sand, quartz) with potash, the silica could be fused. It wasn't until between 1554 BC and 1075 BC that the Egyptians discovered how to make clear glass. At this point in time they learned that they could cast this new glass into rods and while hot, mold them around sand cores to create vessels. The colors they created were more accidental than design due to the impurities in the materials they used. Color could be somewhat controlled by heating or cooling (Brisac).

The blowing iron came into use somewhere in the second century BC. This allowed the artisans to attach a blob of glass to the end of a tube and blow air into it. The glass could be easily shaped by heating, blowing, rotating, and then repeating the process again until the desired shape was achieved (Lee, Seddon, Stepens, pp 10).

By the first century AD, it was discovered how to make glass transparent and colorless. Color could be controlled by adding certain oxides.

The Romans had also been working with flat glass in the first century AD. They had inserted small pieces of colored glass into mounts for decoration. The Muslims used the flat glass to make mosaics in windows.

The earliest known pictorial glass is from records dating back to the 9th century. The oldest remnants were of a depiction of Christ's head from the Lorsch Abbey in the Rhineland (France) dated between the 9th and 11th century (Lee, Seddon, Stepens, pp 13). Medieval stained glass was not used to pass light but more to capture and reflect it and really did not take off until the Middle Ages in Paris. The Abbot Suger commissioned the windows for the Abbey Church of St. Denis between 1144 and 1151, starting the stained glass trend. Soon after that windows were commissioned for the Charters, Bouges, and Le Mans cathedrals. Stained glass reached its peak in the Middle Ages between 1130 and 1330 (History of Glass Engraving, pp 1). Popular scenes were iconic and religious. Another popular style is called a "rose" such as the one commissioned at St Denis. Most rose windows use one of two themes: either the glorification of Christ and the Virgin or Christ as the apocalyptic judge. Sources of inspiration of stained glass come largely from the Bible (Brisac).

Black Walnut Stain

I used the black walnut ink for making the mold for my lead came and solder, not on the glass itself. I have to give Dana Robertson, credit for providing the ink. Even though I did not make the Ink I took notes as she made it. NOTE WELL: When making black walnut ink wear gloves and old clothes as the ink stains everything.

The black walnut tree (Jeglans regia) is native to the Capathion Mountains in eastern Europe. It was introduced to the Americas via Spain through Chile and to California in 1867 (see Juglans regia L. pp 3of 6). Juglans nigra or Black Walnut is a hybrid of the European Walnut. (see Black Walnut – hybrid pp 10 of 14).

The ink recipe below is an amalgam of several recipes found in the Translation of Manuscript of Ibn Badis ca. A.D. 1025 (Levey pp18-21), and experimentation.

The Recipe is as follows.

1) Shuck green outer layer from nut or pick up walnuts from the ground with the husks already rotted off being wary of any territorial squirrels.
2) Fill a bucket with the walnuts & top of bucket with water (this batch had 35 walnuts).
3) Soaking the walnuts in water releases the tannins from the walnuts. The batched used for this project had been soaking for five months.
4) Place all the water now brown from soaking walnuts into a pot with some of the walnuts (this batch yielded about 19.5 cups).
5) Boil the walnut and water combination to release the last bits of tannin.
6) Strain walnuts from liquid and return liquid to pot.
7) Reduce ink by continuing to boil.
8) Every half hour test for darkness. This batch boiled for two hours.
9) When satisfied with color add 1 tsp gum Arabic, 1 tsp kosher salt, 1 tsp vinegar.
10) Let settle overnight.
11) Strain out silt and solids.
12) Put ink into bottles.

This batch yielded about 12 four ounce bottles.

References

Books:

Brisac, Catherine. “A Thousand Years of Stained Glass”. Doubleday & co, Inc. Garden City, N.Y.; 1986.
*This is a great source for examples of glass, history and procedur*e

Child, Heather, “Heraldic Design”, G. Bell and Sons LTD. Baltimore, MD, 1998.

Cornelius S. Hulbert Jr.; Cornelis, Klien, “Manual of Minerology 19th ed.”, John Wiley & Sons, New York, 1977.

Davies, “A Complete Guide to Heraldry” Thomas Nelson & Sons LTD, London, W.I, 1969. *Great heraldry source.*

Liban & Mitchell, “Cloisonne’ and Jewelry Making”, Dover Publications, Inc, New York, 1989.

Lillich, Merdith Parsons, “ Stained Glass Before 1700 In Upstate New York”, Miller Pulblishers, London, 2004. *Fantastic source for research information on glass in NY.*

Lee, Lawrence; Seddon, Georg; Stephens, Francis; “ Stained Glass”; Crown Publishers, inc.; New York, 1976.

Mcgrath, “The Encyclopedia of Jewelry Making Techniques”, Running Press, Philadelphia, 1995, PP 52-59.

Raguin, “ Stained Glass from its origins to present”, Quintet publishing Limited. New York, NY, 2003

Theophilus “De Diuersis Artibus” translated from the latin by C.R. Dodwell;Thomas Nelson & Sons Ltd. 1961. ***Primary source for this paper.***

Valldeperez, Pere; “Stained Glass”, Barron’s Educational Series inc, New York, 2001.

Journals:

Hayward, Jane; “Painted Windows”; The Metropolitan Museum of Art Bulletin, New Series, Vol 30, No. 3, Stained Glass Windows. Dec., 1971-jan., 1972, pp 98-101.

Levey, Martin, “Mediaeval Arabic Bookmaking and its Relation to Early Chemistry and Pharmicology” Transactions of the American Philisophical Society, New Ser, Vol. 53 No. 4. (1962), pp. 1-79.
Source for ink recipes.

Rambusch, Viggo; “Preservation and Restoration of Leaded Glass Windows “ Bulletin of the Association for Preservation Technology, Vol 13, No 3 Architectural Glass: History and Conservation. 1981,pp 11-17.
Good source for information on period lead came analysis.

Royce-Roll, Donald; “Twelfth Century Stained Glass Technology”, Avista Forum, Volume 10, Number 2/Volume 11 Number 1, Fall 1997/Spring 1998
Great analysis of medieval glass color.

Royce-Roll, Donald; “The Color of Romanesque Stained Glass”, Journal of Glass Studies, Volume 36,1994
Good follow up to last reference.

Simburger, Neelmeijer, Schalm, Fredrix, Schreiner, De Vis, Schryvers, and Caen; “The colour of silver stained glass-analytical investigations carried out with XRF, SEM, TEM and IBA” The Journal of Analytical At Spectrocom, 2002,17 321-328.
Very in depth analysis of the different compounds of silver stain.

Techniques of Stained Glass: Illustrations to the Introduction, Metropolitan Museum of Art Buletin, New Series, vol. 30, No. 3, Stained Glass Windows. Dec.,1971-Jan., 1972,pp. 102-109.
Shows drawings of what a medieval glass shop might look like.

Zerwick, Chloe. A Short History of Glass. The Corning Museum of Glass, Corning, N.Y.;1980.
Good history of glass but not really for stained glass.

WEB SITES

Art History Final Project
http://loonfoot.com/ian/stained%20glass/learningmodule/index.html
Great source for procedure and supports the information from Brisac and Lawrence.

Armor & Fish Man
http://www.time.com/time/magazine/article/0,9171,7252457-1,00.html
good article on the history of Bashford Dean

Black Walnut
http://www.na.fs.fed.us/pubs/silvics_manual/volume_2/juglans/nigra.htm

Chapter 3: Electrochemistry- make a solar cell in your kitchen
http://sci-toys.com/scitoys/scitoys/echem/echem2.html
production of black copper oxide

Fleur-de-lis
http://www.answers.com/topic/fleur-de-lis

The Fleur-de-lis
http://www.heraldica.org/topics/fdl.html
good article on the background and history of the fleur-de-lis

History of Glass Engraving
http://diamondpoint.fsnet.co.uk/history.htm

Juglans regia L.
http://homecooking.about.com/gi/dynamic/offsite.htm?zi=1/XJ&sdn=homecooking&cdn=food&tm=51&gps=200_284_1020_595&f=00&su=p284.7.420.ip_p284.5.420.ip_p674.0.400.ip_&tt=2&bt=1&bts=1&zu=http%3A//www.hort.purdue.edu/newcrop/duke_energy/Juglans_regia.html
an overview of the English Walnut

Medieval window lead cames from Pedralbes (Catalonia) and Altenburg (Germany): a comparative study.
http://www.fcpcrv.com/images/pdf/article_friburg-1999.pdf
Great source for background on the composition and development of lead came

Silver Nitrate Manufacturing
Silver Nitrate Manufacturing
How to make your very own silver nitrate and the steps needed to be resesitated.

Stained Glass – a Brief History: the Stained Glass Museum.
http://www.stainedglassmuseum.com/briefhis.htm
Good reference for history overview.

Stained Glass
http://uk.encarta.msn.com/text_761565194_0/stained_glass.html
Good history summation.

Stained Glass answers.com
http://www.answers.com/topic/stained=glass?hl=lead&hl=came
Brief but has a lot of information.

Topic 5 Chemical Solutions
http://www.uq.edu.au/_school_science_lessons/topic05.html
Good information on solder

The History and Craft of Stained Glass
http://www.bbc.co.uk/history/lj/churchlj/stained_technique.shtml
Good history summation.

The Colouring of Stained Glass
http://www. Ihbc.org.uk/contect_archive/48/colouring_dir/colouring_s.htm

The Method to the Madness: Creating Glass in the Medieval Period
http://oak.atlantia.sca.org/19/glass.html
Good overview paper

The restoration of Medieval Stained Glass
www.international.icomos.org/publications/93stain5.pdf

http://www.metmuseum.org/toah/hd/glas/ho986.285.1,2.htm – examples of 13th century windows

http://www.ariadne.org/studio/michelli/sgtechniques.html - nice links to examples