What's On the Surface Does Matter: The Conservation of Applied Surface Decoration of Historic Stained Glass Windows

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Submitted in partial fulfillment of the requirement for the degree
Master of Science in Historic Preservation

Graduate School of Architecture, Planning and Preservation

Columbia University

May 2014

Abstract

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A stained glass window is both an architectural building element and an individual work of art. Like architecture, a stained glass window is composed of a variety of materials, mainly glass, lead, and surface decoration, each of which has its own conservation issues. Surface decoration, which includes vitreous glass paint, silver stain, and enamels, is the component of a stained glass window that is sometimes underappreciated. While it may not pose a major threat to the physical stability of the window or the safety of the window's environment, it is the decoration that defines the windows as works of art, with imagery that holds the window's history, including a direct view into the traditions, ideals, and beliefs of the people of their time.

The conservation of the surface decoration of stained glass windows has never been fully analyzed, and both glazing and conservation professionals are constantly seeking information regarding the history of the materials and techniques used in order to create or restore a stained glass window. With conservation, the methods and techniques used to maintain and conserve the decoration will vary depending on a number of circumstances, including the location of the window, the history and traditions of the people involved, and the tools available to the conservators. As with all conservation fields, there are also ethical considerations to address in order to be sure that the authenticity of each work is maintained. For this history, it is also important to note the past restoration techniques used on these types of decoration, as well as what is being used today. This includes successes and failures, both of which bring essential information to the conservator. Each window brings with it an entirely new

history and set of decoration conservation problems so there are no universal solutions for this field.

Stained glass is a fascinating field because it combines the worlds of art and architecture with a single object and the surface decoration plays an important role in this. By analyzing the history and techniques of these three surface decorations, it is possible to not only preserve an underappreciated element inherent to these historic stained glass windows, but also the overall aesthetic of true works of art that serve to enhance the buildings in which they reside.

Acknowledgements

This thesis would have been impossible without the constant encouragement and advice from my advisor, George Wheeler, and my two readers, Drew Anderson and Julie Sloan. I am sincerely grateful for their guidance and endless support throughout this entire process.

I would like to dedicate this thesis to my family and friends, who keep me calm and grounded while providing much needed love and support. A special thanks to my parents, who are always there for me and continuously remind me to never stop believing. Thank you for everything.

Finally, I would like to thank my golden retriever, Briggs, who reminded me of the importance of taking a break every now and then. His companionship, often sitting across my lap, was a constant reminder of the love and support I have around me always.

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I. Introduction

Illuminated by transmitted rather than reflected light, stained glass inspired a special sense of wonder and mystery that was rich in symbolism—heavenly light from the sun traversing matter to produce radiant images that evoke the mystery of creation and the passage of time as light rises and falls in a window over the course of each day.[1]

Timothy Potts, Director of The J. Paul Getty Museum

Stained glass windows are not only a practical element to a building but each one is also a unique work of art. Similar to architecture but unlike many works of art, they comprise several different components and materials, all of which need individual attention and care. The three main components of a window are: (1) the glass; (2) the lead; and (3) the surface decoration. All three are integral to a stained glass window and therefore deserve equal attention when it comes to preservation. Decoration is the component of a stained glass window that is sometimes underappreciated. While it may not pose a threat to the physical stability of the window or the safety of the environment in which the window resides, the paint is essential to these windows as works of art. It is the imagery that they present that holds the majority of the history of the windows, including a direct view into the traditions, ideals, and beliefs of the people of their time. Without the imagery, most of the meaning behind these windows to the past would be lost.

Unfortunately, much has already been lost; stained glass is considered by many in the conservation industry to be one of the most vulnerable of art forms[2]. The preservation of these windows is crucial to the retaining of valuable information and insights into the past. In terms of conservation, the methods and techniques used to maintain and conserve the paint will vary depending

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[1] Raguin, Virginia Chieffo. *Stained Glass Radiant Art*. 2013: 7.
[2] Brown, Sarah. *Glass-Painters*. 1991: 4.

on a number of circumstances, including the location of the window, the history and traditions of the people involved, and the tools available to the conservators. As with all conservation fields, there are also ethical considerations to address in order to be sure that the authenticity of each work is maintained. It is important to note the previous techniques used as well as what is being used today; successes and failures are both important to understanding the nature of the materials with which one is working. Stained glass is a fascinating field because while the windows themselves are viewed as works of art, they are meant to be placed within an architectural setting thereby combining the worlds of art and architecture with a single object. By analyzing the history of glass painting, it will be possible to not only preserve an underappreciated element inherent to these historic stained glass windows, but also the overall aesthetic of true works of art that serve to enhance the buildings in which they reside.

The Creation of a Stained Glass Window

Before delving into the history of glass painting, it is important to understand these windows as a whole, including how the different elements interact with one another. Every stained glass window begins with a design that is then drawn as a cartoon, or an outline of the window's design to be formed by the glass pieces and over which the glass is cut (Figures 1 and 2). Before the introduction of paper, it was usually drawn on a whitewashed table or plaster floor.

Figure 1. A medieval glazier's table used for design outlines for stained glass. Image from Sarah Brown, *Stained Glass: An Illustrated History*. 1992: 18.

Figure 2. An early 16th century cartoon and resulting stained glass panel. Image from Sarah Brown, *Stained Glass: An Illustrated History*. 1992: 23.

Often a charcoal drawing was done first and then the final one was fixed with ink. In the 14th century, parchment and paper were available for this purpose[3]. Accuracy was essential in this process because the final product fully depended on this drawing. The cartoons were typically very detailed and precisely organized, using a "color by numbers" system to show each artisan which shape was each color. In addition to this type of system, each piece of glass was usually given a letter or number that was either painted or scratched on the back; this made sure that no matter how many different people worked on a window, each piece would always end up in the correct location. These drawings were assets that were often handed down or reused. Cartoons were often reused for different projects but also for designs that were meant to be repetitive in a single project. On the other hand, there are also many ways to create several windows based on the same cartoon design. These techniques varied from changing details and altering inscriptions to reversing certain elements, moving the colors around, and changing painting styles. Therefore, one cartoon has a myriad of possibilities.

Next, the glass needed to be cut. In the 12th century, glass cutting was done primarily with two tools: (1) a hot iron and (2) a notched iron bar called a grozer, which was a tool that leaves a "nibbled" edge. The iron tool was thicker at one end; this end was heated and then applied to the glass where it was to be cut. Water was then dropped onto the heated area in order to produce thermal shock. The result is a crack along the surface, which then allows for the glass to be easily broken by hand. The grozer is then used to chip away at the broken edges to create intricate shapes. In the 16th century, the iron was replaced with the diamond-tipped glass cutter but the grozer remained in use[4]. Because the glass sheets being produced at the time were very thin and therefore prone to easily shattering under stress, the diamond was used in the cutter because it required less pressure to cut the glass than the iron and the grozer. This saved time, money, and glass. Furthermore, in the 19th century, the tungsten-carbide wheel was introduced, having all of the cutting capabilities of the diamond cutter plus the ability

[3] Cannon, Linda. "History of the Techniques and Materials" 1991: 61.
[4] Ibid, 64.

to make many more intricate cuts[5].

After being cut, the glass can be decorated, either by painting or staining. The materials, techniques, and styles used for painting and staining glass are the primary focus of this thesis and will therefore be discussed in detail in the chapters to follow. The three main types of surface decoration are (1) vitreous glass paint, (2) silver stain, also called yellow stain, and (3) enamels. While these are the three main types, two other techniques of stained glass decoration are insertion and the addition of jewels. Insertion is a technique first seen around the late 15th and 16th centuries[6]. Glaziers would abrade the glass such that a hole was cut through it. The hole was filled with another piece of glass of a different color that was perfectly cut to fit in this hole. The original piece and the new inserted one were separated by a thin strip of lead (Figure 3). Finally, in many cases, jewels can also be added to the glass but because they are difficult to adhere to the surface, they often fall off (Figure 4). Both of these methods can be used as creative ways to add color to a window without the need of firing in a kiln.

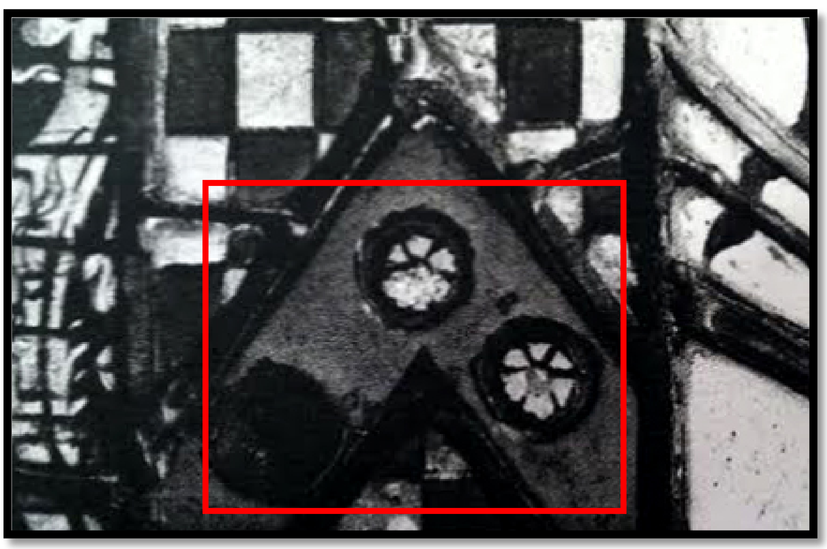

Figure 3. Inserted circles in a stained glass window. Image from Linda Cannon, "History of the Techniques and Materials." 1991: 81.

[5] Ibid.
[6] Ibid, 80.

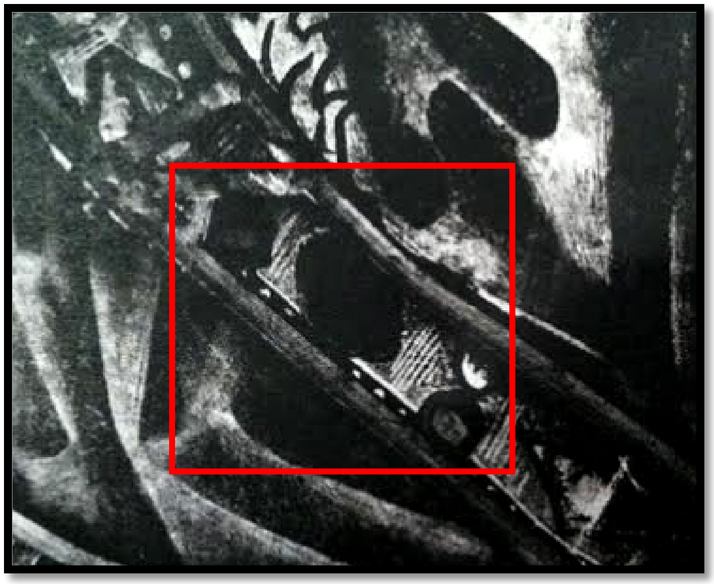

Figure 4. Jewels on a stained glass window. Image from Linda Cannon, “History of the Techniques and Materials.” 1991: 81.

Once all of the pieces were decorated, the final assembly of the window begins with the lead cames. Lead has proven to be the best material to hold together the glass pieces of a window by its survival over the centuries. Lead in general is soft and malleable, making it easy to adapt to very intricate shapes; at the same time, lead is strong enough to weather the force from wind. It also has a low melting point and can be soldered together with a lead-tin alloy that will not harm the glass. Lead does not weather readily or corrode easily. While the metal used in the windows is between 94-100% lead, sometimes tin, antimony, silver or copper are added to enhance the strength and resistance to corrosion[7].

Between the 12th and 16th centuries, cames were cast[8]. This process was done in either wood or iron pre-shaped molds or a wooden box lined with sand and twigs. The latter of the two resulted in cames with a rough and uneven surface. The upper and lower sections of the cames were usually rounded but at times were planed into a V-shape. The heart of the lead was very thin and the space on

[7] Ibid.
[8] Ibid, 83.

either side was concave. Approximately around 1500, milled lead was used[9]. For this process, short, thick pieces of lead, called pigs, were cast in a mold. Then these pigs were squeezed between two wheels which pulled the lead through the milling machine; this resulted in long, thin cames. This process usually had to be done several times in order to obtain the desired length and thickness; however, it is important to note that after each draw, the lead becomes more hard and brittle so there is a limit to the amount of times the lead can survive the process. Each milling machine produced cames with distinct markings from the wheels. This is helpful in potentially identifying where and when the cames were produced. Cames were available in a number of shapes and sizes, each used for particular technical and aesthetic needs (Figures 5 and 6).

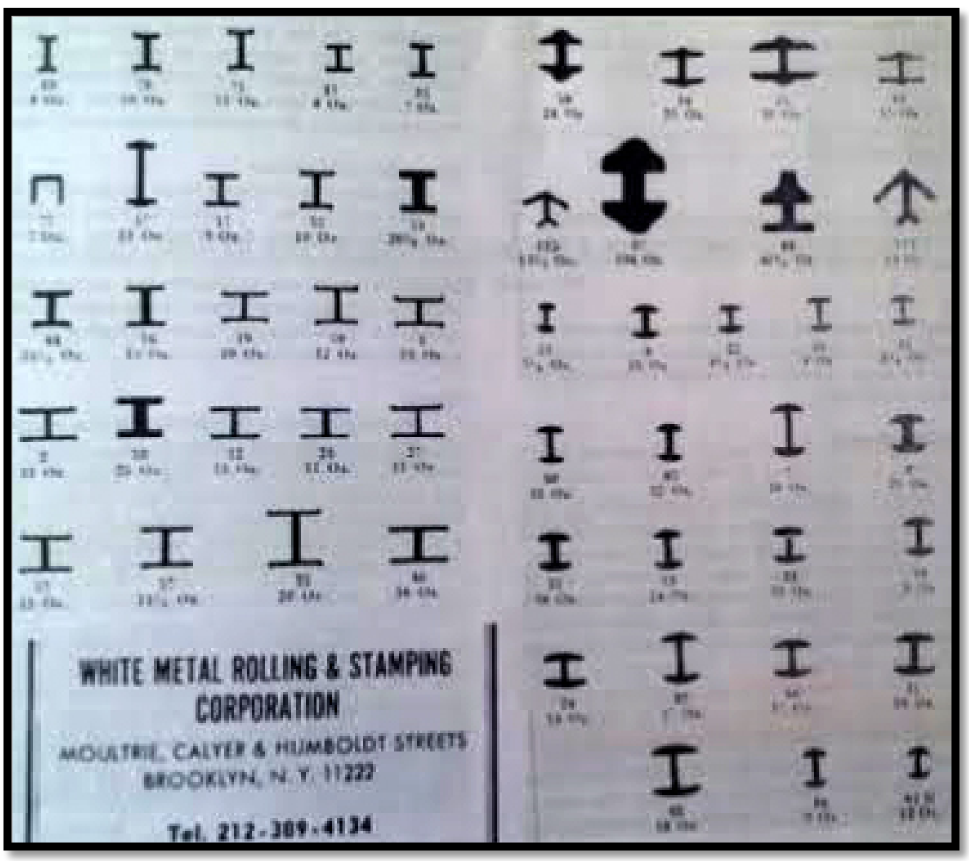

Figure 5. A varied selection of different lead came shapes. Image from Viggo B.A. Rambusch, “Preservation and Restoration of Leaded Glass Windows.” 1981: 13.

[9] Ibid, 84.

Figure 6. Lead cames in a stained glass window. Image from The York Glaziers Trust, "Illustrated Glossary."

Before the final process of installation, a window must be waterproofed with putty, also called cement. This material comprised the following: boiled linseed oil; whiting; plaster of Paris; turpentine; red, yellow, or white lead; lampblack; metallic salts; and pigments[10]. Over time, the putty can harden, crack, and fall out of the window, leaving spaces for rainwater to gather and corrode the glass under the leads. This water can also cause corrosion of the leads, which can be made weaker from the loss of putty; wind forces and the downward pull of gravity will also affect leads and can be exacerbated by already weakened leads. The putty offers the window some extra support and flexibility and without it, the lead can deform and crack; this will ultimately result in massive stresses on the glass of the window, which will lead to breaks in the glass.

In terms of installation, saddle bars are used to support the window and are fastened to it with copper or lead ties. These bars are then held in place at the sides of the window by channeling them

[10] Ibid, 86.

into the surrounding stone. As early as the 11th century, windows were made as multiple smaller panels as opposed to one large panel[11]. The smaller panels are usually put together in one of two ways: (1) set into an iron grid called a ferramenta (Figure 7); or (2) placed on top of each other and supported by larger saddle bars and T-bars (Figure 8).

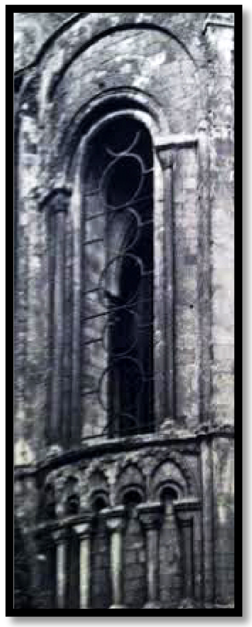

Figure 7. Ferramenta on the Canterbury Cathedral, UK. Image from Sarah Brown and David O'Conner. *Glass Painters*. 1991: 64.

Figure 8. A saddle bar and ties used for supporting a stained glass window. Image from CVMA Glossary. 2010.

[11] Ibid.

Before the mid-1100s, the overall size of a window was limited because the surrounding walls had to be sturdy enough to support the roof of the building[12]. With the introduction of internal and external architectural supports, including flying buttresses, the problem of a lack of support for large-scale windows was solved. As a result, expansive windows, some even ranging from floor to ceiling height, were made possible. Unfortunately, other problems remained. Old windows have almost always been re-leaded several times, during which, glass repairs, replacements, and re-paintings were also done. In some cases, complete reconstructions were performed.

While this process for constructing a stained glass window has remained mostly consistent over the course of history, the admiration for the amount of skill and effort that it takes to complete such windows deserves to be substantially increased over time. With increasing pollution and vandalism, however, stained glass windows are still in danger today. Fortunately, the international *Corpus Vitrearum Medii Aevi* (CVMA), formed as a result of the massive losses during the last world war, is focusing on preserving as many of these windows as possible. In terms of conservation, the following statement by Sarah Brown summarizes the situation today—"the survival of the works of the medieval glass-painters will depend on the skill and the craftsmanship of today's conservators."[13] In addition, Linda Cannon, author of *Stained Glass in The Burrell Collection*, quotes the CVMA Technical Committee in their discussion of the importance of conservation:

> Research and conservation are basically invisible activities. The prerequisites for conservation should not only include technical study, but also art historical understanding; the historical development of artistic aspects, and of available materials and techniques (types of coloured glass, lead profiles, working methods, manner of painting, special technical characteristics and so on)…Especially important is the history of the glass, because a knowledge of former restorations can be particularly informative about the nature of any damage it has suffered…the restoration and conservation of monumental stained and painted glass requires…attention and painstaking care.[14]

[12] Ibid.
[13] Brown, Sarah and David O'Conner. *Glass Painters*. 1991: 70.
[14] Cannon, Linda. "History of the Techniques and Materials." 1991: 87.

The purpose of this thesis is to attempt as best as possible to compile a history of the materials and conservation techniques and problems for the three main forms of surface decoration. Five main causes for the deterioration of paint have been identified: (1) chemistry of both glass and paint; (2) methods of application and firing; (3) environment, including moisture and condensation; (4) pollution; and (5) over-cleaning. The application of paint and/or stain to the glass surface is one of the most important developments in the history of stained glass. It "both released its enormous decorative, devotional and didactic possibilities and raised its creators to the status of artists as well as artisans."[15] In addition, Brown writes that "the painting carries all the details of the design, ornament and shading, but it has a practical function too in carefully modulating the light."[16] Whether one calls it "stained glass" or "painted glass," the surface decoration is essential; therefore, in order to maintain the inherent meaning of the windows, its conservation is just as essential.

[15] Brown, Sarah and David O'Conner. *Glass Painters*. 1991: 8.
[16] Ibid, 59.

II. A History of Glass for Stained Glass Windows

The house of God…a human eye cannot decide on which work it should first fix its attention…if it gazes at the abundance of light from the windows, it marvels at the inestimable beauty of the glass and the variety of this most precious workmanship.[17]

Theophilus

The one particular feature which makes glass truly special is its ability to assume any color imaginable while at the same time remaining translucent. Hence, it is only logical…that because of its translucency, glass long has been used as an architectural element; it can both admit light into a building while at the same time protect the interior from the elements. But glass has one major disadvantage in this regard: it is extremely fragile and thus, strictly speaking, it is unsuitable for use in buildings. Because of their extreme brittleness, glass windows break as a result of impact or stress, and must, over time, frequently be replaced or restored.[18]

Sebastian Strobl

In order to understand the nature of glass paint and the techniques used in the creation of stained glass windows, it is essential to first understand the substrate upon which the paint is placed—glass. Being one of the main components of a stained glass window, glass has a direct effect on the firing and application of glass paint. The techniques and methods used by early glassmakers were passed down from masters to apprentices; there were very few written records. While a few documents exist from the 12th to the 19th centuries, which provide insight into the history of the field, much early knowledge of these methods has been lost.[19]

[17] Theophilus. *On Divers Arts*. 1963: 79.
[18] Strobl, Sebastian. "From Plumber to Glazier." 2010: 34.
[19] Cannon, Linda. "History of the Techniques and Materials." 1991: 49.

Where to Start?

The beginnings of glass are relatively obscure but the two predominant theories both consider its discovery an accident. Many experts believe in Pliny's tale of its accidental discovery by Phoenician sailors. He writes that after leaving a fire on the beach overnight, the sailors woke to find that the sand and soda mixture had been melted by the fire's heat.[20] The resulting mass had hardened into glass. On the other hand, many other professionals believe that it was potters who truly discovered glass by accident when they were firing their vessels. Regardless which story one believes, there are a few definite facts about glass: (1) glass is a very old material; (2) glass-making as an art is fire-based; and (3) glass was found in nature before it was created artificially. The use of obsidian, a glass formed from volcanoes, dates all the way back to the Stone Age (ca. 3,500,000-5,000 B.C.) when it was shaped into arrowheads, spearheads, and knives[21].

The invention of the blowpipe is one of the most important in the glass industry, occurring somewhere between 300 and 20 B.C.[22] C.J. Phillips writes that "it caused an industrial revolution which changed glass from a luxury into a necessity. It gave revealing glimpses of the true capabilities of the material and made possible the quantity production of glass articles in shapes and designs previously impossible to produce."[23] With this hollow pipe, it was possible for the glass-makers to blow air into the glass to create hollow pieces and objects; this ability to create an almost infinite variety of shapes was a significant advance in the field.

The fall of the Roman Empire toward the end of the 5th century led to changes for flat glass in architecture. During this time and subsequent centuries, glass was used predominantly in church settings and in addition to the use of color already employed by the ancient Romans, images and

[20] Stained Glass Association of America. *History of Stained Glass*. 2012.
[21] Phillip, Charles John. *Glass, the miracle maker.* 1948: 3.
[22] Ibid.
[23] Ibid.

symbols were now painted onto the glass. It was here that glass moved from being strictly a means of protection from the weather and became a means to deliver a visual message. Unfortunately, not much is known about the first five hundred years of painted and colored glass; while evidence exists of painted and colored glass from these centuries, there are no reliable sources to directly document their history and so it remains shrouded in mystery[24].

Stained glass has been around almost as long as window glass. Charles Phillips writes that:

> One of the earliest records of the use of stained-glass windows was made by Adalberon, Bishop of Reims, when rebuilding the cathedral in A.D. 969-988. Slowly, year by year, and century by century, the use of stained glass in church windows grew until, during the later Middle Ages, no church could be considered complete without this form of decoration. These glorious stained-glass windows were more than windows alone, and more indeed than a form of decoration, no matter how beautiful. They were literally sermons in glass, sermons in color for an illiterate age.[25]

The use and popularity of glass continued to spread and by the end of the 16th century, the glass industry was prominent throughout Europe. The 17th century brought a number of important developments that impacted the field, as did the Industrial Revolution in the 18th and 19th centuries. The creation of coal furnaces transformed glass-making from a rural to an urban industry due to the increased mechanization of the processes. In addition, during the 17th century, glass came to America with the first English settlers at Jamestown, Virginia[26]. In recent times, namely the 20th century on, the most important advancements to the industry came in the form of efficiency. The mechanical processes used in glass production were altered and enhanced with modern advancements and the understanding of the need to control the physical and chemical components of the processes became essential. The history of the manufacture of window glass and these different advancements in the different processes will be discussed later in this chapter.

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[24] Strobl, Sebastian. "From Plumber to Glazier." 2010, 34-35.
[25] Phillip, Charles John. *Glass, the miracle maker.* 1948: 3.
[26] Ibid, 15.

The history of glass is long and detailed and it would be impossible to cover it in its entirety in this thesis. For the purposes of understanding glass used for stained glass windows, both medieval and modern, it is important to look at the types of glass used for these windows and the different manufacturing methods used to create them. Antique glass consists of two basic subcategories: (1) full antique glass and (2) drawn antique glass, also called semi-antique. Full antique glass refers to glass that is produced by the mouth-blown cylinder method. The craftsmen blows a glass cylinder, which is split lengthwise, separated, re-heated, and folded out to create a flat sheet. Antique glass usually includes linear striations and a pristine surface. There is also drawn antique glass, which is also known as machine antique or new antique glass. It is created by the vertical draw method. This method consists of molten glass being pulled up through a refractory block that floats on the glass surface. The annealing lehr is located vertically over this draw chamber. In general, drawn glass is more pristine than rolled glass due to the fact that its surface is untouched during its formation. Any textural striations are applied mechanically and the cost to create drawn antique glass is less than that to create full antique glass[27].

Rolled glass can be created in two ways: the single roll method or the double roll method. In the single roll method, molten glass is poured onto a metal table and a single metal roll flattens the glass into a sheet; this can be called "hand-cast" sheet glass[28]. In comparison, the double roll method has the molten glass passing between two rotating metal rolls, forming a sheet. Scribed antique glass is made using this technique, creating a simulated full antique glass with its linear striations engraved into the glass surface when hot.

In addition, cathedral glass is also created using either of these rolling techniques. It is a "cast and rolled glass, and is furnished in smooth surface or in an ornamental 'hammered' effect produced by

[27] "Art Glass Dictionary." *Spectrum Glass Company.* 2014.
[28] Ibid.

rolling a pattern into it while it is still plastic."[29] It is a monochromatic, transparent glass that can be smooth or textured, depending on the rollers used. Unlike antique glasses, cathedral glass is of a uniform thickness due to the mechanical nature of its creation; it sought to have the textured look of antique glass while allowing the glassmakers to create the glass more efficiently. This type of glass was brought into the industry around the mid-19th century with James Hartley, who developed the "Hartley's Patent Rolled Plate" glass in England.[30] Cathedral glass is still produced and used today.

Opalescent glass is another type of glass, used in the 19th and 20th centuries by stained glass manufacturers like Tiffany and La Farge. A material, such as fluorine or phosphorus, is added to the mixture of raw materials for the glass in order to cause an emulsion, thus resulting in opacity in the finished glass. The degree of this opacity depends on the glass composition and temperatures in the manufacturing process. There are two types of opalescent glass: (1) solid color and (2) mixed. Solid color opalescent glass is a single-colored, opaque sheet that is both colored and opacified. On the other hand, mixed opalescent glass is white glass mixed with one or more colors in order to produce a multi-colored, streaked sheet. For mixed opalescent glass, light transmission will change depending on the mixture of white and colored glasses[31].

Amidst all of these types of glass and manufacturing methods, both discussed here and later, perhaps the most important thing to remember is that glass-making was not an exact science for the majority of the history of stained glass windows. The science behind glass-making was not established until the 20th century and while proportions were essential to medieval glass-makers, precise measurements were not taken. As a result, each mixture of glass has a unique chemical composition; while the basic ingredients were approximately the same, even the slightest variation can have an effect on the final glass product. This, in turn, makes the issues of conserving the decoration on the glass all

[29] PPG Industries. *Glass; history, manufacture and its universal application*. 1923: 147.
[30] Smith and Fidler. *Notes on Building Construction.* 1879: 426.
[31] "Art Glass Dictionary." *Spectrum Glass Company.* 2014.

the more difficult because with each piece of glass potentially having a different composition, it may be very difficult to know exactly what is causing the deterioration.

Raw Materials

The chemistry of glass is quite complex but the three main ingredients in glass are formers, fluxes, and stabilizers. Formers make up the largest percentage of the mixture to be melted down into glass; in the majority of cases, the former is silica, (SiO_2), or sand. Fluxes are used to lower the temperature at which the former(s) will melt; both soda (sodium carbonate) and potash (potassium carbonate) are used for this purpose. Both of these are alkalis but the resulting potash glass is denser than the soda glass. Finally, stabilizers enhance the strength of the glass and protect it from water and humidity, which would attack and dissolve the glass; calcium carbonate, or limestone, is often used for this purpose[32].

According to the Corning Museum of Glass, the creation of glass starts with the combination of several components, the most common being: silica; soda; lime; potash; lead; boron; magnesium; aluminum; and iron. The ingredients typically come from, but are not limited to, the following sources: silica from sand and quartz pebbles; soda from soda ash (Na_2CO_3) and marine plant ashes; lime from chalk or limestone; and potash from inland plant ashes. In addition, the lead is found in nature as lead oxide or lead carbonate, boron is a modern component, and magnesium, aluminum, and iron are all considered impurities[33].

Table 1 below shows some of the most common glasses and their compositions.

[32] "Chemistry of Glass." *Corning Museum of Glass.* 2011.
[33] Ibid.

Table I. *Glass Compositions.* (In Weight Percentages)						
		Modern Soda-Lime-Silica	*Typical* Roman*	*Typical Baking or Laboratory*	*Optical High Lead*	*96% Silica*
Silica	SiO_2	73.6%	67.0%	80.5%	35.0%	96.5%
Soda	Na_2O	16.0	18.0	3.8	—	—
Potash	K_2O	0.6	1.0	0.4	7.2	—
Lime	CaO	5.2	8.0	—	—	—
Magnesia	MgO	3.6	1.0	—	—	—
Alumina	Al_2O_3	1.0	2.5	2.2	—	0.5
Iron Oxide	Fe_2O_3	—	0.5	—	—	—
Antimony Oxide	Sb_2O_5	—	1.5	—	—	—
Manganese Dioxide	MnO_2	—	0.5	—	—	—
Boric Oxide	B_2O_3	—	—	12.9	—	3.0
Lead Oxide	PbO	—	0.01	—	58.0	—

Table 1. Glass compositions of various glass types. Image from Brill, Robert H. "A Note on the Scientist's Definition of Glass." 1962.

As the table shows, modern soda-lime glass is composed predominantly of silica, SiO_2, (~74%), soda, Na_2O, (~16%), and lime, CaO, (~5%). Using soda, or in some cases potash, allows for the fusion of the silica at temperatures lower than its typical melting point whereas lime is used to create glass that is less likely to be attacked by water. The table includes an example of the composition of a Roman glass for comparative purposes. The three similar ingredients of the Roman glass and the modern soda-lime glass show the three main components of most glasses—silica, soda, and lime, each of which are comparable in both glasses despite the vast time difference. The main difference between the two is the impurities found in ancient glasses, which found their way into glass compositions in the form of raw materials or poor refractories; such impurities can include, but are not limited to the following: iron, manganese, antimony, and lead[34]. By the 19th century, the manufacturing of the ingredients of glass had been vastly improved, leading to purer components.

The sand or silica used for glass occurs in nature in geological deposits formed from the disintegration of silicate rock. Fragments are formed by being sifted and transported by water, which

[34] Brill, Robert H. "A Note on the Scientists' Definition of Glass." 1962: 132-134.

wears away the particles, giving them a round or angular shape depending on the amount of wearing away in the water. As a result, the chemical composition of the sand used will vary depending on the composition of the rock from which it was derived. Rocks that are composed mainly of quartz will result in very pure sand; however, it is more likley that the sand will also contain pieces of feldspar as well, which contains aluminum, iron and alkalis[35].

The first type of glass to be used for stained glass windows was potash-based. In the 12th century, demand for glass increased greatly and, with it, the need of more abundant supplies of ash. The forests of northern Europe provided plenty of beech ash for the job. Because of this, the centers of colored glass production (Figure 9) were found closest to forests with the following two properties: (1) an abundance of beech trees to provide the necessary ash; and (2) rivers to allow for quick transportation once the product was complete. Some areas that fit this description included the Rhineland, Normandy, Lower Burgundy, and Bohemia[36].

Figure 9. Operations of a medieval glass house. Image from Sarah Brown and David O'Conner. *Glass Painters*. 1991: 47.

[35] Rosenhain, Walter. *Glass Manufacture*. 1908: 38.
[36] Cannon, Linda. "History of the Techniques and Materials." 1991: 50.

It was during the Middle Ages that glass windows switched from potash-based to soda ash-based. This development was crucial to window glass because the soda glass would prove to be more durable than the potash glass. During the mid to late 14th century, the Black Death killed a substantial amount of the work force in the industry. This was another reason for the loss of many early methods and techniques in the field. It was during this time that much glass would prove to be unstable but by the 17th century, the soda glass was back on track. The glass produced at this time was notably more durable than that of the five previous centuries[37].

As with many materials, the ratio of the ingredients is crucial. Too much sand and the melting temperature of the glass would be too high and basically unattainable. On the other hand, too much ash and the glass would not harden and would be soluble in water. Lime was added as a third ingredient in order to stabilize the glass, harden it, and make it more durable[38]. The ratio of the lime to the mixture is also important because too much or too little will cause the glass to deteriorate. In addition, cullet, or pieces of broken glass, is also added to the glass mixture to help the final mixture melt together. Because there is no way to know the exact chemical composition of the cullet being used, the amount of cullet used in each mixture of glass can throw off the final glass composition, even if you know the precise ingredients and amounts.

The changes from potash to soda ash-based glass can be seen in a number of ways. While the sodium present in soda-glass made the glass stable, the potassium in beech ash made the glass more likely to corrode. The beech ash also contained varying amounts of lime depending on where the trees had grown and where they had been burnt down to ash; therefore, the lime in each mixture was hard to control and the glass quality was often very poor. Then again, beech ash did have a number of positive results as well. It contains both iron and manganese, “impurities” which under the proper conditions could result in a wide range of colors. While it is metallic oxides that technically color the glass, the

[37] Ibid.
[38] Ibid.

beech ash directly affects the color. With the right amount of heat in the furnace, supply of oxygen, and time that the mixture was molten, the following colors could be produced from beech ash: white, pale blue, green, yellow, amber, brown, flesh, pink, purple, and violet[39].

Glass Kilns and Furnaces

Fuel is a significant part of the history of glass-making furnaces. The earliest furnaces were fired by wood and the resulting ashes were used as potash for the glass mixture. During the early 1800s, wood and charcoal were the main sources of fuel but soon after, coal became the primary fuel used in the mid-19th century until the invention of the gas-fired kiln[40]. Natural gas is used as furnace fuel today.

Fire-clay is used to create the bricks that make up the glass-melting furnaces. Large blocks of fire-clay make up the floor of the furnace, on which the pots are placed. These blocks are made of coarse materials in order to give them greater strength; eventually, they will be worn away at the points where the flame enters the furnace, partially by melting from the heat and partially by abrasion from the force of the flames themselves. The pots hold the glass during the melting, refining, and working processes. The individual blocks that make up the basin are not cemented together but become impenetrable as the molten glass overflows into the crevices and is hardened by the cold temperatures of the outer parts of the block[41].

In comparison to the bricks used for contact with molten glass, the roof-vaults, or crowns, of the furnaces are usually made of some form of silica brick. Pure silica cannot be baked into bricks because it does not have the necessary plasticity to be molded in such a way; by adding a small amount of lime and alumina, it allows for the needed plasticity and thus relatively strong bricks can be formed[42]. Rosenhain

[39] Ibid.
[40] Phillips, Charles John. *Glass, the miracle maker.* 1948: 137.
[41] Rosenhain, Walter. *Glass Manufacture.* 1908: 59-60.
[42] Ibid, 61.

writes that “for positions where intense heat is to be borne, and at the same time mechanical strength is required, silica brick is a most valuable material, but owing to its chemical composition it is rapidly attacked by molten glass or by any material containing a notable proportion of basic constituents, so that the silica bricks can only be employed out of contact with glass.”[43]

In general, the two main types of furnaces are the pot furnace and the tank furnace. For the most part, pot furnaces are regenerative by nature, as opposed to needing to preheat the gas and air (Figure 10). For industrial production of window glass, the pots themselves can hold 1-2 tons of glass and their hooded design with plugged openings allows for both protection and accessibility; historically, smaller pots were used to create stained glass. Modern pot furnaces are in essence the same as their predecessors. While they have been mostly replaced with tank furnaces, they remain especially useful for producing optical glass, art glass, or glass with special compositions because multiple pots are essential[44].

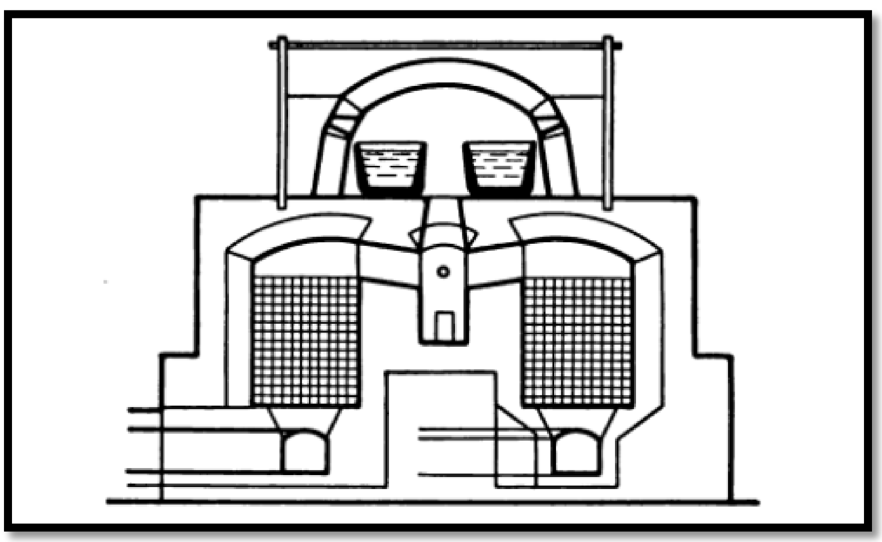

Figure 10. A cross section of a regenerative pot furnace. Image from C.J. Phillips, *Glass, the miracle maker*. 1948: 146.

[43] Ibid, 62.
[44] Phillips, Charles John. *Glass, the miracle maker.* 1948: 146-148.

Tank furnaces come in a variety of types and sizes (Figure 11). A day tank is the smallest type and holds only 5-10 tons of melted glass[45]. On the other hand, the largest tanks are used to produce window glass and can handle up to 1400 tons[46]. Window-glass tanks are "continuous" tanks, which means that the glass travels through the tank at the same level the entire time; it is fed into the tank at the same rate as it exits at the opposite end. These furnaces are also predominantly regenerative.

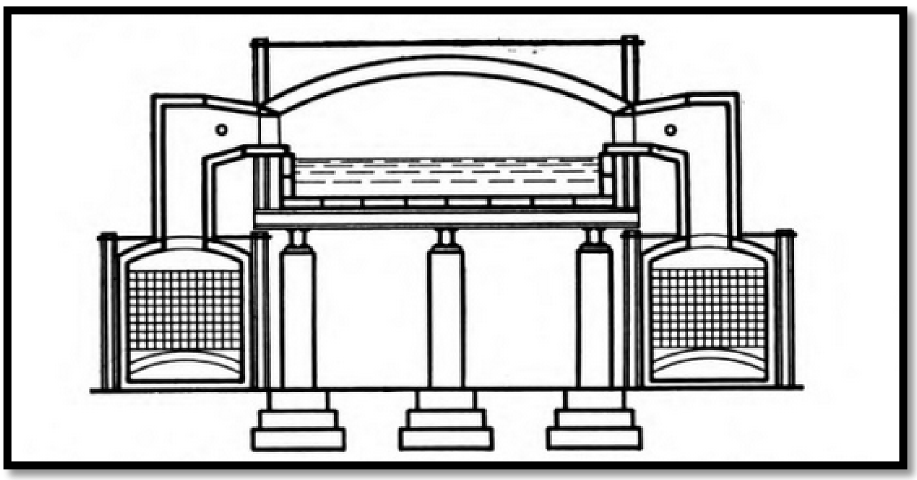

Figure 11. A cross section of a regenerative tank furnace. Image from C.J. Phillips, *Glass, the miracle maker*. 1948: 149.

For pot furnaces, the openings through which the gas and air enter the chamber are located on the floor or in a place where the pots could be heated as evenly as possible. For a tank furnace, the tank is built of fire-clay blocks and the ports for the entrance of gas and air and the exit of the combustion products are located in the side walls, just above the level of the glass itself. Both of these types have pros and cons. A tank furnace uses the flame's heat more efficiently because the glass is exposed to the heat of the tank, which covers the surface area of the furnace; in comparison, the pot furnace contains more unused space. The tank furnace has no idle periods and each part of the furnace stays at a constant temperature during the whole process; this results in a larger output with less fuel consumption. In addition, the tank furnace does not require pots, which not only eliminates the cost of

[45] Ibid.
[46] Ibid.

production of these pots but also the chances that the pots will fail during the process; this in turn saves time. With pot furnaces, the glass composition is more easily regulated and the molten glass can be better protected from contamination. The pots also allow the materials to be effectively melted together; these materials could not be kept together long enough to mix in the tank furnace[47].

The Fusion and Working Processes

The first step in the glass-melting process is to make sure that the ingredients are properly proportioned. The raw materials are weighed separately and then passed into the mixing chamber of the mixing machine. Once this is done, the cullet, or broken glass, is added as the final ingredient in order to assist in bringing the other ingredients together during the early melting in the furnace. Now the mixture enters the furnace. In the case of the tank furnace, the mixture is placed through a large door at the "melting end" of the furnace covered by a large firebrick block; using a counter-weight and pulleys, the block is lifted to reveal the opening for the raw materials to enter. The addition of the mixture to the furnace is known as the charging process. In comparison, with a pot furnace there are additional issues to contend with. During the early stages of fusion, the glass mixture will form foam and some overflow and/or leakage is inevitable with the pots. This overflow falls into the chamber built to catch it, preventing it from hindering the furnace's process. The pockets of this chamber must be cleaned out of this overflow regularly. In addition, the raw materials take up more space in the pot than the glass that is formed from them; therefore, as the ingredients are turned into glass, the raw materials have to be replenished in the pot several times in order to produce a substantial amount of glass[48].

The second stage of the melting process comes when the glass has formed such that there are no more undecomposed raw materials and the glass itself is transparent with gas bubbles throughout.

[47] Rosenhain, Walter. *Glass manufacture.* 1908: 68-72.
[48] Rosenhain, Walter. *Glass manufacture.* 1908: 73-76.

The removing of these bubbles is called the "fining" process and is done by another intense heating of the molten glass, resulting in more "pure" liquid and permitting the bubbles to rise to the surface. To complete this process, small samples of glass are removed and examined for remaining bubbles; if there are none, the glass is considered to be "fine." Often, the surface of the "fine" glass has spots of foreign matter contaminating it; this layer is skimmed off before the glass can be worked. The last step is to reduce the glass' temperature such that the glass can be worked as needed; this drop in temperature is achieved by either (1) lowering the temperature of the entire furnace, as with the pot furnace or (2) by sending the molten glass into the working chamber of the tank, as with the tank furnace. In the latter case, the working chamber is kept constant at the working temperature and does not affect the rest of the furnace temperatures[49].

Now that the glass has cooled, it is ready to be worked. The first working process is to remove enough of the molten glass from the furnace; this is done in one of three ways: (1) ladling; (2) pouring; and (3) gathering. While using a ladle is the simplest method, it is inevitable that doing so will contaminate all of the glass in the furnace by introducing air bubbles to it. In addition, the cold ladle causes the glass in it to harden to the point where it cannot undergo the other working processes; this results in a loss of glass. Ladling is the precursor to the working process of rolling. The rolling of glass occurs in two different ways: (1) putting the glass on a flat table and rolling it out into a sheet with a single roller, a process used to create plate glass; or (2) passing the glass through two moving rollers with the resulting sheet ending up on a flat table, a process used for creating textured or patterned sheet glass[50].

The process of gathering is limited by the amount of glass that can be gathered at the end of the pipe used to take the glass from the furnace and for this reason, pouring is usually used to handle the large amount of glass needed to create plate glass. Once the glass has been poured onto the rolling

[49] Ibid, 80-83.
[50] Ibid, 84-87.

table, a large roller spreads the glass out into the large plate. Gathering is a more laborious process in that it takes several extra steps to achieve the necessary amount of glass to create a plate. The glass or iron rod is placed into the furnace and a small amount of glass adheres to it; this is done over and over again, with each entry into the furnace allowing for more glass to adhere to the existing glass on the rod until the proper amount is reached. There are certain disadvantages to this process as well, including the multiples exposures to the air which is likely to contaminate the glass and cause bubbles, the manual labor and skill required, and the overall exposure of the craftsman to the heat[51].

Like ladling is to rolling, gathering is to blowing. Gathering is the first step to blowing, which is the process used to make antique glass. This is the process used to create the majority of glass windows, stained glass windows included until the development of float glass in the 1950s. It is the first step to blowing, which is the process used to make antique glass. Once the proper amount of glass is obtained on the end of the pipe, a small hollow sphere of glass is blown. From the basic sphere, a number of shapes can be created by various manipulations of the glass, using either hand tools or molds. The amount and force of human breath limited the size of a sheet of mouth-blown glass until the Lubbers Process was created, utilizing compressed air; this allowed for much larger cylinders to be created. The Lubbers Process, however, was not used for colored glass, but rather for clear window glass. It will be described in detail shortly.[52]

Since the 1st century, sheets of glass were made by collecting molten glass on the end of a blowpipe[53]. Once enough molten glass has been gathered on the end of the pipe, it is shaped using blocks in order to create a round bubble (Figure 12). Using gravity and centrifugal force, the blower takes the pipe with the bubble on the end and holds it in the furnace to heat up. Once it is hot, he then swings the pipe like a pendulum in a pit while blowing into the pipe, allowing the bubble to become

[51] Ibid, 87-89.
[52] Ibid, 89-91.
[53] Cannon, Linda. "History of the Techniques and Materials." 1991: 53.

longer under its own weight, forming a hollow cylinder. This process is done a number of times until the cylinder is equally thick on all sides and of the desired length; this cylinder is called the muff. The ends of the cylinder are heated and cut off, thus leaving a hollow cylinder. A singular cut is then made down the length of the cylinder using a hot iron and/or diamond cutter (Figure 13). The cylinders are then taken to a kiln called the "lear" or "lehr." They are lifted into the kiln one at a time and heated enough to soften the glass. With the split facing up, a wooden tool is used to flatten both sides of the cylinder and a flattening slab is then used to completely even out the sheet[54]. The sheets are then sent into the tunnel-shaped annealing kiln and cooled.

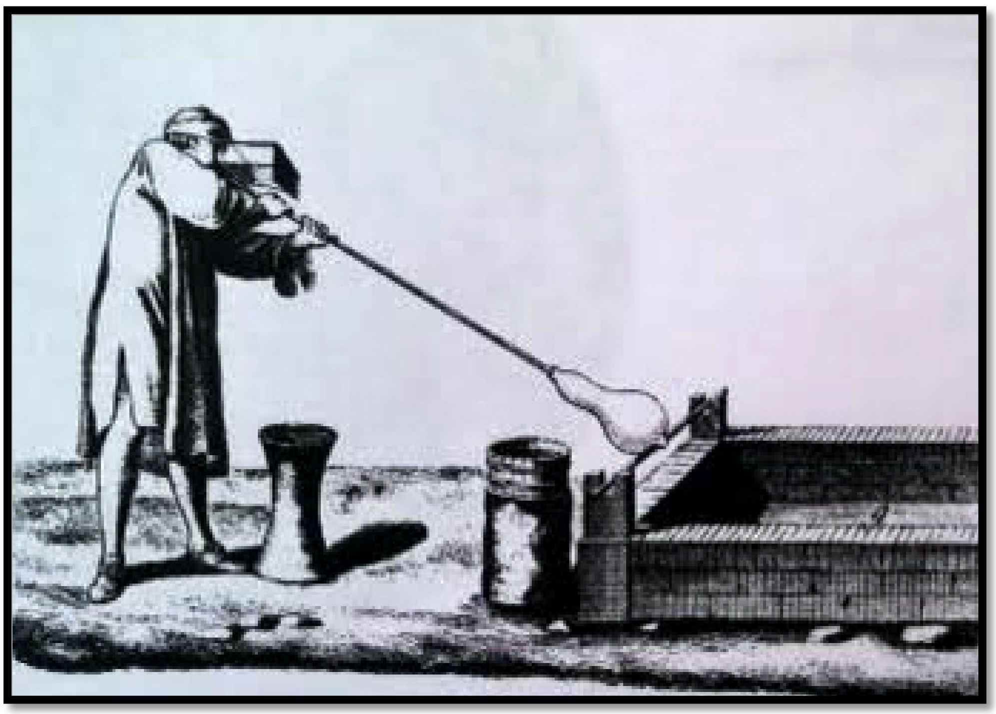

Figure 12. Blowing the muff after gathering molten glass on the blowpipe. Image from Linda Cannon, "History of the Techniques and Materials." 1991: 54.

[54] Rosenhain, Walter. *Glass Manufacture*. 1908: 161-165.

Figure 13. Cutting and flattening the muff glass. Image from Linda Cannon, "History of the Techniques and Materials." 1991: 54.

Throughout the history of the manufacturing of window glass, five major methods have been employed: (1) the crown method; (2) the hand-cylinder method; (3) the machine-cylinder method; (4) the sheet-drawing method; and (5) the float-glass method. The crown method was introduced by the ancient Romans as early as the 4th century and being used up through 1800[55] (Figures 14 and 15). It is a process done by hand and is described by Phillips as follows:

> This hand process consisted in first blowing a hollow sphere on the end of a blowpipe. A punty was attached to this hollow ball, opposite the blowpipe, which was then detached, leaving a ragged opening in the sphere. The ball was then heated until very soft and vigorously rotated. Centrifugal force caused the glass to flatten out into a disk which was cooled, broken from the punty, annealed, and cut into small sheets. Every disk had a lump of glass, the "bull's eye" or "crown," at the center, and therefore only small sheets could be made by this laborious process.[56]

For both the muff and the crown types, the glass needed to be cooled in an annealing oven in order to prevent it from shattering (Figure 16).

[55] Phillips, Charles John. *Glass, the miracle maker.* 1948: 206.
[56] Ibid.

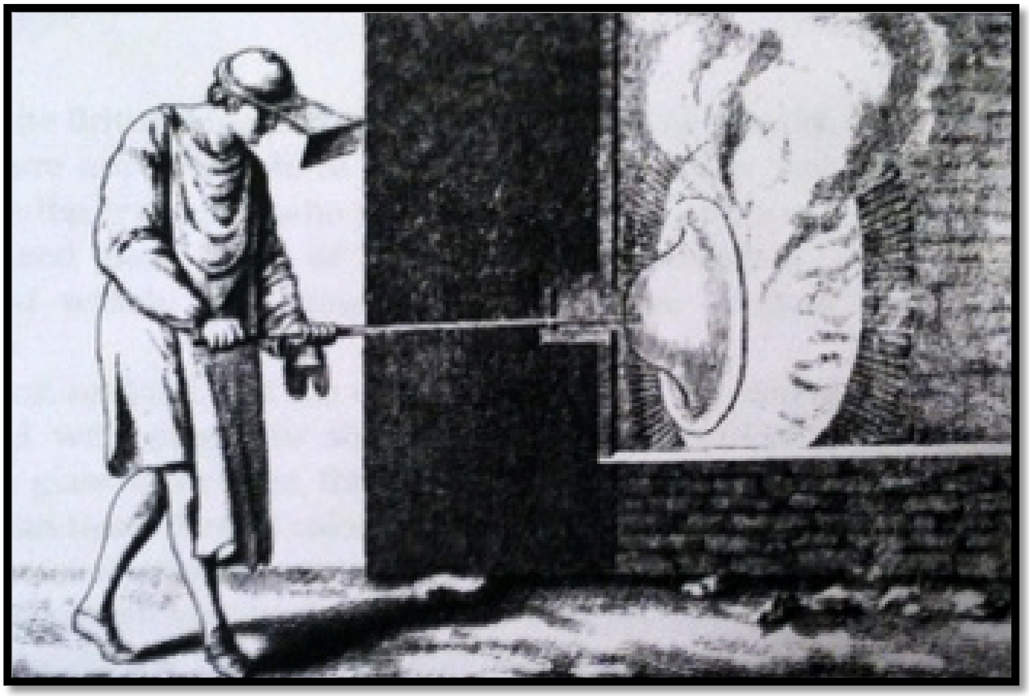

Figure 14. Spinning a bubble of glass to form the crown. Image from Linda Cannon, “History of the Techniques and Materials.” 1991: 55.

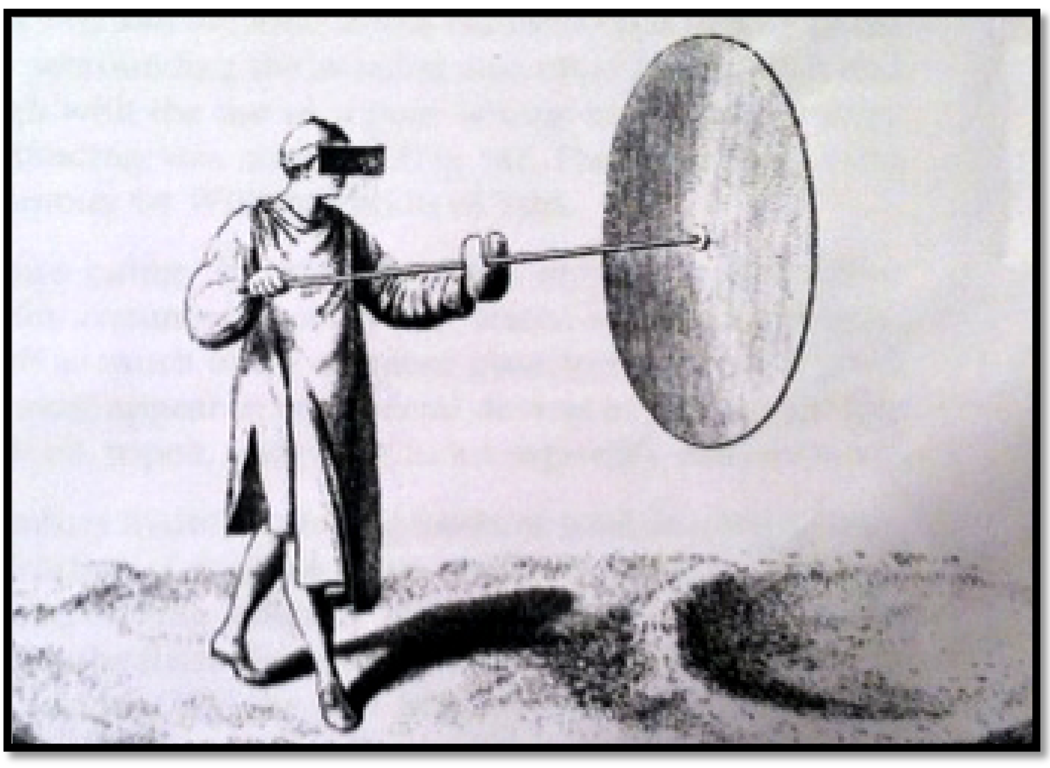

Figure 15. Crown glass after spinning is completed. Image from Linda Cannon, “History of the Techniques and Materials.” 1991: 55.

Figure 16. Placing the finished crown into the annealing furnace. Image from Linda Cannon, "History of the Techniques and Materials." 1991: 55.

The 19th century saw the replacement of the crown method with the hand-cylinder method, which was previously described and also known as the muff method. Then, in 1903, the machine-cylinder method was introduced by J.H. Lubbers[57]. In this process, the molten glass is poured into a pot. Then a metal ring, about 10 inches in diameter, was lowered into the glass. It was lifted slowly and by controlling the compressed air for blowing and an electrical hoist, a continuous glass cylinder was created that could reach a height of 40 feet[58]. The splitting, flattening, cooling, and cutting were done in the same way as the hand-cylinder method. The largest difference between the hand-cylinder and the machine-cylinder methods is that the machine-cylinder methods result in much larger cylinders that can be made much more quickly.

The sheet-drawing methods were developed in the first quarter of the 20th century. While there are a variety of types, they are all inherently the same in that the "molten glass is drawn continuously,

[57] Ibid, 207.
[58] Ibid.

day and night, mile after mile of it, from large continuous tank furnaces"[59].

The fifth and most modern glass-producing technique is the float method, developed in the 1950s. In this process, the ingredients are closely controlled in order to maintain the best quality of glass. According to Pilkington, a float glass manufacturer, "float makes glass of near optical quality."[60] After the ingredients are melted, they flow over a refractory spout onto a surface of molten tin, called the float bath; once the process is done, the glass leaves the bath as a solid ribbon. Then coatings can be added to the cooling glass ribbon to alter the optical properties of the glass; on-line chemical vapor deposition is the process used to lay down this coatings onto the glass[61]. Once the coating(s) have been applied, the glass is annealed, inspected, and cut to size, similar to the previous glass manufacturing processes. Overall, it is important to recognize that no commercial window glass is created by blowing, casting, or rolling processes anymore; only colored glass is made using these old techniques, which is why they are so essential to stained glass windows, even today.

While the tank furnace is the predominant type used to produce sheet glass, the pot furnace can be used as well. When it comes to colored glass, melting the glass in pots proves to be easier. Tinted glasses, whether they are considered pot-metal or flashed, can have their exact compositions controlled better in pots. Sheet glass is lighter than plate glass but as a result, it is often weaker and can only be used in smaller sizes. Over time, there have been developments that have allowed for the production of very thin plate glass such that it can be used for architectural purposes; however, the manufacture of sheet glass is significantly cheaper than plate glass, which is why it remains so popular today[62].

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[59] Ibid.
[60] "Step-by-step Manufacturing of Float Glass." *Pilkington.* 2014.
[61] Ibid.
[62] Rosenhain, Walter. *Glass Manufacture*. 1908: 150.

Coloring Glass

In terms of color, it was mostly left up to chance during the Middle Ages because it was never certain which impurities had made their way into the mixture. The 19th century saw glass coloring as a more scientific process and by then coloring recipes were recorded and the colors they produced were known with greater certainty. Even so, repetition of an exact color was still difficult because it depended on the chemical composition of the ingredients and the atmosphere of the furnace[63].

There are a number of elements that are used to color glass and others will affect these coloring agents. The alkali metals, including sodium and potassium, will not color glass but if they are present in the ash used in the glass, they will affect the colors that result from elements such as manganese and nickel. Copper is one of the most powerful coloring agents, resulting in a green color as a pure metal or oxide compound; however, when used in silicate compounds, the color is green-blue. In addition, it is possible to create an intense ruby color from copper by adding tin; by preventing the full oxidation of the copper with the use of a reducing body, the glass can be cooled slowly to create this color[64].

Silver is usually not used directly in glass mixtures because it gives the glass a black, metallic appearance; however, it is widely used as the well-known silver stain, which is applied to the glass surface, yielding a range of yellow colors[65]. Silver stain will be discussed in detail in a later chapter.

Carbon has an effect on the color of glass in two ways: (1) directly, through the presence of pure carbon or carbides in the glass itself or (2) indirectly, as a result of the reducing action of carbon on other substances in the glass. Due to the lightness of carbon particles, carbon that is added directly to the glass produces a color that ranges from brown to yellow; on the other hand, carbon added indirectly as a reducing agent will cause the resulting glass to have a green-yellow tint to it[66].

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[63] Sloan, Julie L. *Conservation of Stained Glass in America.* 1995: 79-80.
[64] Rosenhain, Walter. *Glass Manufacture*. 1908: 184.
[65] Ibid, 185.
[66] Ibid, 186-187.

Tin oxide will produce opalescence and in some cases, white opacity; calcium phosphate will also produce this opalescence and the use of antimony will result in a white opacity as well. In addition, when combined with copper, tin will produce the "copper-ruby" color previously mentioned. Lead and Thallium are not used for coloring glass but will enhance the coloring effects of other substances[67].

Sulfur compounds, namely sulfides, have the ability to color glass. In addition, the presence of sulfur gases in the annealing kilns can also cause the resulting glass to have a milky yellow color. Selenium, chemically related to sulfur, can cause glass to have a yellow-pink color; the intensity of this color depends on the chemical composition of the glass and the amount of selenium left in the mixture after melting[68].

Chromium, in addition to being one of the most intense coloring agents, is also relatively cheap to obtain and its color can be accurately predicted. The colors range from a bright green to a "cold blue," created when combined with iron. Cobalt is another one of the most powerful coloring agents, resulting in a range of blues. This blue is one of the most reliable colors produced by glass-makers[69].

Manganese is one of the most important coloring agents for glass. When used on its own, the color ranges from pink-purple to deep violet. The precise color depends greatly on whether the glass includes a lime, lead, or barium base, as well as whether soda or pot ash was used. In addition, manganese is often used with other coloring agents to produce an even greater variety of colors when warm and cool colors are combined[70]. The most important use of manganese is to counter the green tint of clear glass that comes from iron; too much, however, will make the glass turn purple when exposed to sunlight.

Iron is also found to have an effect on the color of glass. Ferrous compounds result in a range of green colors, whereas ferric compounds, the more highly-oxidized compounds, result in a variety of

[67] Ibid, 188-189.
[68] Ibid, 189-190.
[69] Ibid, 190-191, 197.
[70] Ibid, 193.

yellows. Nickel results in a brown-green color but the exact color will depend on the glass composition and the condition of oxidation in which the nickel is found[71].

As already mentioned, ruby glass comes with a unique set of circumstances. Copper oxides under certain conditions will produce this color. This particular color was so dense that it had to be streaked through the glass; this exact way in which this was done is unknown, however, it is possible that the color was simply not mixed thoroughly in the pot. By the 14th century, however, the ruby glass was rarely streaked anymore but rather a new technique had been developed to achieve it—flashing[72]. The glassmaker would dip the blowpipe into molten ruby glass and blow a bubble. This bubble would then be dipped into a second pot filled with clear glass; the result would be a sheet of transparent glass with two superimposed layers—a thin ruby on top with a thicker clear layer below (Figure 17). This process allowed for the necessary transparency while maintaining the overall strength of the glass.

Figure 17. A window created using the flashing of ruby glass. Image from CVMA Glossary. 2010.

[71] Ibid, 196-197. R
[72] Cannon, Linda. "History of the Materials and Techniques." 1991: 56.

Another benefit to this technique was that the glaziers soon recognized that they could abrade the top ruby layer of glass to reveal the clear beneath, thus enabling themselves to work with two different colors on the same sheet of glass (Figure 18). This abrading, the scratching and grinding away of the flashed layer, was done with emery or a similar hard medium and the technique was often restricted by time and money. It was not until the 15th century that other colors like blue and green were flashed in this way[73]. By the 16th century, copper wheels were being used instead of the emery, thus producing a much neater and smoother result than the previously rough and scratched glass[74]. Since the 19th century, hydrofluoric acid has been used in a process called acid-etching[75]. Replacing abrasion, this process leaves a clean, hard outline on the flashed glass in a fraction of the time it took to abrade the glass by hand.

Figure 18: Example of abrading a piece of flashed glass. Image from York Glazier's Trust "Illustrated Glossary."

[73] Cannon, Linda. "History of the Materials and Techniques." 1991: 57.
[74] Ibid. C
[75] Ibid. C

Glass Properties

The chemical composition of glass is a complex subject but as Robert Brill notes in his article "A Note on the Scientist's Definition of Glass," "It can be readily seen that the chemical composition of glass is not the thing that makes glass 'glass,' since hundreds of thousands of different chemical compositions can be made into glasses…We must resort instead to an examination of physical structure and atomic arrangements to define what we mean by 'glass.'"[76] To do this, it is useful to briefly examine the Kinetic Theory of Matter. The foundation of this theory is the idea that all matter is composed of very small molecules, made up of atoms held together by chemical bonds, which are always in motion. The amount of kinetic energy of a molecule directly relates to temperature—as temperature increases, the kinetic energy will increase as well.

Take water as an example. At high temperatures, the kinetic energy is large. Therefore, the amount of kinetic energy can overcome the attractive forces that exist between molecules, allowing each molecule to move around individually. In this case, water is in the gaseous state, with the molecules being separated from one another and moving at a high velocity. Now if this temperature is lowered (for water, to below 100°C), the water molecules will lose some of their kinetic energy, thereby making the amount of kinetic energy approximately equal to the attractive forces holding the molecules together. Physically, the molecules are forced to stay closer together than when they were in the gaseous state, but there is still enough kinetic energy to allow them to continue moving around. This is the liquid state, where there is no rigidity and the molecular arrangement is constantly change from one configuration to another. When the temperature is dropped even lower (for the case of water, below 0° C), the attractive forces are much greater than the kinetic energy so the molecules are held in place, "occupying a definite position in a perfectly ordered array."[77] This is called a crystalline structure, where

[76] Brill, Robert H. "A Note on the Scientist's Definition of Glass." 1962: 127.
[77] Ibid, 129.

kinetic energy is seen in the vibrations of the molecules in their individual places. Unlike liquids, there is definite rigidity to a crystalline structure.

The question remains—where does glass fit in these three classifications? Physically, the answer is nowhere. While glass has the rigidity of a crystal, it also has the disordered structure of a liquid. In order to categorize glasses, a new category must be made—a glassy state—which falls between a liquid and a crystal. According to Brill, "the scientist's definition of a glass, then, is that a glass is a substance in the glassy state, a state in which the molecular units have a disordered arrangement, but sufficient cohesion to produce over-all mechanical rigidity. The term 'vitreous state' is sometimes used and has exactly the same meaning."[78] Listing the universal characteristics of glass is difficult because such qualities as transparency, hardness, and brittleness, do not apply to all forms of glass. The physical structure of glass is a characteristic universal to all glass.

There are a number of factors that affect how glass is made. One such factor is the limitations of the temperature of the furnaces used. Too much silica, lime, alumina, etc. will raise the temperature necessary for the fusion of the glass; if this temperature goes above 1600° Centigrade, the creation of glass in an ordinary furnace is impossible[79]. Another limitation is the chemical behavior of the glass itself, both during manufacturing and in use. A glass that is rich in silica and lacking in bases will dissolve in basic materials; on the other hand, a glass rich in bases and lacking in silica or other acidic components will absorb acids from its environment. During firing, the glass is contained in fire-clay vessels, which are selected such that they offer the molten glass some of the materials that it is lacking; however, glass rich in bases will attack this fire-clay. The atmosphere, including moisture and carbonic acid, will also have an effect; for example, glass with additional alkali will undergo rapid decomposition in damp atmospheres because increased alkalis result in a decrease in chemical resistance[80]. In

[78] Ibid, 129,131.
[79] Rosenhain, Walter. *Glass Manufacture*. 1908: 5.
[80] Ibid, 6-9.

summary, the chemical composition of glass is chosen according to its intended use, considering all of these limits.

Another chemical issue to contend with involves the changes in glass due to light exposure. If the glass contains manganese, a long period of exposure to strong light, including sunlight and ultra-violet light, will result in a change in color of the glass. In his book *Glass Manufacture*, Walter Rosenhain writes that:

> The coloured glass in stained-glass windows also shows signs of having undergone changes of tint in consequence of prolonged exposure to light; glass removed from ancient windows usually shows a deeper tint in those portions which have been protected from the direct action of light by the leading in which the glass was set, and it is at least an open question whether the beauty of ancient glass may not be, in part, due to the mellowing effect of light upon some of the tints of the design.[81]

In addition to these chemical properties of glass, there are also a number of important physical properties to address. One of the most important properties of glass is its "thermal endurance" or the amount of heating or cooling that glass can undergo without fracturing. It depends on a number of qualities, including coefficient of expansion, thermal conductivity, specific heat, Young's modulus of elasticity, and tensile strength. A high coefficient of expansion and a low modulus of elasticity will result in fracturing whereas a high tensile strength will stop it. Thermal conductivity also plays a part in endurance; the tensile strength in the colder layers of glass will depend on the temperature gradient in the glass. The heat capacity, or specific heat, is another characteristic that will affect the endurance; heat will infiltrate more slowly through glass whose temperature rise requires more heat[82].

Expansive properties of glass are also important, especially in stained glass where several kinds of glass are often put together. An example of this is "flashed" colored glass; for this process, it is imperative that their coefficients of expansion should be as close to one another as possible. If not,

[81] Ibid, 16.
[82] Ibid, 23-25.

there will be substantial stresses when the glasses cool. In addition, the thickness of the glass is a quality that has changed over time due to technological advancements. Between the 11th and 13th centuries, glass was very thick and had an uneven surface[83]. Over time and with the introduction of better technology, it became thinner and smoother and during the 18th-19th centuries it was approximately 1mm thick[84].

For opalescent glass, opacifiers are an essential ingredient in the glass mixture; in addition to creating the opacity of the glass, they also make the glass harder and less easy to paint. In general, opalescence is achieved by bringing a colloidal suspension of a suitable compound in the glass, where a colloidal suspension refers to a material that has a solid permanently suspended in a liquid. When the particles increase in size, the glass becomes opaque. For the most part, phosphorus and fluorine are responsible for creating opalescence in glass. Calcium phosphate, typically from bone ash, will create a muddled white glass that is seen once the glass has been re-heated. Fluorides are the most common opacifiers, creating a milky white glass; while opalescent glass created with calcium phosphate transmits red light, the opalescent glass created with fluorides will not transmit red light. Fluorides are commonly added to the glass in the following forms: fluorite, orthoclase, or cryolite. Finally, in addition to phosphorus and fluorine, tin oxide is also able to produce opalescence and if enough is added, white opacity can be achieved[85].

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[83] Ibid, 58.
[84] Ibid.
[85] Fettke, Charles Reinhard. *Glass Manufacture and the Glass Sand Industry of Pennsylvania.* 1919: 89.

Glass Deterioration and Corrosion

All of these factors affects the durability of glass. In summary of the previous section, some factors include the following: (1) the glass's thermal history, including what stresses were built into the glass and whether alkalis were lost during the formation process causing a change in the surface composition; (2) the heterogeneity of the glass, including any separations of materials or bubbles in the surface; (3) surface roughness, or pits, usually formed along scratch lines in the glass; (4) the glass's orientation, namely whether it was sheltered from or exposed to the natural elements; (5) the composition of the atmosphere; (6) any bacteria or fungi growing on the glass; (7) poor storage conditions that may have increased decay, such as those used during World War II; and (8) the presence of paint, which may also serve to protect the glass underneath it.[86] This final factor is of particular importance to this thesis because it emphasizes the under-appreciation of these glass paintings. From a technical point of view, it seems as though paint was meant to serve as a sacrificial layer that would be offered up in order to protect the glass underneath; this idea will be discussed throughout the chapters to follow.

Chemical deterioration of glass is one of the most difficult problems to deal with because once it has started it is nearly impossible to fix; the best options are the ones that successfully slow down the corrosion. R.G. Newton writes that "the main factors which affect the type and rate of glass decomposition are the *composition* of the glass and its *environment*; other factors are temperature, time, the pH of an aggressive solution, the surface area of the micro-organisms, traffic vibrations and earlier conservation treatments."[87] Composition makes the difference between durable Roman soda-lime-silica glass and the easily deteriorated medieval window glass, composed of too much potash and lime. At the same time, it is important to note that over time Roman glass has developed several

[86] Gillies, K.J.S. "Scientific Studies and Conservation of Stained Glass." 1989: 6.
[87] Newton, R.G. *Conservation of Glass*. 1989: 135.

surface layers, replacing the original Roman glass and providing the prolonged durability[88].

One clear factor causing glass deterioration is air pollution, namely sulfur dioxide, which is known for the deterioration of medieval stained glass windows made with potash glass. Ironically, the sulfur dioxide does not technically attack the glass. The glass itself is attacked by water, which results in the production of hydroxides. Combining with the carbon dioxide in the atmosphere, the hydroxides are converted to carbonates, which are then converted to sulfates after reacting with the sulfur dioxide in the air pollution[89].

Environmental causes of deterioration include water in the atmosphere, both from inside and outside the buildings and surroundings. Water can take the form of precipitation, humidity, and/or condensation. While water can be good for a window in that it rinses it and cleans off some surface films, water or water vapor that remains in constant contact with a window can be devastating. The concern with water damage is that one cannot see the damage occurring because it takes decades to occur; but it is important to recognize that it is inevitably happening and must be prevented and/or dealt with.

Not surprisingly then, water is the primary environmental factor that causes glass deterioration. When glass reacts with water, chemical changes occur on the surface, which sometimes spread to the rest of the glass. Some surfaces formed can be protective while others are simply harmful; this depends mainly on the composition of the glass itself and the pH of the liquid. The simplest way to describe the reaction is as follows: an exchange occurs between the alkali ions in the glass and the hydrogen ions in the water; the alkalis cannot leave the glass until protons have taken their place, thus maintaining the material's neutrality; these protons are much smaller than the alkali ions and therefore, the alkali-depleted surface layer of the glass has a smaller volume than the original surface; the reduced volume

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[88] Ibid.
[89] Ibid.

of the leached layer caused shrinking to occur[90]. In addition, if the alkali-depleted layer is hydrated with water and then this water is lost, further shrinkage will occur.

Therefore, dehydration is not causing the deterioration, it is a sign that it is already taking place in the glass. This decrease in volume can cause microporosity in the surface layers and subsequently result in the multi-layered surface crusts often seen on medieval glass. This alkali-deficient surface layer is now responsible for the decrease in alkali diffusion since the alkali ions now have an additional layer through which they must diffuse in order to get to the unaltered glass. In other words, it may appear that over time, glass has become more durable but this is rarely the case. If these alkali ions continue to gather in the water, the pH will inevitably increase; if it reaches 9.0, the silica content of the glass will be attacked[91]. Newton observes that medieval painted glass, which contained beech ash and a very high lime content, experiences this phenomenon. The breakdown of the silica network will occur readily and surface crusts are formed, which hold moisture, causing them to become highly alkaline[92]. Sloan notes that the compositional differences between medieval and modern glass explain some of their respective conservation issues; medieval windows experience deterioration of the glass itself due to the exposure of the potash glass to the atmosphere while modern soda-lime glass is much less susceptible to atmospheric deterioration[93].

Atmospheric gases, pollution, and micro-organisms all affect glass chemically as well and water exacerbates these types of deterioration. The glass becomes thinner as a result of the erosion of the glass surface and the pitting of the glass can ultimately cause permanent loss of material (Figure 19). Another reaction between the drained alkali ions and the gases in the atmosphere causes salt deposits on the glass surface. The deposits "attract and hold moisture on the glass and thus supply more corrosive agent; repeated drying and wetting cycles cause micro-cracks both in the glass surface and in

[90] Ibid, 136.
[91] Ibid.
[92] Ibid, 137.
[93] Sloan, Julie L. *Conservation of Stained Glass in America.* 1995: 78.

the painted decoration."[94] In addition, both damp and corroded areas provide the perfect environment for micro-organisms to thrive.

Figure 19. Glass pitting on a stained glass window from Caterbury Cathedral. Image from Leonie Seliger, "The South Oculus Window of Canterbury Cathedral." 2011: 5.

Other issues of deterioration include acid rain, crizzling, and devitrification. Over time, any acid will etch glass and acid rain can have additional deteriorating effects on the glass if left on too long. Crizzling refers to the crystallization of the glass because of a chemical imbalance in the glass, resulting in fracturing or in some cases cracking across the surface. Devitrification occurs when the glass is allowed to be molten for too long; it is not a chemical alteration but rather a crystallization of the glass if left in the vitreous state for an extended period of time. These two types of deterioration have no known conservation method other than replacement[95]. In terms of mechanical deterioration, most windows are up high enough that they are affected by high wind, rain, hail, other violent forms of

[94] Seliger, Leonie. "The South Oculus Window of Canterbury Cathedral." 2011: 8.
[95] Sloan, Julie L. *Conservation of Stained Glass in America.* 1995: 92-94.

weather, and general fluctuations in temperature. This does not take into account any accidental damage or that inflicted by humans. On a large scale level, the largest issue would be damage to the leadwork, which could in turn result in glass fractures and loss of adhesion to the metal framework supports. In addition, on a smaller scale, temperature changes cause glass deterioration on the surface which leads to paint flaking and loss (Figure 20).

Figure 20. Paint loss from a stained glass window in Canterbury Cathedral. Image from Leonie Seliger, "The South Oculus Window of Canterbury Cathedral." 2011: 5.

Medieval glass has both a texture and inherent movement that modern-day glass does not; its unevenness is highlighted by its variations in tone and hue caused by air bubbles and chemical impurities of the raw materials. When comparing the important difference between ancient and modern glass used in stained glass, Rosenhain writes:

> This very perfection of modern glass rendered it less adapted for these artistic purposes. A perfect piece of glass, having smooth surfaces and no internal regularities, allows the rays of light falling upon it to pass through undeflected in direction, and merely changed in colour, according to the tint of the glass in question. On looking at the glass, external objects can be quite clearly seen, and much of the interest and mystery of the glass itself is lost. On the other hand, when falling upon a piece of glass having an irregular surface, and containing all manner of irregularities such as striae, air bells, and even

> pieces of enclosed solid matter, the light is scattered, refracted, and deflected into all manner of directions until it almost appears to emanate from the body of the glass itself, which thus appears almost to shine with an internal light of its own; the eye can hardly perceive the presence of external objects, and the whole window appears as a brilliant self-luminous object.[96]

This distinction led to glass-makers attempting to recreate these imperfect qualities of ancient glass while at the same time, seeking to use modern techniques to obtain a more stable glass and a larger variety of colors. Regardless of whether the glass is ancient or modern, its manufacture and characteristics are essential to the understanding of the surface decorations used upon it. In fact, "this unevenness of the antique glass…gives textures which make the glass painting more alive."[97]

[96] Rosenhain, Walter. *Glass Manufacture*. 1908: 202.
[97] Tryggvadottir, Nina. "Painting with Light through Colored Glass." 1968: 130.

III. Stained Glass Painting Techniques

The chief excellence of a glass painting is its translucency. A glass painting by possessing the power of transmitting light in a far greater degree than any other species of painting, is able to display effects of light and colour with a brilliancy and vividness quite unapproachable by any other means.[98]

Charles Winston

The qualifying of light coming into a building is fairly straight-forward. What calls for a leap of imagination is the idea of putting the figurative element of a fresco or painting into the very source of light. This is where the art of stained glass begins to separate itself from the mere craft of keeping the weather out. As soon as any representation is incorporated as an element of design in glass it brings with it a range of associations and meanings that were inconceivable before.[99]

Patrick Reyntiens

Its aesthetic function is very complex: since a building has an interior and an exterior design, the stained glass window must complement both simultaneously, with color and image on the interior and geometric pattern on the exterior. The window must be attractive in the ever-changing reflected light of the outdoors and the filtered, transmitted light of the interior. And the stained glass window must control light in the manner the artist desires.[100]

Julie L. Sloan

Having examined a brief history of glass, it is important to build upon this foundation and look at the history of glass painting. Glass painting is an art that, like all other art forms, has developed and changed over time. Sloan recognizes that stained glass is architecture, art, and craft simultaneously:

[98] Winston, Charles. *An inquiry into the difference of style observable in Ancient Glass Paintings*. 1847: 239.
[99] Reyntiens, Patrick. *The Beauty of Stained Glass*. 1990: 9.
[100] Sloan, Julie L. *Conservation of Stained Glass in America*. 1995: 15.

> In that stained glass windows are often designed and painted by artists, in that they often involve sophisticated color selection, design, and draftsmanship, and in that many stained glass windows of different eras have found permanent homes in the collections of museums of fine art, stained glass can be considered an art form. Often serving a purely decorative purpose as an element of interior design, they are also a decorative art. Because stained glass windows are usually fabricated by craftspeople or artisans, the techniques are craft. And since they function as windows, letting light in and keeping weather out, they are elements of architecture.[101]

Before examining the three main types of surface decorations, one should discuss the various painting techniques and styles for stained glass windows in order to understand how each of them was utilized to fulfil the aesthetic and stylistic needs of the time in which they were used.

"Stained glass" is a term that implies the medium of windows. Lewis Day writes that "glass staining and glass painting are two quite different things. To build up a mosaic with pieces of coloured glass, each separate tint cut out of a separate sheet of 'pot metal,' is one thing; to paint upon a sheet of white or coloured glass is another thing altogether. In fact, they are not merely two different ways but two opposite ways of arriving at a result."[102] In addition, Alfred Werck writes that "'stained' glass…is understood to apply to windows, or separate stained and painted panels…either separate or inserted in the lead-work of the window."[103] It refers to colored glass, created by mixing "white" glass with metallic oxide to color it. Stained glass first appeared during the Byzantine and Romanesque periods but was a necessity of the Gothic style.

The Rise and Fall of Stained Glass

Before looking at the styles of these historic stained glass windows, it is important to understand the development of stained glass, the rise and fall of which is somewhat independent from

[101] Ibid.
[102] Day, Lewis F. *Stained Glass*. 1903: 2.
[103] Werck, Alfred. *Stained Glass: A Handbook on the Art of Stained and Painted Glass.* 1922: 23-24.

the overall history of glass; looking at this provides the necessary context for understanding how these styles developed and were used.

While the history of glass objects takes off in Egypt, it is the Romans in the first century A.D. that put glass into their glazed windows.[104] To do this, they cast glass slabs and used blowing techniques to create discs and cylinder glass; unfortunately, this glass was irregular and lacked transparency. Sarah Brown writes that "it was the Romans who first fully appreciated the enormous potential of this material, light, impermeable, cheap to produce…Its use was no longer confined to decorative and luxury purposes; it became a material with a functional role."[105] It was the Romans that used glass for windows, although they also used other materials to fill the spaces as well, including mica, alabaster, shells, and linen[106]. While window glass was used in domestic contexts as early as the ancient Romans, it was their use in churches that really established its place in history among the decorative arts.

The development of stained glass came from the progression of early wall paintings to tile and glass mosaics to windows completely made of glass. In terms of painted glass, Brown writes that "it is not known when paint was first applied and fired onto window glass, for it is the combination of coloured glass and painted details that is the essential characteristic of stained glass. Archaeological evidence has now provided us with a considerable corpus of early painted glass."[107] During the restoration of the church of San Vitale in Ravenna, a painted glass fragment from a 6th century cloister was found, believed to be one of the earliest, if not the earliest, surviving painted glass[108]. On the other hand, literature discussing glass-painting has been around since the 9th century[109]. In addition, the earliest surviving painted glass windows in an architectural setting is a group of four prophets from

[104] Stained Glass Association of America. *History of Stained Glass*. 2012.
[105] Brown, Sarah. *Stained Glass: An Illustrated History*. 1992: 9.
[106] Ibid, 10.
[107] Ibid, 11.
[108] Ibid.
[109] Ibid, 12.

Augsburg Cathedral, dating back to about the year 1100[110].

While the Gothic period of architecture clearly highlights stained glass, the earlier Romanesque period was not without it. Stained glass windows during this time period were small, simple, and filled the rounded openings of Romanesque architecture. For these reasons, the designs of such windows had to allow as much light in as possible, but corrosion and dirt inevitably distorted the visuals. For glass painting during this time, there was some evidence of modeling in the figures but the depiction was very two-dimensional, with large eyes, linear treatments of the beard and hair, and a harsh frontal profile[111]. According to the Stained Glass Association of America "History of Stained Glass":

> Some figures in Romanesque stained glass stand or sit staring straight ahead. Some are involved in action as witnessed by their billowing garments. Some windows are made up of a series of events enclosed in medallions. The earlier windows of this style are more simple, primitive, and rare. They depict well-known saints or stories from the Bible. Reverence for the Virgin mary is prevalent at this time and she is often depicted as a queen. The windows use stylized vegetal ornament and decorative beading around the scene and figures. The redominant colors are red and blue. This style of stained glass seems to have developed from cloisonne enamels and miniature paintings.[112]

Unfortunately, very few of these windows survive.

Gothic architecture is incomplete without stained glass; the two are practically synonymous. Not only did window subjects expand from figures to include complex iconography, but also heraldry in windows began to show the increased secularity of stained glass. This period was characterized by the erection of a large number of churches and cathedrals. The Gothic cathedrals were the driving force for the popularity and importance of stained glass windows. The cathedrals had much larger windows providing larger canvases for designs; however, they are often hard to see from the ground, usually being recessed in galleries or set within thick walls. These windows were filled with much more richly-

[110] Ibid, 13.
[111] Ibid, 38.
[112] Ibid.

colored glass than those of the Romanesque period and there was a great deal more of painted glass. Sarah Brown notes that:

> Every piece of glass was painted; all the lozenges, squares, leaves and palmettes in the backgrounds were highly painted and every narrative compartment had a painted fillet around it. This presented the glass-painting workshops with an enormous amount of intricate cutting, painting, firing and leading. There is evidence, not surprisingly, that as a result of this pressure, glass-painters streamlined their painting techniques. The elaborate three-tonal procedure described by Theophilus gave way to a greater reliance on basic trace-lines and a simple wash, although even the wash was sometimes omitted. In some respects, this loosening-up of the technical procedures led to a greater naturalism in painting, although there is also a perceptible loss in legibility.[113]

In the 13th century, windows became ways to tell a story and one of the most important forms of monumental painting. The larger and numerous compartment arrangements made these windows ideal for storytelling, although their small sizes and their location at great heights made them difficult to read. By the end of the medieval period, around 1300-1350, characteristics such as perspective, volume, and depth were being seen in windows as well as more pictorial subjects. In comparison, Renaissance stained glass contain figures in period clothing and various allegorical themes. It was during this period that silver stain, flashed glass, and colored enamels were used.

The Renaissance and Reformation periods saw an increase of interest in human anatomy and the way in which figures were depicted. Brown writes that "although fifteenth-century glass painters employed perspectival devices in the depiction of the architectural components of their windows, they were relatively slow to dispense with the conventions of an earlier era, wisely recognizing that theirs was a two-dimensional medium."[114] It was not until the later fifteenth century that glass-painters began to abandon the framing of images under architectural canopies, instead choosing to depict the scenes in picture space.

Despite the various and complicated histories of stained glass, there seems to be an overall

[113] Ibid, 55.
[114] Ibid, 100.

agreement that interest in stained glass was lost between the late medieval age and the 19th century. There could be many reasons for this but the most likely comes from a religious and aesthetic viewpoint. The church had been the arts' greatest patron and between new Protestants being against ornate art and decoration and the Counter-Reformation asking for more simple religious buildings, the request for new stained glass was significantly diminished. In addition, wars, like the Thirty Years War (1618-1648), found countless castles and other buildings being destroyed, resulting in a further loss of valuable stained glass windows. By 1640, colored glass was very rare[115].

In America, glass-making was the first industry to be set up in Jamestown, which was founded in 1607, resulting in mostly bottles and window glass[116]. Around 1637-38, a painter and glazier named Evert Duyckingh arrived in New Amsterdam, bringing with him his small house windows depicting coats of arms in silver stain and enamel. Churches in America were simple buildings of wood or brick and stained glass windows were unnecessary both economically and aesthetically. However, the 19th century saw a rise in stained glass in America with the 1850s bringing a series of important studios to the industry, including artists like William Gibson, Henry Sharp, and William and John Bolton[117]. While the industry was improving, it was far from successful; it grew slowly and directly reflected the dedication and efforts of the individual craftsmen.

The Gothic Revival (1830-1900) brought stained glass back into favor. Because colored glass had lost its popularity, very little of it was available for restoration projects in Europe during this period and what was made was of a poor quality. In England, it was Charles Winston who analyzed Theophilus' work on creating stained glass and was able to successfully create colored glass of good quality. Brown writes that:

[115] Stained Glass Association of America. *History of Stained Glass*. 2012.
[116] Ibid.
[117] Ibid.

> all of the techniques described by Theophilus would have been familiar to the glass-painters and glaziers of the nineteenth century. The revival of stained glass at this period was fostered by a determination to restore the traditional skills of the Middle Ages. The apologists of the Gothic Revival revered the craftsmen of the past and a close study of their work was essential to the recovery of the technical intricacies of the craft.[118]

Regarding stained glass in the 20th century, Brown writes that "the new century began with a widespread desire to formulate new modes of expression unencumbered by the artistic vocabulary of the past."[119] The natural world provided a great source of new forms that permeated glass designs. The Art Nouveau period (ca. 1880s-1914) saw the increased desire to improve upon the artistic quality of machine-made products as well as to revive handcrafted quality. Louis Comfort Tiffany was a predominant figure in this period, creating impressionistic nature scenes of opalescent glass. The other important figure in American stained glass is John La Farge, who is known as the creator of the opalescent stained glass window[120]. This type of glass allowed for both highlights and shadows that translucent glass did not.

In America, the Great Depression (1930s-40s) and World War II (1939-1945) greatly reduced the amount of new buildings being constructed and, therefore, the stained glass industry was slowed significantly. In Europe, the later 20th century saw a lot of replacement glass in order to replace what had been destroyed by World War II. This resulted in an increase in the amount of work for the time but it was done in the same styles as the originals. The newest technique of stained glass today is called dalle de verre or faceted glass. It is set into an epoxy or other material, creating a very colorful mosaic-like appearance that can be used for windows or walls. Its popularity began at the end of World War II

[118] Brown, Sarah. *Stained Glass: An Illustrated History.* 1992: 29.
[119] Ibid, 149.
[120] Stained Glass Association of America. *History of Stained Glass*. 2012.

and demands for new buildings after the war provided a market for the material, which proved to be inexpensive, colorful, and easy to fabricate[121].

The Styles

Lewis Day notes the ambiguity of the origins of stained glass when he writes the following:

> Although,…there is not very much existing glass to which we can with certainty ascribe a date earlier than the thirteenth century, there is enough to prove to us by the evidence of our eyes that stained glass had by the twelfth century been brought to a point of execution arguing the development of a craft already long in practice; and the ever-quoted Theophilus, writing presumably in the latter half of the twelfth century, refers to it as though that were so.[122]

Regardless of the exact origins, stained glass can be summarized by Virginia Raguin's quote: "Light, color, and space are the artist's materials."[123]

There is some debate as to the exact time periods for the styles of stained glass windows and of course, styles will vary from country to country and will directly reflect the tastes of the time. Charles Winston, author of *An inquiry into the difference of style observable in Ancient Glass Paintings*, writes of this idea:

> One may perceive, I think, to a certain extent, in the general preference for coloured or white windows in a building, the prevalent taste of the time, not only as regards fondness for colour, but for gloomy or light interiors. Thus in the twelfth, and early part of the thirteenth century, when the window openings, however spacious, were at long intervals apart, the glass paintings used throughout the whole building were generally dark with colour. Afterwards, in proportion as the windows became more numerous, and were placed closer together, the richer glass paintings at first were confined to the further extremities of the edifice…the rest of the windows, both of the aisles and clearstory, being filled with white patterns, and at length they were dispensed with altogether. The effect of these arrangements, coupled with the greatly increased

[121] Stained Glass Association of America. *History of Stained Glass*. 2012.
[122] Day, Lewis F. *Stained* Glass. 1903: 4.
[123] Raguin, Virginia Chieffo. *Stained Glass: Radiant Art*. 2013: 9.

> number of apertures, was materially to promote the admission of light into the building.[124]

Regardless of the country, it can be said that changes in stained glass style are directly linked to changes in architectural style. For example, because stained glass windows are connected to Gothic architecture, perhaps the clearest way to classify stained glass styles is as follows: (1) Early Gothic (13th century until ~1280); (2) Decorated Gothic (~1280-1380); and (3) Perpendicular Gothic (~1380-1530).

Early Gothic (pre-1280)

Early Gothic windows are composed of white or colored glass, with a colored border around it. White windows of this period are silvery and cold due to the greenish-blue tint of the glass. On the other hand, the colored windows are like mosaics with intense tint and rich colors. This style of windows excludes more light than the other painted windows and gives an impressive yet solemn effect[125].

During the Early Gothic period, the color of stained glass windows was given by the glass. Lewis Day writes that the:

> paint was never used to give it colour. It served in the first place to give detail, by defining the outline of forms: it marked the features of the face, the folds of drapery, the serration and veining of foliage, and so forth, none of which lead-glazing could give. But lines and hatchings of brown were from the first (twelfth century) used not only to give form bur to qualify colour and regulate the distribution of the rays of coloured light shining through.[126]

[124] Winston, Charles. *An inquiry into the difference of style observable in Ancient Glass Paintings*. 1847: 39.
[125] Ibid, 32.
[126] Day, Lewis F. *Stained* Glass. 1903: 15-16.

In fact, the paint was solely brown in color during this time period, as a result of the iron oxides used[127]. Day states that "the object of paint in Early Gothic glass was…to give detail by stopping out the light in lines finer than lead could give; and artists availed themselves liberally of it, using it for the most part solid, because, whilst black gave brilliancy to the coloured glass, a scum or film of pigment dimmed it."[128]

There were four basic types of window designs during the Early period: (1) grisaille windows, essentially colorless, that depicted some form of pattern; (2) figure windows, richly colored, depicting saints or holy figures under an architectural canopy; (3) medallion windows, richly colored, which placed images in medallions into an ornamental framework; and (4) Jesse windows, richly colored, depicting the family lineage of the Savior[129].

The word "grisaille" means "grey" but really refers to a kind of ornamental glass work. It began in the 13th century and the bulk of these windows is white, clear, or gray depending on the type of glass used and the use of paint for details on the surface[130]. The earliest grisaille windows are composed predominantly of geometric lines, which create the overall design (Figure 21). Foliated details are also very common with these windows. The details themselves are outlined boldly in brown, and the background is crosshatched with very fine lines; this results in a window that appear to have purely white ornament with a tinted background. Another technique used on these windows is to paint a very thick brown line and use the hard end of the brush to create a pattern within the line by removing the paint to let the light through. In addition, to show depth the painters would paint a set of shapes with another set disappearing behind the first[131].

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[127] Ibid, 14.
[128] Ibid, 19.
[129] Ibid, 20.
[130] Isenberg, Anita and Seymour. *Stained Glass Painting*. 1979: 28.
[131] Day, Lewis F. *Stained* Glass. 1903: 21-22.

Figure 21. A grisaille window. Image courtesy of Drew Anderson.

With the exception of these grisaille windows, the main characteristic of Early Gothic period glass is deep colors. Figure windows were found in the triforium or the clerestory of cathedrals, portraying apostles, kings, prophets, etc. on a very grand scale. While the images are larger than life-size, proportion is key. For this reason, for long windows, the figures are often depicted in two rows, one on top of the other; for broad windows, a border is usually employed at the top or bottom of the window or both[132]. The figures are facing the viewer and they stand within small niches of architectural design. While the designs of some windows are meant to simply create a brilliant patch of colors, others highlight the figures by using a single-colored background, like red or blue.

The portrayal of the figures was considered archaic, with exaggeration in the lines of the faces

[132] Ibid.

and a simplification of the fingers of the hand. The hands in particular appeared grotesque up close but the design intent was for the painter to both offset the scattering of light and to express the shape of the hands in general, seen by the majority of people from the church floor far below. Figures faces were made of reddish-brown glass because it was the closest color to flesh that was available at the time; at times, white glass was used for the whites of the figures' eyes, resulting in an unsettling glare upon the viewer. Stylistically, the figures appear to be Byzantine, with a rigid appearance and drapery which clung closely to the figure; by the 13th century, figures became much looser, often shown in action with drapery flowing about them[133].   Because of their simpler composition and window size, these windows were much more distinctive than medallion windows because they were easier to see; however, the images in general were entirely flat and two-dimensional (Figure 22).

Figure 22. Early Gothic figure window from Lincoln Cathedral, UK. Image from Lewis Day, *Stained Glass*. 1903: 23.

[133] Ibid, 24, 27.

Medallion windows were considered the a standard form of Early period windows. They typically consist of a number of colored picture arranged symmetrically and decorated with a mosaic background. Day describes them as follows:

> It has a broad border of ornament, in wide windows often very broad (a full sixth or more of the width of the light), and, within that, a series of medallions (circles it may be, quatrefoils, or other regular shapes) one above the other, occupied by figure subject on a small scale. The figures are simply displayed on a single plane against the blue or ruby ground, and the shape of the medallion is defined by a broad band of contrasting colour (red against blue or blue against red), itself bounded by narrow lines of white. The interstices between the medallions are filled in with ornament, consisting, in England of scrollwork, in France usually of geometric diaper.[134]

Before the use of this type of window, the window space was simply divided into rectangular sections and each one was considered its own picture panel. One particular development with these windows was using the support bars to both support the window and enhance its design. The bars were shaped according to the shape of the medallions, which serves to highlight the overalll effect of the window. These windows were used as "storied windows," which each medallion telling a piece of an overall story or to depict theological ideas. Originally, the pictures were small because a number of them had to fit in a single window but over time, they became larger and fewer within each window when made for clerestory lights, which were viewed from a much greater distance down below. Each picture had a solid background color so that the figures were clearly depicted. When architecture introduced lancet windows with mullions to divide these already narrow windows into further pieces, these medallion windows decreased in popularity but did not go extinct[135]. The well-known rose windows are actually an adaptation of the medallion window that fits its shape to the radiating tracery (Figure 23).

[134] Day, Lewis F. *Stained* Glass. 1903: 27.
[135] Winston, Charles. *An inquiry into the difference of style observable in Ancient Glass Paintings*. 1847: 34.

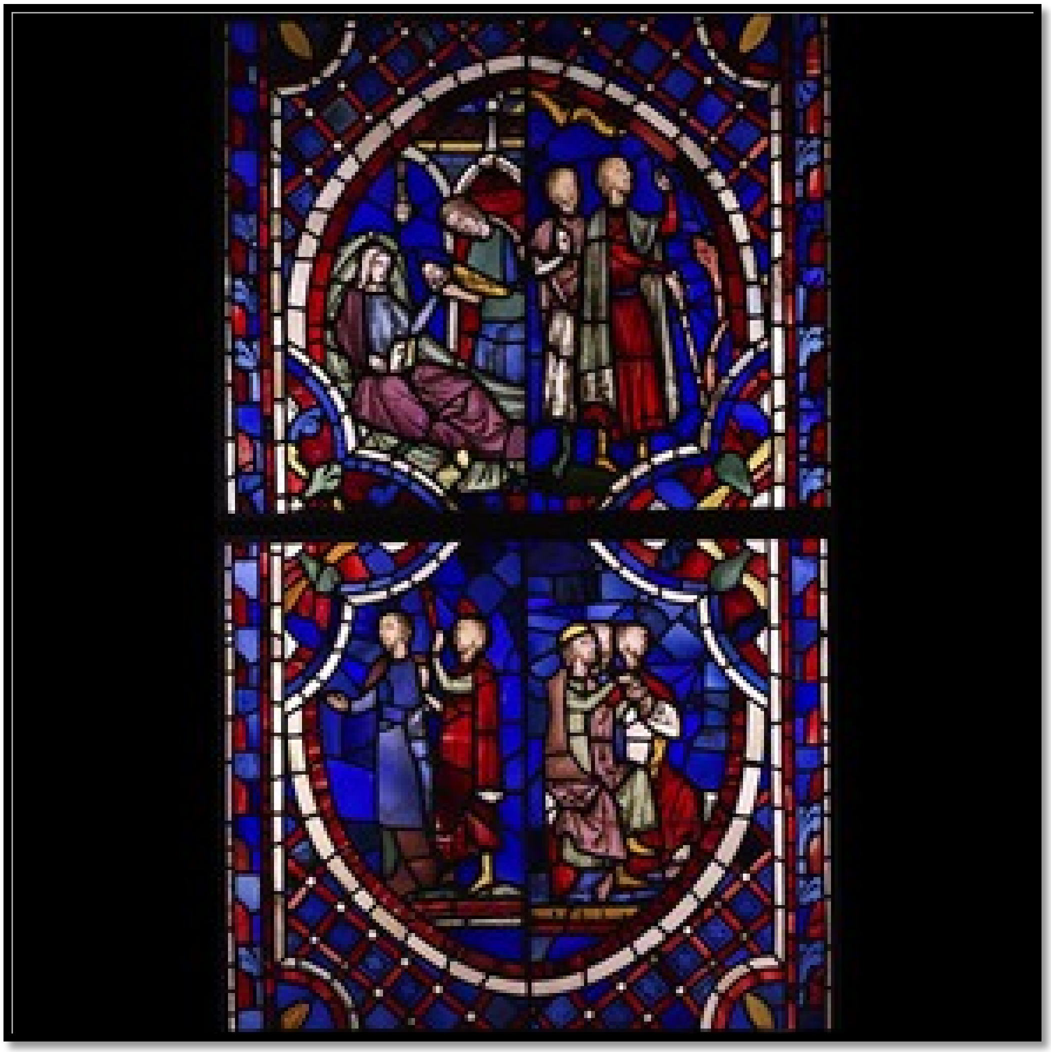

Figure 23. Early Gothic medallion window from Sainte-Chapel, France. Image from the Victoria and Albert Museum.

Jesse windows are based on the idea of the tree of Jesse, or the geneology of Christ, and depicts several images among foliation (Figure 24). The tree branches form around vesica-shaped medallions containing various holy figures, which usually increase in importance as one progresses up the window[136]. Near the top is usually the Virgin Mary, Christ, and the Holy Spirit in the form of a dove. Within the scrollery or in the border of the window are figures of angels and prophets. The number of pictures and the layour of the design vary depending on the length and width of the window.

[136] Day, Lewis F. *Stained* Glass. 1903: 32.

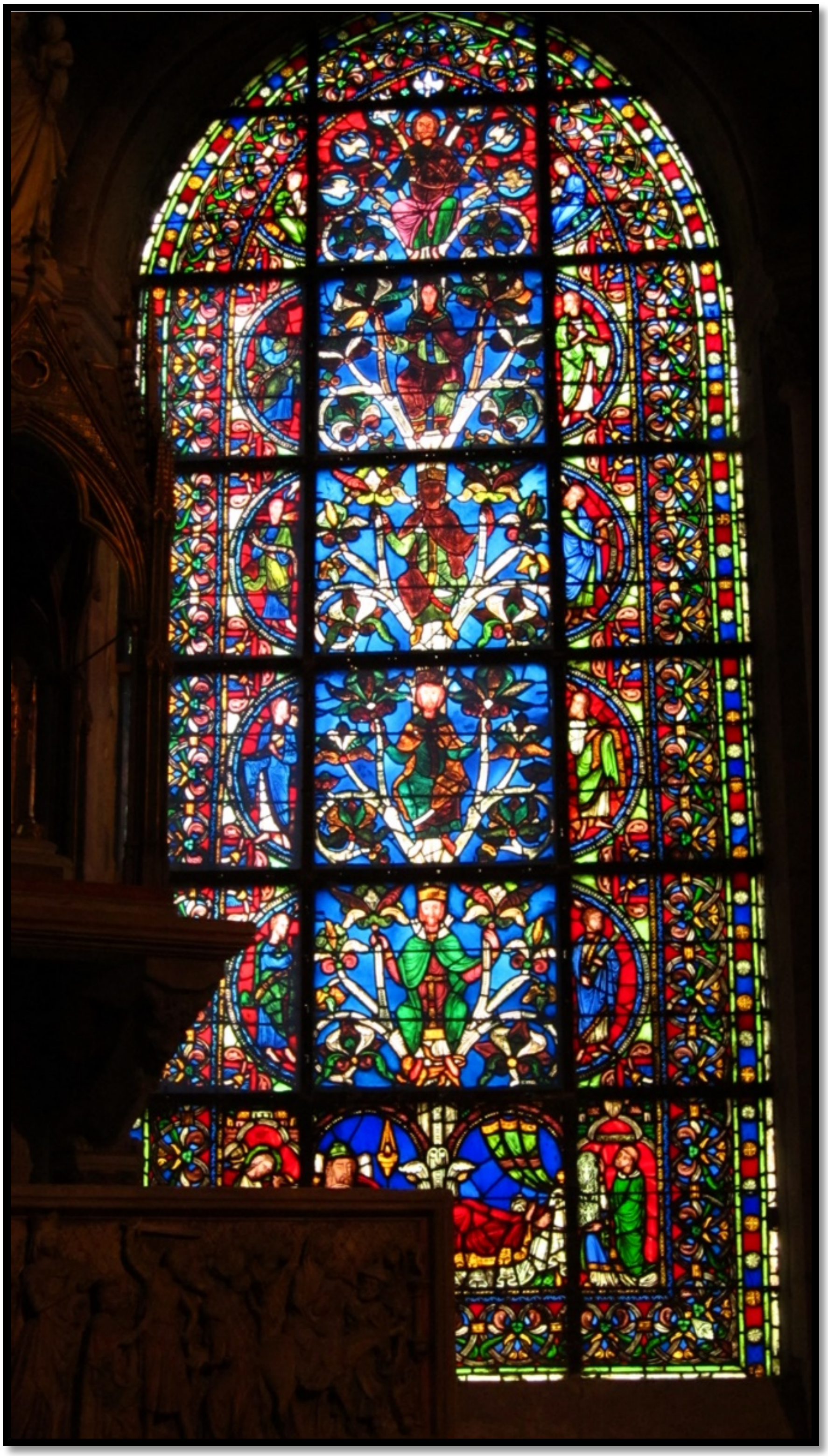

Figure 24. Early Gothic Jesse window from St. Denis, France. Image from http://imaginemdei.blogspot.com/2011/12/o-flower-of-jesses-stem.html

During this period, the color palette of the glass-painter was restricted but did contain a variety of deep, rich tones including ruby, sapphire, emerald, moss, olive, brownish-purple, yellow, turquoise, and dusky white[137]. The main goal of windows of this time was to create a mosaic effect; because most of the windows were so high up in churches and cathedrals, the details of the images were deemed less important than the overall effect. In terms of paint during this period, it was more of a practical tool than anything else; Day writes that the early glazier aimed for "an effect of jewelled light, produced by a mosaic of quite small pieces of glass, coloured in the pot, and only so far obscured by paint as was necessary to keep out the light, to give coherence and definition to the ornamental details of the window, to represent the person, or to tell the story, it was designed to picture."[138] Paint was used to break up the intensity of the light coming into the space and to regulate it in an aesthetically pleasing design.

Regardless of the types of windows, there are some general characteristics to be noted for this style. The figures depicted are rigid and not properly proportioned. Their drapery clings to their bodies and both their clothing and facial features are sharply outlined for distinction. The faces, created with pink glass for flesh tones, were Byzantine in style. Faces were oval in shape, with large eyes and a small mouth. The hair of the figures was depicted in flat curls and beards were shown as perfectly symmetrical. The heads were outlined heavily and smear shaded. Physically, the glass always appears very thick with red and blue being the predominant colors, used often as the backgrounds for figures. While the glass of this time was sufficiently transparent, it was not completely clear; this provided a characteristic look to Early Gothic period glass, one in which all colors appeared to have inherent richness and strength[139].

The paint was dark brown and outlined the forms and figures in the design as well as highlighted

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[137] Ibid, 32-33.
[138] Ibid, 34.
[139] Winston, Charles. *An inquiry into the difference of style observable in Ancient Glass Paintings*. 1847: 43-44, 48-49.

and shaded them using cross-hatching. In addition to cross-hatching, smear shading was also used, often in the drapery folds, architectural details, and in the foliage and other ornaments; a smear of paint is applied broadly and softened at the edges to suggest depth and realism in the design (Figure 25). Foliage makes up the majority of the decorative work for this period. The foliage used for this style was conventional, a series of short stalks of white or colored glass. When white glass is used, the foliage is boldly outlined and shaded with cross-hatching to make it stand out in the window. Common elements include concentric spiral scrolls, trefoils, cinquefoils, and rows of beads[140]. Finally, in terms of construction, because of the mosaic nature of Early Gothic period windows, a lot of lead was required to hold the window together.

Figure 25. Smear shading, as seen in drapery folds. Image from CVMA Glossary, 2010.

[140] Winston, Charles. *An inquiry into the difference of style observable in Ancient Glass Paintings*. 1847: 42-45, 51-52.

Decorated Gothic (~1280-1380)

The Middle Gothic period, also known as the Decorated Gothic period, began with a change in taste in stained glass, including the differently-shaped windows, desire for more light, more pictorial imagery, and increased resources of both the glazier and glass-painter. According to Day, therefore, windows of this period differ from that of the Early period "by the design being schemed to spread over several lights; by the lighter, brighter, gayer key of colour; by the natural forms of the ornamental foliage, now deliberately taken from growing plants; by the more serious attempt at realism in the drawing and painting of the figure; and by the adoption, finally, of a practice, unknown to glaziers of earlier times, of *staining* white glass yellow."[141] Windows were designed such that the most light was let in; therefore, a lot of white glass used, often surrounded by borders of colored glass. The figures themselves were still not perfect, but during this time they were improved by artists giving them a more graceful pose. Figures were still depicted under canopied architecture but it was a different shape, proportion, and color than the Early Gothic period (Figure 26). Windows that were rich in color were laid out in bands of color with layers of white or yellow glass between tiers with figures[142].

[141] Day, Lewis F. *Stained Glass.* 1903: 39.
[142] Ibid, 51, 44.

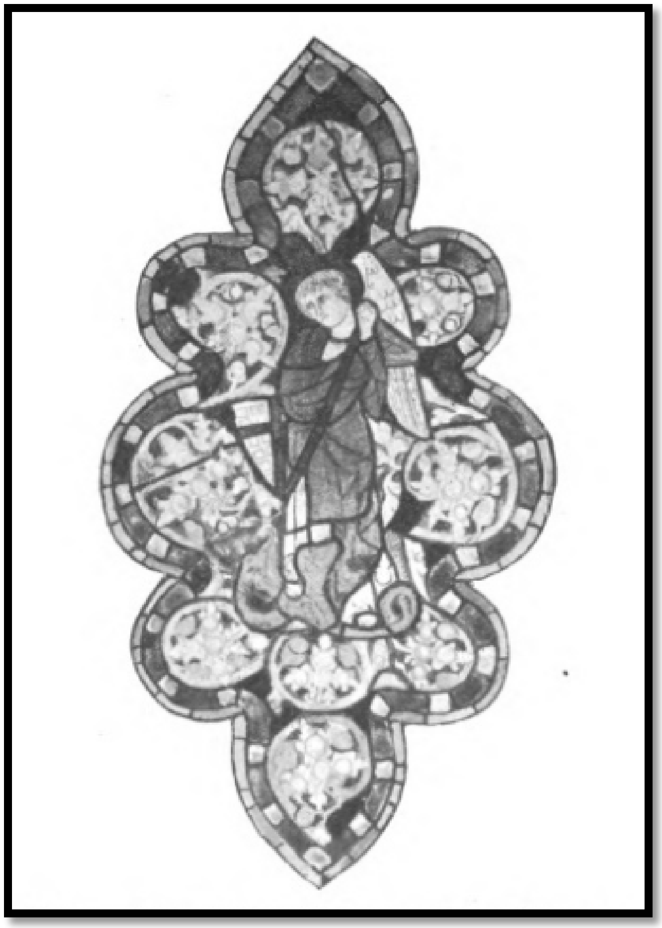

Figure 26. Decorated Gothic figure in tracery light in Wells Cathedral, UK. Image from Lewis Day, *Stained Glass*. 1903: 53.

White glass of this time had a greener tint to it and was thinner overall. The texture and color of the glass is very similar to that of the Early Gothic period, although some colors were created to be a lighter shade. Shadows were obtained almost solely by the smear method which gave the design depth; the paint was laid on so thick in places it created opacity[143].

Another characteristic of windows of this period was an increase in window area. This allowed for more elaborate images of figures to be depicted effectively on a larger scale and successfully seen from a distance down below. Also, the process of stippling was introduced during this time in order to create a more even and pleasing texture to the glass. The smeared paint of the Early Gothic period not

[143] Winston, Charles. *An inquiry into the difference of style observable in Ancient Glass Paintings*. 1847: 75, 77.

only resulted in an uneven tint but it also dulled the glass; in comparison, the stippled paint resulted in a much more even surface texture and because the paint gathers in small hills, the glass remains mostly translucent. This technique was used to paint shadows, a characteristic of window imagery during the Middle period[144].

Perhaps the most significant development in this period is the introduction of yellow stain, also called silver stain (Figure 27). At the start of the 14th century, it was found that silver compounds painted on glass would stain it yellow when fired; in addition, depending on the temperature, the color could range from a greenish-yellow to a deep orange[145]. This stain was permanent and could only be removed if the surface of the glass itself was removed as well. The glass painter took full advantage of this technique, using the various shades of yellow to highlight their compositions where needed, thus brightening the windows as a whole.

Figure 27. Silver Stain Roundel. Image from Sarah Brown, *Stained Glass: An Illustrated History.* 1992: 89.

[144] Day, Lewis F. *Stained Glass.* 1903: 49, 52.
[145] Ibid.

Other notable color developments during this period were the increased use of green glass, even in backgrounds where ruby and sapphire were almost exclusively used, and the improved "flesh" color of glass, resulting in a paler brownish-pink color which eventually gave way to the use of white glass used for flesh with hair stained yellow. This period overall is considered a transitional one, residing between the Early and Late Gothic periods; Day writes that it "has neither the colour of the earlier, nor the draughtsmanship of the later."[146]

Again, more noticeable changes came with the representation of figures. Both their proportions and their drapery were more realistic, giving the figures a more natural appearance. The heads were more natural as well, being depicted more refined but still with heavy outlines. Many of the facial characteristics, like the oval-shape and the small mouth, were retained from the Early Gothic period; however, the hair, like the figures themselves, were depicted more naturally as longer, flowing lines. Foliage was substantially more natural and definitive forms could be recognized, including maple, oak, and ivy leaves. Instead of the scalloped ornament, the crossed ornament was introduced. Whether the border is thick or thin, it almost always includes a strip of white glass between it and the stonework. Canopies were used to cover both single and groups of figures and vary in size and shape. Some even extend far above the figures, unlike during the Early Gothic period where they framed them closely[147].

Perpendicular Gothic (~1380-1530)

Picking up where the Middle period left off, the Late Gothic period, also known as the Perpendicular period, progressed further in both imagery and light. The 15th century also brought the glass-painter into the most important role, surpassing the glazier for the first time. With the Early

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[146] Ibid, 55.
[147] Winston, Charles. *An inquiry into the difference of style observable in Ancient Glass Paintings*. 1847: 78-79, 83-93.

Gothic period, the window was first designed in glazing, much like the pieces of a puzzle are put together; painting is used as a supplement to be added in the end if needed. In comparison, the Late period saw the glass-painter sketching the design first and then deciding on the glazing. According to Day, the designer:

> was no longer a glazier, thinking how he could carry his design further by the aid of paint, but a painter, thinking how by the aid of glazing he could get colour into his design. His window consisting by this time largely of white glass, the problem of design resolved itself into a question of introducing colour in the midst of white, and (now for the first time) *avoiding*, as much as possible, the use of leads, which he began to think a blemish upon it.[148]

The more white glass used, the more possibilities there were for the painter; on the other hand, during this time the leads became a detriment to the painted design because they interrupted the delicate visual.

The predominant form of window in the Late Gothic period was a canopy window (Figure 28). Unlike previous canopy windows, these forms of canopy were almost entirely white and restricted to a single light; the canopies themselves were meant to frame the picture, not be a part of it. With a base of almost completely white glass, these windows also had a banded effect to them, similar to that of the Middle period; the difference is that the Late Gothic windows have alternating bands of white and color. Also unlike its predecessors, Late Gothic windows did not have to contend with extremely tall openings due to the architectural introduction of the transom in the Perpendicular style. Ornamental details were less naturalistic during the 15th century than the 14th; natural forms were reduced to represent much simpler ornaments, turning away slightly from the realism of earlier on[149]. Where canopies of the Decorated period used pot-metal glass of various colors, those of the Perpendicular period used mostly

[148] Day, Lewis F. *Stained Glass.* 1903: 61.
[149] Day, Lewis F. *Stained Glass.* 1903: 61-62, 67-71.

white glass and yellow stain; the colored glass is used for the background and the figures within the niche[150].

Figure 28. Perpendicular Gothic figure window from Winchester College Chapel, UK. Image from Lewis Day, *Stained Glass*. 1903: 63.

Another tactic used during this time was the landscape effect. Now that pot-metal blue glass could be made light enough to paint on, creating a detailed sky with clouds was possible. In addition, the yellow-stain was used to enhance the effect by creating shades of green for the landscape itself when placed on the blue glass. It also became a technique to use a white glass background and paint the entire scene, using yellow stain to enrich where necessary. These painted windows are very delicate

[150] Winston, Charles. *An inquiry into the difference of style observable in Ancient Glass Paintings*. 1847: 105.

and detailed and therefore should be seen up close. Glass-painters of this time were finally skilled enough to handle this type of pictorial windows, after centuries of training and perfecting their craft.

These works are distinguished by more masterful drawings, more delicate painting, and successful modeling of flesh which was done using a stippling technique (Figure 29). This technique is described as follows:

> paint shadows thinly, stipple them, and enforce them with hatchings or scribblings of fine lines over that…a further development was, having traced the outlines and burnt them safely in, to coat the glass all over with a film of brown, to matt the painted surface, and then to wipe out the parts where the glass was meant to be clear, and with a stiff brush to scrub away from other portions of it just so much of the paint as would give the gradation of tint required; finally the painter put in crisp, dark touches with the brush, and with the pointed end of the stick scraped out sharp lines of light…the all-important thing was to get light into the shadows.[151]

Charles Winston notes the effect that this stippling technique had on the field:

> The introduction of stipple shading may also be regarded as having sensibly affected the colouring of glass paintings; for the ancient artists appear to have soon perceived that mosaic arrangements of stiff and powerful colours, were unfavourable to a display of the more minute gradations of light and shade in pictorial compositions; and that the very shadows themselves tended to correct the coldness of white glass, and to increase the richness of the lighter kinds of coloured glass.[152]

These deeper shadows give richness and depth to the windows, allowing the pictures to become more realistic and less flat. In addition, shading was also added to the foliage in order to enhance the realism.

[151] Day, Lewis F. *Stained Glass.* 1903: 82.
[152] Winston, Charles. *An inquiry into the difference of style observable in Ancient Glass Paintings*. 1847: 103.

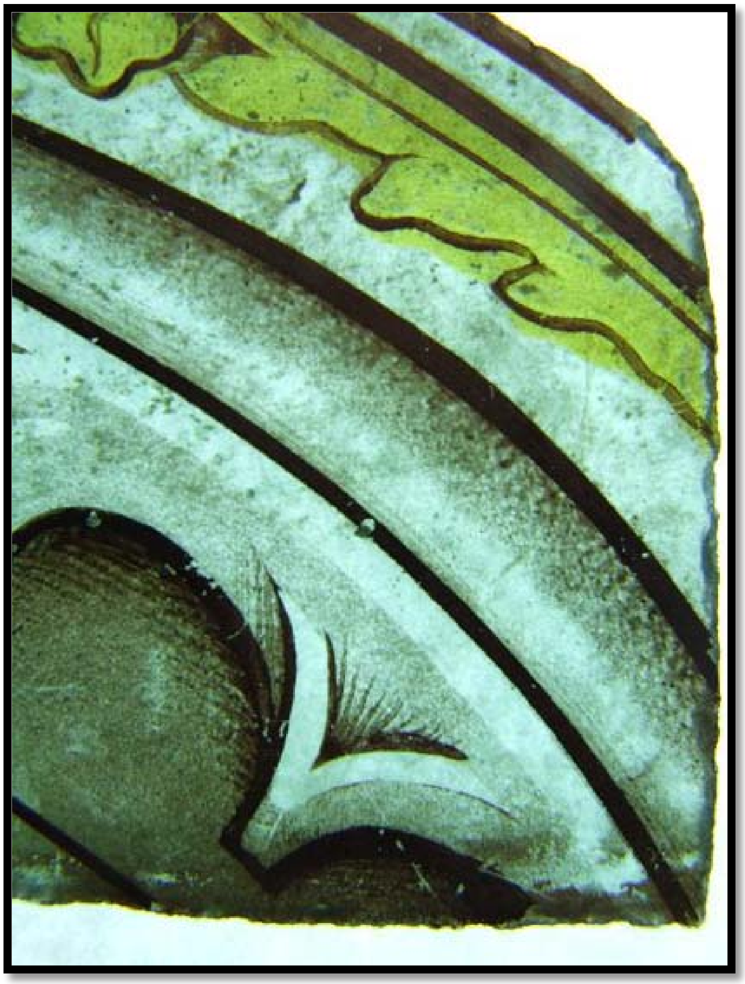

Figure 29. Stipple shading. Image from CVMA Glossary, 2010.

In addition, the quality of glass also affected these painted images. Imperfect glass had to be used in very particular and creative ways. Unevenly-colored glass had to be used such that its transition from light to dark aided the depiction of the roundness of the drapery instead of distracting from it. Glass that was streaked or spotted was also used in imaginative ways wherever possible; this can be seen in particular with ruby glass, whose imperfections were utilized to create architectural effects such as marbling[153].

Coating glass and abrasion techniques were also developed and utilized during the Late Gothic

[153] Day, Lewis F. *Stained Glass.* 1903: 82-83.

period. The flashing method used for ruby glass was used for other colors as well, mainly blue. Between abrasion and yellow stain, a single piece of blue glass could contain blue, white, yellow, and green. In terms of white glass, it was still not clear and colorless, but it was significantly lighter than during previous periods; it still contained a tint of either blue or green, but this resulted in a silvery appearance that was characteristic of the Perpendicular style of this period[154].

Perpendicular windows are usually more pale and are less rich in color than those of the Decorated period; however, they are more delicate, silvery, and brilliant. Winston says that "what they seem to lose in power, they gain in refinement."[155] The white glass became thinner and changed from the greenish-blue tint of the Decorated period to a yellow-green during the Perpendicular period. In addition, ruby glass became more versatile with the increased popularity of abrasion techniques which allowed for the designs to be more creative. One of the main characteristics of Perpendicular glass is its delicacy, as seen through its finely-executed figures, complete with more refined outlines. Finally, the Late Gothic Period saw the transition from the single-figure and small groups of figures of the earlier Gothic styles to entire scenes. This can be summarized in the following quote from Alfred Werck's book:

> Figures idealized or symmetrically arranged groups no longer appear isolated in the design. The rigid monotonous background is eliminated, while perspective is opened to the eye and its possibilities utilized to their fullest extent. All natural phenomena, the earth and the sky, distance and proximity, mountainsides, green meadows, fruit-laden trees, the comfort and adornment of human dwellings, all the equipment and necessities of life are represented in the works of this period. The human figures appear in their environments, and joined in organic relation with them, they form a complete unit. The details are recorded with the most meticulous care and an admirable effect of realism is achieved. Faults may still be detected in places, as rigidities in the modeling and in the draping of the garments, nor is there yet a correct anatomical understanding of the human body. These defects, however, disappear in the general harmony of the whole, which is achieved by the blending of clear and brilliant colors and by the deep sympathy of the interpretation which presents to us the glorification and transfiguration of earthly life in the midst of all its restricted conditions.[156]

[154] Ibid, 85, 92.
[155] Winston, Charles. *An inquiry into the difference of style observable in Ancient Glass Paintings*. 1847: 104.
[156] Werck, Alfred. *Stained Glass: A Handbook on the Art of Stained and Painted Glass.* 1922: 126-127.

Renaissance

The Late Gothic period and the early Renaissance, like other time periods, experienced a degree of overlap. The differences between the two lay with the details, including the figures' dress, architecture, foliage, and ornament. At first, the style of the Renaissance remained very similar to the Late Gothic, with pot-metal colored glass and brown paint for details.

Over time, the difference between the Late Gothic period and early Renaissance became apparent. While mosaic windows were still found during this time, there was great change in terms of window design. Figural images, like the Last Supper, were often carried across several lights, forming one large picture that continued as far as the tracery would allow. The Renaissance canopy was richly stained as opposed to the all-white of the Late Gothic. In addition, the canopies were mostly borderless, allowing instead for the masonry of the architecture to serve as the frame of the window. The use of the canopy in Renaissance windows was short-lived, replaced with the tactic of binding the window together with painted architecture. Tone and shadow were able to be achieved but at the cost of the glass's luminosity. Paint itself surpassed glazing in importance to the windows, now often being used to provide the color to the glass, not just create the forms on it[157].

The middle of the 16th century brought the introduction of enamel colors (Figure 30). Day writes that their introduction began slowly:

> It was used at first for the flesh tints, an ochreish red being used for modelling the heads and hands, and, earlier still, for tinting them on the other side of the glass after they had been painted in brown. Then blue enamel was upon pale blue or white to give more delicate gradations of tint in the skies, and eventually other enamel colours. Enamel colour was used also upon coloured glass to give depth to the shadows; for by this time a thinner, evener, and poorer quality of glass came to be made, which served the immediate purpose of the painter better than deep, dense, and unequally coloured glass.[158]

[157] Day, Lewis F. *Stained Glass.* 1903: 94-98, 101, 106.
[158] Ibid.

In many ways, enamel painting was similar to oil painting. The pigments were made of metallic oxides mixed with powdered glass and at a certain temperature, the compound melts and fuses to the glass; however, with enamels, the compound does not infiltrate the glass and even when attached, it was never completely secure. It was very difficult to make sure that the levels of expansion and contraction of both the glass and the enamels were the same, which inevitably led to flaking and ultimately loss of paint. On the other hand, enamels were exceptional in creating delicacy and refinement[159]. Enamels will be discussed further in a later chapter.

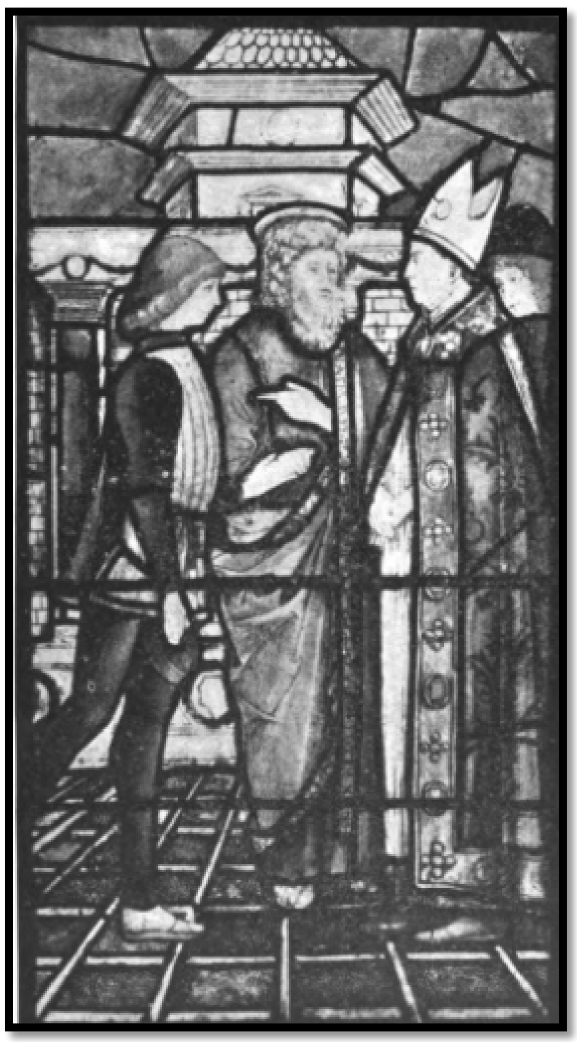

Figure 30. Renaissance figure window from Milan Cathedral, Italy. Image from Lewis Day, *Stained Glass*. 1903: 99.

[159] Ibid, 102-105.

Early Renaissance painters are often criticized for "the degradation of glass to the position of a mere translucent ground to paint on, in colour which had neither the permanence nor the depth and brilliance which had been the glory of older glass."[160] The highlights of the Renaissance came with painting and the achievement of architecture in perspective, figures with realistic light and shading, and even atmospheric distance in landscapes. Painting was further developed in the technique of scraping out lights and modelling was done with stains as well as paint, sometimes using staining on stain to show further mastery of the technique.

In summary, the Renaissance period style can be characterized by the following: large and small pictorial subjects, often with landscape backgrounds; paint laid on more thickly and highlights wiped out with a stiff brush; enamel colors were introduced and first used as a thin wash to represent flesh color; glass is very thin, of a more even surface and inclined to be brittle; heraldic glazing was highly developed; medallions produced in numbers, painted in monochrome or paint and stain; and various geometrical designs used in secular buildings with white glass.[161]

Additional Styles

In addition to these three major categories, most historians include a number of other styles as well. The two most common are the Cinque Cento style and the Intermediate Style; similar to the transition of the Gothic periods, these two styles have overlap with one another as well as the Gothic styles.

The Cinque Cento style is said to have taken place during the first half of the 16th century (Figure 31). This style used brilliant color displays and abrupt changes in light and shadow that somehow

[160] Ibid.
[161] Thomas, Roy Grosvenor. *Stained Glass: Its Origin and Application.* 1922: 15-16.

allowed the glass itself to remain transparent. On the down side, glass painters of this period continued to try to improve upon this effect and ultimately, the transparency was lost with multiple layers of paint layered to create shadows. New tints and colors of glass, like “streakies,” were made, allowing painters to take advantage of these bold or subtle effects[162].

Figure 31. Cinque Cento Style figure. Image from Anita and Seymour Isenberg, *Stained Glass Painting*. 1979: 25.

Some historians state that the Intermediate style (Figure 32) was the one to introduce enamels; despite the fact that there is debate as to whether to credit the Renaissance period or the Intermediate period for it, one can easily draw the conclusion that these two styles experienced characteristic overlap. The Intermediate style utilized enamel colors mainly on clear, white glass[163].

Figure 32. Intermediate Style window. Image from Anita and Seymour Isenberg, *Stained Glass Painting*. 1979: 26.

162 Isenberg, Anita and Seymour. *Stained Glass Painting.* 1979: 25-26.
163 Ibid.

While the painting styles addressed in this section cover a majority of the styles, each country, in each time period, will have its own unique characteristics so although it is useful for this purpose to discuss the styles in general terms, it is important to note that there are additional stylistic differences depending on time and location. In addition, it should be noted that for the more recent centuries, namely the 19th and 20th centuries, there is no truly distinct style to be recognized. During this time period, figural windows were not used as much and those that were created were done in a previously existing style. These centuries saw windows that were more architectural in nature, with not as much need for painting and therefore, no real need of a unique style.

Glass Painting Techniques

In his *Rudimentary treatise on the art of painting on glass*, M.A. Gessert defines glass painting as follows: "the art of painting on transparent glass (either colourless or already coloured in the process of its manufacture) with vitrescible metallic colours, which are afterwards burnt into the surface of the glass on which they are laid, leaving it more or less transparent."[164] All colors used in glass-painting are metal oxides and can be divided into two classifications: (1) where the oxide is laid on the glass in its original combination with an earthly vehicle, such with as silver stain; and (2) where the oxide adheres to the glass with the help of a flux of glass. This second group is further divided into two subcategories, both of which involve the use of a flux, or "a vitreous compound, which fuses more easily than the foundation, the glass plate"[165]: (1) the unchanged oxide is mixed with the flux before being attached to the glass, such as with vitreous glass paint; and (2) the oxide is vitrified and fused with the flux before being attached to the glass, such as with enamels. The latter of the two is called "fused colors" whereas

[164] Gessert, M.A. *Rudimentary treatise on the art of painting on glass.* 1851: 5.
[165] Ibid, 6-7.

the rest of the colors are called “mixed colors.”[166]

There are three types of glass painting: (1) the colors of the figure are laid on a single sheet of clear glass, including all principal colors and tints; (2) the figure is composed of different colored pot-metal pieces and only the shadows and outlines are painted on (mosaic glass painting); (3) a combination of the two.

For painting to be done on a single glass sheet, it is important that the sheet itself be of pure white glass and free from flaws. Then the ground or foundation must be laid. This can be done in two ways. The first is to dip a cloth in oil of turpentine and brush the glass surface until evenly coated. The other way is to give a clear ground of black color, just enough that it does not extinguish the glass’s transparency but provides a dead ground glass appearance. Both methods provide the even, viscous surface that takes the paint design better than a simple polished surface but the black foundation also provides the additional benefit of preparing the glass for the shading and painting effects[167]. It is possible for this ground to be etched away later with a wooden style to allow more light to shine through the design before the glass is fired.

Next, the cartoon of the drawing is placed underneath the glass and it is held down with wax; then the glass is propped up so as to allow light to pass through it while the painting is taking place. The pigments themselves are mixed with oil, or another medium, allowing for clean, sharp edges, and then it is painted onto the glass with a brush. The depth of the colors’ tones will depend on how thickly the pigments are laid on the glass and the pigments themselves must be applied thicker than in other forms of painting because they lose some of their depth when fired. In general, the “under-painting,” or outline of the drawing, intermediate tints and shading are done on the front of the glass, facing the viewer while the colors themselves are laid on the other side. In addition, often two colors are overlapped, one on the front and one on the back, to create a new color (i.e. yellow and blue to make

[166] Ibid, 6.
[167] Ibid, 43-44.

green).[168]

For mosaic painting and a combination of these two types, the process is essentially the same with slight variations. For example, mosaic painting requires two cartoons instead of one. The first is finished, colored and contains numbers for each of the pieces; this cartoon is used as a guide to where each piece of glass belongs in the window. The second cartoon, which includes only the black outlines of the design, is used as the working cartoon to provide a physical outline when cutting the glass pieces to size[169].

Anita and Seymour Isenberg define the three methods of glass painting methods in a slightly different way. They write that the three types are: (1) the mosaic method; (2) the enamel method; and (3) the mosaic-enamel method. The mosaic method consists of taking pieces of colored or uncolored glass and joining them together like a puzzle; the outline is formed by lead cames and painting is limited to tracery pigments, matts, and stain. Tracery lines are the painted outlines of the design on the glass and the matts are the layers of paint spread thin to provide shading and contrast to the painting. The color comes from the glass itself and while the general rule of this method is one color per piece of glass, multiple colors on a single piece can be achieved using acid-etching or silver staining. The enamel method does not use colored glass and can be done with a single piece of glass since the colors are painted on. The glass acts as a transparent canvas upon which enamel colors are painted. Finally, the mosaic-enamel method involved putting together the window as a mosaic and both enamels and glass stainer's colors are utilized. Enamels are used on clear glass or to enhance the tones of colored glass while glass paints are used to create shadowing and detail[170].

[168] Ibid, 45-49.
[169] Ibid, 51-52.
[170] Isenberg, Anita and Seymour. *Stained Glass Painting*. 1979: 27-28.

Visual Principles of Glass

According to Mary Merrifield in her *Medieval and Renaissance Treatises on the Arts of Painting*, there are three things needed for a good glass painting: (1) luminous transparency; (2) good composition; and (3) brilliant coloring.[171] But it is Peter Van Treeck who notes perhaps the most significant feature of a glass painting—that it requires two surfaces (glass and paint) to work together. He writes that "the technical and optical requirements of painting on glass differ from painting on plaster, canvas, or wood. The only comparable feature shared by both techniques is the opaque, linear contour. Every other painted detail on glass, whether color or tonal value, achieves its intended effect through melting and becomes a filter of light."[172] The true colors of a glass painting cannot be seen in normal reflected light; transmitted light is a necessity to see the existing hues.

Both the reflection and transmission of light are basic optics principles. They occur because the frequencies of the light waves do not match the natural vibrational frequencies of the objects being hit. When light hits an object, the object's electrons begin to vibrate and energy is released in the form of a light wave. If the object is opaque, the electrons on the material's surface will vibrate and emit energy as a reflected light wave off this surface. If the object is transparent, as with glass, the electron vibrations pass from one atom to another within the bulk of the material; the resulting energy is emitted on the other side of the object in the form of a transmitted light wave[173]. Van Treeck notes that visible colors or tonal values are made up of these transmitted light waves. He writes: "Chromatic values are produced by ions of specific metals dissolved in glass and vitreous paint, often in concentrations lower than 1 percent. Bright values appear only through intense transmitted light. Dark zones and colors require a reduction of light, achieved by applying a vitrifiable medium densely mixed with substances

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[171] Merrifield, Mrs. Mary P. *Medieval and Renaissance Treatises on the Arts of Painting*. 1967: lxxxiv.
[172] Van Treeck, Peter. "On the Artistic Technique of Glass Painting." 2000: 57.
[173] Hecht, Eugene. *Physics: Calculus.* 2000: 917.

that provide coloring and opacity."[174] Figure 33 shows the optical principles of reflection and transmission of light.

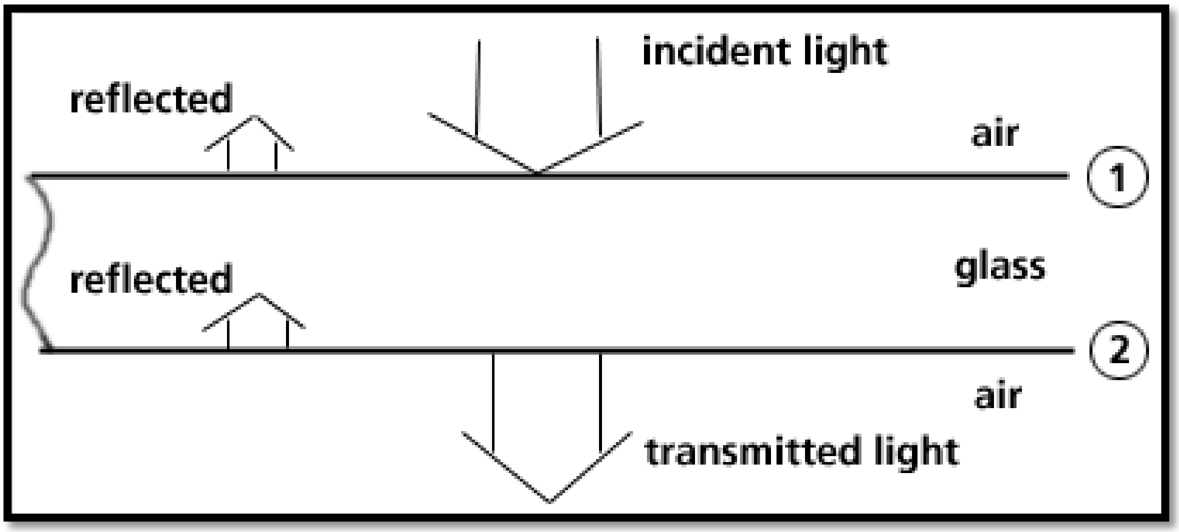

Figure 33. Reflection and Transmission of Light. Image from
http://www.asu.edu/courses/phs208/patternsbb/PiN/rdg/interfere/interfere.shtml

It is useful to look at these two optics principles through an example of a stained glass window. Figures 34 and 35 show a stained glass window through reflected and transmitted light, respectively. These two images not only make it clear how essential light is to stained glass but also how essential the paint is in controlling this light.

[174] Van Treeck, Peter. "On the Artistic Technique of Glass Painting." 2000: 57.

Figure 34. 16th century Swiss stained glass panel in reflected light. Image courtesy of Drew Anderson.

Figure 35. 16th century Swiss stained glass panel in transmitted light. Image courtesy of Drew Anderson.

For the purpose of this thesis, it is also beneficial to observe paint and surface decoration deterioration and loss in both kinds of light. Some forms of damage and corrosion are easier to see in one light versus the other; for example, while dirt is more obvious on a window viewed in reflected light, loss of paint and surface decoration is more clearly seen through transmitted light. Figures 36 and 37 show paint deterioration in reflected and transmitted light, respectively.

Figure 36. Paint deterioration on "The Annunciation" window by Otto Heinigke, ca. 1890, shown in reflected light. Image courtesy of Julie Sloan.

Figure 37. Paint loss on "Adoration of the Magi" by Harry Eldredge Goodhue, ca. 1898, shown in transmitted light. Image courtesy of Julie Sloan.

Around 1430, glass painters began to adapt stylistic treatments of oil paintings and other graphic arts to suit their own needs. It was during the 15th century that stained glass windows became pictures. Colors were used for naturalistic purposes, stepping out of the two-dimensional forms of the medieval windows. Van Treeck notes the following devices taken from oil paintings: opening up pictorial backgrounds to the "outside"; utilizing an imaginary light source to create light spots and shading throughout the picture; and using figural modeling and shadows[175]. The leads were used now to connect the piece, not as compositional divisions. While glass images could now be created in more complex configurations, the artists were still limited by the technical practicality of the material.

Similar to the glass manufacturing process, there were also improvements to glass painting. The

[175] Ibid.

14th century saw both the introduction of silver stain and the method of scratching, which scratched the design features into the matts using bristle brushes. In addition, stippling was also used, removing dots of the matt with a bristle brush to lighten it and create detail. Around 1475, stained-glass artist Peter Hemmel developed a technique that further expanded the possibilities of glass painting. There would be several layers to his paintings. Colored glasses would continue to provide the foundation for both the overall color and organization of the window. Then the typical semi-translucent, somewhat streaky matt was painted onto the surface. The next layer included the contour drawing and either etched or stippled "lights." His final and innovative layer was then added—an accentuated graphic modeling of several layers of washes and hatching. This step allowed for more softness to his works through chiaroscuro values.[176]

When several layers were built up on one another, the paint was required to be a certain consistency and corrections while painting was incredibly difficult once the paint is fired. Contrasting binding agents had to be used in order to prevent the new wet paint layers from detaching the ones beneath; according to Van Treeck, experiments show that water-based binders must be alternated with oil-based substances[177]. Another issue the glass painter had to contend with was the thickness of the individual glass pieces. The thickness directly relates to the optical quality of refraction (Figure 38); this phenomenon can be described as follows:

> as light propagates through a transparent…medium, there will be elastic scattering from the atoms. The initial beam, call it the *primary wave*, results in the emission of scattered wavelets. These, in turn, cancel each other in all but the forward direction, wherein they combine to form what we shall call the *secondary wave*. The result is two waves (the primary and secondary), not necessarily in-phase with each other, overlapping and propagating together as one net disturbance—the refracted wave.[178]

[176] Ibid.
[177] Ibid, 59.
[178] Hecht, Eugene. *Physics: Calculus.* 2000: 925.

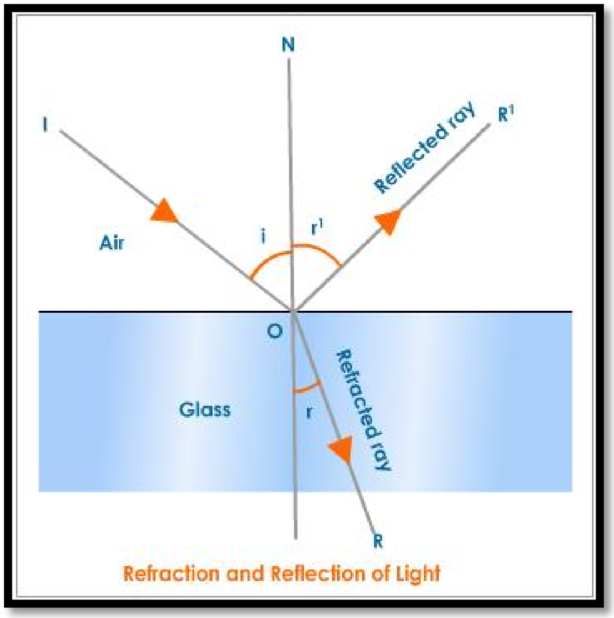

Figure 38. Reflection-Refraction Diagram of Light through Glass. Image from http://www.tutorvista.com/content/science/science-ii/refraction-light/refraction-light.php

In terms of application, it was essential that a glass painter worked in front of a light; otherwise, it would be impossible for him or her to see the translucency, thickness of paint, and transitions within the overall design. The thickness of paint and overlapping layers create a depth that was not utilized until around the 16th century when it was added to improve upon the existing modeling techniques. Van Treeck writes that these "effects indicate the increasing extent to which artists and glass painters came to terms with the expressive potential of drawing, either in a traditional, more graphic sense or with newer, pictorial, three-dimensional creative means."[179] Stained glass must be backlit in order to realize its true beauty, thereby making light an immensely important factor in the way in which a stained glass window is seen. However, it is also important to recognize that "a diminishing of the daylight does not have to diminish the effect of the stained glass. Instead, as the waning light strikes the glass from a different aspect, certain features and colors that were muted before now become highlighted."[180]

The steps of paint buildup from the 16th century through most of the 19th century and those

[179] Van Treeck, Peter. "On the Artistic Technique of Glass Painting." 2000: 61.
[180] Isenberg, Anita and Seymour. *How to Work in Stained Glass*. 1983: 25.

followed from the late 19th century onward are different. Starting in the 16th century, artistic ideas were as important in determining these steps as the technical considerations involved. In comparison, the late 19th century saw predominantly reproductive techniques, seeking to reproduce exactly the contours of their model drawings. After the contour lines were drawn, the figure could be highlighted and elaborated upon. In the older tradition, the figure or representation remained available for artistic expression until the last possible step, thus reinforcing the importance of artistic expression of the individual glass painters. The application of the contour lines first are restricting to the painter because it gives him or her no room for expression, but rather provides them with a set outline in which to work. Therefore, glass painting during the 16th century up until the 19th century "was not reproduction but interpretation. It aimed at the execution of a creative intent, not at a copy."[181]

A window's location in its intended setting is an important factor to consider when painting, not only in terms of distance from the viewer but also in terms of where the natural light source is coming from. If the figures are going to be seen from great distance, then strong and readable facial features are essential; in comparison, if the window will be viewed from up close, then it is useful to use softer lines and matting for the features. In terms of light, the light and dark areas of the figural painting will be directly affected by this light source so it is important to make it look as natural as possible. This highlighting process is not one that can be rushed, notes Dorothy Maddy in her article "Anatomy of a Glass Portrait." It is crucial to take this slowly to provide the best result.

Overall, it can be said that the purpose of glass paint is three-fold: (1) to outline the figures and drawing being used; (2) to model and highlight the design, using shadowing; and (3) to control the light that comes through the glass. Different brushes will be used depending on the desired effect and each of the three main types of decoration—vitreous glass paint, silver stain, and enamels—will create

[181] Van Treeck, Peter. "On the Artistic Technique of Glass Painting." 2000: 62.

various effects on the glass. These concepts and ideas will be addressed in detail in the three chapters to follow.

Glass Paint Firing

In order to secure the paint to the surface, it had to be fired in a kiln. At 600° Celsius, the soft glass, or flux, melts and fuses the paint with the glass surface[182]. With firing, temperature and duration are everything. Too low a temperature and the paint would be unable to secure itself to the glass; too high a temperature and the paint would burn and cause blisters on the glass. These blisters led to deterioration by retaining moisture and water on the glass, which made the loss of paint even greater. Early kilns were made from bent canes covered in clay and horse manure. 15th century kilns were made of iron and early 17th century ones were stone or brick[183]. In addition, the size of the kilns also increased over time. Modern kilns utilize microwave technology that heat up and cool down the space in a matter of a few hours as opposed to the few days that brick kilns needed for the process.[184]

Today, two of the most popular types of kilns used to fire glass paint are the electric front-loading kiln and the electric top-loading kiln. Both work well for this purpose but the latter type has the distinct advantage of allowing the painter to look in and check on the firing process. Another type of kiln used is called a flash kiln, a gas kiln; this type permits both the glass and the flame are in the same chamber. This kiln fires very fast which is especially helpful if one is doing a large amount of work at a time but requires a separate chamber for cooling. Regardless of the amount of firing, glass absolutely must be cooled slowly; if the cooling happens too quickly, the glass will fracture[185]. After the glass passes this point, it is safe to open the kiln and cool the glass this way.

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[182] Cannon, Linda. "History of the Techniques and Materials." 1991: 69.
[183] Ibid.
[184] Ibid.
[185] Isenberg, Anita and Seymour. *Stained Glass Painting*. 1979: 65-66.

Multiple firings are also possible but the goal should be to achieve as much as possible during each firing. This can be done through the use of color vehicles that do not mix with one another, providing layers of paint at a time, and by painting on both surfaces of the glass. For multiple firings, the glass has to be cooled more slowly than a single firing because the stresses that occur during cooling are intensified with each additional firing. That being said, each firing does not have to be done at the maximum firing temperature; if it is tack fired, or fired only to about 90%, it will have adhered enough that painting or staining the next layer will not affect the previous one[186]. After each layer has been tack fired and all the painting is completed, then the entire piece can be fired at the maximum temperature to make sure that the paint is permanent.

It may seem natural to wonder why glass-painters chose to paint on colored glass at all. After all, the glass has already been colored. While many people feel that for this reason the painting is unnecessary, there is in fact three important reasons for glass painting. The first is to control light more effectively. Glass painting allows for the artist to create completely opaque areas to bring out their designs, including facial lines and solid shapes to direct the viewer's eye. This is also a practical reason because it saves the use of additional lead lines. The second reason is to provide different degrees of transparency. Depending on how the paint is applied, it is possible to create a blending over the surface such that it slows down the light as it passes through the glass; while this effect can come from an inherent quality in the glass, paint is still the only means of controlling this effect. The final major reason is to create texture on the glass surface. In other words, paint gives the smooth glass surface some dimension, making many designs all the more elaborate and interesting.

[186] Ibid, 67.

Anita and Seymour Isenberg discuss the essential difference between painting on glass and painting on canvas, noting that the two processes require two very different ways of thinking:

> Watercolor or oil painting involves reflected light and the putting in of shadows, values, and colors. Glass painting deals with transmitted light, light transitions, and the taking out of highlights…a painting on canvas is not meant to enhance the canvas. It utilizes the canvas as a practical necessity. But the whole purpose of painting on glass is to enhance the essential glassiness of the conception. It is therefore important that there be a balance between the glass and the paint. As soon as the paint obliterates the character and quality of the glass, it is being misused.[187]

In addition to requiring an entirely different way of thinking about painting, glass painting can be looked at in two distinct ways:

> The first is the light-controlling method used when the glass is found to be lacking in either depth or texture, or when it is permitting too much light into the surrounding area. Various tracing and matting techniques…will not only allow you to enrich the window and to modify the brilliance of light entering the area, but will provide you with the means to balance the intensities and the contrasts among the individual pieces of glass. In the second approach, painting on glass is the focal point of the window…the third dimension introduced with the painted images or areas extends the limits of flat glass and thus provides the artist with extraordinary possibilities for design solutions.[188]

The techniques discussed in this chapter are generic to glass painting; the more specific techniques pertaining to the individual types of surface decoration will be discussed in the chapters to follow. Regardless of the technique, Albinas Elskus describes the inherent importance of using glass paints:

> Glass is by its very nature a magical medium. Yet, to some of us the use of glass and lead alone means imposing a limitation—a rose garden with a fence around it…By its physical properties, unpainted glass carries within itself a certain amount of inherent flatness…However, when artists seek a third dimension to their work, painting on glass provides a means of achieving depth that is not present or possible in unpainted glass. By utilizing the properties contained in vitreous paints and silver stains, and combining them with etching and firing techniques, artists have at their command a unique and pluralistic means of expanding the scope of their visual concepts…you are transforming the face of the glass in a way that is not otherwise possible.[189]

[187] Isenberg, Anita and Seymour. *Stained Glass Painting*. 1979: 4.
[188] Elskus, Albinas. *The Art of Painting on Glass*. 1980: 137-138.
[189] Ibid, 2-3.

IV. Vitreous Glass Paint

A painting can tell a story, but this is not what makes it a work of art. Story-telling in painting is a matter of time and place, involving customs and beliefs, which change with the passage of time, because they are elements in a painting which have nothing to do with a work of art…if it a true work of art, it will, if we let it, speak directly to our senses.[190]

Nina Tryggvadottir

Painting with vitreous paints is based on two principles: to arrest the light on the surface of the glass and to create another dimension that did not exist there before.[191]

Albinas Elskus

Nina Tryggvadottir writes that "although the discovery of glass is attributed to the Phoenicians some two thousand five hundred years ago, glass painting developed only about a thousand years ago."[192] The first and earliest kind of glass paint is often referred to as vitreous glass paint or as glass stainers' colors. It refers to the majority of early glass paints, including the common black or dark brown paints used for trace lines and matting.

Composition and Media

Vitreous glass paint is composed of a mixture of ground glass and either a pigment oxide or a group of metallic oxides like iron, copper, cobalt, or manganese. The ground glass contains silica,

[190] Tryggvadottir, Nina. "Painting with Light through Colored Glass." 1968: 127.
[191] Elskus, Albinas. *The Art of Painting on Glass.* 1980: 5.
[192] Tryggvadottir, Nina. "Painting with Light through Colored Glass." 1968: 125.

alumina, borax and lead[193]. The lead, typically in oxide form, has good fluxing abilities and softens the powdered glass, providing good adhesion to the window's glass surface.

Unlike other artists' paints, like oils and watercolors, glass paints need two binders: one to work during application, called a temporary binder, and one to adhere the pigment to the glass during the firing. Every glass paint has to have a temporary binder and some form of wetting agent in order to create a liquid paint from the colored pigment; the temporary binder must burn off with heat and leave no residue behind. During Theophilus' time, wine or urine was used as the temporary binder; vinegar is one of the most common binders used today. The second type of binder, the one required by most glass paints during firing, is called the flux; it is a vitreous substance which allows the pigment to fuse with the glass surface. Without a flux, the melting temperature of some of the coloring oxides would be higher than the melting temperature of the glass being painted on; this would prevent a stable painting surface from forming because the glass would melt before the paint had the opportunity to fuse to it. Most fluxes are inherently soft glasses that have the ability to melt at a low temperature and are composed of some mixture of sand, red or yellow lead, and borax[194].

The glass paint comes in powdered form. It is heated to about 1000° C; at this temperature, the combined powders will melt, fuse, and form a glass.[195] This glass then cools slowly so that it does not crystallize and then water is added to make it workable. The purpose of this is to cool the glass and crack it into as many small pieces as possible; these broken pieces are called frit. Machines are used to break down the frit into glass powder, being careful to not let it be ground too fine or else the resulting paint will be of poor quality that will inevitably crack after firing[196].

Next comes the addition of the coloring agents. Coloring during the Middle Ages and the Renaissance was different than the methods used today. Creating pot-metal glass consisted of taking a

[193] Elskus, Albinas. *The Art of Painting on Glass*. 1980: 5.
[194] Sloan, Julie L. *Conservation of Stained Glass in America.* 1995: 160-162.
[195] Isenberg, Anita and Seymour. *Stained Glass Painting.* 1979: 11.
[196] Ibid, 12-13.

soft glass and added the desired colors directly it in the molten state. In terms of the paint, early painters were looking for their colors to block out the light; therefore, they used substances including the following: umber, an iron oxide; manganese oxides; or any of the earthy metallic oxides. Mixing the powder with water allows it to flow over the glass smoothly and during firing, the frit would melt into the glass surface to hold the color in place[197].

In comparison, today paints are made in a different way. A refractory oxide that does not melt is manufactured; substances including cobalt, chrome, clay, alumina, and sand are fired around 1400° C and the elements are fused together but not melted[198]. This forms something called a clinker, which resembles an ash, and is formed from a solid state reaction during which cobalt, chrome and silica come together and form a spinnel, or a chrome alumina silicate. The clinker is ground into a powder and then mixed with the spinnel to create color; the color that you get will depend on the ratio of the color to the flux[199].

Both then and now, the composition of these ingredients will affect the glass paint. For example, vehicles with higher lead content will create a softer glass. More lead will also make the glass substrate more refractive so that as light passes through the glass, there will be an extreme bending of the light rays, resulting in a prism-like effect. Finally, the lead oxide is responsible for enabling the flux to fire at a lower temperature. Another example is that the addition of silica to the glass will result in making it harder[200].

Once in glass-powder form, the paint must be mixed with water and gum arabic or another mixing agent, like white vinegar (acetic acid), turpentine, or oil in order to be used to paint smoothly on the glass. The two categories of vitreous paints are: (1) glass stainers' colors and (2) transparent-glass colors, or enamels. The glass stainers' colors will be the focus of this chapter, while enamels will be

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[197] Ibid, 14-15.
[198] Ibid.
[199] Ibid.
[200] Ibid, 12, 16.

examined in Chapter VI. Anita and Seymour Isenberg differentiate between the two: "To the glass painter, enamels are essentially low-fire, less wear-resistant colored paints, used to alter the color of the glass. Glass paints, on the other hand, are high-fire, permanent paints used to control the light transmission, translucency, and texture of the glass, and to effect changes in the value of the already colored glass."[201]

Glass stainers' colors are the basic paints used for glass painting; they are opaque and have a limited color palette. The major colors are the following: blacks, browns, reds, and gray-greens. These were the only colors used by stained glass artists until later developments, including silver stain in the 14th century, sanguine in the 15th century, and enamels in the 16th century[202]. The Middle Ages mostly used the black and brown vitreous paints and the introduction of sanguine, which is an iron-based paint that ranges from pink to red-brown after firing, provided a slight widening of the limited color range. Peter Van Treeck notes this very simple color palette used for windows up until the 16th century:

> Panels made up to about 1500…are restricted mostly to mats and contours in black vitreous paint. Afterward it became a rule in all regions to use a grayish brown tone first and then the artist continued with black or brown vitreous paint in different nuances. After painting was begun using gray-brown, frequently further work was consciously done in black and then the panel was back-painted with red to brown. The sanguine on the verso serves as a shading color in combination with the matt, the foundation of the recto. This effect becomes particularly apparent where the back-painting is differentiated more toward yellow or red, according to the tone of the matt or that of the glass.[203]

The goal of these paints is "first, to hold the traversing light on the surface of the glass; second, to render the finest details in forms, objects, or figures; and third, to create another dimension by obscuring part of the glass with design, textures, or shading"[204]. These colors melt at a lower

[201] Ibid, 11.
[202] Brown, Sarah. *Glass-Painters*. 1991: 56.
[203] Ibid, 60.
[204] Elskus, Albinas. *The Art of Painting on Glass.* 1980: 5.

temperature than the glass they are adhering to, around 700-750° C versus 850-1000° C[205]. This temperature is right at the point where the glass itself begins to soften, thus allowing for the paint to fuse to its surface. In terms of these paints being used for tracing and matting, Albinas Elskus writes that since "tracing is often regarded as a dark, opaque line…naturally, black would best fit this requirement. Matting, on the other hand, is often thought of as softer and more tonal, suitable for rendering the translucent parts in painting on glass. Browns and gray-greens are therefore the standard matting colors."[206] Both tracing and matting will be discussed later in this chapter.

As previously stated, the glass stainers' colors come in powder form and require a liquid and a binder to allow them to be painted and fired onto glass. Liquids used as vehicles include water, white vinegar, and turpentine; binders include gum arabic, sugar, and oil of turpentine.

In addition to vinegar, water is the other most common and basic of the mixing agents, used to dilute the paint so that it has the proper flowing consistency. The best matts are mixed with water and gum arabic; water requires the gum arabic to allow it to stick to the glass. Gum arabic is another popular mixing agent due to its solubility in water; this comes in white powder form. It is considered "an ideal adhesive for holding vitreous paints to glass because it mixes equally well with water and with pigments," without changing the character of either[207]. As a down side, too much of the gum arabic will cause the paint to become tacky and result in scaling during firing. In addition to adhering the paint to the glass surface, gum arabic, like water, acts as a vehicle allowing the paint to flow easily across the glass surface. It is either mixed into the powdered glass stainers' color before adding water, called the dry-to-dry method, or mixed with water separately and then added to the wet stainers' color which had already been mixed with water, called the wet-to-wet method[208].

In addition to water and gum arabic, there are a number of additional mixing agents used for

[205] Ibid, 6.
[206] Ibid, 7.
[207] Ibid, 24.
[208] Ibid, 24-25.

glass painting as well. Granulated sugar can also be used as a mixing agent in place of gum arabic. Similar to gum arabic, it burns up during the firing in the kiln and thus will not affect the paint being fired; it is well suited for tracing paint but can be a bit tacky for matting purposes. White vinegar is another example, but it is typically used for tracing only. It will harden the painted trace lines and make it water-repellent, allowing for the artist to apply a water-based matting layer before firing; this saves the need for an additional firing. To use white vinegar, gum arabic is also required in order to achieve the needed water-resistance. It is not used for matting because it makes the paint too hard to model; on the other hand, it can be used instead of water for mixing both silver stain and enamels. Turpentine is made of oil and resin from pine trees and is also used as a mixing agent. It does not contain a binder, and will evaporate very quickly; for this reason, oil of turpentine must be added to the paint, providing both the binder and the vehicle for the pigment. Paint mixed with turpentine and oil of turpentine has the ability to dry and harden overnight, thus becoming resistant to water-base matting meant to be placed on top of it[209].

Sodium silicate, also known as water glass, is a transparent liquid sometimes added to the mixing water, but never to the paint directly; while a very good binder, this material is harmful to brushes, glass palette, and glass-top light tables. When the sodium silicate is exposed to air, it crystallizes and hardens like glass, thereby becoming permanent once it is laid down. It affects the paint itself due to the fact that it is such a hard binder; after firing, the paint will look harder and coarser when sodium silicate is used. Where the material is useful is in the cases where one is looking to trace, matt over, or stipple all in one session because this requires only one firing[210].

Where white vinegar is used strictly for tracing lines, alcohol is typically used just for matting purposes; this is because it has no binders and is thus unable to attach the paint to the glass substrate. The pros of using alcohol are that it will evaporate quickly from the paint and that is will not dissolve or

[209] Ibid, 25-26.
[210] Ibid, 26-27.

mix with paint prepared with water and gum arabic; the cons are that the blending of the color on the glass must occur quickly or else the evaporation will cause streakiness. It has been found that a few drops of white shellac mixed with the alcohol matt will slightly extend the blending time[211].

Another material involved in glass painting is glycerin. While not truly a binder or a vehicle, it is a supplement to both used to improve paint flow and smoothness. Finally, there are also a number of oils, in addition to the oil of turpentine previously mentioned, that are used as mixing agents and for different purposes; a few examples include clove oil, aniseed oil, and lavender oil. Clove oil is used for its smoothness and capacity to hold the paint as applied. Aniseed oil also has the ability to prevent the spreading of the paint once laid down on the glass, allowing for precise, very thin lines. Lavender oil is a lighter oil used sometimes to dilute other oils being used such that they become of a workable consistency; in addition, it is also used for softening shadows so as to create more realistic representation of the figures[212].

Van Treeck writes that "the soft application and gentle pastel-like manner of painting was presumably achieved through additives."[213] The quality he calls "paintability" is improved by adding admixtures of slippery material, such as egg, honey, or syrup. He cites mineral borax as the ideal substance for making paints malleable because it gives the glass surface and modeling a soft appearance and also because it reduces the melting point of the paint (in vitreous paints, it also reduces the necessary firing temperature). Unfortunately, additives were not entirely positive in their effects. Most of them decreased the paint's ability to resist humidity and some additives, including gum arabic, sugar, and borax, could also result in damage in the fusing of the paint[214]. Borax, in particular, is known today as a large contributor to paint deterioration.

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[211] Ibid, 27-28.
[212] Ibid, 28-29.
[213] Van Treeck, Peter. "On the Artistic Technique of Glass Painting." 2000: 59.
[214] Ibid.

Sanguine/Carnation

As already mentioned, sanguine is another type of iron oxide-based vitreous paint in addition to the more common brown and black paints used for tracing and matting (Figure 39). It is a transparent pigment and when diluted, the pigment is called carnation. Sanguine is a red-orange color and was often applied to lips, cheeks, flesh, and clothing patterns to highlight the details of an image; it turns from pink to red-brown after firing. The color appears to soak into the glass but it is easily removed with certain solvents. It was used predominantly between the 16th and 18th centuries but was not particularly popular for much longer than this because of the amount of time and difficulty involved in the pigment preparation[215].

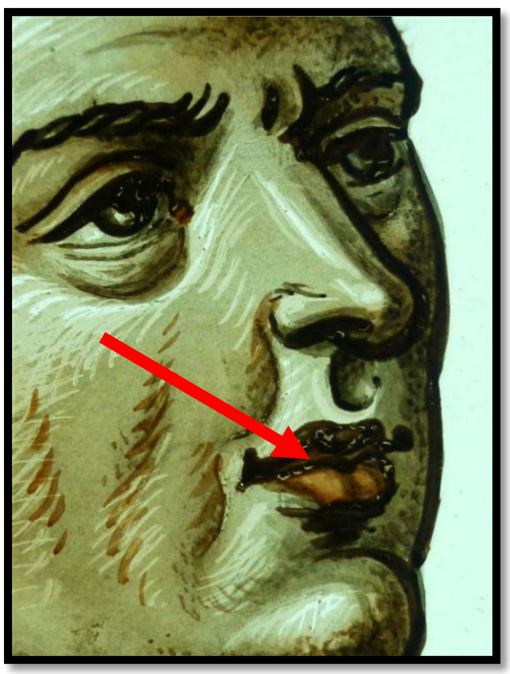

Figure 39. The use of sanguine in a figure's face. Image from York Glazier's Trust "Illustrated Glossary."

Application and Techniques

The paint pigments have a granular structure and can therefore only be ground down to a certain point but if ground with a muller for the proper amount of time, the result will be a smooth

[215] Cannon, Linda. "History of the Techniques and Materials." 1991: 78.

application. In addition, the paint dries very fast so only a few strokes could be made at a time. Depending on the design, it is also important to remember that these strokes were made to have a certain degree of translucency; certain areas of the design will require more liquid or more viscous strokes. The artist usually painted from lighter areas to darker ones because lifting the brush off of the glass at the end of the stroke was often difficult from the dried paint; the darker areas hid any minor slip-ups that may have occurred when removing the brush. The selection of the proper brush was essential—tracers, with a point at the end, were used to paint contour lines while blunt brushes, with uniform hairs, were better equipped for hatching and washes[216].

There are three essential painting techniques for vitreous glass paint: tracing, matting, and highlighting. Tracery lines are meant to be opaque such that they block out the light coming through the window while highlighting the overall design. Those trace lines that are somewhat translucent are called halftones, which allow some light to come through them. In comparison, matt painting is almost entirely translucent. Where tracery lines block out the light entirely, matts modify the amount of light coming through the window in varying degrees. According to the Anita and Seymour Isenberg:

> gum arabic is a necessary, not an optional, ingredient for glass paint which has water or vinegar as a vehicle…the gum is a bonding agent between the paint and the vehicle and the glass. Without it your paint will not seem to have enough body to it. Without gum, the traced line tends to smudge and the matter area to wipe off. The trace line does not flow as well without it, nor does the matt blend satisfactorily.[217]

In general, the ratio of gum to paint is about 1:32, but most painters mix the paint by eye; it is also important to note that the softer the trace lines desired, the less gum is added[218].

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[216] Van Treeck, Peter. "On the Artistic Technique of Glass Painting." 2000: 59.
[217] Isenberg, Anita and Seymour. *Stained Glass Painting*. 1979: 72.
[218] Ibid, 73.

Tracing

Tracing can be called the linear dimension of glass painting (Figure 40). The techniques and results of tracing will differ slightly depending on the mixing agent(s) that is used; the three main types are water, vinegar, and oil. Using water and gum arabic is the simplest method with the least problems. Water will evaporate quickly and any corrections needed can be done almost right away with a stick or needle; in addition, if a line needs to be made darker, an additional line can be painted over it while the paint is still wet, thus allowing the two lines to adhere to one another. Lines produced can be completely opaque or almost completely transparent. This type of tracing must be fired before any matting is added[219].

Figure 40. Painting of a figure, tracing only. Image from Albinas Elskus, *The Art of Painting on Glass*. 1980: 57.

Vinegar tracing is also used often because the tracing become water-repellent after just 24 hours, which in turn, allows for a water-based matt coat to be applied over the tracery before firing. In addition, the added smoothness of the paint from the white vinegar improves the brush flow across the glass surface; however, once dry, the vinegar causes the paint to chip if corrections are attempted with

[219] Elskus, Albinas. *The Art of Painting on Glass.* 1980: 61-62.

needles or sticks. The best advantage to using vinegar over water is to save a firing. When water is used, the glass is fired and then the matt is applied over the trace lines before being fired again; without this double firing, the trace lines and the matt would smudge and blend together. With vinegar, this is not an issue since the unfired vinegar trace lines will remain in place despite the matt being painted over it[220]. In addition, vinegar trace makes it easier to control halftones than water trace. The Isenbergs warn that "improper mixing, insufficient drying time, and humidity variations can contribute to unfired vinegar trace failing to adhere when water matt is applied over it."[221] Despite its many pros, there are also some disadvantages with vinegar trace. First and foremost, it has a very strong odor, which some people find unappealing. Perhaps more important though is that vinegar trace is affected more by the weather than water trace paint.

In comparison, oil tracing has the major advantage of very good adherence to the glass and, once dry, of resistance to water. Using oil, the paint will cover the glass more heavily, which may be useful in some cases but makes it very hard to create intricate, smaller details. In addition, because of the oil content, more pigment is required in the mixture to create an opaque line; this may result in too heavy a paint layer which in turn will not properly fire[222].

One important difference between glass painting and oil painting to note comes with the repainting of a line, especially a trace line. If a trace line that is meant to be opaque appears translucent when held up to the light, it is much better to scrape the line off the glass and start again than to try to take more paint and paint over the line to make it darker. This is because the firing process would cause the lines to "bubble up, curl, and char in the kiln"[223] as the two distinct layers of paint twist away from one another in the heat.

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[220] Isenberg, Anita and Seymour. *Stained Glass Painting*. 1979: 76.
[221] Ibid.
[222] Elskus, Albinas. *The Art of Painting on Glass.* 1980: 64.
[223] Isenberg, Anita and Seymour. *Stained Glass Painting*. 1979: 93.

Matting

The Isenbergs note that while they are two different processes, trace paint and matt paint are not so different:

> While most matt paints tend to have finer particles than trace paint, the difference is not between matt paint and trace paint but between matting and tracing. Each process is employed for a different effect; each involves different techniques. The tracing procedure implies linear detail using an opaque application of dark (not necessarily black) paint. The matting process is more satisfied by the use of a wash of paint for shadowing and highlighting. Matt is used to emphasize, enhance, subdue, modify, or vary the character of the glass. The matt may vary from piece to piece, or even within the same piece of glass. It should be used selectively and meaningfully rather than mechanically or excessively.[224]

Matt comes in different colors, which are chosen based on the desired effect. Typically an umber brown matt is used, but flesh reds, black/greens, gray/greens, and other colors are also available and used often. It is essential to understand that these colors are not meant to give the glass color but instead to provide a translucent layer of materials that will "give variations to the light transmission through the glass."[225]

If tracing is considered the linear dimension, matting can be called the tonal dimension (Figure 41). Albinas Elskus writes that:

> matting serves many functions and is therefore a controlling factor in the window's translucency, dimensionality, contrast, vibrations, balance, and finishing touch. Matting can add spark and liveliness to the window, but it can also destroy this quality by obscuring the traversing light and color of the glass with a layer of paint…On the other hand, matting can change a flat piece of glass into a vision of three-dimensional shape, or it can induce a heavy texture on the glass to intensify its color, or create a lightly hand-rubbed, veil-like coating, to identify the striations on the surface of the glass.[226]

[224] Ibid, 135.
[225] Ibid.
[226] Elskus, Albinas. *The Art of Painting on Glass*. 1980: 71.

Early Gothic period windows have matting applied as a light, even wash, which serves to soften the contrast between the dark, opaque trace lines and the unpainted background. Later windows have more complex matts in order to create the more realistic and complicated figures and designs[227].

Figure 41. Painting of a figure after matting. Image from Albinas Elskus, *The Art of Painting on Glass*. 1980: 93.

Matt is mixed in the same way as trace paint. Water is the typical vehicle used and gum arabic is also added in varying quantities, depending on whether the painter wants a soft or hard matt; the softer the matt, the less gum added. Hard matts will not create the subtle transitions within the shadowing on the glass and will chip off as the painter attempts to remove lights from it; it is also possible that too hard a matt will fry when fired. In comparison, softer matts will allow for easy removal of highlights and result in cleaner lines for inscriptions and lettering. On the other hand, softer matts may also wipe off the glass and the matt may “suck up” extra gum from the trace paint and cling to it in those areas. The other major difference between tracing and matting is the brush used to apply the

[227] Ibid, 71-72.

paint to the glass; for tracing a tracing brush is used, whereas matting uses a badger brush. Tracing brushes are long-haired brushes that come to a point and regardless of the size and type of hair used, their shape is always the same[228]. Badger brushes are used specifically for matting and are much wider than tracing brushes, at least four inches wide; it is made of badger hair and has the unique ability to "distribute the applied matt paint over the glass surface, to gather the matt into specific areas, and to blend all these areas together."[229]

Matts may also be painted on the reverse side of the glass, and often matts are done on both sides in order to achieve more complex shading and highlighting effects. Matts painted on the reverse side of the glass are often done to "strengthen the values without taking the time for multiple firing of the piece."[230] The thing to remember here is that matts on this side of the glass are exposed to the elements and the paint is bound to deteriorate. In addition, multiple matts can be done in order to increase the range of values of the paint; several water matts can be done on top of one another by utilizing low firings, also called tack firings (560° C to 600° C)[231]. If the matts are fired too high, the paint can fry and shrink. In order to reduce the amount of re-firings, matts with alternating vehicles can also be used; typically alternating layers of water matts and oil matts are used as they will not mix with one another and fewer firings are required.

The three basic matts are the flat matt (Figure 42), the stippled matt (Figure 43), and the shaded matt (Figure 44). The flat matt is created by blending the paint to a smooth, even finish. One important fact to recognize when applying the paint for a matt is that about 25% of its intensity is lost when the paint is fired in the kiln; in other words, the paint will look much lighter after firing than before. The stippled matt is produced in the same way as the flat matt, but with one additional step: after reaching a smooth, even finish and while the paint is still wet, the glass is dabbed with the blending brush; this

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[228] Isenberg, Anita and Seymour. *Stained Glass Painting*. 1979: 136, 56.
[229] Ibid, 54.
[230] Ibid, 154.
[231] Ibid.

allows for the tips of the badger brush to pull off small dots of paint from the glass. The result of this matt is an open, flat finish as opposed to the closed, flat finish of the flat matt. Finally, the shaded matt can also begin with an even matt coating; the artist then brushes the paint in the areas he or she wants to be darker. The result is a gradient shading from light to dark or vice versa; this transition can also be stippled at the end. In addition, the shaded matt can also be achieved by starting out with more paint in the areas that are going to be darker and less paint in the areas that are going to be lighter; then the paint is distributed as desired, creating the gradient shading effect[232].

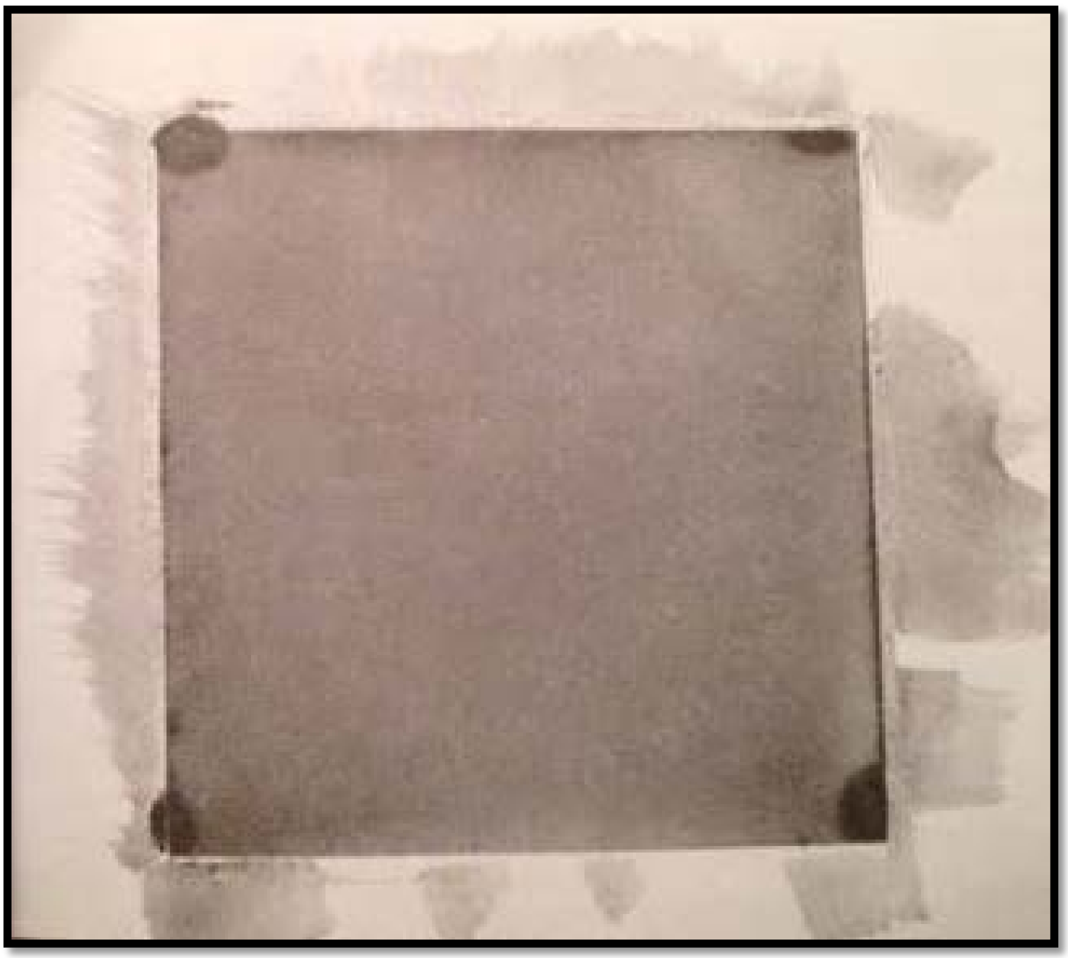

Figure 42. Flat matt. Image from Albinas Elskus, *The Art of Painting on Glass*. 1980: 77.

[232] Elskus, Albinas. *The Art of Painting on Glass*. 1980: 73, 78-82.

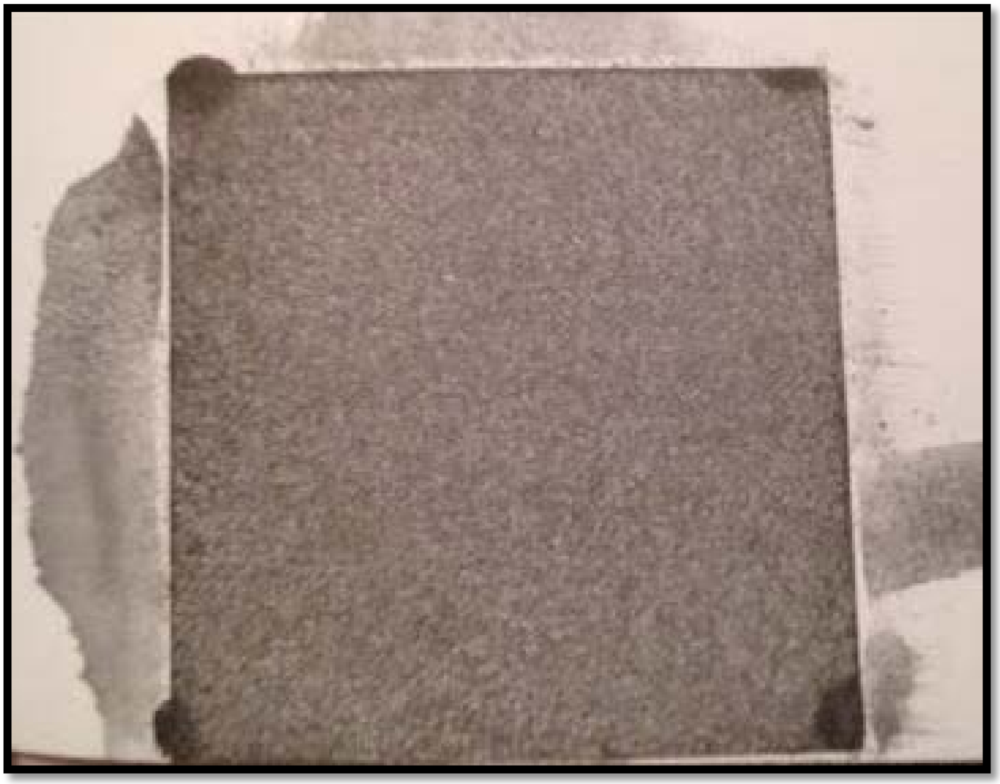

Figure 43. Stippled matt. Image from Albinas Elskus, *The Art of Painting on Glass*. 1980: 79.

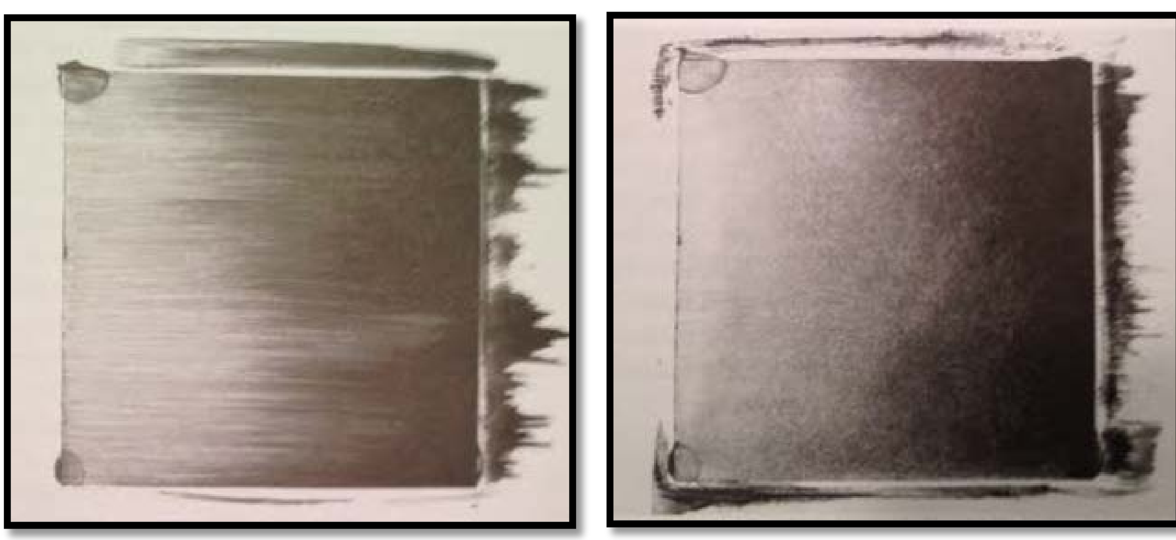

Figure 44. Shaded matts. Images from Albinas Elskus, *The Art of Painting on Glass.* 1980: 81.

In addition to these three basic matts, there are a few others often used. A stippled matt created with an English stippler will have a similar result as the stippled matt previously discussed; the difference between the two is that the English stippler paints the matt directly onto the glass from the bristles of the paint brush, as opposed to lifting paint away from an even matt coating. The alcohol matt has the benefit of allow the artist to paint as lightly or as heavily as he or she likes. When the alcohol, either denatured or isopropyl, is added to vitreous paint and applied to the glass surface, the alcohol will evaporate very quickly and will leave the paint dry and only partially adhered to the surface; because of this, alcohol matts must be handled quickly. Turpentine matts can also be used; they evaporate in about 20 minutes, allowing plenty of time for the blending process. There is also the lavender-oil matt which is often used where soft and smooth matting is desired, such as the faces of figures[233].

Van Treeck writes that the different tints of the vitreous paints, together with the pieces of glass, change their appearance and overall effect depending on their combination, color value, thickness of application, and influence on each other. He also notes that blank areas will provide accidental tones that will also affect the overall look of the window. While black matts remain neutral in color when applied, a colored matt will interact with the glass tone depending on a number of qualities, including whether it is diffuse or transparent, more dull or intense in color, and of a similar color or a complementary color[234].

Highlighting

Highlighting is defined as "a technique of matt removal that provides areas of greater light and transparency in a work than the original matting would allow."[235] It is also called "taking out the

[233] Ibid, 83, 86-88.
[234] Van Treeck, Peter. "On the Artistic Technique of Glass Painting." 2000: 60-61.
[235] Isenberg, Anita and Seymour. *Stained Glass Painting*. 1979: 157.

lights."[236] According to the Isenbergs, "this is a very potent technique of using transmitted light that can be, literally, dazzling. The secret is knowing just where to place the highlights, how intense to make the individual lights, and whether to grade them in intensity or have them in abrupt transition."[237] Highlighting can also be called "painting with light"; Elskus writes that:

> highlighting is guided by the basic principles of drawing used to identify a form: light, highlights, middle tone, shadow, and reflected light. To adapt these principles for painting on glass, you have to take into consideration the available source of light and adjust the highlighting and the density of the matt to its strength. If your window is facing an open sky, the light will be strong, and therefore the highlights should be played down. Sharp contrast between the highlights and the shadows can warp or even destroy the solidity of the intended form…On the other hand, if the window is facing buildings or trees, the highlights should be crisp and clear. The shadows should be strengthened with extra matting put on…on the reverse (back) side of the glass.[238]

In simplest terms, highlighting is the reverse of drawing; where in drawing one adds shadows, in highlighting one removes matt (Figure 45). If highlights are going to be executed, the painter must be sure to lay down enough matt to allow for both primary and secondary highlights to be removed from it; the best matts for highlighting should be resistant and not too soft.

Figure 45. Painting of a figure, complete with tracing, matting, and highlights. Image from Albinas Elskus, *The Art of Painting on Glass*. 1980: 96.

[236] Ibid.
[237] Ibid.
[238] Elskus, Albinas. *The Art of Painting on Glass*. 1980: 92.

A few key terms to understand in highlighting are chiaroscuro, primary highlights, and secondary highlights. "Chiaroscuro" is an artistic technique, used not only in glass painting, but also in oil and watercolor painting as well. It is defined as a juxtaposition of light and shadow[239]. Primary highlights refer to those areas of greatest matt removal whereas secondary highlights, only remove some of the matt. It is the secondary highlights that allow for the transition of light to shadow that brings the painting to life.

As with tracing and matting, highlighting has its own set of brushes which are usually cut down to a certain shape depending on the required use of the painter. In order to create a highlight, the matt is removed entirely from the selected area and then an area of the surrounding matt is blended to create a translucent effect around the primary light; this modification produces the secondary lights. This process is done one thin layer at a time so as to achieve the desired effect. The Isenbergs note that "the more intensity there is between the highlight and the surrounding matt, the more effectively the face will read from a distance."[240] Where to place these highlights will depend not only on the skills of the artist, but also on the direction of the light source and in the cases of figures, an understanding of the normal contours of the human face or other features (Figure 46). Together, these three techniques provide the essential foundation for all glass painting; perhaps Anita and Seymour Isenberg say it best when they write that "Glass painting requires dark and light in extremes in order to be really effective, and it requires variation, as well, between these extremes. The matt, trace, and the highlighting procedure contribute to all this."[241]

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[239] Isenberg, Anita and Seymour. *Stained Glass Painting*. 1979: 158.
[240] Ibid, 167.
[241] Ibid, 157-158.

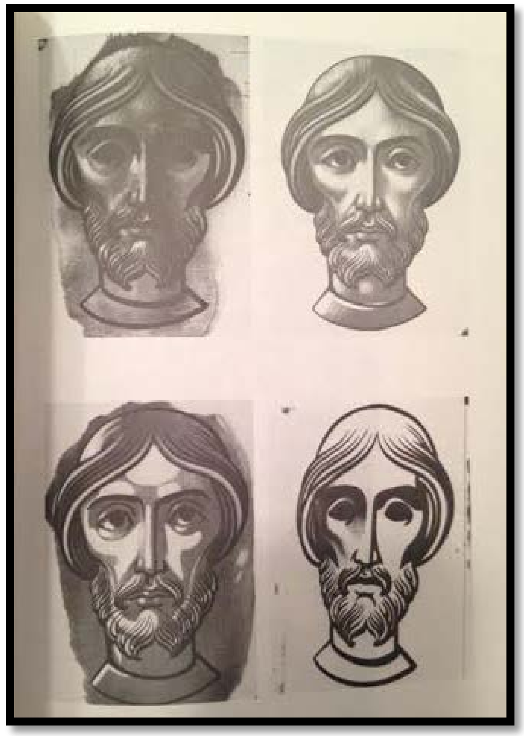

Figure 46. Examples of different types of highlighting on the same tracery drawing. Image from Anita and Seymour Isenberg, *Stained Glass Painting*. 1979: 173.

Regardless of the amount of glass painting used, it is essential to recognize that even the lightest paint application is going to affect the transmission of light so these techniques must be utilized accordingly.

Deterioration

Paint deterioration can be divided into two general categories: peeling or flaking, caused by the micro-cracks in the paint layer, and powdering, due to corrosion of the paint layer[242]. Medieval glass paintings must deal with the additional issue of glass corrosion, which can cause the raising of the paint layer; in comparison, 19th century glass is of a more stable composition and therefore, the paint layer itself is more likely to deteriorate.

[242] Gilchrist, Alison. "The tears wept by our windows." 2010: 34.

Vitreous glass paint can crack or flake off of the glass (Figure 47), seen in both traces and matts. Paint can also fade as a result from the loss of paint particles or a change in the index of refraction of the flux used. In some cases, the trace lines disappear, leaving a negative image on the glass surface; other times, the matt will disappear, leaving a simple outline of the design. While some paints can oxidize and turn black, others will turn black from the collection and trapping of dirt in the paint itself[243]. In a number of cases, SEM (scanning electron microscope) micrographs showed that the outer side of the paint layer was often corroded due to its increased exposure to water condensation, air pollutants, and salt deposits; on the other hand, the paint layers in contact with the glass surface remained in good condition[244]. Chemical deterioration of the glass also poses problems because the glass no longer has a consistent surface to adhere itself to. The majority of the issues will come from the amount of water, the amount of time that the water remains on the glass surface, and the acidic pollutants of the environment.

Figure 47. Flaking paint. Image courtesy of Drew Anderson.

[243] Sloan, Julie L. *Conservation of Stained Glass in America.* 1995: 165.
[244] Verita, Marco. "Paintwork in Medieval Stained-Glass Windows." 2010: 212.

When it comes to the composition of glass paint, perhaps the most important factor is the pigment to flux ratio. It has been proven that 1:3 and 1:2 pigment to flux ratios yield the best fired layers; more pigment will lead to the creation of soft, granular layers[245]. The manufacture of the paint is also a factor in its deterioration. For glass stainers' colors, the quality of the flux is essential to the adherence of the pigment to the glass. The purity of the ingredients will directly affect this, as will the amount of borax used to soften the flux; more borax will lower the melting point of the flux but will force the glass paint to become water-soluble, a very risky consequence. The glass stainers' colors do not require as much flux as enamels and often prove to be more durable than the later enamel paints, possibly as a result of lesser flux as well as a simpler manufacturing process with less ingredients. Poor craftsmanship is another consideration. Loss of paint may simply be due to inexperienced glass painters; too many firings or improper mixtures of paint because of lack of knowledge can be responsible for significant losses on some windows[246]. In her thesis "The tears wept by our windows," Alison Gilchrist notes that "as fired glass paint is largely composed of a low melting glass, this glass is subject to the same corrosion process as any other type of glass."[247]

Roy Newton notes that while some of the earliest surviving window glass has paint in perfect condition, some glass of the 15th century on experienced a noticeable decline in the paint's condition. Some of this deterioration can be attributed to the addition of borax to the paint as well as improper firing techniques; for example, many craftsmen were concerned about the loss of color depth that comes with kilns at higher temperatures and thus under-fired their panels, which ultimately led to paint loss especially during the 19th century[248].

Not surprisingly, underfiring has been considered to be one of the primary causes for paint deterioration and loss; simply put, if the kiln is not at a high enough temperature, the paint will not fuse

245 Gilchrist, Alison. "The tears wept by our windows." 2010: 38.
246 Sloan, Julie L. *Conservation of Stained Glass in America.* 1995: 167-168.
247 Gilchrist, Alison. "The tears wept by our windows." 2010: 36.
248 Newton, R.G. *Conservation of Glass*. 1989: 99.

to the glass properly and thus will be more easily lost. In addition, it is safe to say that any painted glass near areas where water collects will inevitably deteriorate. Humidity and water vapor will also contribute to paint deterioration, made worse in a closed environment. Another environmental issue comes with thermal expansion. Sloan writes that "the paint and the surface of the glass have different rates of thermal expansion, particularly if one is dark and the other light or highly reflective. The darker portion, whether glass or paint, absorbs more heat and expands more, possibly causing flaking."[249]

It is also possible for glass paint to corrode further if it has too high an alkali content; on the other hand, it could protect the glass if it lost most of its alkali content to the atmosphere during the firing process. Another method of corrosion is called back-matching corrosion, where corrosion on the outside of the glass is confined to the areas where the original artists had applied additional matting in order to highlight the design of the window when viewed from the inside; the matting proved to be porous and retained water, thereby increasing the chances for corrosion. Yet another corrosion form is seen in ghost imagery. According to Newton, this is caused by "the volatilization of alkali from the paint on another piece of glass from the same panel when both were fired, one on top of the other, in the same kiln; the volatilized alkali rendered the glass less durable so that it lost 0.2mm thickness in eight centuries."[250]

The corrosive effects of other materials are another issue to cause paint deterioration. Because stained glass windows are composed of so many different pieces—lead, putty, metallic oxides, alkaline deposits from surrounding mortar or stonework, etc.—the forms of corrosion for any of them may also have an effect on the paint of the window. Alkalis in particular are known for the corrosion of glass, so this is a likely contributor to paint loss depending on the surrounding materials of the window. Ironically, certain cleaning treatments are also responsible for paint loss. In various cases, hydrofluoric acid, the acid used to etch glass, was used to remove surface crusts of windows and even to remove

[249] Sloan, Julie L. *Conservation of Stained Glass in America.* 1995: 170.
[250] Newton, R.G. *Conservation of Glass*. 1989: 145.

original paint layers so that the windows could be repainted entirely[251]. This unsurprisingly proved to result in devastating losses of original historic fabric of these windows.

Finally, mechanical weathering can also lead to paint deterioration and loss; it results in micro-fractures and flaking of the glass paint. It is important that the thermal expansions of the glass and the paint be as similar as possible to prevent loss; otherwise, permanent stresses will occur at the boundary between them and paint loss will be inevitable. The appearance of micro-cracks, however, indicates that the intensity of the stress has surpassed the amount that the paint layer can handle. Paint loss from mechanical weathering is most critical when the window undergoes a sudden cooling, leading to thermal shock. In addition, it is possible for salts to crystallize in these micro-cracks, increasing the mechanical stresses at the tips of the cracks, thus furthering the fracturing overall. If the salts are soluble, they can change the pH of the condensed water. Hygroscopic salts will help water to be retained on the glass surface, causing chemical corrosion[252]. Mechanical loads due to wind and other vibrations will also inevitably affect the paint layer(s). Surface dirt and weathering crusts that remain on the surface will harden over time and any attempts to remove them is endangering to the paint beneath, which may or may not be fragile (Figures 48 and 49).

[251] Sloan, Julie L. *Conservation of Stained Glass in America.* 1995: 170-171.
[252] Verita, Marco. "Paintwork in Medieval Stained-Glass Windows." 2010: 212-215.

Figure 48. Surface dirt. Image courtesy of Drew Anderson.

Figure 49. Weathering crusts on the surface of the glass. Image courtesy of Drew Anderson.

V. Silver Stain

A medieval stained-glass window, ablaze with the sun behind it, gives an effect of splendor so intense that the air itself appears to be burnished. The transmuted light is splintered into a shower of colors that waver before it, replenished and muted as the light brightens and fades. To come upon such an incandescence unexpectedly…is an unforgettable experience.[253]

Anita and Seymour Isenberg

This sort of sensation was made all the more miraculous with the introduction of silver stain to stained glass windows. It would prove to be one of the most revolutionizing innovations of the field's history, opening myriad possibilities to glass painters and artists.

Composition and Application

At its development in the 14th century, silver stain was created using either silver nitrate or silver sulfide[254]. The effect of silver stain depends on a number of factors, including the amount of stain used, the number of applications of the stain, the temperature at which the stain is fired, and the chemical composition of the glass. Modern soda glass and other hard glasses, for example, will not take silver stain due to their chemical composition; on the opposite end of the spectrum, soft glasses will obtain a deep orange-gold color with a light wash of the stain. According to Roy Newton, one of the nest glasses for staining is called kelp, which has a good alkali content from seaweed; used from the 16th to the 20th centuries, kelp could obtain stains of almost a true red while obtaining the clarity of pot-metal glass[255].

During the medieval period, silver stain was prepared by first cutting silver metal into small pieces or sheets and burning them with sulfur; this resulted in its conversion into a sulfide. The sulfide

[253] Isenberg, Anita and Seymour. *How to Work in Stained Glass*. 1983: 2-3.
[254] Newton, R.G. *Conservation of Glass*. 1989: 98.
[255] Ibid, 100.

was finely ground and mixed with “an earthy vehicle” like clay, making the stain easier to apply. In terms of its use during this period, silver stain was painted on clear glass and highlighted details of figures, canopies, or grisaille patterns. Not surprisingly, the peak of the stainer’s art occurred when there was a lack of availability and variety of pot-metal colors[256].

In modern times, silver stain comes from silver chloride suspended in a kaolin base. Once it has been ground down, it is mixed with water to create a creamy consistency and applied to the back of the glass. Using a badger brush, an even layer is created. The firing of silver stain takes place at a lower temperature than the paint, approximately 550° C; the stain and the paint should be fired separately because of the difference in temperature. If fired together, often a dense yellow-green metallic “scum” will result on the outside of the glass as a result of over-firing, as seen in many late 19th and early 20th century glass[257].

In general, silver stain is a pigment that is made of silver compounds and gamboge gum, an orange-brown gum resin[258]. The silver can also be mixed with red or yellow ochre. These silver compounds are typically nitrates, but can also be chlorides, oxides, or sulfides[259]; in some cases, carbonates or phosphates are used as well. The manufacturing of the pigment is as follows: pure silver is combined with pure nitric acid and then mixed with water; approximately 2-3 times the amount of the silver and nitric acid combination of water is added here causing the acid to attack the silver and creating a yellow liquid. The liquid is then poured into a clean pan and boiling water and salt are added to it; the salt cases a white precipitate to form from the silver. This mixture is stirred until all salt is dissolved and all the silver is precipitated. The liquid is carefully poured out of the pan, leaving the silver precipitate in the bottom, and then fresh boiling water is added; this process must be repeated until the liquid is clear, indicating that all of the acid has been removed from the silver. Finally, this silver is

[256] Ibid.
[257] Ibid.
[258] Elskus, Albinas. *The Art of Painting on Glass.* 1980: 97.
[259] Cannon, Linda. “History of the Techniques and Materials.” 1991: 70.

blotted dry and combined with yellow lake in a 1:2 ratio until mixed completely; this is then left to dry[260].

Similar to vitreous glass paint, it comes in powdered form, ground from this dried mixture; the pigment is mixed with water and the gamboge gum which serves as both the binder and the vehicle. By itself, silver nitrate is not a good stain because it is hard to control when it melts; therefore, it is almost impossible to predict the intensity of the resulting color. Adding silver salts to the silver nitrate helps with this issue, whereas other additional chemicals allow the stain to act as a sponge, pulling certain elements out of the glass and allowing the silver to enter in their place; this is how the stain permeates the glass, becoming an inherent part of the glass itself[261].

If one looks at glass as an irregular network of silica, it is understood that this network has empty space within it which additional elements fill. For example, in glass that contains sodium the silver pulls out the sodium so that the silver can take its place and color the glass. The silver that is now in the glass changes its light transmission, allowing yellow light to pass through but absorbing the rest of the spectrum; the result is a yellow-colored glass[262].

Once fired, the gamboge gum can be washed away and the result is a clear, transparent yellow stain now inherent to the glass. It is important to note that "silver stain can be fully or partly accepted or it can be totally rejected by the surface of a particular piece of glass."[263] Because the reaction between the stain and the glass during firing is a chemical one, some types of glass will stain better than ones, possibly resulting in an uneven color. Medieval soda-glass in particular took to the stain very well and resulted in a strong, even color[264]. Glass painters rose to the occasion and took on the challenge of experimenting with this new material.

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[260] Miller, Fred. *Glass-Painting*. 1885: 22-23.
[261] Isenberg, Anita and Seymour. *Stained Glass Painting*. 1979: 212.
[262] Ibid.
[263] Elskus, Albinas. *The Art of Painting on Glass.* 1980: 97.
[264] Cannon, Linda. "History of the Techniques and Materials." 1991: 71.

In terms of application, there are two ways to apply silver stain to glass. The first method is called the direct method, which involves taking the mixed silver stain and diluting it further with more water; this is then applied to the glass and no blending is done. This method often results in uneven intensity changes and even reveals brush strokes. The second method results in the stain to be evenly flat on the glass surface or stain that increases steadily from pale to intense[265]. Again, the pigment is mixed and diluted but the blending is done with a badger brush. Unlike both vitreous glass paints and enamels, silver stain requires no flux to be painted onto the glass; the pigment is suspended directly in water and applied to the glass. In many cases, white vinegar is the vehicle of choice because it allows for the stain to more evenly distribute across the glass. Unlike trace and matt paints, the use of gum arabic is not necessary because it already has the ability to "bite" into the glass; using it will make the stain un-removable from the glass even before the firing.[266] Because the gamboge gum has such good holding power, any corrections that need to be made must be done before the pigment has dried.

In both the direct and indirect methods, the stain is painted onto the reverse side of the glass, or the back face; this is so that it does not interfere with the vitreous glass paint or enamels painted on the front side because it would ruin it during firing. Regardless of the method of application, silver stain is best fired face up, at a temperature of 510-550° C for softer glass and 550-570° C for harder glass[267]. It is possible for the artist to do two separate firings, one for paint and one for stain, but this is not absolutely necessary and one firing is often done. If done together, the stain is fired face down and the temperature of the kiln can go up to 650° C and still be safe for both materials; however, any further above that and the stain will get a dark, rust color[268].

In terms of aesthetics, the stain can vary from pale yellow to very deep orange in color (Figure 50). Miller writes that "the charm of stain is its variety, and this results from its being put on more

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[265] Elskus, Albinas. *The Art of Painting on Glass.* 1980: 98.
[266] Isenberg, Anita and Seymour. *Stained Glass Painting*. 1979: 214.
[267] Elskus, Albinas. *The Art of Painting on Glass.* 1980: 117.
[268] Isenberg, Anita and Seymour. *Stained Glass Painting.* 1979: 216-217.

thickly in some places than in others. The thicker the stain the darker it will fire."[269] The resulting color of the stain depends on a number of factors. The amount of stain applied is a clear factor, and both transparency and depth will vary according to it. Firing time is another issue that affects the color; usually, the longer the firing time, the more intense the stain.

Figure 50. Silver stain used to create halos. Image from http://suevelstudios.com/473/

[269] Miller, Fred. *Glass-Painting.* 1885: 29.

Historical Use

While the origins are unclear, it is believed that the earliest silver stained glass objects were created in Egypt, possibly somewhere between the 4th and 7th centuries[270]. Other than this, silver stain appears seemingly out of nowhere in western Europe in the 14th century. Many early 14th century examples come from France, particularly Normandy; by 1320, silver stain was being used throughout Europe. It is said that "the addition of silver stain to the glass painter's repertoire completely transformed the appearance of decorated window glass in Europe."[271]

There have been attempts to make a connection between the stains used on Islamic glassware and those used on European windows centuries later but the lack of examples between the 11th and 14th centuries "leaves open the question of whether there really was continuity with the Byzantine world or whether silver stain was discovered independently in France."[272] Byzantine silver stain is very opaque, looking like yellow enamel; it was used predominantly on a small scale and in a linear fashion or filling in small areas. On the other hand, European silver stain in the 14th century is brilliant and transparent; this transparency is due to the improved technology in glassmaking and furnaces which allowed for new and improved glass compositions and the ability to precisely control the firing temperature[273].

Stained glass saw the introduction of silver stain In Europe during the Decorated Gothic period, also called the Middle Period. The two significant developments during this period were: (1) the introduction of silver stain and (2) the utilization of abrasion for flashed glass. Silver stain added a variety of colors from deep orange to dark yellow to the brown paint of the Early Period. In addition, abrasion allowed for two distinct colors to be present on a single piece of glass. The introduction of both green and violet flashed glass further increased the color repertoire of the windows and the abilities to create larger windows allowed a greater canvas on which to design. Between these new

[270] Pilosi, Lisa and David Whitehouse. "Early Islamic and Byzantine Silver Stain." 2000: 330.
[271] Ibid.
[272] Ibid, 336.
[273] Ibid.

discoveries and the addition of silver stain, the range of colors that could be found on a single piece of glass was significantly improved; for example, a piece of blue flashed glass with silver stain applied to the back could potentially have four colors—blue, yellow, green, and clear. In addition, when combined with abrading ruby flashed glass, silver stain allowed for the process of creating heraldry into glass to become much simpler, requiring significantly fewer lead lines. One final example is using silver stain to create halos over figures heads without requiring an additional piece of yellow glass (Figure 51). Each of these cases represents the use of silver stain to save the use of additional lead lines, which results in a much clearer design.

Figure 51. Example of the color variety and design of silver stain. Image from http://www.vam.ac.uk/content/articles/n/netherlandish-painted-glass-1500-1530/

Deterioration

In general, silver stain is the least susceptible to deterioration of the three types of surface decoration, making it the most durable. This is mostly due to the fact that upon firing, the silver stain and the glass substrate become chemically combined, a permanent change to the glass which cannot be removed. Silver stain's protection may come from the silver ions that replace the sodium ions on the glass surface during the firing process; therefore, the leaching of the silver would not create an alkaline solution like the sodium ions would in the case of vitreous glass paint [274]. According to Roy Thomas, "yellow stain for some reason has a strong anti-corroding effect, and one very often finds a piece of glass deeply corroded but with the stained part untouched. The colour cannot be the protecting influence, because the yellow pot-metal glass shows no signs of special immunity."[275] In terms of paint, he says that "thick outline paint generally protects from corrosion, whereas matt shading and thinly painted outline, by holding moisture, often induce corrosion."[276]

Unlike vitreous glass paints, under-fired silver stain seems not to be affected in terms of longevity. A poor firing will result in glass that is not transparent in reflected light and the surface will have an iridescent reflection with a blue tint around the stained sections; despite the physical appearance, the under-fired silver stain is still very durable. On the other hand, over-firing will have an effect on the silver stain—the gamboge gum, which is typically removed to reveal the brilliant yellow stain, can adhere to the glass surface, making it impossible to remove.

While silver stain is not prone to corrosion, the silver nitrate used to create the stain has corrosive properties. For this reason, it is recommended that quill brushes, not metal ones, are used because the metal would be corroded. In addition, contamination of the pigment could occur. The fact that the pigment is suspended in water and painted directly onto the glass allows for little possibility for

[274] Newton, R.G. *Conservation of Glass.* 1989: 145.
[275] Thomas, Roy Grosvenor. *Stained Glass: Its Origins and Application.* 1922: 11.
[276] Ibid.

error in the manufacturing process[277]; even so, this process contains a risk of contamination of the pigment, which could potentially lead to corrosion or failed stain.

[277] Isenberg, Anita and Seymour. *How to Work in Stained Glass*. 1983: 190, 167.

VI. Enamels

For many years the use of enamels for stained-glass windows was…not accepted, because of their low fusing point and therefore poor adhesion and uncertain permanence on the surface of the glass. This still holds true today…What has changed, though, is our approach toward the possibilities of utilizing enamels for painting on glass.[278]

Albinas Elskus

The final main type of surface decoration that had an important effect on stained glass windows is enamels. Anita and Seymour Isenberg describe them as follows: "transparent enamel colors are very soft paints with low-firing temperatures; they are not very resistant and will end up fading in a comparatively short time…these paints do have a great deal of depth, are very dense and give almost the impression of a piece of flashed glass when you look at them."[279]

Types of Enamels

Enamels can be divided into types in a few different ways. One way is high-fire versus low-fire enamels. According to William Gudenrath, "high-fire processes can soften and possibly damage an object, while low-fire processes never soften an object to the point of imperiling it. High-fire processes can be carried out in a glass furnace or, after the 18th century, in a kiln, while low-fire processes always take place in a kiln."[280] High-fire enamels were the only type available to decorate glass until the 19th century. The process of creating a low-fire enamel is more complicated and requires precise managing of the color, temperature, and viscosity of the enamel. The low-firing method is the easier of the two firing processes and the form of the object is not threatened because the temperature is never too high.

[278] Elskus, Albinas. *The Art of Painting on Glass*. 1980: 101.
[279] Isenberg, Anita and Seymour. *Stained Glass Painting*. 1979: 217-218.
[280] Gudenrath, William. *Enameled Glass Vessels*. 2006: 23.

The flash-firing method for high-fire enamels requires a kiln "capable of great, sudden, and highly controlled temperature changes."[281] In this process, the object is slowly heated to a temperature that is just under the annealing point of the glass; the temperature is then blasted up to a point where the enamels become quickly fired, a jump from about 450° C to 650° C. This high temperature is maintained only for a short amount of time before it is reduced to the stable annealing temperature, around 480° C. Gudenrath notes that "because of the great thermal agility of modern kilns and the precision of the computers that control them, this flash-firing method is used in mass production today nearly as often as the low-fire method with low-fire enamels. This is because high-fire enamels invariably have markedly higher durability than low-fire enamels."[282]

The other way that enamels can be divided is pre-melted enamel versus cold-mixed enamel. Pre-melted, or pre-fritted, enamel is composed of finely ground colored glass in a liquid medium and must be mixed so that the resulting color is intense but also physically compatible with the glass substrate. Therefore, when the glass is cooled after firing the enamel, "the enamel must decrease in volume at about the same rate and to about the same degree as the glass to which it has been fused, or they will crack apart. Almost all modern commercial enamels are of this type."[283] In comparison, cold-mixed enamel, also called un-fritted enamel, is created by a colorless glass ground and combined with a coloring agent, such as a metallic oxide, and a liquid medium. In his article on "Enameled Glass Vessels," William Gudenrath notes the differences between these two types:

> The manner in which the enamel attains its color is distinctly different between the two types. The cold-mixed type acquires its color during the firing process, while the color of the premelted type was achieved by chemical reactions that took place long before the firing process, when the ingredients were melted in a crucible within a glassmaking furnace…The premelted enamel appears essentially homogeneous, since its ingredients were well mixed by convection in the crucible when they were 'cooked.' By contrast, the cold-mixed enamel appears as a sea of colorless glass that is somewhat sparsely populated with colorant particles, each of which is surrounded by a veil of colored glass.

[281] Ibid, 26.
[282] Ibid, 27.
[283] Ibid.

> The coloration of the glass is strictly limited to the immediate vicinity of the interface of the colorless glass and the colorant.[284]

Composition and Application

The raw materials used to create enamels are divided into six groups: refractories, fluxes, opacifiers, colors, floating agents and electrolytes. The refractories are a part of the acidic materials of the melt and help to give body to the resulting glass; substances include quartz, feldspar, and clay. The fluxes are basic in nature and will react with the acidic refractories to create the glass; substances include borax, soda ash, cryolite, fluorspar, and red lead. They also have the capability of lowering the fusion temperature of glasses; however, if too much flux is added, then slags will result. The opacifiers are responsible for giving the enamel its white opaque appearance and are generally refractory in nature. True opacifiers, including tin oxide, antimony oxide, sodium antimonite, and zirconium oxide, are frequently accompanied by accessory opacifiers, like cryolite and fluorspar, which allow for the enamel to be more fusible. Colors may consist of oxides, elements, salts, or frits and they may also act as either refractories or fluxes; it is important to note that the choice of colors used will be affected by the enamel composition. Floating agents, including clay and gums, are added to the enamels mixture in the mills in order to suspend the enamel in water; for this process, the clay must be free of all impurities. In order to achieve and help the clay in maintaining proper suspension, electrolytes are also added, which include borax, soda ash, magnesium carbonate, and magnesium sulfate[285].

In simpler terms, enamel is a relatively soft glass and is composed of a mixture of flint or sand, red lead, and soda or potash, all melted together to create a glass with a blue-green tint that serves as a flux. The more lead and potash the mixture contains, the more brilliant the enamel will be; however, it will also be softer[286]. While softer enamels need less heat during the firing process, they are not very

[284] Ibid.
[285] Andrews, Andrew I. *Enamels*. 1935: 10-11.
[286] Newton, R.G. *Conservation of Glass*. 1989: 101.

durable.

The pigments used to create enamels are similar to those used to create pot-metal glass, because enamels are inherently ground glass. Pigments including iron, copper, cobalt, gold, and silver are first fused and precipitated, allowing them to be converted into a form that is easily fusible with the chosen flux. The flux is the base of how enamels are made and according to Newton, 2-3% of oxide to molten flux will provide good color[287]. The amount of flux needed is one of the main characteristics that differentiate the three main types of surface decoration: glass-stainers' colors, stain, and enamels. Silver stain needs no flux, while enamels typically need a lot of flux; the ratio of flux to pigment for enamels is greater than that of the glass stainers' colors. For enamels, an initial fusing of the pigment with the flux is usually necessary before being painted on the glass; this process is called sintering and involves the pigment and flux being melted together, cooled, and then ground to make the paint[288].

Enamel-painting requires the use of four substances: (1) glass vehicle, or flux; (2) ground; (3) colors; and (4) secondary vehicle. It is different from other forms of glass-painting in the vehicle used for the colors. Enamels use glass which becomes fluid after being mixed with the desired color and fused. Because it mixes with the colors in the liquid state, the two form a solid mass when cooled. The glass flux used is considered "soft" when it is easily fusible and "hard" when it requires a greater degree of heat to melt it. According to Gessert, "it is always necessary…that the enamel of the ground should be considerably harder than the mixtures for the colours; for if they both melt with the same degree of heat, they will necessarily run together."[289] Like the ground, the colors used must also be able to withstand the heat from the melted glass. This limits the colors that can be used to metals, earths, or other minerals. Finally, the secondary vehicle is a "fluid body for laying on the ground, and working,

[287] Ibid, 102.
[288] Sloan, Julie L. *Conservation of Stained Glass in America*. 1995: 162.
[289] Gessert, M.A. *Rudimentary Treatise on the Art of Painting on Glass*. 1851: 64.

with the pencil, the flux and colours when mixed together."[290] This vehicle is meant to aid in the spreading and laying the enamel, not hold the colors together or bind them to the glass surface. Due to this, the vehicle should be made up of a substance that will evaporate and dry without leaving any residue. Essential oils are often used as the secondary vehicle because they dry easily.

According to Charles Phillips, "Enamels for glass decoration consist of very low-melting glasses: colorless, opaque, or colored, applied in a very finely pulverized form by sprinkling or dusting upon the surface. The design is previously applied to the surface as a solution of gum or varnish, causing the enamel to adhere where it is desired."[291] Glass enamels used too thickly will make a design too heavy and crude with their harsh colors. When using enamels, the glass should be heated more than usual in order to provide the necessary flux for the colors; enamels that are not well-fired often look too harsh as well. This flux is designed to lower the firing point to a temperature below that of the glass. Because they are firmer, oxhair brushes are often used to paint with enamels.

Once fired onto the glass, the enamel regains some of its transparency that was lost as it was powdered, becoming a coat of transparent colored glass on the original glass's surface. During firing, the vehicle used to paint the enamel is burned out. Enamels must be fired at around 560-600° C for proper adhesion[292]. While the fired enamels will have a color that is brighter than the one it had when it was originally applied, they are still not considered a substitute for pot-metal or flashed glass; instead, they should be utilized as complements to these types of colored glasses. Elskus notes that "Enamel looks best when it is applied in an even, flat manner. Its transparency stays crisp and its tonality is constant. Any blending from light to dark presents problems in firing."[293] The enamels are fixed to the glass as a smooth surface and their true colors can only be seen after firing. After the firing, the enamel will have a dull shine, although many times the result is a matte finish. Intensity-wise, the enamels will

[290] Ibid, 65.
[291] Phillips, Charles John. *Glass, the miracle maker.* 1948: 242.
[292] Elskus, Albinas. *The Art of Painting on Glass*. 1980: 101.
[293] Ibid.

range from light to medium dark; any attempts to further saturate the color will not work because heavily painted enamel will not be absorbed into the glass and will blister on the surface during firing.

Originally, enamels were found predominantly in darker colors, including shades of blue, purple, and red. Dark blue was obtained originally with saffre or smalt, both of which contained cobalt oxide for color plus contaminations and other ingredients; the 19th century also saw the use of cobalt oxide but this time it was in a pure, industrially-produced form. Copper oxides are also used to create a blue-green color. Purple enamels were achieved using manganese oxides while a red-purple color, popular in the 19th and 20th centuries was created with colloidal gold; colloidal gold, also called Cassius Purple, was created by dissolving gold in a mixture of nitric and hydrochloric acids and then precipitating it with a solution of tin chloride[294]. According to recent analysis done in 2009 on enamels in stained glass:

> Recipes and chemical compositions indicate that glassmakers of the 16-17th century had a full control over the color of the enamel glass paints they made. They used three types of coloring agents: (1) a cobalt-rich product such as saffre or smalt resulting in a dark blue color, (2) a manganese-rich product such as pyrolusite resulting in a purple color, and (3) a copper-rich product such as brass resulting in a light-blue or green-blue color…The chemical compositions are in agreement with the historical recipes, except for the use of fusing agents such as arsenic, bismuth or mercury compounds which were recommended in several recipes but never encountered experimentally. It is unclear if these recipes were ever applied in the past or not.[295]

Newton notes that "at no time were the colours as transparent as those of silver-stained glass, or of coloured pot metal, nor did the enamels have a durability comparable to that of the coloured glass."[296] The enamel colors are of a much wider range, including transparent yellows, greens, blues, violets, pinks, rubies, browns, etc. Their use is limited however due to their poor adhesion to the glass surface. Elskus notes that while they are not as permanent as the glass stainers' colors, they do increase the artists' color palette substantially without requiring additional leads which would detract from the

[294] Schalm, O, et.al. *Enamels in Stained Glass Windows.* 2009.
[295] Ibid.
[296] Newton, R.G. *Conservation of Glass*. 1989: 100.

overall visual of the design. Enamels are applied to the inner surface of the glass and fired in the same way as vitreous glass paint, albeit at a lower temperature. This firing is done before the silver staining but after the tracery lines. Enameling was first done on metals, but then later it was realized that it could be done on glass as well.

Historical Use

It is believed that enamels were first made and used by the Egyptians based on early evidence of enamels found on jewelry[297]. That being said, enameling as a technique dates back to the 15th century B.C. where it was found on glass vessels of the ancient Egyptians[298]. The Romans also utilized the technique but not until the first century A.D.[299] As an art form, enameling took off during the Christian era, also known as the Byzantine Period, with two distinct types of enamels: cloisonné and champlevé. Cloisonné was most likely made by goldsmiths, who soldered wire to create a border around the design to be enameled (Figure 52). He filled the areas with the powdered glass and other materials and pressed them into place before placing the entire piece into the furnace; the heat then melted the enamel, creating a smooth surface of glass[300]. During firing, the enamel will fuse to the metal wire and any background material. On the other hand, coppersmiths were responsible for the champlevé method, where the designs to be enameled were carved out of the metal instead of using wire; then the enamels were applied and fired in the same way (Figure 53). This type could involve the enamel being fused into sunken cells, carved, cast, or stamped into the object[301].

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[297] Andrews, Andrew I. *Enamels.* 1935: 1.
[298] Newton, R.G. *Conservation of Glass*. 1989: 84.
[299] Ibid.
[300] Andrews, Andrew I. *Enamels.* 1935: 2.
[301] Newton, R.G. *Conservation of Glass*. 1989: 102.

Figure 52. Example of cloisonné enamel. Image from
http://www.rubylane.com/shop/romanovrussia/ilist/,c=Antique_Silver,cs=Silver:Antique

Figure 53. Example of champlevé enamel. Image from http://www.pinterest.com/pin/200199145908674224/

In terms of painting with enamels, this idea did not arise until the end of the 15th century and it is believed to have begun in Venice, although no hard evidence actually exists. It was Angelo Brovierio who first discovered using enamels on glass; a glass worker, Brovierio practiced this method in Murano for many years[302]. Up until about 1810, enamels were opaque; after this time, the transparent enamel took over. Artists from Germany and the Low Countries introduced early enameling, called thin or wash enamel. This type of enamel was most suited for soft glass and was accomplished within outlines that had already been etched into the glass surface. Over time, dense enamel became the generally-used medium and was used on both clear and opaque white glass[303].

In terms of stained glass, the Reformation is known as the "agency of much destruction and despoliation of stained glass."[304] The second half of the 16th century on saw political unrest and religious changes of the Reformation that would lead to a significant decrease in the popularity of stained glass over the course of the 17th and 18th centuries. In addition, the changing aesthetics and styles that were developing over time influenced the designs of stained glass along with the multitude of other arts. Those who did pursue stained glass careers during this time were faced with a number of significant challenges. First and foremost, there were very limited amounts of pot-metal glass. Despite this lack of supply, by the year 1550, enamels were already being used, giving the glass-painter a new set of painterly effects and dominating the stained glass windows for the 17th and 18th centuries[305] (Figure 54).

[302] Andrews, Andrew I. *Enamels*. 1935: 4.
[303] Newton, R.G. *Conservation of Glass*. 1989: 85.
[304] Brown, Sarah. *Stained Glass: An Illustrated History.* 1992: 111.
[305] Ibid, 114.

Figure 54. Example of enamel painting. Image from http://www.cvma.ac.uk/images/full/enamels.jpg

While the general methods of medieval glass-painters remained relatively constant, it was the 16th century—the Late Gothic period—that brought an "experimentation in painting…which, it has been argued, led to the total collapse of traditional techniques."[306] During the 1530s, enamel pigments with metallic oxides were used regularly, having gotten their start with coloring glass vessels. Artists were now able to paint colors directly onto the white glass instead of being forced to use colored pot-metal glass. Similar to the development of silver stain, enamels allowed glass painters to paint multiple different colors on one piece of glass. Brown writes that "both the manufacture of the enamels and their successful firing were fraught with difficulties; their origins remain obscure."[307] It is possible that like many other art experiments that the use of enamels began in the Netherlands[308]. Blue was the first color to be used, followed by violet, brown, red, and green. Examples of blue enamel can be found dating back to 1538 in Antwerp[309].

The real influence of enamels was seen in smaller-scale domestic panels where white glass dominated and less leads were required; in addition, the increased opacity of the enamels was not as much of a problem on a small scale. Sarah Brown writes that "enamel colours lack opacity and are less effective when viewed in great expanses from a distance. They were, however, ideal for delicate detail on small panels that were to be viewed close up. A glass-painter could imitate the easel painter, working on a single sheet of white glass rather as the painter works on canvas."[310] Designs were pulled from a variety of sources, ranging from landscapes and religious subjects to heraldic and mythological scenes. According to Brown, "enamel stains are now recognized as being particularly well-suited to the sort of small panels, roundels, armorials and medallions produced in large numbers in the seventeenth century

[306] Brown, Sarah. *Glass-Painters.* 1991: 66.
[307] Brown, Sarah. *Glass-Painters*. 1991: 66.
[308] Ibid.
[309] Ibid.
[310] Brown, Sarah. *Stained Glass: An Illustrated History.* 1992: 28.

to fulfill commissions for houses and private chapels"[311] (Figure 55). While enamels were originally used on a small-scale, such as for heraldry and colored ornaments, it would eventually graduate to use in figural flesh tones and ultimately was used to replace pot-metal glass in many windows.

Figure 55. Example of an enamel heraldry window. Image from http://www.vitraux.co.uk/about/ron323.htm

[311] Ibid, 115.

The 19th century brought advances in technology that would make firing enamels on glass substantially easier than before—the development of these low-fire enamels. As a result, "for the first time in the then 3,400-year history of enameling glass vessels, firing could occur while the objects sat in a kiln."[312] Low-fire enamels require three necessary criteria: (1) correct color and intensity; (2) enamel compatibility with the glass substrate; and (3) enamel's ability to be fired at a temperature well below the point where the glass could become distorted[313].

Deterioration and Other Issues

In a recent article from 2009, it is written that "not only 16th-17th century enamel paint layers suffer from severe degradation, also 19th century enamel paint layers (i.e., in windows less than 100 years old) are in some cases heavily degraded."[314]. Historically, in order to achieve the low melting glass paint, recipes called for large amounts of: (1) fluxing agents, like lead oxide; (2) one or more alkali rich materials, including wood ash, salts of tartaric acid, potassium nitrate, and sea salt; and/or (3) borax. The article from 2009 concludes that "it is likely that the (non-optimal) chemical composition of the flux is one of the reasons of the accelerated deterioration of some of the enamel paint layers."[315]

In general, stains are the most durable of the three categories, with enamels being considered the most unstable and glass stainers' colors inevitably flaking and fading over time. For both glass stainers' colors and enamels, the quality of the flux is essential to the adherence of the pigment to the glass. The purity of the ingredients will directly affect this, as will the amount of borax used to soften the flux; more borax will lower the melting point of the flux but will force the glass paint to become water-soluble, a very risky consequence.[316] The glass stainers' colors do not require as much flux as

[312] Gudenrath, William. *Enameled Glass Vessels*. 2006: 66.
[313] Ibid, 66-67.
[314] Schalm, O, et.al. *Enamels in Stained Glass Windows*. 2009.
[315] Ibid.
[316] Sloan, Julie L. *Conservation of Stained Glass in America*. 1995: 165-167.

enamels and often prove to be more durable than enamels, possibly as a result of lesser flux as well as a simpler manufacturing process with less ingredients. With enamels having various steps requiring proper mixing, melting and combining of ingredients, there are more chances for things to go wrong than any other surface decoration.

While organic pigments will fade in sunlight, the silica-based ones do not. The lightening of color in this case is caused by the deterioration of the bond between the powdered enamel and the surface of the glass. The enamel will flake off and leave unsightly white patches on the glass. After recognizing that the cause for this loss, it was discovered that to prevent unnecessary loss of enamel the glass and the enamel should have similar rates of expansion and contraction; this would help to keep the interface between the two materials intact and less likely to separate.[317]

One of the major issues with enamels is the cleanup. Enamels often spread past their boundaries within the design of the window and because the oil in the mixture does not dry quickly, smears are common and often very difficult to clean off[318]. Residual smears will be very noticeable after firing.

In general, because an enamel is essentially glass, much of the physical and chemical properties and considerations for glass apply to enamels as well[319]; therefore, similar concerns with deterioration must be addressed. Examples of enamel loss or deterioration can be seen in Figures 56, 57, and 58.

[317] Cannon, Linda. "History of the Techniques and Materials." 1991:75.
[318] Elskus, Albinas. *The Art of Painting on Glass*. 1980: 102.
[319] Andrews, Andrew I. *Enamels*. 1935: 23.

Figure 56. Example of enamel loss due to a problem with the coefficient of expansion of the glass and/or the enamel. Image courtesy of Drew Anderson.

Figure 57. Enamel loss and deterioration on "The Good Shepherd" by Tiffany Studios, ca. 1900. Image courtesy of Julie Sloan.

Figure 58. Enamel deterioration on “Suffer the Little Children” by the Ford Brothers, ca. 1907-1910. Image courtesy of Julie Sloan.

VII. Conservation Principles and Ethics

The restoration…of an ancient glass painting to its pristine beauty, would in the majority of cases be more truly designated the premeditated destruction of an original work. It is generally incompatible with that conscientious preservation and retention in its original place of every portion of ancient glass…every fragment possesses a degree of interest quite independent of its size, its effects, or the subject it represents, and therefore, though apparently insignificant, should by no means be cast aside…With such restorations as scrupulously preserve the original glass, and admit of no more modern painted glass than is requisite to supply the deficient parts of a design, clearly indicated by the portion of it which remains, little or no fault can be found. But when they are carried beyond this point…They diminish or altogether destroy the value of the work as a specimen of ancient art…As a general rule therefore, it is prudent, and…very desirable to abstain altogether from restoring the deficient parts of a glass painting, except where the original work affords a model and guide according to which such deficiencies can be supplied.[320]

Charles Winston, 1847

Any proposed interventions should (a) be reversible, if technically possible, or (b) at least not prejudice a future intervention whenever this may become necessary; (c) not hinder the possibility of later access to all evidence incorporated in the object; (d) allow the maximum amount of existing material to be retained; (e) be harmonious in colour, tone, texture, form and scale, if additions are necessary, but should be less noticeable than original material, while at the same time being identifiable; (f) not be undertaken by conservator/restorers who are insufficiently trained or experienced.[321]

Virginia Raguin, 1986

Conservation is a complex field, filled with both technical and ethical dilemmas. In many cases, the "value" of a stained glass window will determine how much care and attention it receives, a fact

[320] Winston, Charles. *An inquiry into the difference of style observable in Ancient Glass Paintings.* 1847: 304-305.
[321] Raguin, Virginia. *Conservation and Restoration of Stained Glass.* 1986: 165.

that shows the central role of ethics in stained glass conservation. In his article "Handle with Care: Ethics, Approaches, and Best Practice in Stained-Glass," Ivo Rauch notes that age and rarity are two essential categories when determining artistic worth. He notes that modern conservation ethics center around the argument that every piece of art has "a particular, individual and unmistakable 'aura.'"[322] This can be reinforced in Walter Benjamin's essay "The Work of Art in the Age of Mechanical Reproduction." He writes:

> Even the most perfect reproduction lacks one element: the here and now of an artwork, its unique presence at the place where it is found. The individual history that an artwork gathers over the course of its existence is dependent on that unique presence alone. This history includes the structural modifications an artwork has suffered along with the change of hands that may have befallen it.[323]

Benjamin goes on to express his viewpoint on the matter: "It is impossible to separate the uniqueness of a work of art from its being embedded in tradition. Tradition itself, though, is something living, something extraordinarily changeable…The unique value of the 'authentic' work of art is based in the rituals where it finds its first and original use."[324]

Using Benjamin as a foundation, Rauch goes on to ask how a question that expresses the one of the fundamental issues of conservation practice—how does one differentiate between an 800 year old window in a cathedral and a 70 year old window of a medieval mansion? He answers as follows:

> Both glass paintings possess unique and unmistakable, although very different, auras. These auras render both windows valuable historical witnesses. Their art historical importance, of course, varies…However, the sense of value with which a conservator must approach each one is equivalent. Both deserve equal care and painstaking attention from the conservator's point of view. This is due not to the content of the windows or to their material, but to the individual aura of each composition…Every work of art demands conservation on its own terms.[325]

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[322] Rauch, Ivo. "Handle with Care." 2010: 45.
[323] Benjamin, Walter. *The Work of Art in the Age of Its Technical Reproducibility*. 2008: 11-12.
[324] Ibid, 16.
[325] Rauch, Ivo. "Handle with Care." 2010: 47.

The Ethics Issues

Stained glass conservation as a field is a relatively recent development, within the past few decades. In fact, it was not until 1989 that there were guidelines specifically developed for stained glass. That being said, there were a number of general conservation guidelines that were applicable to stained glass before then. Even though the medieval glaziers had no written principles to guide them, conservation was still an idea. In addition to designing and creating new windows, the medieval glaziers and glass-painters were also responsible for knowing how to maintain and repair existing windows, making their skill set even broader. Sarah Brown notes that "today, a glazier, or a stained glass artist, or a conservator, is called in; the medieval glass-painter combined aspects of all three."[326] She also writes that unfortunately, "much damage was done by generations of glaziers who lacked the raw materials and the technical skills to maintain or restore the old glass properly."[327]

One of the earlier sets of guidelines that impacted the stained glass industry is the Venice Charter of 1964. It is one of the few references that was available to conservators of stained glass before specific guidelines were established; while it does not directly address stained glass, conservators still look to it for important ethical principles. It begins as follows:

> Imbued with a message from the past, the historic monuments of generations of people remain to the present day as living witnesses of their age-old traditions. People are becoming more and more conscious of the unity of human values and regard ancient monuments as a common heritage. The common responsibility to safeguard them for future generations is recognized. It is our duty to hand them on in the full richness of their authenticity.[328]

In terms of restoration, the Charter states that "the process of restoration is a highly specialized operations. Its aim is to preserve and reveal the aesthetic and historic value of the monument and is

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326 Brown, Sarah. *Glass-Painters*. 1991: 18.
327 Ibid, 70.
328 Second International Congress of Architects and Technicians of Historic Monuments. "The Venice Charter." 1964.

based on respect for original material and authentic documents."[329] Relating to previous additions, changes and repairs, the Charter rules that "the valid contributions of all periods…must be respected, since unity of style is not the aim of a restoration."[330] For replacements, the Charter states that they must "integrate harmoniously with the whole, but at the same time must be distinguishable from the original so that restoration does not falsify the artistic or historic evidence."[331] Again, while the focus of the Charter is monuments, many of its principles can easily be interpreted and were interpreted to fit the needs of the stained glass industry, which for a long time did not have its own set of guiding ethical standards.

Similar to the Venice Charter, the Burra Charter of 1979 does not address stained glass directly, but instead discusses the preservation and conservation of places of cultural significance. Also similar to the Venice Charter, this set of guidelines can also be adapted to fit the needs of the stained glass industry and defines some important general terms. The following terms can be easily applied to stained glass windows by replacing the word "place" with "object:"

> *Conservation* means all the processes of looking after a place so as to retain its cultural significance. *Maintenance* means the continuous protective care of the fabric and setting of a place, and is to be distinguished from repair. Repair involves *restoration* or *reconstruction*. *Preservation* means maintaining the fabric of a place in its existing state and retarding deterioration. *Restoration* means returning the existing fabric of a place to a known earlier state by removing accretions or by reassembling existing components without the introduction of new material. *Reconstruction* means returning a place to a known earlier state and is distinguished from restoration by the introduction of new material into the fabric.[332]

In the year 1994, there were two documents that discussed the issues of authenticity and ethics in terms of conservation. The first of these is the Nara Document on Authenticity, which states that "authenticity…affirmed in the Charter of Venice, appears as the essential qualifying factor concerning

[329] Ibid.
[330] Ibid.
[331] Ibid.
[332] Australian National Committee of ICOMOS. "The Burra Charter." 1979: 2-3.

values."[333] The Nara Document defines conservation as "all efforts designed to understand cultural heritage, know its history and meaning, ensure its material safeguard and, as required, its presentation, restoration and enhancement."[334]

The second of these documents is the American Institute of Conservation's "Code of Ethics of Historic and Artistic Works." According to this "Code of Ethics," "the primary goal of conservation professionals, individuals with extensive training and special expertise, is the preservation of cultural property…It is materials which has significance that may be artistic, historic, scientific, religious, or social, and it is an invaluable and irreplaceable legacy that must be preserved for future generations."[335] One of the points on the ethics code discusses the importance of preventive conservation: "The conservation professional shall recognize a responsibility for preventive conservation by endeavoring to limit damage or deterioration to cultural property, providing guidelines for continuing use and care, recommending appropriate environmental conditions for storage and exhibition, and encouraging proper procedures for handling, packing, and transport."[336]

While these two documents were created in 1994, it was in 1989 when the first guidelines for stained glass conservation were put together, with the completed set finished in 2004. The "Guidelines for the Conservation and Restoration of Stained Glass" were created to outline the ethical issues of the field in an attempt to help conservators, consultants, and other individuals involved in the field to better understand the principles of their work. The guidelines are universal and can be applied to stained glass of all historical periods. These standards were first instituted by the International Committee of the Corpus Vitrearum for the Conservation of Stained Glass in association with the Stained Glass Committee of ICOMOS. The document cites the Corpus Vitrearum as "an international scholarly organization whose aim is to research and publish historic stained glass. Its Conservation Committee promotes conservation

[333] "The Nara Document on Authenticity." *The Nara Conference on Authenticity*. 1994: 2.
[334] Ibid.
[335] AIC. *Code of Ethics for the American Institute for Conservation of Historic and Artistic Works.* 1994.
[336] Ibid.

and restoration in accordance with these guidelines, coordinates research, and encourages professional exchange."[337]

The document specifically defines stained glass to include painted glass, plain leaded lights, copper-foiled glass, *dalle de verre*, and other types of architectural glass as well as typical stained glass. It also does not differentiate between glass that is in situ and glass that is removed to be placed in a museum. Perhaps one of the most significant points in the entire document reads as follows:

> The intrinsic value of stained glass is equivalent to that of any other work of art or cultural heritage, therefore its conservation merits the same degree of attention and professionalism regardless of its date or monetary worth. Stained glass cannot be considered in isolation. Its historical and physical context, including its architectural and environmental setting, must be taken into account in the planning and execution of any conservation program. The conservation of stained glass thus involves the collaboration of a team of specialists including, but not limited to, conservators/restorers, art historians, architects, scientists, building technologists, and, where they exist, governmental organizations responsible for the protection of cultural heritage. The choice of the professionals involved in the conservation process should be based on their education, their continuing professional development and their experience, favoring quality over financial considerations.[338]

While the context of most conservation projects is important, it is particularly vital when it comes to stained glass because it is rare that stained glass is found to be independent of an architectural setting. As much as it is an object to be conserved, it is also an architectural element that is part of a greater whole. This is a huge quality to keep in mind as a conservation treatment is created for a stained glass work. The introduction of the document ends by stating that while minor issues might not be pertinent in certain projects, each of the principles in the guidelines absolutely must be considered before any decisions regarding its restoration are made.

The guidelines are composed of three main sections: research and documentation, preventive conservation, and interventive conservation. Research for any conservation project is essential. For

[337] "Guidelines for the Conservation and Restoration of Stained Glass." CVMA. 2004.
[338] Ibid.

stained glass in particular, some important things to consider for each work are the following: its history; its function; materials and techniques; its past treatments; and its current condition. From this compilation, a foundation is established to serve as a guideline for the evaluation both during and after the restoration. This Guidelines document also notes the importance of not only creating the written reports for the conservation treatments but also their accessibility to anyone who may need them once the treatments were completed.[339]

The two types of conservation in the Guidelines are preventive and interventive. The first section of preventive conservation in the guidelines is about protective glazing. Architectural stained glass is susceptible to mechanical damage as well as damage from its surrounding environment. A protective glazing system is designed to remove the window's function as a protective shield from the weather. It also serves to protect against atmospheric damages and condensation from moisture collecting on the window. The design of these system depend upon a number of conditions, including the preservation needs of each window, the architectural setting, the physical impact on the building, and the overall aesthetic effect of the space. The types of glazing systems range from external installations of ventilation layers to internal isothermal glazing, which the guidelines cite as "the most effective method currently available" as of 2004.[340] In addition, wire guards can aid in preventing mechanical damage but they are detrimental to the window's aesthetic. These methods can diminish the amount of intervention needed for the conservation of the window but their functioning and effects must be researched thoroughly before making a selection.

The second portion of preventive conservation involves handling, transportation, storage, and display principles. Logically, only a trained professional should handle the panels. When being transported, full support of the window across the entire surface is crucial. In most cases, this can be achieved by packaging them in an upright position; however, with panels suffering from lead failure,

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[339] Ibid.
[340] Ibid.

flaking paint, or loose glass, it is also acceptable to lay them down horizontally for full support. Similarly, the packaging materials must be selected in order to provide physical and chemical stability and protect from moisture absorbency and abrasions. In terms of display, the document focuses solely on museum settings, saying that barriers should be utilized, light levels should be minimized and heat levels around the light boxes must be monitored so that the conservation materials used on the windows are not harmed.[341]

After careful consideration and a great deal of research, interventive conservation treatments can be explored. These treatments should be done in situ if possible so as to not pose an additional threat to the window's integrity. If this is not an option and the panel must be removed, it must be stabilized using "fully reversible and nondestructive measures."[342]

Before anything is done to the glass or its decoration, the original materials of these components and the reasons for their alterations must be identified. The guidelines states that even the corrosion products are counted as evidence of the glass's material history and must be identified as well. The main goal is to conserve the glass itself, not necessarily make it transparent again by removing the corrosion. Cleaning should be done in one small area at a time after recognizing the risks involved by using the tools and methods chosen and large-scale cleaning, such as soaking a piece or glass or even an entire panel, should be completely avoided. In terms of paint specifically, the guidelines state the following: "Paint consolidation is only recommended when paint is in imminent danger of loss. In the case of unstable—but not flaking—paint, preventive conservation methods are preferred. The re-firing of stained glass is never acceptable."[343] As with many fields of conservation, it is much better to perform prevention techniques that are not so invasive than to attempt interventions that may further damage the work.

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[341] Ibid.
[342] Ibid.
[343] Ibid.

The next section discusses the treatment of missing areas and later additions to stained glass panels. To this, the guidelines specify that such elements as losses, rearrangements, and later additions are an important part in the history of the window and should be studied as evidence before any successive conservation processes are undertaken. The principles read as follows:

> The insertion of infills, inpainting and restoration of missing paint, rearrangements, or replacements of later additions should only be undertaken when fully justifiable based on thorough art-historical and technical research. Such treatment must be guided by the principles of minimal intervention and reversibility. Every addition of a new piece of glass must be identified in a permanent manner with a date and signature or other identifying symbols.[344]

Therefore, the most important consideration when performing a replacement is to make it known that that is exactly what it is—a replacement piece. Now, that does not mean that the piece should be obviously different from those of the original panel because preserving the aesthetic of the window is one of the most important conservation goals. That being said, it is important to not deceive the observers and future preservationists of the work by trying to pass off restoration work as original. Restorations should be made to respect the originals that surround them as best as possible to honor the integrity of the panel.

The final section of the guidelines document is about structural consolidation. It is recognized that this consolidation may require outside assistance from other professionals to be sure that the architectural surroundings are all taken into consideration before anything takes place. The supporting structure of the glass window includes lead, zinc, or other metal cames, copper foil, concrete, putty, and other materials. Following the same standpoint voiced throughout the document, this section states that each component contributes to the history of the window and should be documented as evidence of the historic value of the panel. In many cases, some form of intervention is necessary to preserve this structure such that it can then support the stained glass. In addition, certain selective interventions can

[344] Ibid.

be made in order to regain some of the legibility of the imagery of the window; for example, a bowed or bent piece in the panel should be straightened rather than replaced in order to maintain the overall aesthetic of the image as well as the original material of the window. Re-puttying may be done but only depending on the condition of the window and on its future location. Overall, these guidelines provide a comprehensive overview of the principles of stained glass conservation and serve as a great foundation for every stained glass project.

Conservation Issues and Techniques

Despite the negatives, glass has been used in architecture since the ancient Romans. The question is who would have repaired the windows? Based on a decree from the year 337 B.C., during the time of Constantine, there exists a list of thirty-nine professions that were privileged enough to be tax-exempt. One of the titles on this list was called "vitrearius," which is assumed to refer to what is today known as a glazier[345]. So while it is known that a profession existed to handle such repairs, it is impossible to know how these repairs were done.

Peter Van Treeck writes that "the present-day appearance of glass paintings is dependent on their specific material attributes and the working practices used to produce them. For the care and conservation of glass paintings, recognizing the causes of the processes that lead to damage is of the greatest relevance."[346] Breaks to the glass are the most obvious type of damage with stained glass windows, often patched using repair leads or replaced with new pieces of glass. While broken or missing pieces may be the most apparent form of damage, just as important and often just as noticeable is the damage that affects the clarity of the glass painting. Van Treeck notes several types of painting damage and while not extensively the only forms of damage, they provide a number of important forms; they

[345] Strobl, Sebastian. "From Plumber to Glazier." 2010: 34.
[346] Van Treeck, Peter. "On the Artistic Technique of Glass Painting." 2000: 62.

are: corrosion of the vitreous paint, loosening of painted details, loss of contours on the matts or in the under-drawing, damage in the dark sections of the shading, spotty paint loss in the matts, and planar reductions of the paint.

In reflected light, the corrosion of vitreous paint looks gray or white in color; in transmitted light, the paint appears darker and much less transparent. The corrosion itself is caused by the chemical alteration of the glass particles within the paint, having been impacted by humidity together with either an alkaline or acidic substance. This corrosion causes the paint to become soft and lose its inherent stability; what was once a glassy, solid structure becomes crystalline and thus loses much of its strength.

Rauch makes the important connection of damaged paint layers and glass corrosion. He notes that while the paint will show damage due to production errors, more likely causes are extended weathering, wet conditions, and air pollution. Enamel paints will often flake away after having pulled off the glass, which Rauch says is a result of glass corrosion not from very old age since enamels are found from the 16th-20th centuries. This damage will occur as follows: weathering washes out the alkali elements of the glass, leaving a “silicate skeleton” which is called the gel, or leached, layer. This gel layer sits on top of the base glass which is a jagged sheet filled with micro-cracks; it is this gel layer that contains the original paint as well as corrosion products, pollution, and microorganisms[347].

In comparison, for vitreous glass paint, the loosening of painted details comes from a lack of fusion between the vitreous paint and the glass surface. In this case, the paint itself is most likely still in good condition, but because the hardness and smoothness of the glass surface did not allow the paint to fully bond to it, the paint flakes and detaches[348].

Both loss of contour on the matts or under-drawings and the damage to the dark parts of the shading are found mainly where the black vitreous paint had been painted on top of other vitreous paint. It is known that certain vitreous paints are incompatible which could explain these conditions at

[347] Rauch, Ivo. “Handle with Care.” 2010: 48.
[348] Van Treeck, Peter. “On the Artistic Technique of Glass Painting.” 2000: 62.

times. Van Treeck notes the results from testing original glass paintings. On one hand, it was found that paints mixed from a glass flux and coloring oxides will not fuse enough when applied on top of paints in which the glass and coloring oxide had been pre-melted. On the other hand, those paints are less durable when applied directly to the glass surface. Therefore, it is possible that the underpainting has something to do with the damage. In addition, Van Treeck states that similar damage is seen when silver stain and vitreous paints come into contact with one another[349].

The spots of paint loss in the matt can come from the paint being affected by the application of wet paint to a layer of dry, unfired paint. Humidity is permitted to enter the surfaces, allowing the paint structures to become porous in the affected areas; this prevents the proper fusion to the glass. These corrosive effects appear as spots. An additional cause for this type of deterioration is certain admixtures used in the paint or binding agent; both borax grains and oil and resin particles will cause these spots if not dissolved sufficiently[350].

Finally, the planar reductions of the paint result in paintings that look dull and washed out; this look is often the result of over-cleaning literally washing away the paint. Van Treeck notes that both small-scale panels and large-scale monumental works experience these types of deterioration. He states that with the larger-scale works, the main forms of damage found are corrosion, pollution, and strong incrustations formed by humidity; the results of this damage was spottiness and detaching paint. In addition, over time, new and sometimes radical cleaning methods were developed and executed; this also played a part in paint loss and scratching on the glass painting. The paint reduction and subsequent density change caused the paint to have both a different light and tonal value. For example, corrosion causes a loss of translucency and will look more gray or white in color; in comparison, the tonal change comes from the difference in the way that light reflects, scatters, and refracts due to the change in the

[349] Ibid.
[350] Ibid.

plane of the painting[351].

There have been many concerns over the years that historic stained and painted glass are in poor condition and in dire need of conservation. In an 1847 book, Charles Winston notes that there has already been much loss that nothing can be done about but that preventing further destruction can be achieved. He correctly states that the decomposition of the glass itself is an inevitable condition, and that most attempts to fix this issue would only make it worse. For glass painting, there are a number of issues that can be prevented. Winston writes:

> From wilful and wanton destruction, it is true there is little to be apprehended. The iconoclastic mania has happily passed away; the most zealous reformer sees in an ancient picture only a specimen of ancient art, though its subject abstractedly considered may be one to which he entertains the most profound antipathy; and as for the mischievous attacks of the childish and ignorant, they may be effectually resisted by an external wire guard. The great danger to which a glass painting is exposed, arises not from these sources, but either from neglect, or, from well-intentioned, but mistaken zeal for its preservation and restoration. It is difficult to say which of these evils is the more to be deprecated. There can be no doubt that innumerable glass paintings have already perished or become mutilated through the neglect to keep their leadwork and saddle-bars in repair, or to defend them against injuries from without by a wire guard; and that many others are at present in jeopardy for want of similar precautions: but I am sorry to add that an almost equal amount of damage has accrued to these works, in many cases, either through *restorations* conducted on false principles, or their unnecessary removal from their original situations into other windows.[352]

Many of these panels have been previously restored and in some cases, the failing conditions can be traced back to these attempts at restoration. Even stained glass from the 19th and 20th centuries are in need of some maintenance and preventative conservation or else they will not survive to the next century. The second half of the 20th century saw the increase in stained glass literature and heightened interest in the repairs and restoration of stained glass windows. In fact, Julie Sloan notes that "It is really only the nineteenth century that we can examine closely for attitudes and practices of stained glass restoration. Prior to the nineteenth century…all work, whether replacement windows or repairs, was

[351] Ibid.
[352] Winston, Charles. *An inquiry into the difference of style observable in Ancient Glass Paintings.* 1847: 303-304.

done in the style of the restorer's time; rarely was there an effort to honor the original style of the window that was being restored."[353]

Unlike in Europe, the U.S. does not have a thousand-year history of stained glass craft. In the U.S., the oldest stained glass is approximately 250 years old[354]. Understandable then, the conservation needs of stained glass in the U.S. are different from those in Europe and thus the principles for the conservation of medieval stained glass will not be able to apply in many cases to American stained glass. The U.S. developed the Census of Stained Glass in America, an organization loosely based on the CVMA that is designed to record the existing stained glass windows in the country; unfortunately this group has little say when it comes to conservation because those decisions are almost always made by the hired conservators, the owners, or involved architects, consultants, etc. The importance of the past and the care of these windows became recognized and with a complete set of guidelines, modern conservators have concrete principles to refer to when performing their restorations. These restorations address a wide variety of issues when it comes to surface decoration conservation.

Defining the Terms

In the conservation field, there are some general terms that are essential to understanding the techniques and processes being used and there are a number of different sources that provide them. For example, according to the Census of Stained Glass Windows in America, there are three basic forms of interventions when it comes to stained glass windows: (1) conservation; (2) restoration; and (3) adaptation. Conservation's goal is "to retain the existing design, material and aesthetic value of the stained glass window."[355] This may require simply regular maintenance or it may need more direct

[353] Sloan, Julie L. *Conservation of stained glass in America.* 1995: 43-44.
[354] Ibid, 51.
[355] *Conservation and restoration of stained glass: an owner's guide.* 1988: 10.

interventions. In comparison, the aim of restoration is "to return the stained glass window to its original form and design (or in rare cases to the form and design of a later period of significance."[356] This option may entail removing previous repairs or replacing any missing or damages pieces with replacement ones. Finally, adaptation's objective is "to rework the stained glass window for a new installation."[357] In this case, glass may need to be added or taken out to fit the window to the new size or configuration. This may also involve preparing a window for museum display.

Cleaning Treatments

The conservator must find a way to deal with this complex combination of original structure, glass corrosion and paint loss. Rauch notes that "harsh cleaning methods are out of the question. Attempts to clean glass with sandpaper, steel wool, steel brushes, sponges, acid baths, or strong soapy water—all of which occurred in inexperienced workshops some years ago—are thankfully, for the most part, a thing of the past."[358]

First and foremost, the removal of surface deposits and dirt of all kinds is essential because, unless removed, it could destroy the original glass painting; in addition, before undertaking any cleaning, the paint material and techniques must be identified in order to carry out a proper restoration. Sadly, stained glass is often neglected in many places. Bacterial growth is permitted on the exterior of the windows and the interior sides are rarely cleaned and the atmosphere inside becomes gloomy instead of pleasant. The appearance of windows is substantially altered by a simple cleaning of a weak solution of ammonia applied with a soft brush and an overall washing with distilled water. However, these processes cannot be used on painted surfaces because both water and ammonia would remove

[356] Ibid.
[357] Ibid.
[358] Rauch, Ivo. "Handle with Care." 2010: 48.

pigment, tracing, and shading and worsen any existing conditions of paint loss or flaking.

Before undertaking any sort of cleaning, it is desired to expose the different layers of corrosion on the glass. Cleaning at various levels of intensity should be done and samples should be taken to perform further analysis and in order to find the boundary between the corrosion layer and the underlying gel layer. This gel layer is more chemically stable than the core glass and therefore, less susceptible to corrosion; however, too harsh a cleaning will result in increased corrosion in the future. One way to avoid this is to leave a thin layer of corrosion in situ. Restoration work is especially challenging when original paint lines sit on top of a corrosion layer; the paint becomes fragile and easy to detach and must be secured before any cleaning takes place. Unfortunately, it is also possible that paint detaches without being forced by a corrosion layer; these cases often involve enamel colors, which were fired onto the support glass. Stresses regularly occur in the paint structure due to the differing expansion coefficient of the support glass and the paint layer. The brittle support glass suffers from these stresses and the result is crystal-like flakes which are difficult to secure before cleaning.[359]

Restorative cleaning methods will vary. There are conservators who chemically remove corrosion with poultices and gel pads; cotton-wool poultices soaked in ethylenediaminetetraacetic acid (EDTA) are placed directly on the glass to loosen chalky surface crusts. On the other hand, with fragile paint, this proves to have significant disadvantages like the threatening of the already loose, damaged paint flakes. In cases like this, mechanical methods are often used instead. Many conservators work with cotton buds dipped in deionized water or chemical cleaning agents like ethanol to remove crusts layer by layer (Figure 59); soft brushes and scalpels are also used to remove these crusts where possible[360]. It is important to note that any one of these techniques can be dangerous to a stained glass window if performed by an inexperienced conservator.

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[359] Rauch, Ivo. "The Conservation and Restoration of Historical Stained and Painted Glass." 2004.
[360] Rauch, Ivo. "Handle with Care." 2010: 48-49.

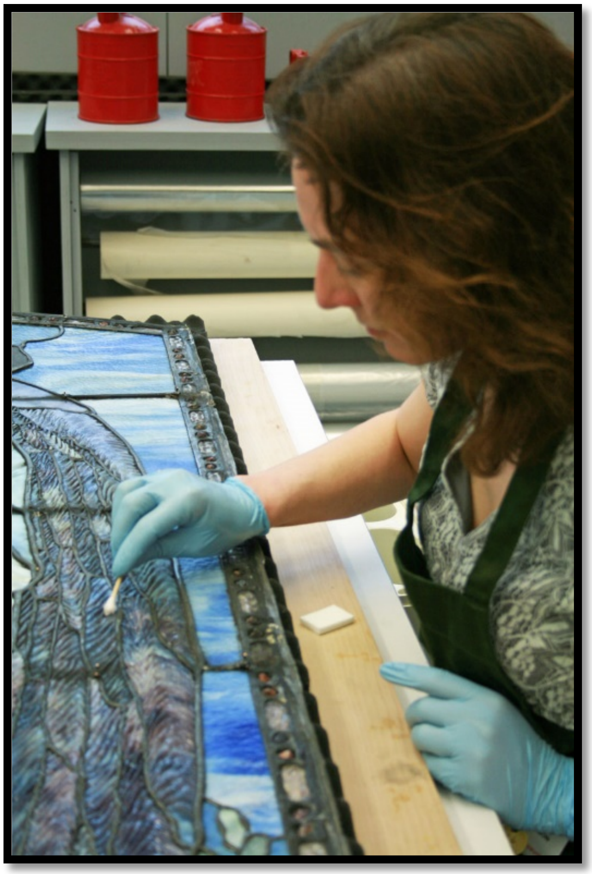

Figure 59. Cleaning with a cotton swab, one of the most common cleaning techniques. Image from http://episcopaldigitalnetwork.com/ens/2012/05/04/new-life-light-for-tiffany-windows/

In addition, various countries have different methods to clean stained glass. In England, they are using the micro-jet process which removes corrosion with regulated pressure. This technique uses softer materials like walnut shells, sodium hydrogen carbonate, and wheat flour. In France, they often use poultices or gel pads to remove corrosion. They are dipped in EDTA, an acid that loosens chalky crusts, and placed directly onto the glass surface. The pad can be removed or renewed and while this method can be used for focused cleaning, it is believed that such chemically cleaned surfaces corrode more swiftly. In addition, these methods endanger fragile painted glass. In Germany, cleaning is done using mechanical means, involving cotton buds and scalpels. This cleaning is done under the microscope and takes corrosion off in layers.[361] When performed by an inexperienced hand, any of these three restoration processes could have seriously damaging consequences to a panel.

R.G. Newton is correct when he writes that "*all methods of cleaning medieval painted glass* have, at some time and by some person, been shown to be potentially harmful to the glass."[362] Water is typically considered to be the safest cleaning method but even this has potentially damaging effects, especially to loose paint. For this reason, Newton observes that "the real key to the cleaning of delicate and poorly durable glass lies in the care which is exercised by a skillful and conscientious conservator."[363] Other than water, there are a number of cleaning techniques for stained glass windows that have been and currently are used. One of these is the ultrasonic bath, in which the individual pieces of glass are put into a wire basket and submerged into a bath of dilute ammonia; the steel bath is then powered by an ultrasonic generator for about three minutes. Glass that has flaking paint or over-painting should not be cleaned this way; it is also not recommended that enameled glass be cleaned this way either[364].

Other cleaning methods are mechanical in nature. For example, glass fibre brushes are often used effectively in removing hard weathering crusts in small areas at a time; this work must be done slowly and under a microscope so as to not damage the glass. Another method that succeeds in removing the very hard crusts is the air abrasive machine, which uses a jet of compressed air to propel the abrasive; this process is done within an enclosed chamber. The abrasives used range from very hard silicon carbide to very soft sodium bicarbonate and the selection depends on the nature of both the solid to be removed and the glass itself. It is also possible to use protective coatings like rubber latex to prevent the paint from damage during these cleanings. There are a number of ways to control air abrasive cleaning such that damage is minimized; the following changes can be made to the method

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361 Rauch, Ivo. "The Conservation and Restoration of Historical Stained and Painted Glass." 2004.
362 Newton, R.G. *Conservation of Glass*. 1989: 248.
363 Ibid.
364 Ibid.

according to the situation: the size and type of nozzle; the air pressure; the distance between the nozzle and the piece being cleaned; the duration of the bursts of the jet; and the sweeping or constant motion of the jet stream[365]. Mechanically speaking in general, scrapers and wire brushes should not ever be used due to the certainty of damage to the glass.

There are also various chemical cleaning methods used. Calgon and other detergents succeed in removing ions from the glass surface[366]. Surprisingly it has been said that hydrofluoric acid can also be used to clean glass; however, its negative effects are numerous, including dangerous to use, difficult to control, and leaving the glass susceptible to attack.

Another useful technique is resurfacing, which also removes hard and opaque crusts from the glass surface. If the glass is relatively flat and thick, the crust can be ground away with a metal wheel which is fed by "an aqueous slurry of carborundum powder…first with coarse grit, and then with a fine one."[367] Once the crusts are gone, the surface is polished and while this restores the glass's transparency, the glass composition remains unchanged and will therefore inevitably deteriorate again unless protected from rain and condensation. Another major downside of this technique is that not only is the original thickness of the glass ruined, but often the external painting and silver stain are lost as well. In fact, Newton concludes that "resurfacing cannot be recommended for use on medieval glass because of its destructive nature and non-reversibility."[368]

Consolidation Treatments

The 20th century saw the development of synthetic resins as conservation materials. These materials proved to be simply to apply and succeeded in edge-bonding glass fractures, adhering loose

[365] Newton, R.G. *Conservation of Glass*. 1989: 248-251.
[366] Ibid.
[367] Ibid.
[368] Ibid, 252.

paint, and more; however, it is important to realize that the synthetic materials were created for to be industrial adhesives or varnishes and therefore, their long-term effects on glass were not discussed[369].

There are a number of important "bonding agents" used in stained glass conservation today, each with its own pros and cons. Polyvinyl acetates are commonly used resins with low melting points and high adhesive strengths. While they are believed to not darken over time, they are susceptible to moisture which makes them weak as a protection layer. These resins are used as glue for plating and as paint consolidants, but unfortunately studies have shown that over time, the protective film cracks, flakes, and pulls away from the glass. On the other hand, because they do not lost solubility over time, polyvinyl acetates can be removed relatively easily with the proper solvents, including ethanol, ethyl acetate, etc.[370]

Polyacrylates are also durable resins used as bonding agents for paint but their adhesive qualities are inferior to the polyvinyl acetates. Paraloid B72 is perhaps the most widely used acrylic resin in the conservation field since the 1970s. It has proved to withstand the ultimate test—time. Used in the glass industry for paint consolidation, glass breaks, and protection for crazed glass, B72 has a durability that is shown in its lack of changing molecular structure despite exposure to light and weathering. In addition, its thermal qualities, physical qualities, and solubility all remain stable after natural weathering. Despite its common use, B72 has relatively poor adhesion to glass and depending on the glass's condition, the protective film will loosen and flake, especially in areas with tensile pressure. The film itself is vulnerable to attack from both rain and condensation which is why B72 is best used to stabilize paint after the installation of protective glazing[371].

In addition to the acrylic resins, epoxy resins are the most common artificial resin used in stained glass conservation. While epoxy resins are used predominantly for glass breaks, they are also

[369] Jagers; et al. "Conservation: Materials and Methods." 2000.
[370] Ibid.
[371] Ibid.

used to fix paint outlines. Their greatest advantage is their adhesive strength, which is better than both polyvinyl acrylates and acrylic resins, and their ability to adhere to the base glass layer. Their greatest disadvantage is their relatively poor durability due to their polarized molecular structure; this makes it easy for oxidation reactions to occur, causing the glass to turn brown or yellow and become more fragile. Two examples of epoxy resins are Araldite, of which a variety of types have been made and used for various purposes in the field, and HXTAL-NYL-1, the current recommendation for glass conservation[372].

The conditions of the conservation used from early restorations can be divided into two general groups. The first consists of those materials which have been affected by light, oxygen, and humidity over time and are now brown and brittle; this group includes epoxy resins. Failure of materials in this group were predominantly due to failed adhesion to the glass surface, including the most harmless of cases, where they simply pulled away from the surface alone, and the most harmful of cases, where they took complete layers of paint off with it. It is known that "both in the past and now, waxes, acrylic resins and, less commonly, silicium-organic products have been used to stabilize paint layers."[373] How waxes behave depends on the temperature—at low temperatures, they will crack and become brittle, while at high temperatures, they become soft. They are opaque and show no signs of yellowing. In terms of paint stabilization, a few new materials have been developed, including Silicium-Zircon-Alcoxide, or SZA, which has been tested successfully in preliminary studies, and sol-gel treatments[374]. B72, SZA, and these sol-get treatments will be discussed in detail shortly.

While it is recommended that loose paint be reattached to the glass panel before being removed from a site, it is often very difficult to do so due to the vertical position of the window, weather, accessibility difficulties, etc. The recommended treatment is a reversible adhesive with a low

[372] Ibid.
[373] Ibid.
[374] Ibid.

viscosity and surface tension. There have been a wide variety of techniques put forth for this issue, many bringing their own set of problems along with them. In 1971, use of silicone lacquers was dominant but by 1975 Viacryl was a very popular option. There was doubt about the reversibility of such processes with claims that loose paint could easily be lost in the solvents when applied; in response to this, it was recommended that a small amount of epoxy resin be added to the chosen adhesive in order to bring control to the reversibility of the process. Another option was to use Cyanolite, a hardened adhesive that could be removed with dimethyl formamide. In Germany in 1975, a solution of metal soap in oil and turpentine was being used; after being applied with a paint brush, the glass would be fired at 250° Celsius in an oxidizing environment. Piaflex solution was also used but the composition of this material is not known. At the end of the 20th century, techniques included beeswax, a mixture of paraffin wax and microcrystalline wax, and laser treatments[375].

There have been numerous surface coatings and paint treatments for stained glass that include organic polymers that were initially developed and used for industrial purposes; these include epoxies, polyvinylacetates, and acrylates. Many of these treatments have failed and even resulted in more damage by coming off the surface and hurting the paint further. Historically-speaking, one of the paint consolidants used in cathedrals was natural wax. Today, Paraloid B72 is considered to be one of the most common consolidants, with its reversibility being considered as a major advantage for its use; unfortunately, the long-term stability of the product is hindered by the inevitable exposure to the environment of the organic materials[376].

Consolidation of paint refers to two things—the recreation of the smooth quality of the paint layer and the re-attachment of the existing paint to the glass. The ideal paint consolidant would have the following qualities: ability to adhere to glass; low viscosity; ability to resist environmental, water, pollution and biological attacks; light stability and adhesion for at least a century; a coefficient of

[375] Newton, R.G. *Conservation of Glass*. 1989: 246-247.
[376] Carmona, Noemi; et al. "Consolidation of paint on stained glass windows." 2009: 404.

expansion identical to that of the glass and the glass paint; and reversibility. Every one of these qualities is difficult to achieve, proving to make the creation of this ideal consolidant impossible to create. Epoxies have proven to be the best choice for consolidants because of their ability to withstand most environmental forces and their resistance to heat. The main issues with epoxies are that they are easily affected by water, they have relatively limited light stability, and they expand more than both glass and glass paint[377]. Water damage is not a big of a concern providing that the paint is on the interior of the window; condensation, however, is still an issue to contend with. It has been noted that "twenty years is the maximum amount of time any adhesive presently used in glass conservation can be expected to remain clear."[378] For the more opaque trace lines, the yellowing or greying of the epoxy is often not a problem; however, where there is great amounts of matting and enamels used, the transmitted light will be greatly affected by this change in color[379].

As previously mentioned, one of the popular epoxies used is Paraloid B72, which is an ethyl methacrylate varnish used often in objects conservation. Usually sold as a solid, it must be dissolved in toluene, which is a toxic solvent and in the cases of very fragile paint, the B72 mixture is further dissolved in diethyl benzene so that it can be sprayed onto the glass instead of brushed. This spraying clearly offers the conservator much less control than if the epoxy was painted on. In addition, B72 does not resist weathering attacks and will be affected by both water and thermal changes. For these reasons, it is recommended that B72 not be used on single layer windows unless they are going into a controlled museum environment[380].

B72 has a very good resistance to weathering, however, its adhesion to the glass is decreased significantly when in wet, humid environments. In comparison, SZA, a much newer material still undergoing experimentation, is a material designed for powdery paint layers; this material is

[377] Sloan, Julie L. *Conservation of Stained Glass in America.* 1995: 178-180.
[378] Ibid.
[379] Ibid.
[380] Ibid.

recommended to be applied to the glass in highly dilute form and if applied too thickly, improper adhesion may take place. SZA is created as follows: silicium alkoxides and zirconium alkoxides are put through a hydrolysis-condensation process in order to create a pre-condensed reactive product—SZA; this is then applied to paint layers, combining with the moisture in the air and forming an inorganic gel. This inorganic gel can form stable bonds with the glass and after hardening, it becomes irreversible. One particular advantage of SZA is that it does not block the pores of the glass's paint layers, allowing for treatment with additional materials, like B72, without having to remove the SZA first[381].

B72 has a number of significant advantages. It is easy to handle, can be applied to very specific areas, and its viscosity can be changed without threatening its effectiveness. On the other hand, paint treated with B72 becomes noticeably darker and shinier. In comparison, SZA is not designed to glue paint layer pieces together, but rather to consolidate the paint's porous structure. Unlike B72, it is hard to manage in very specific areas due to its fluidity and is prone to run beyond the paint outlines if not careful. Where one application is generally enough with B72, several coats of SZA are needed, with a few days in between each one to allow for the best set. In addition, SZA has a shelf life of only six weeks. Perhaps one of the most notable pros of SZA is that it does not alter the paint's appearance when viewed in reflected light; this feature shows that SZA is the best material for application over wide areas than any other available consolidant[382].

In summary, both B72 and SZA are relatively successful in stabilizing failing paint on stained glass and the choice between the two depends on the nature of the damaged paint (Figure 60). B72 is particularly flexible in its use and has proven to be just as effective in stabilizing loose paint layers as it is for conserving flaking paint outlines. The article notes that "from a restoration point of view, SZA is particularly useful, since it effects practically no change to the surface of the glass; it is also inorganic

[381] Jagers; et al. "Conservation: Materials and Methods." 2000.
[382] Ibid.

and chemically very similar to glass."[383] On the other hand, SZA is unsuitable for all damage, including fixing paint that is already flaking away from the glass; however, it is ideal for helping poorly fired paint and washes and is used over wide areas of paint[384].

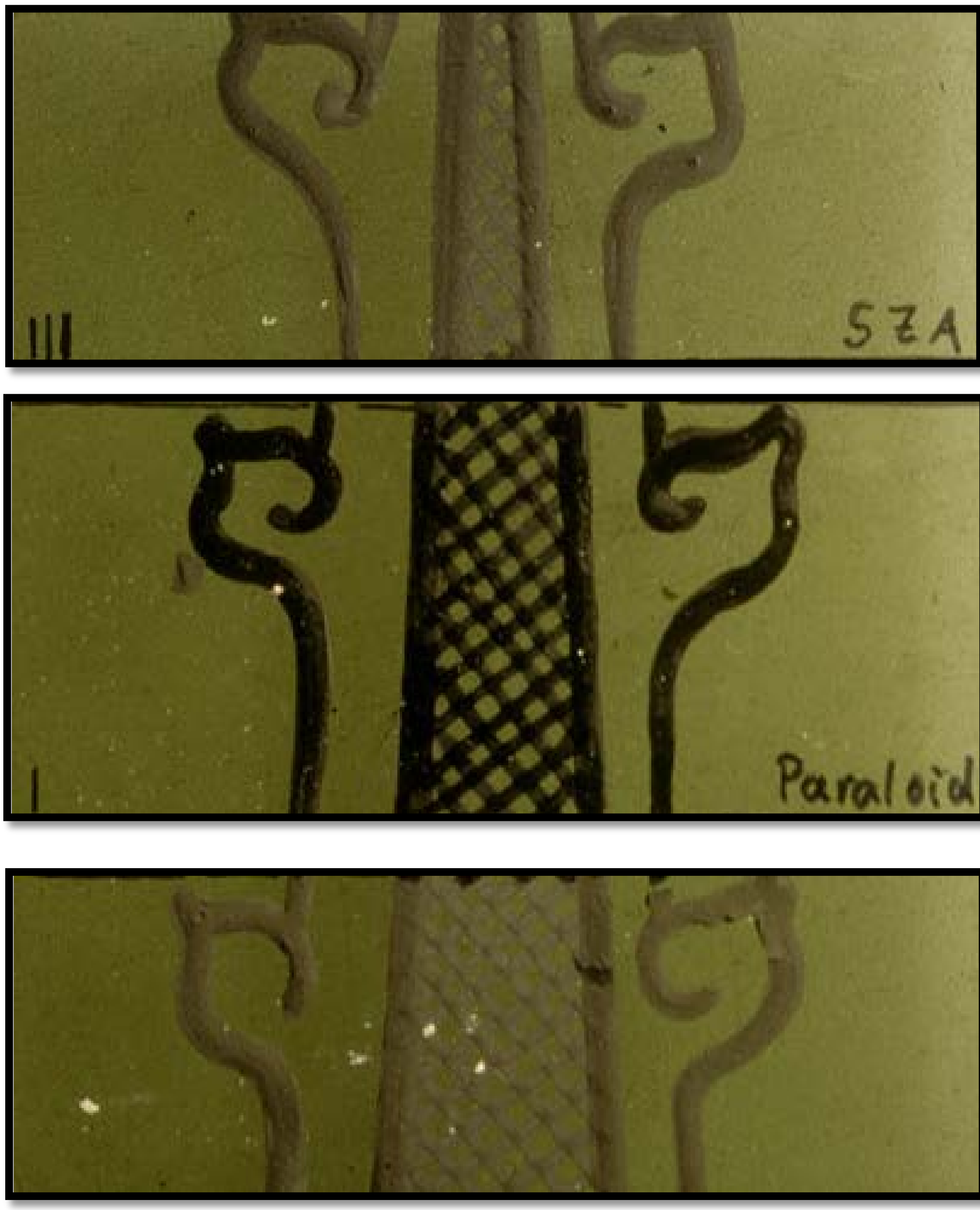

Figure 60. Paint consolidation tests with SZA and B72. Image from http://www.cvma.ac.uk/conserv/conservation.html

[383] Ibid.
[384] Ibid.

A sol-gel refers to a solution which gradually forms a gel-like network that is physically between a liquid and a solid state. Sol-gel treatments are some of the most recent consolidation treatments to be used with stained glass. Sol-gel methods and technology have clear advantages with the preparation of glassy matrices at low temperatures, including better chemical resistance, low viscosity, and adhesion to glass substrates. According to a recent article detailing new recipes for sol-gel consolidation treatments, "the sol-gel method allows the introduction of organic molecules inside an inorganic network, forming 'hybrids' with a broad variety in their composition and properties."[385]

According to a recent article from 2008, trials were done to assess how new sol-gel recipes performed as paint consolidants; it was concluded that they performed well in both alkaline and acid conditions. Consolidated and unconsolidated areas were exposed to extreme acid and alkaline conditions in order to ascertain how the sol-gel treatments would hold up. For acid conditions, it was found that some flakes came off the glass completely after approximately four months, but the consolidated areas were less deteriorated than those that were not consolidated, where paint was entirely lost. In addition, the adhesion of the Paraloid B72 under these acidic conditions was reduced, showing that this treatment may become inefficient under high humidity. The SZA treated samples, on the other hand, experienced some cracks after exposure to the acid but the paint adhesion remained stable; however, it is important to note that the efficiency of this treatment depends on the humidity in the atmosphere. For alkaline conditions, the painted samples with the new sol-gel treatments showed no signs of corrosion or any visual change[386].

The study of the sol-gel consolidants draws the following generic conclusions:

> The three new consolidants fulfil the main requirements demanded for a paint consolidant. They are transparent and colourless, causing no visual impact on the paint or the glass. Their low viscosities allow a good penetration in the porous structure of the

[385] Carmona, Noemi; et al. "Consolidation of paint on stained glass windows." 2009: 405.
[386] Ibid, 407.

> paint. They should be applied and dried at ambient conditions. They improve the adhesion of the paint itself and with the glass substrate.[387]

After these general results, the more detailed results based on the different compositions of the sol-gel methods showed the following: "the new consolidants are not reversible, but re-treatments are not restricted, if necessary, during a following restoration campaign."[388]

According to a recent article from 2008 on paint consolidation,

> the main requirements for a good paint consolidant are the following: it needs to penetrate well into the porous structure of the paint; the material should improve the cohesion of the paint itself and the adhesion to the glass substrate; a reasonable stability of the solution is necessary before application (storage conditions) and a long-term resistance to degradation is essential after application of the material; the application should have a minimal visual impact on the aesthetic value of the paint or the glass around or below the paint.[389]

In terms of expansion, epoxies are a plastic material and will therefore expand more than the glass and glass paint; this additional expansion can not only add to the existing tension of the paint, but also accelerate the loss of paint. But it is reversibility is perhaps the most difficult quality of any consolidant to achieve due to the simple fact that no matter which material is used, any attempts to remove adhesive will inevitably remove paint as well. In general, most in the field like to use paint consolidation treatments for their reversibility; however, another way to think of treatments is based on their ability to allow for additional or further treatments. The important fact to recognize is that "all of the commercial products used until now as consolidants have some drawbacks."[390] In addition, even the commonly used B72, known for its supposed reversibility has its issues. The testing of the reversibility of B72 has shown that the loose paint that had been consolidated will inevitably come off with any attempts to remove the consolidant; therefore, it can be stated that no consolidation treatment is

[387] Ibid, 408.
[388] Ibid, 409.
[389] Ibid.
[390] Ibid.

technical reversible. There are exceptions that are made though and consolidants are sometimes used in some drastic cases where the paint is at the point where it could be lost completely; in these circumstances, the issue becomes an ethical question—is it better to lost paint now or to risk loss in the future with a paint consolidant? Sloan reminds us of the sad truth: "There is no perfect way to either halt the deterioration or to re-adhere the paint…The reality is a difficult one to accept: that in this space age when we can put men on the moon…we have to make the choice of losing glass paint now or later, resigned to the fact that we must lose it in any event. The problem is ubiquitous, and is increasing."[391]

Replacements and Previous Restorations

Replacements in general should not be done unless absolutely necessary, simply because the replacement is not the original (Figure 61); it is much better to attempt to salvage the existing piece with paint loss than to try to recreate an entirely new piece; that being said, if the original has been lost entirely, then replacement is a viable option when done properly. Restorers are constantly faced with the question of how to deal with previous attempts at repair and how to carry out their own restorations. Aesthetically speaking, any earlier, incoherent additions should be removed entirely so long as it can be done without damaging the window. The situation becomes more difficult when dealing with synthetic and artificial resins. Replacements are yet another issue to contend with. Often times, replacement pieces are indistinguishable from the originals; however, with time, these additions are inevitably revealed as they will deteriorate differently from the originals.

[391] Sloan, Julie L. *Conservation of Stained Glass in America.* 1995: 172.

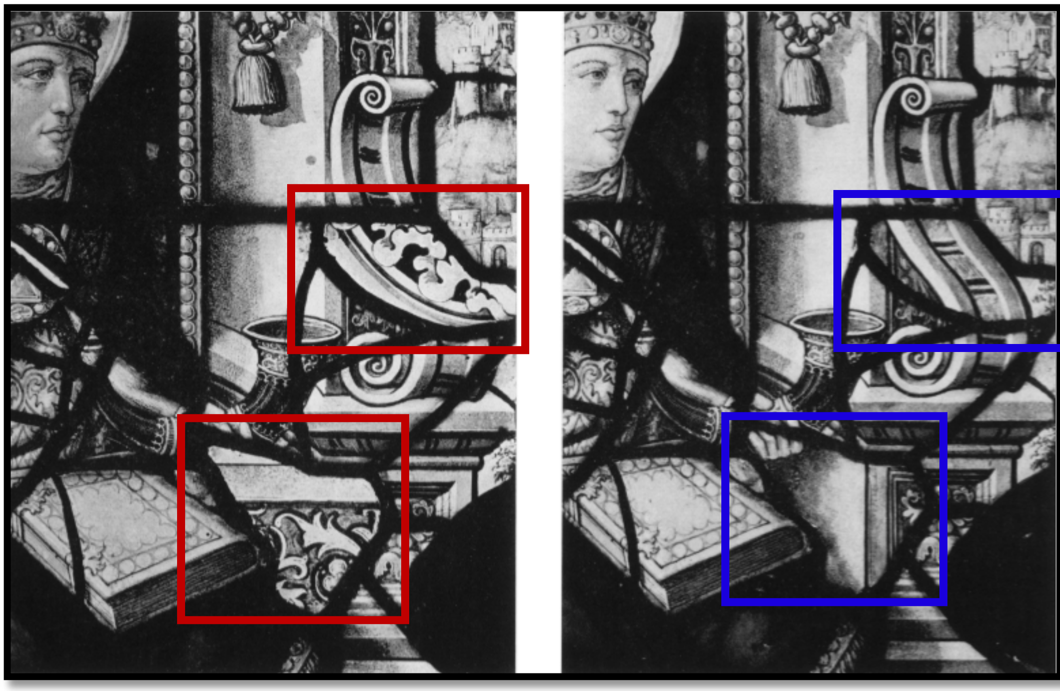

Figure 61. An example of poor replacements incompatible with the original window. Image from Lowe, William. "The Conservation of Stained Glass." 1960.

Opinions vary when dealing with the question of restoring missing areas of the stained glass windows. Some come from a historical standpoint, saying that it is better to fill the missing areas with plain glass instead of making a copy of the original. Others would prefer that the introduction of new glass imitating the original design where the glass is cracked or marred by corrosion. In addition, there are those who consider the restorer to be the enemy of stained glass because the works have undergone irreparable wrongs in the name of preservation. Then there are still others who say that reproduction, so long as it is understood to be a reproduction, is acceptable. In his article, "The Conservation of Stained Glass," William Lowe seeks a compromise by stating that where a piece of glass is missing, it should be replaced with a piece matching in both technique and style so long as it conforms to the following three criteria: (1) that it is agreed that the missing piece destroys the design of the window and an unpainted replacement is visually disruptive; (2) that the details of the missing piece can be determined by and matched to the existing original pieces of the panel; and (3) that the new glass is initialed and dated on the back using a diamond pencil or photographs are taken to avoid confusion as to what is new and what is original.[392]

When a new piece of glass is needed, one must be very careful in selecting the correct color and tint. There is a huge variety available, although there has been some loss of range from the standardization of production thus eliminating some of the beautiful accidental effects caused by impure chemicals. Tracing line colors vary according to the time period, from black to dark brown to red-purple and were created using iron or copper oxides. The style of the tracing depends on the medium used.

In order to learn the different ways to paint replacement pieces, the original glass was examined. According to Sebastian Strobl, the glass painters of the Middle Ages would follow the original outlines and remaining details on the damaged glass, but they usually did not reproduce the originals exactly; the replacements created were more based on the styles of the times during which the repairs were being done rather than the styles of the original glass[393]. In many later restorations, these early replacements were replaced again to create a more uniform window overall; these decisions are very questionable considering that the early restorations were an important part of the window's history.

When it comes to replacements, what is important is to not try to pass off a replacement piece for an original piece. While a complete aesthetic is one of the most important goals, a conservator should seek to do so as authentically as possible. York Minster Cathedral has come up with a good solution to this issue by creating replacement pieces that are lightly scored with diagonal lines (Figure 62); not only does this differentiate the replacements from the originals, but it provides a complete design as well. Techniques like this one allow for a very good solution to a prominent issue in stained glass conservation, both aesthetically and technically.

[392] Lowe, William. "The Conservation of Stained Glass." 1960: 146.
[393] Strobl, Sebastian. "From Plumber to Glazier." 2010: 36.

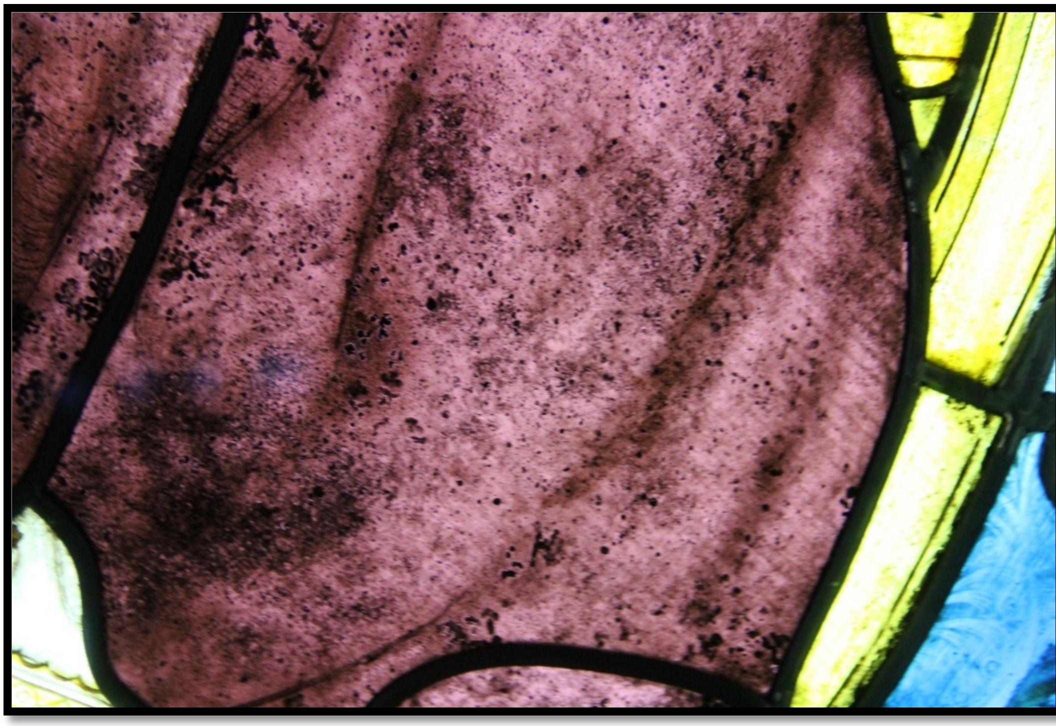

Figure 62. Replacement piece with scored lines from York Minster Cathedral, England. Image from personal collection.

Plating

The first way that a missing detail can be recreated is by finding its shadow. Documentary evidence may exist, like photographs or written descriptions, which must be considered but not taken as the final word; again, any number of undocumented changes could have taken place that the pictures or descriptions do not show or discuss. Physical evidence is more accurate than documentary evidence. Fired paints will typically leave a shadow on the glass surface, which works well for trace lines but not usually for lost matts. Enamels may not leave a shadow at all and while the shadow will show the location and shape of the lost lines, it leaves no indication as to the paint's color, how many layers of paint there were, and the location of paint layers that may have been on top of the lost layer(s)[394].

Finding the shadow is not as easy as it sounds. Often, shadows will only be visible from the side of the piece and thus, making an accurate recording of it will be difficult. In addition, ultraviolet light

[394] Sloan, Julie L. *Conservation of Stained Glass in America.* 1995: 174.

may help depending on the type of paints used. There are also other techniques possible providing that the glass and remaining paint are stable. For example, lamp black or a fine and powdery substance can be dusted onto the glass surface in the hopes that any tooth from the shadow will trap some of it and show the missing design[395].

One of the most important principles in the field is that original stained glass is never to be repainted. That piece is essential to the inherent authenticity of the original window and it is not to be touched so as not to lose its integrity and to not cause further damage. In addition, re-firing original glass is forbidden as well because it can bring harm to both the glass and the paint, not to mention alter the visual qualities of the original glass. Due to these principles, a technique called plating is often used where a new, separate piece of clear glass is painted with the missing parts of the design and plated in front of or behind the original glass. The result is that when both pieces are looked at together, they appear to be a single piece of glass with a complete design. When painting such pieces, the artist must consider the visual effects of parallax; Sloan describes it as “the phenomenon of a visual change of position of the viewed object caused by the viewer’s change of position.”[396] From certain angles, the thickness of the glass can cause the two layers of paint decoration to be misaligned with one another. The easiest way to best resolve this issue is to have the surface of the new glass with the painted design closest to the original glass; this way, the visual distortion will be decreased because the distance between the new paint and the original paint will be less[397].

If the new plate will be exposed to weathering, then the paint should be fired; however, if not, cold paint can be used as well. Color-wise, it is important to have a coherent visual image; that being said, the colors of the new paint do not necessarily have to exactly match the originals depending on the tinted color of the glass. If the original glass is textured or warped in some way, the new plate must be

[395] Ibid.
[396] Ibid, 176.
[397] Ibid, 175-176.

created to fit it accordingly; a plaster mold can be made of the original glass so that the new plates can be made from this. An important note on this process is that these plates should be scribed with the artist's initials, the studio's initials, and the date so that future restorers will clearly know that this not an original piece; this is often placed near the edge of the glass piece where it can be easily covered with the flange of the lead and is done after the firing. Finally, attaching this plate to the original can be done in two different ways—one, it can be attached in its own cames as a separate plate or two, it can be attached directly to the original plate, requiring only one came for both. For this second option, it is often recommended that the edges of the plates be sealed to prevent any moisture or dirt from entering any spaces between them; this is typically done with copper foil or silicone[398].

In the cases where the legibility of faces and hands are a significant concern in the restoration of the window, plating is often utilized. Back-plates, which are typically attached behind the original glass, are painted with the missing paint from the original glass; this technique is accepted by the majority of the field because it leaves the original paint untouched. While it can be hard to choose how much or how little to paint because of the overall loss, imaging technology has allowed conservators to recreate the figures' faces and hands without risking changing the artist's original imagery (Figure 63). The process is described as follows:

> place [the pieces] in a photographic scanner and obtain a full-scale image. A one-to-one digital copy was then available to manipulate on the computer. Using Adobe Photoshop, a negative of the scan was generated thus making visible most of the missing tracelines and shadow matting that had been lost from the original. This negative was superimposed onto the positive to form a combined image in which the features were now becoming more distinct. The contrast and highlights were then adapted in such a way as to produce a visibly accurate, albeit monotone, representation of the original painting. Using this digital image as a guide, glass artist…painted only the areas of loss on a piece of glass that had been cut and slump molded in a kiln to match the outline and undulating profile of the original glass. Only the details of losses to the original painting were painted on the backplate, in essence filling missing tracelines as well as

[398] Ibid, 177-178.

> some of the matting. The paint was fired; the backplate was placed behind the original and sealed around the edges with an inert silicone adhesive.[399]

Figure 63. Example of this scanning technique to complete a restoration. Image courtesy of Drew Anderson.

According to the conservators:

> not only were the generated images an invaluable guide for reproduction of the backplates, they also document, with considerable accuracy, how the faces were originally intended to appear. This method of reconstruction prevented any undue interpretation on the part of the conservator and insured that the final image was faithful to the artist's intention. It is completely reversible, the original is intact, and we have used what is essentially the original face as the model.[400]

This technique is relatively new and not utilized as often as it could be; it is a safe and successful way to deal with paint loss on these fragile stained glass windows.

Back-plating satisfies the moral dilemmas of paint restoration because it does not disturb the original glass or paint but still manages to complete the visual of the original window. Even though this seems to be one of the best conservation practices for lost paint on stained glass, there are still a

[399] Anderson, Drew; et al. "Rediscovering Henry E. Sharp." 2010: 89.
[400] Ibid.

number of concerns. For example, if the seal between the plate and the original glass is broken, then it opens up space for moisture to become trapped and cause damage. Also, the weight of the back plate can be potentially dangerous if it is too large; thin glass, about 1 mm, will allow for an additional weight to be negligible. In addition, back plating is not particularly suited for colored glass, as it is difficult to see the new paint through a lot of colors; for this reason, front plating can be used in these cases, although additional potential damage to already damaged paint layers on the front side of the original glass must be considered. Lastly, the back plate must be secured within a lead. It can be done with an extra-wide came but this would require the window, or at least major parts of it, to be re-leaded; this process is irreversible. It is also possible to lead the plate individually and attach it with solder it to the original leads; the down side to this is the additional weight of the new glass and leads to the window, which could prove to affect the strength of the window[401]. Despite these issues, the use of plates is perhaps the most successful conservation technique in terms of paint restoration today.

Over-painting and Cold Paint

Re-painting and re-firing the glass are very dangerous to the original windows and often destroy them; however, surprisingly these techniques are still used in restorations. Often, re-firing glass that has been repainted not only results in the loss of the new painting, but also a loss of the original paint layers beneath as well. It is another irreversible treatment and ethically is considered wrong. In addition, another concern is that any dirt or weathering crusts that were not cleaned will be sealed into the glass, leading to unavoidable deterioration[402]. This massive loss of paint leaves the window as a ghost of what it once was.

Over-painting is another issue dealt with in the restoration process. This was done with oil and

[401] Gilchrist, Alison. "The tears wept by our windows." 2010: 110-111.
[402] Newton, R.G. *Conservation of Glass*. 1989: 257.

tar-based paints and was common in the 19th and early 20th centuries. Over time, this over-painting has become black and has started to come loose, taking original paint off from the glass with it (Figure 64). Removing over-painting is a controversial topic. First, it must be confirmed that the unfired painting layers are not retouchings done by the artist himself; this would warrant that they never be removed. If the over-painting is compromising the historical paint layers beneath it, then the binding agent between the two should be identified; then the over-painting can be removed one layer at a time without damaging the original underneath.[403]

Figure 64. Loss of over-painting lines. Image from http://www.cvma.ac.uk/conserv/rauch.html

The technique of cold painting dates all the way back to the ancient Romans. Because it does not have the durability found with fired paints, it is easy to rub off and be lost and is therefore

[403] Rauch, Ivo. "The Conservation and Restoration of Historical Stained and Painted Glass." 2004.

considered a poor form of decoration. Cold painting is the application of oil or lacquer paints directly to the surface of the glass without firing. The best way to utilize the cold paint is to apply it to the back surface of the glass and protect it with a layer of varnish, metal foil, or a sheet of glass. Before the invention of larger kilns, glass that was too large to fit inside the existing kilns was often painted with cold paint because it was physically incapable of being fired properly; in addition, it was done by anyone who did not have access to or could not afford the necessary kiln[404].

During the 19th century, cold paint, or unfired paint, was applied for some restorations instead of fired paint. For the most part, cold paint has been considered by many restorers as a later addition meant as a quick repair; for this reason, many windows have had their cold paint removed. Because cold paint has been identified on an increasing number of late 19th century windows in America, this restoration view is finally being reconsidered. Sloan writes that "in examining some of these windows, new conclusions about the origins and importance of cold paint have been drawn, leading to the theory that much of it was applied by the artists or craftsmen who created the windows, although for what reason we may not yet be able to discern. Nevertheless, if it is an original part of the window, it must be preserved."[405]

Cold paints can be anything from oil paints, with linseed oil binders and organic pigments, to water-based paints, like acrylics. While initially the overall design was seamless and the newly-painted glass could not be distinguished from the original, within a mere few decades, the repairs were almost completely gone. Keith Barley, author of "A History of Protective Glazing," notes that conventional glass paint mixed with water or gum arabic, Paraloid B-72 or acrylic paints can all be used as pigments for cold painting[406]. While in general cold paint is more fragile than fired paint, many examples of cold paint from 19th century windows has survived. A lot of times, cold paint is found between layers of plating

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[404] Newton, R.G. *Conservation of Glass.* 1989: 86.
[405] Sloan, Julie L. *Conservation of Stained Glass in America*. 1995: 160.
[406] Barley, Keith. "A History of Protective Glazing." 2010: 114.

which served to protect them from weathering and the environment. In addition, cold paints used with linseed oil, which is waterproof, resulted in relatively durable films that protected the paint. The washing and cleaning of windows is the primary cause of cold paint loss. Most cleaning agents will dissolve paint, not to mention the intensity of scrubbing will definitely affect the amount of paint lost.

In terms of conservation, cold paint cannot always be easily identified on a stained glass window. Sometimes it will fluoresce under ultraviolet light, which fired paint will not. Once it has been removed from the glass, there is no remaining trace of cold paint, which proves to be an extremely difficult conservation issue. Without accurate documentation, there is no way to know the location, color, and amount of cold paint that was lost; therefore, recreation is next to impossible. In summary, "in no instance can these be measured against the longevity of fired paint. At their worst, nonfired paints will wash off. At their best, they will be almost impervious to nay outside influence, except a considerable amount of scrubbing."[407]

It is worth noting that using cold paint adds no additional weight to the window overall and large sections of the window can be treated at a time without a great amount of intervention. Ultimately, this technique is not reversible; if the cold paint is painted over already fragile paint, then it is guaranteed to suffer additional damage if there are attempts to remove the cold paint. In addition, one of the biggest issues with cold paint is documentation. Because cold painting is done on the original glass, it is impossible to create a signature of sorts to document which paint is new; the only evidence of the new paint additions will be before and after photographs of the glass[408].

[407] Isenberg, Anita and Seymour. *How to Work in Stained Glass.* 1983: 192.
[408] Gilchrist, Alison. "The tears wept by our windows." 2010: 111.

Protective Glazing

Once a window has been conserved, providing further protection is another issue entirely. Dangers come in all shapes and sizes ranging from mechanical damage, including vandalism, rocks, ladders, tree branches, etc., to weathering and micro-organisms, including rainwater, condensation, algae and mosses. One recommendation is the installation of wire-mesh guards made of copper, galvanized iron, or stainless steel (Figure 65). Copper will not rust but will result in green patina-stains and while stainless steel will not corrode, it is very expensive. These guards are unpleasant to look at and disturb the beauty and light transmission of the windows; however, if they are used it is recommended that they be installed individually on each window for aesthetic purposes. Other than the wire-mesh, glass or plastic sheets are also used for protection. Although expensive, these sheets will protect the glass from any thrown projectiles or weather damage. Another downside is that these sheets result in glaring reflections and hide the true texture of the stained glass. Acrylate sheet, including Perspex and Oroglas, are known for good impact resistance but they scratch easily. In comparison, polycarbonate sheets like Lexan are strong and easy to install but are affected by weathering. Laminated glass, composed of interlayers of poly are both bullet and thief-proof but it is heavy and expensive. Finally, Georgian wired glass can be broken but the embedded wire mesh prevents them from falling out; while not expensive comparatively, it is visually distracting to the stained glass[409].

[409] Newton, R.G. *Conservation of Glass*. 1989: 266-267.

Figure 65. Wire guards used to protect stained glass windows. Image from http://www.abbeystainedglass.co.uk/protection/wire-guards

Water is perhaps the most dangerous threat to a stained glass window. Not only does it cause deterioration of the glass, but it also leads to the weathering of the paint layers and corrosion of the lead. A window in general serves both an aesthetic and functional purpose, or in other words, it is a means of protecting an interior from the elements while allowing light and a view to the outside. While wire meshes will not help to protect from water damage, protective glazing is often used to protect the window from the rain and pollution outside it. The process works as follows: first, the protective panel takes the place of the original leaded glazing. A supporting structure is mounted on the existing iron support system, extending into the interior of the space; it is here that the original leaded glazing is installed, with a distance between it and the protective panel. Ventilation of this space between the two panels is crucial, otherwise moisture will inevitably collect there and cause severe damage. Protective glazing can greatly reduce damage to these historic windows and has the added benefit of limiting restorations to a minimum because the painted glass no longer needs to enclose the space now that the protective glazing is doing so. However, problems can arise with the installation of exterior protective glazing because it involves altering the building's architectural structure.

It is important to recognize that these panels as an architectural feature which will have an effect on the exterior of the building so the selection of the framing and materials should be chosen accordingly. Viggo Rambusch, author of "Preservation and Restoration of Leaded Glass Windows," writes that "the framing for the protection glass should be compatible with the wall opening in the building, both in color and structure, with its members following the original framing. In general, the protection glass should be kept as unobtrusive as possible; from the stained glass point of view, it would be best if it were not there."[410] The pros of using protective glazing, however, are significant; Alison Gilchrist writes that "The glass is protected in several ways; firstly, by removing its function as the external 'skin' of the building, so that it is no longer exposed to wind and rain; secondly, by reducing (or removing) the likelihood of condensation forming on its inner face; and thirdly, by reducing the thermal stress of the daily temperature cycle."[411]

Protective glazing systems are an interesting debate when it comes to stained glass windows. When they are installed correctly, they not only have the ability to protect and increase the lifespan of the historic stained glass but also the potential to decrease the energy requirements of the building in which the window resides. On the other hand, if the installation is not done properly, the risks are both

[410] Rambusch, Viggo B.A. "Preservation and Restoration of Leaded Glass Windows." 1981: 16.
[411] Gilchrist, Alison. "The tears wept by our windows." 2010: 103.

aesthetic, diminishing the window's beauty, and structural, causing issues such as condensation and additional stresses to the window frame. According to the Owner's Guide produced by the Census of Stained Glass Windows in America, the best form of protective glazing is one that finds a compromise among the importance of protection, aesthetics, and cost.

There are three main types of glazing systems. The first is leaded panels, which either duplicate the most prominent leads of the original window design or are composed of a geometric design meant to both protect the original glass from the elements and serve as an aesthetic improvement to the exterior of the building (Figures 66 and 67). While these are aesthetically the best option, they are also the most expensive and are open to vandalism attacks. The second type is laminated or tempered glass. It is not unpleasant aesthetically but it is not as attractive as the leaded panels; in addition, the protection from vandalism is better with this option. The third option is to use either acrylics or polycarbonates. This method offers the strongest protection from vandalism and other attacks made on the glass. Unfortunately, it also has a high co-efficient of expansion which, if the window if not installed properly, could cause great strain on the original window frame. Both materials will bow and are susceptible to scratching. Acrylics in particular will deteriorate from ultraviolet radiation, often resulting in a cloudy surface and decreased breakage resistance. On the positive side, polycarbonates are technically crack-proof[412].

[412] *Conservation and restoration of stained glass: an owner's guide.* 1988: 30.

Figure 66. Quarry pattern protective glazing on York Minster Cathedral. Image from personal collection.

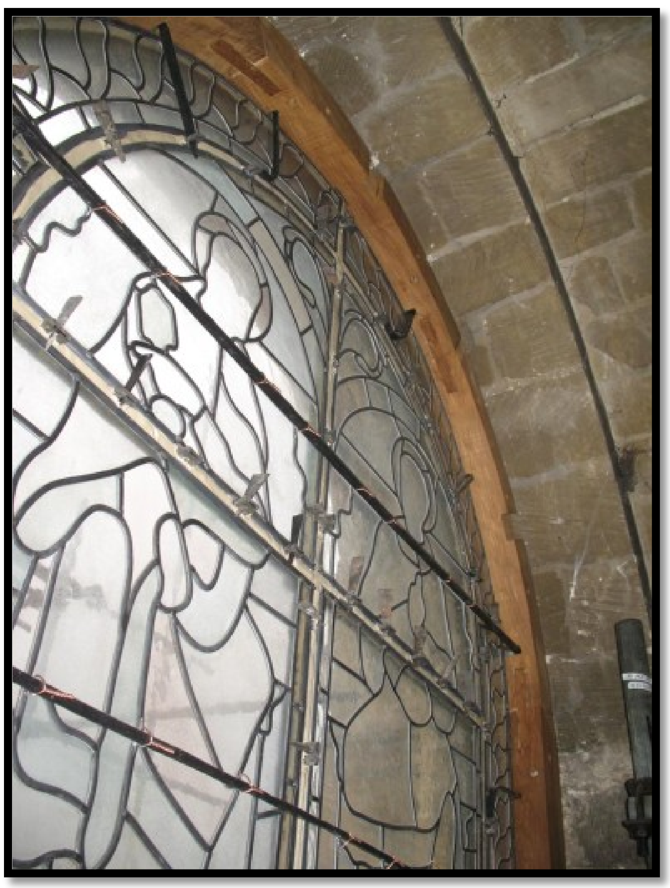

Figure 67. Protective glazing done with the major lead lines of the window for better aesthetics. Image from http://vidimus.org/issues/issue-27/news/

In addition, protective glazing can be unventilated, internally ventilated, also known as isothermal glazing, or externally ventilated. Unventilated protective glazing has been used for over 130 years[413]. Large glass plates are inserted into iron frames, which ultimately rusted causing the plates to fall out. Both isothermal glazing and externally ventilated glazing involve an interspace between the original glass and the protective glass sheet that requires ventilation in order to inhibit condensation and promote evaporation of any rainwater which manages to enter the space. In these situations, there are four glass faces to deal with. The first is the outer surface of the protection glass which will remain exposed to the weather, water, rocks, etc.; this is made of replaceable modern glass for this reason. The second face is the inner surface of the protection glass. When it is cold, condensation is likely to form on this face but often evaporates quickly during the day. The third face is the outer surface of the original glass, which faces the inner surface of the protection glass. This surface may include painted decoration of some kind and so condensation should be avoided. The final face is the inner surface of the original glass which faces the interior of the building; this is where the paint work will be and protection from condensation is a necessity.

The air used for ventilation can come from inside or outside the building and by measuring the temperature and relative humidity of both the interior and exterior, it can be determined where the condensation will occur in the glazing system. Ideally, the temperature of both faces of the original glass should be kept close to the same so that condensation on the painted faces will be rare. Isothermal glazing in particular was designed such that it is meant to provide conditions that are similar to a museum setting. The main issue with this glazing system is the rehanging of the medieval glass inside the building and then finding a way to fit the modern window into the glazing groove. If the protection glass is placed on the outside, the original glass does not have to be disturbed and ventilation can come from the air outside the building. Early examples of both isothermal glazing and external

[413] Newton, R.G. *Conservation of Glass*. 1989: 267.

ventilation were done using large flat glass, causing disruptive reflections. For the purposes of external ventilation, the lead lines of the protection glass should mimic the original, or at least give the impression of the painted glass it is protecting[414].

The Owner's Guide also includes a list of "Do Not's" when it comes to protective glazing. The list reads as follows:

> 1. DO NOT install without proper weep-holes and venting.
> 2. DO NOT expect the installation of protective glazing to obviate the need for a proper restoration program.
> 3. DO NOT screw fasten acrylics or polycarbonates to existing framework unless special installation details are specified to allow for the expansion and contraction of these materials.
> 4. DO NOT destroy the aesthetic beauty of the exterior in order to protect the stained glass.[415]

External protective glazing has been used throughout Europe and in the U.S. for more than a century. Three early examples include (1) Tattershall Church in Lincolnshire, ca. 1804; (2) York Minster, ca. 1861-62; and (3) St. Patrick's Cathedral, ca. 1859. Keith Barley writes in his article "A History of Protective Glazing" that "the exceptionally good condition of the paint found at these sites demonstrates the historic benefits of protective glazing when compared with similar, unprotected glass from the same time periods."[416] In terms of paint loss, it has been found that after monitoring the performance of internally ventilated systems, the environment for the outer face of the stained glass is stable enough to use cold painting to repair lost paint[417].

Barley recognizes a number of general statements when it comes to using protective glazing. Any unventilated method of protection is going to be harmful to the window and any glazing treatment that allows the window to breathe is better than one that does not. Internally ventilated systems, or

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[414] Ibid, 268-272.
[415] *Conservation and restoration of stained glass: an owner's guide.* 1988: 31.
[416] Barley, Keith. "A History of Protective Glazing." 2010: 112.
[417] Ibid, 111-114.

isothermal glazing, have proven to be better than externally ventilated ones, especially in protecting susceptible and unstable paintings. He writes that:

> isothermal glazing systems allow the air within a building to pass freely over both faces of the stained glass. The air, being of equal temperature on both sides, keeps the glass dry in as near museum conditions as can be achieved within an historic architectural setting. Isothermal glazing systems have proven to be the most effective method of preventive conservation currently at our disposal.[418]

These systems are also noted to protect against weathering and air pollutants which would otherwise increase the deterioration of both the glass and the paint.

In his article, Barley advocates for the internally ventilated systems and explains the needs if it is to work effectively. First, the outer glazing must be waterproof and sealed; it resists mechanical damage as well and uses laminated glass, toughened glass, or stainless-steel guards. Small gaps must be included to the base sections in order to allow for drainage of condensation from the outer glazing; ventilation gaps are also needed at the base and the top of the stained glass lights in order to allow for the circulation of internal air. In these cases, a larger gap at the bottom of the window and a smaller one at the top provides a chimney effect that reinforced the necessary circulation. All materials used are durable and are compatible with the inherent fabric of the existing building. The systems are designed such that removing the panels is easy if needed and flexibility is designed with the fixings in order to allow for the expansion and contraction of the window[419].

Developments in protective glazing are continuing to be explored even today. Perhaps the most recent innovation in the field is the introduction of glass with built-in UV protection. Lamberts mouth-blown cylinder glass with a layer of titanium oxide is currently being used for the glazing system of the Great East Window at York Minster Cathedral in York, England. The layer of titanium oxide is designed to filter the UV-rays from the sun in the isothermal glazing system. While it is a very expensive option,

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[418] Ibid, 115.
[419] Ibid, 115-117.

selecting it guarantees the protection of the newly-restored windows for centuries, even protecting resin fills from discoloring. According to the material's data sheet, "LambertsGlas restauro-UV": "protects art objects and historic interior...filters daylight and protects against UV-rays below 400nm…is the only UV-protection glass where the filter effect is directly integrated. There is no film, no coating, no lamination…is manufactured as…cylinder glass according to traditional manufacturing methods. Therefore it is perfect for time honored buildings."[420] Although this material is relatively new to the field, its design and proven qualities highly promote its use for many stained glass window restorations to come.

With all of these factors in mind, protective glazing can be a very effective means of protecting stained glass windows. However, it is essential to understand that "in each case, the protective glazing system must be designed for the specific technical, architectural, spatial, and aesthetic requirements of the site in question. There is no 'one size fits all' formula; every object and every site requires an individualized approach."[421]

Despite all of the hard work that has already been done, it is essential to recognize that "the survival of the works of medieval glass-painters will depend on the skill and the craftsmanship of today's conservators."[422] The complexities of the damage to historical stained glass windows require extensive research for each restoration case. It helps to have several specialists in different areas giving input to the conservation method. The client, the "expert" in the field, and the restoration workshop should all work closely together in each situation. According to David Lawrence, author of "The Care of Stained Glass," the underlying principle of conservation is that of minimal intervention. He writes that this

[420] Glashuette Lamberts. *LambertsGlas restauro-UV*. 2014.
[421] Rauch, Ivo. "Handle with Care." 2010: 51.
[422] Brown, Sarah. *Glass-Painters*. 1991: 70.

principle "aims to respect and retain existing fabric and intervene only when absolutely necessary."[423] Ivo Rauch writes that:

> this means that whenever possible, when a stained-glass composition comes to the conservator, all its elements, including glass, pigment layers, lead, and framing, must still be present after the treatment. Strict observance of this principle is absolutely necessary for conserving, not only the physical bod of an object, but its history and aura. All interventions by the conservator must be reversible, including material such as adhesives or supports.[424]

There is also the issue of unnecessary work which comes from people worrying about the condition of these historic stained glass windows. In almost all cases, a window is not about to fall out of its place; rarely is there a real sense of urgency and owners or those responsible for the windows should take their time in order to hire a qualified conservator. It is safe to say that today, stained glass preservation techniques are predominantly preventative in nature. Sebastian Strobl says it best when he writes:

> Today, everything seems possible, from the faithful reconstruction of a lost window to the equally debatable approach of 'let's do nothing and fill the hole with a blank.' History has shown, all too clearly and sometimes painfully, that binding guidelines for the reconstruction, completion, and restoration of stained-glass windows cannot and should not be established…restoration in the true sense of the word requires much artistic courage, technical skill, and a critical awareness of style in order to avoid repeating the mistakes of the nineteenth century. Sympathetic restoration, which differs from case to case, is possible as long as the extremes at both ends of the scale are avoided. Learning from the past and turning this knowledge into awareness is essential and will help to do our cultural heritage justice.[425]

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[423] Lawrence, David. "The Care of Stained Glass." 1.
[424] Rauch, Ivo. "Handle with Care." 2010: 47.
[425] Strobl, Sebastian. "From Plumber to Glazier." 2010: 42.

VIII. Conclusion

Could we see some of the abbeys as they appeared in the fifteenth century…with each window glowing and sparkling with painted glass…we should, perhaps, doubt our sense of sight, so astonished should we be at the gorgeousness of the effect.[426]

Fred Miller

To what extent in any given instance should art simply ornament architecture, and to what extent should architecture set off the artist's image? The question really has no single, simple answer. Though architect may claim priority for their medium since it is architecture that must establish the larger context, it is no less true that when the image is sufficiently important, it becomes the function of architecture to serve that image…The way that art is related to architecture in any given case is itself a part of the aesthetic statement, and as variable as the resources of the particular medium make it. Stained glass, for example, may be quite validly treated at one extreme as little more than the colored infilling in a structure that itself nearly says everything that wants to be said; at the other extreme it may play a highly important iconic role…Whatever the relation established, it, the art, and the architecture may each vary tremendously in quality or effectiveness in any given instance.[427]

Robert Sowers

While stained glass windows are composed of a number of parts, it is the surface decoration that allows for these windows to surpass their identity as an architectural element and become individual works of art. As works of art, their conservation and restoration is essential; in addition to preserving a building element and a piece of history and in some cases, iconography, the history of the

[426] Miller, Fred. *Glass-Painting.* 1885: 2.
[427] Sowers, Robert. *Stained Glass: An Architectural Art*. 1965: 94.

materials and techniques used to create these windows is also important to conserve. Looking at this thesis, the conservation issues are innately tied to the history of both the techniques and materials of stained glass. Understanding how glass is created will allow for a better understanding of how the surface decorations will adhere to it. Examining painting styles over time will provide a foundation for analyzing various glass painting techniques.

The three main types of surface decoration—vitreous glass paints, silver stain, and enamels—are all responsible to creating and detailing the imagery of the window. Each one comes with its own history, chemistry, and deterioration and conservation issues. Discussing previous and current conservation techniques is incredibly important both in understanding how the techniques work, but also in terms of looking to the future conservation possibilities. Being exposed to many harmful situations, stained glass and its surface decoration are vulnerable to damage and sadly, much decoration has already been lost, for one reason or another; gone with it is the valuable information that went into making the window, painting the window, and understanding the context of the window.

In addition, with each conservation choice comes the ethical dilemmas that conservators of all objects must deal with. These dilemmas allow for interesting debates in how these restorations should be handled and hopefully, will lead to a beneficial discussion as to the best possible conservative tactics available. By analyzing the types of surface decoration and glass painting in general, it is possible to examine in detail an element that is essential to a stained glass window, the element that allows stained glass to truly shine regardless of its setting.

As it was stated at the start of this thesis, its purpose is to attempt as best as possible to compile a history of the materials and conservation techniques and problems for the three main forms of surface decoration. Initially, the glass and paint chemistries and the application and firing techniques can result in materials that will inevitably lead to paint deterioration. Once these windows are completed the environment, pollution, and over-cleaning will be added to the list of deterioration causes. While the signs of these types of deterioration are different and their effects on the different types of decoration will vary, each one contributes to the loss of valuable historic material and must be addressed. Fortunately, in many cases, there are methods that will allow the return of lost fabric, including plating and replacements. However, the focus of conservation of stained glass windows should really be prevention, both for the present and the future.

The introduction of surface decoration would prove to be one of the most significant developments in the history of stained glass windows. While it is the duty of present-day glaziers to continuing to explore the possibilities of glass-painting and designs, it is the responsibility of present-day conservators to save and protect the existing material. Stained glass painting is in danger and it is up to the conservators to find a way to preserve this most beautiful of artworks so that it may continue to enlighten generations to come.

Figure 68. Angel stained glass window. Image from http://orbiscatholicussecundus.blogspot.com/2012/08/canadian-stained-glass-windows.html

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