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The Color Purple: Dating Solarized Amethyst Container Glass

ABSTRACT

From the late-19th century on, there was an increased production of colorless bottles for a wide variety of products. Producing colorless glass is not difficult if pure sand with a very low iron content is available. Iron in sand gives the glass a range of colors from light green to dark amber, depending on the amount of iron in the sand. To overcome this problem, some factories that used iron-bearing sands added manganese to their batch as a decolorizer. While this produces colorless glass, that glass will turn a light purple or amethyst color when it is exposed to sunlight. Dating of solarized glass by archaeologists has relied on information from a variety of sources, including books produced by bottle collectors. Some of this information is good and some of it, erroneous. The objective here is to provide a useful chronology of the development and use of manganese as a decolorizer and to dispel some of the myths that have crept into the literature.

Introduction

Historically, both container glass and window glass have generally been colored varying shades of green and aquamarine. This color was produced by the natural inclusion of iron impurities in the sand used to produce the glass (see detailed information below). Gradually, lead glass came to be used for fine tableware, but the process was too expensive for the general line of containers. Throughout the 19th century, a gradual trend occurred in the glass industry toward light shades of aqua and colorless glass. Relatively inexpensive means were sought to produce colorless bottles. One of the cheapest methods was to add manganese to the glass mixture to create a colorless environment. This additive generated an interesting side effect—the glass became purple with prolonged exposure to the sun.

The color purple (or amethyst), when created by the inclusion of manganese in the formula of container glass, has long been a source of fascination for the archaeologist and the bottle collector. Although scientists and collectors are often at odds over issues of curation, access, ownership, and techniques in dealing with historical bottles, both have contributed to the literature used by archaeologists in dating and researching glass containers. Often, collectors have been on the cutting edge of descriptive and historical research on the glass industry, local users and bottlers, and local/national containers (McKearin and McKearin 1941; Munsey 1970, 1972; Zumwalt 1980; Fowler 1986) and are frequently cited by archaeologists. In researching solarized amethyst glass, archaeologists and collectors alike have made contributions. Archaeological and collector literature as well as contributions by chemists, physicists, and the glass industry is examined to study the dating and use of manganese dioxide as a decolorizer for impure container glass.

Background

Chemical and Physical Properties of Manganese Decolored Glass

Sand is one of the basic ingredients in the manufacture of glass, and most sand contains iron impurities in varying types and quantities. These impurities impart a green, blue-green, blue, or yellow tint to the glass, depending on the percentage of iron in the glass mixture and whether the iron is ferrous (blue-green), ferric (yellow), or a combination of the two. Because container glass was generally made as cheaply as possible (especially prior to the 20th century), most bottles displayed the blue-green or greenish tints often referred to by archaeologists and collectors as aqua but known in earlier times as "common green" (Harrington 1952: 28). The use of the term was so prevalent that one of the unions was called The Green Glass Bottle Blowers' Association of the United States and Canada (Scoville 1948:201). In most cases, "the *colour* of the glass [was] nearly, or quite, immaterial so that the introduction of relatively

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large proportions of iron oxide [was] permissible [emphasis in original]" (Rosenhain 1908:96).

Colorless glass became important for use in windows and tableware before it was widely introduced to containers, requiring a method of eliminating the tint caused by the iron impurities. L. M. Angus-Butterworth (1948:64) suggested that there were three ways to overcome the problem of unwanted color: (1) use a pure grade of sand with as low a percentage of iron impurities as possible (the best solution, but frequently impractical); (2) use oxidation to reduce undesirable color; or (3) add complementary colors (usually purple or pink) to offset the green tint caused by iron. George Miller and Antony Pacey (1985:44) add that the color may be masked by adding "other metallic oxides, such as cobalt" to change the color, or the color could be accepted as is. Pure sand produces a glass without color, and some locations are noted for sands lacking in impurities. Glasshouses, located in such areas, generate colorless glass without the use of complementary colors or oxidizers. Benjamin Biser ([1899]: 28) noted, "American sands, especially, show supremacy over all others, many of them being free from excessive organic matter and in almost absolute state of purity, and the supply nearly always inexhaustible." He also notes that Minnesota, Missouri, Illinois, Pennsylvania, Maryland, New Jersey, and the New England states are especially good places to find pure sand.

Although the distinction is of little practical use to historical archaeologists (at least using currently practiced methods), chemically, glass is formulated in four basic ways: soda-lime glass, potash-lime glass, potash-lead glass, and lime glass. Each of these glass types can be produced in colorless form without the addition of decolorizers. Glassmakers of Venice discovered a method to create colorless soda-lime glass by the 13th century, and colorless potash-lime glass was produced by the 17th century (for a more detailed discussion, see Jones and Sullivan 1989:10–12). It is clear that colorless glass for containers (as well as other uses) has been available for some time.

Historically, the most common method used to produce colorless glass was to add complementary colors, often using the purple hue created by manganese dioxide (MnO^2). At the close of the 19th century, Biser ([1899]: 43) explained the decolorization process: "Manganese imparts to glass a pink or red tint, which being complementary to green, neutralizes the color and permits the glass to transmit white light." The required quantity of manganese varied with the amount of iron in the mixture along with the nature of other chemicals present. D. J. McSwiney (1925a:23) noted, "the desired results are actually achieved by adding more color to the glass instead of taking it away." F. W. Hodkin and A. Cousen (1925:133) noted, "manganese is a more successful decolouriser in potash glass than in soda glass," although that distinction is of little practical use to archaeologists. There is no doubt that manganese was the most successful decolorant used in the latter part of the 19th century and the early part of the 20th century (Rosenhain 1908:192–193; Scholes 1935:207). Manganese-decolored glass that has undergone a color change due to exposure to the ultraviolet rays of the sun is variously known as sun-colored amethyst (SCA), solarized amethyst, solarized purple, or irradiated glass.

Through the years, chemists have argued *why* mixing complementary colors green and purple result in (to the eye, at least) a colorless glass (Fettke 1918:83; Weyl 1959:500–507; Paul 1982: 260). For the archaeologist it is sufficient to note *that* the phenomenon takes place. For a more technical explanation of how manganese dioxide functions as a decolorant, see A. Paul (1982:260) and Woldemar Weyl (1959: 500–507).

J. F. White and W. B. Silverman (1950: 255,257) sliced thin layers of glass to reveal that the solarization of manganese-bearing glass extends through the entire body of the piece rather than just appearing on the surface. Although the color extends all the way through, C. R. Bamford (1977:51) records, "ultra-violet irradiation gives a purple colouration extending with decreasing intensity into the body of the glass from the glass surface." It is clear that direct sunlight (or artificial irradiation) is required to create the color change. In 1905, S. Avery (1905:910) noted that a partially-buried bottle "showed the greatest change of color where most exposed to the sun's rays." Charles Hunt (1959:10) also illustrated the phenomenon in a way that suggested solarization would not occur through soil packed into a bottle or fragment. Further confirmation was offered by Mary Zimmerman (1964:31) that "partially colored bottles, those that are half-purple-and-half-clear, are commonly found by bottle diggers."

The combining of manganese and the impure sand must be conducted under oxidizing conditions (in this case, exposure to ultraviolet light). As early as 1948, Angus-Butterworth (1948:58) noted, "reducing agents destroy the purple tint." Reducing may be accomplished by heating the glass to a temperature between 450° and 500° F. This reverses the chemical change created by the exposure to solar radiation, and sun-colored amethyst glass becomes colorless once more. It should be noted that these temperatures are perilously close to the point where glass becomes plastic and the sample can become damaged (Weyl 1959:508–509; Paul 1982:261).

Early Investigations, Gaffield's Observations, and Gortner's Experiment

Chemists have been interested in color changes in glass caused by solar irradiation since the early-19th century. Scientists began discussing the phenomenon at least as early as 1823, although the controversy at that time centered around window glass rather than containers. The change of color in British windows was already becoming obvious early in the century (Gaffield 1867:244–252, 1881:4; Weyl 1959:498–500).

Thomas Gaffield (1867) conducted what may be the first actual testing of the effects of solarization on window and plate glass. He first placed what he called "really *colored* glasses, red, green, yellow, blue, and purple [emphasis in original]," in the sun but noticed little change except for the purple glass which "became slightly darker" (Gaffield 1867:245). He then exposed "white" (colorless) glass and lightly tinted glasses to sunlight and was rewarded by an increase in tint, mostly to a light-bluish or yellowish color with some pinks. He did not test any container glass.

Gaffield began his second set of experiments in 1870 and presented his findings in 1880 to the American Association for the Advancement of Science meeting in Boston (Gaffield 1881:7). He exposed "rough and polished plate; crown and sheet window glass; flint and crown optical glass; glass ware and glass in the rough metal" to sunlight over a 10-year period. Gaffield "witnessed a perceptible change in a single hour of sunlight exposure upon the top of a post in a country garden, at noontime, on a clear and hot day of August." Other changes took place much more slowly. He observed changes in most types of glass except some "fine glassware and optical glass" (Gaffield 1881:4–5). Again, he did not test any container glass.

Gaffield (1881:5) observed a variety of color changes, including "from white [colorless] to yellow," colorless to purple, and several changes in lightly tinted glass of various shades. It is important to note that even prior to 1880, other decolorants (besides manganese) were in use. Gaffield (1881:7) indicated the presence of other decolorants (even prior to 1880) when he stated, "a yellowish or purple color was produced" when colorless glass was "painted by the magic pencil of the sun." Manganese does not create a yellowish color. Gaffield (1881:9) correctly attributed the cause of the aqua coloration in most glass to "the presence of oxide of iron" and "oxide of magnesium" as "the great colorist in all of these changes [solarization to a purple color]."

Gaffield (1881:6) also noted that sun-colored fragments of glass could be "restored to their original color by being placed in the kiln during a single fire." In other words, heating the glass would reverse the sun's action and alter the specimens back to a colorless form (see the chemical discussion of this phenomenon above). He noted that this phenomenon had been reported as early as 1867.

The discussions on solarization virtually ceased after 1881 only to be rekindled in the early-20th century in debates over the color change in container glass. Avery (1905:909–910) and Charles Rueger (1905:1206) each published brief notes that suggested the likelihood that color change was caused by irradiation from the sun among other possible explanations.

Such discussions spurred Ross Gortner (1908) to seriously study the phenomenon. On 9 July 1906, he attached 22 colorless glass containers and other colorless glass objects (including a glass funnel, a laboratory flask, and pieces of glass tubing) to a board atop his roof to assess their susceptibility to sunlight. Some of the containers were filled with various ingredients including manganese dioxide, lampblack, potassium permanganate, and other substances. After one month, five items had begun to turn purple. He did not check the experiment again for almost a year, at which time he discovered 17 items had turned purple, 4 remained unchanged, and 1 had been "blown away by the wind" (Gortner 1908:159).

Gortner's results showed that some contents retarded the solarization on the backs of the bottles (but not the fronts) and some (notably lampblack) eliminated the coloration from the backs entirely. Gortner ground up the samples of glass he had placed on the roof and tested them to obtain the chemical composition of each container. All but one of the test items that remained colorless contained no manganese, but the unaltered Jena glass (laboratory glass) flask had a manganese component (Gortner 1908:159–161).

In conclusion, Gortner (1908:1962) demonstrated that when glass is "colored violet by the action of sunlight, proof is furnished that the glass contains manganese." He further confirmed that even glass containing small amounts of manganese will turn violet or purple after prolonged exposure and that length of exposure will deepen the color intensity. Finally, he established that some glass (notably Jena glass) contains a chemical combination that inhibits color change during solarization despite the inclusion of manganese dioxide in its composition (although it is likely that only a very tiny percentage of glass fits into this category).

Dating Solarized Amethyst Glass

Background Literature

Until recently, bottle-collector literature has been the major source for information and dating of glass containers by historians, archaeologists, and collectors alike. Although some collectors' literature is well written and well researched, much of it is compiled without scientific methodology or accuracy. While some collector dating and wisdom have been disproved (for example, the idea that the proximity of mold marks to the lip of a bottle is relevant to its relative age), the dating and history of solarized, manganese-bearing glass has not been seriously researched by archaeologists.

The first collector to attempt dating purple glass was Grace Kendrick (1963:54–56). Kendrick dated the phenomenon of "sun-colored glass" as lasting from 1880 to 1914. Although she provided no justification for her beginning date, she stated, "[w]ith the advent of World War I, our main source of manganese (German suppliers) was cut off" (Kendrick 1963:56), thereby providing an end date that has been more or less accepted (along with her beginning date) ever since. Zimmerman followed Kendrick a year later, referencing solarized purple, flat (window) glass and tableware along with bottles as being used between 1850 and 1910 (Zimmerman 1964:7,19). She noted that many innovations in the glass industry began about 1890 (Zimmerman 1964:20–21), and the changeover to selenium was a process that continued from about 1910 until about 1930. Although Cecil Munsey (1970:55) cited Zimmerman as one of his sources, he accepted Kendrick's basic dating scheme and added, "around 1880, . . . the demand for clear glass forced the manufacturers to perfect the technique of decolorizing with manganese." Rick Baldwin (1985:23) combined the Kendrick and Zimmerman dating schemes to suggest a beginning date of 1880 and an end date between 1915 and 1930. T. Stell Newman (1970:74) modified that range by adding 10 years to all dates to allow for industry transition; Olive Jones and Catherine Sullivan (1989:13) and Miller and Pacey (1985:44) generalized it; and Richard Fike (1987:13) ignored it completely.

Kendrick was only partially correct in her reasoning for the industry's cessation of the use of manganese. In 1910, the United States imported 4,928 long tons of manganese from Germany, 2.03% of our total import for the year. By 1915 that was reduced to 258 long tons (0.08% of total import), followed by a reduction to zero in 1916. It was not until 1920 that the U.S. returned to German suppliers, and then the total import was only 11 long tons. In other words, Germany was never an important supplier of manganese during the period in question. Prior to World War I, British India supplied the most manganese to the U.S.: 58.2% of the total import in 1910, decreasing to only 11.4% by 1915. Brazil had contributed 22.2% of U.S. manganese imports in 1910, increasing to 85.9% in 1915.

The United States itself became an important manganese supplier by the end of the war, generating 31.4% of its supply (an increase from less than 1% in 1910) (U.S. Geological Survey 1913:207–208, 1919:734–736, 1922: 274–276). The United States Tariff Commission (1918a:13) stated that clay, not manganese was a major import from Germany.

Import records failed to tell the complete story. The U.S. Tariff Commission conducted two hearings concerning the effects of the war on the glass industry in 1917. In the second meeting, representatives from "65 flint-glass manufacturing firms" (not all bottle manufacturers) met with government officials in December 1917 to discuss the state of U.S. glass production. Despite the evidence produced above, glass manufacturers imported most of their manganese from Russia, although some was imported from Germany along with a small amount from France. It is clear that war disruption played a significant role in the importation of manganese (U.S. Tariff Commission 1918b:32).

It is instructive to note that the disruption produced a very complex reaction from the glass industry, rather than the simplistic response posited by Kendrick. Not counting plate glass manufacturers, 43 representatives discussed imports. Of those, 25 discussed manganese. Nine discussants continued to use manganese derived from other sources. Most of these used domestic manganese, although a few were dissatisfied with its quality. Two imported manganese from countries (like Canada) where shipping was unaffected by the war. Three discussants discontinued the use of manganese with no replacement; three others substituted selenium. A single glassmaker continued to pay higher prices and was still using imported manganese. The final nine were using other decolorants in place of manganese (Table 1). Five of them substituted a decolorizer manufactured by the Frink Laboratories, Lancaster, Ohio (U.S. Tariff Commission 1918b:32–37). The U.S. Tariff Commission hearing makes two points clear: (1) a significant number of manufacturers (36% of those who discussed manganese use) continued to use manganese as a decolorant in 1917; and (2) by that point, selenium was only one of a number of substitutes for manganese.

Beginning Dates

Manganese was used as a coloring agent at least as early as 660 B.C. in Egypt (Angus-Butterworth 1948:49) and in Roman glass from the 4th century B.C. to the 9th century A.D. (Werner 1968:34A). Helen McKearin and Kenneth Wilson (1978:10) note that the decoloring properties of manganese were demonstrated prior to 1662. Scholes (1935: 207) even claims that "it was used for hundreds of years as the only satisfactory decolorizer." Manganese appears in tableware at least as early as the 18th century (Jones and Sullivan 1989:13). Window glass that had solarized to a purple color was investigated in England as early as 1823 (Gaffield 1881:4) and 1825 (Weyl

TABLE 1
EFFECTS OF IMPORT DISRUPTION ON MANGANESE-USING GLASS MANUFACTURERS IN 1917*

Reaction to Import Disruption	N	%
Substituted other manganese sources (mostly domestic)	9	36.0
Discontinued use of decolorant	3	12.0
Substituted selenium	3	12.0
Continued to use existing imported supplies	1	4.0
Substituted various other decolorants**	9	36.0
Totals	25	100.0

* Data derived from U.S. Tariff Commission (1918b:32–37).

** Five glass manufacturers (20.0% of the total number) used a decolorant developed by Frink Laboratories, Lancaster, Ohio.

1959:498–500). Gaffield (1881:3) observed, "changes of some light colored plate glass to a purple" had been noted "after the beginning of this century [19th]," placing manganese use in flat glass about 1800 or shortly thereafter. Manganese-decolored flat glass was also in use in the United States prior to 1880. In his report for the 1880 census, Joseph Weeks (1883: 1062–1063) claimed,

> manganese is used to correct this greenish color, and is often termed "glass-maker's soap," but glass so decolorized is liable under the action of sunlight to acquire a purplish tint of "high color." Window glass in which manganese has been used often assumes this tint to such an extent as to lead to the belief that it was originally colored.

It becomes clear that manganese-bearing glass was in use long before 1880 and was used in the United States prior to that date.

Prior to the use of manganese-decolored glass, most containers were manufactured as cheaply as possible, a technique that retained the green, blue-green, aqua, yellow, or light blue colors associated with the presence of iron oxides in the glass mix. Contemporary sources that deal with glass colors (Fike 1987:13; Jones and Sullivan 1989:13) are strangely silent on the subject of the light blue bottles that appear primarily in pre-1917 contexts. Bamford (1977:51–52), Walter Rosenhain (1908:190), and Donald Sharp (1933:762) identify blue as a color associated with iron impurities in glass. In a 1929 experiment, B. Bogitch "obtained colours [of glass] varying from brown to blue according to the condition of the iron" (Gooding and Murgatroyd 1935:45). Biser ([1899]:13) described this glass as "coarse and inferior in quality, used extensively for the commonest grades of bottles and hollow-ware, and is usually of a greenish, amber, or black color."

Because color was often unimportant (Rosenhain 1908:196), certain types of bottles continued to be made from "naturally colored" (iron bearing) glass, notably soda and beer bottles. Although occasional beer bottles appear in light blue or colorless forms, most were amber from the last quarter of the 19th century. Soda bottles generally retained the green, aqua, or light blue tints caused by the iron impurities. Biser ([1899]:86) suggested that soda and beer bottles remained colored because of the fear that "the liquid contents of a flint glass [colorless] bottle were seriously impaired in strength and in color by the actions of light, which a green or amber bottle excluded, and thus protected its contents." The use of unaltered glass was so common in the manufacture of bottles that green glass was synonymous with "bottle glass" (*Harpers* 1889:257).

Two factors confound the selection of a single date as a beginning for the use of manganese as a decolorant in the United States: process and terminology. Process is a problem because manufacturers rarely (if ever) all switch to a new technology simultaneously or even in a relatively short time (Newman 1970:70). Weeks (1883:1062–1063) reported the use of manganese decolorization in 1880, but he was very unclear about the context.

When Gaffield (1881:5) examined the effects of sunlight on glass in 1867 and 1881, he reported that he used "rough and polished plate; crown and sheet window glass; flint and crown optical glass; glassware and glass in the rough metal" for his experiments. Like Weeks (above), the lack of reference to container glass is significant. Although not conclusive, these references create a lack of clear context for early manganese use in container glass.

The second problem is terminology. In their justification for the use of the term "colourless," Jones and Sullivan (1989:13) state that "terms like 'clear,' 'white,' 'flint,' or 'crystal' . . . have not been used consistently by contemporary authors or in historical documents." Originally, the term *flint* was used to mean lead glass (or potash-lead glass), highly prized for tableware because it was "colourless, heavy, and lustrous" (Jones and Sullivan 1989:11; also McKearin and McKearin 1941:8). Because the process was more expensive, its use in containers was limited, although *Harpers* magazine (1889:257) noted that it was used in the U.S. to manufacture "fine bottles." Later, the use of the terms grew more lax, and *flint* or *white* often meant glass made from pure sand, glass manufactured by techniques such as that developed by William Leighton in 1864 (Jones and Sullivan 1989:11) or glass made with a decolorant. Leighton, working for the glasshouse of Hobbs, Brockunier and Co., developed a soda-lime glass (often called "lime" or "lime flint" glass) that was colorless, of high quality, and much cheaper than lead-flint glass

(McKearin and McKearin 1941:8; Douglas and Frank 1972:40). Frank Gessner (1891:54–56) presented recipes for "flint hollow-ware" that all contained manganese as a decolorant.

George Griffenhagen and Mary Bogard (1999:20,35) note that imported "flint glass" medicine bottles were offered for sale in the U.S. as early as 1773 and American-made flint glass containers by the 1850s. Edward Perrish wrote in 1856, "flint vials are considerably more expensive than the green, though they are far more elegant for prescription purposes" (Griffenhagen and Bogard 1999:27). Although Perrish was most likely talking about lead flint glass, a more expensive process, his statement is important because it shows that people in the U.S. were showing a desire for colorless glass (at least in pharmaceutical containers) by the mid-19th century.

Although Leighton's "lime-flint" glass was well known for its use in pressed table glass (Jones and Sullivan 1989:11), no reference is found for its use in containers. Although Julian Toulouse (1971:369–370,387–388), mentions the company several times, it is always in connection with pressed tableware and never in a context connoting containers. It is obvious, that some form of colorless glass was used to produce medicinal containers in the U.S., possibly just glass made from essentially pure sand.

The combination of process and terminology creates a final hurdle that must be cleared before an understanding of when the use of manganese-decolored glass began among glassmakers can be achieved. The combined aspect centers around container type. Makers of different types of containers appear to have adopted glass decolorized by manganese at different times. Whitall Tatum & Co., for example, opened a "flint glasshouse" in 1864. Initially, the company used William Leighton's formula for colorless glass (without manganese), although it only met with limited success (Pepper 1971: 228–232). By 1870 the process had improved at Whitall Tatum through the use of manganese dioxide (Horner 1969:98). Personal communication with numerous collectors of drug store bottles indicates that, regardless of manufacture date, virtually all pre-1924 Whitall Tatum colorless drug store bottles (generally oval-shaped, pharmacy bottles with plate molds identifying local drug stores) will solarize to a light amethyst color. Attempting to quantify collector data is difficult. The author observed one collection of about 1,850 drugstore bottles, about half of which were marked with the Whitall Tatum logo. All were solarized to a light amethyst. Various collectors have reported looking at hundreds of drug store bottles from Whitall Tatum that showed similar characteristics.

By 1904, Whitall Tatum had developed a semiautomatic machine for wide-mouth containers and had one for narrow-mouth bottles operational by 1912 (Toulouse 1971:544–547); however, these were not used for drug store bottles. Because of the use of plate molds, these bottles were available to local storeowners at a slight additional charge and were popular during the late-19th and early-20th centuries. For drug store bottles (and, presumably other medicinals) the beginning date is about 1870.

An examination of soft drink bottles shows a different pattern completely. As stated above, most soda bottles were allowed to retain whatever colors the natural impurities in the glass mix created. The use of manganese-bearing, colorless glass in soft drink bottles seems to have begun sometime in the mid-1890s (William Lindsey and numerous bottle collectors 2004, pers. comm.). Less information is available for other bottle types, although beer bottles, even today, are generally not colorless.

Personal communication with collectors also indicates that many of the early milk bottles, most of which were made of colorless glass, will solarize to varying shades of amethyst or purple. Although the record of the earliest milk bottles is unclear, when the Thatcher milk bottles were first made in 1886, they were formed of colorless glass (Tutton [1996]:6). Colorless glass continued to be the industry standard until glass milk bottles were almost completely replaced by waxed paper and plastic containers.

Apparently, at least with Hemingray Glass Co., jar manufacturers did not begin using manganese to any strong degree until after 1893. Although Hemingray was best known for the making of insulators, the company, like its predecessors Hemingray Brothers & Co. and Gray & Hemingray, made such items as tableware, tumblers, chemical apparatus, perfume bottles, pickle bottles, fruit jars, and other bottle types (Toulouse 1971:224–225,246). Bob Genheimer (2004, pers. comm.) described his excavation of the Hemingray Glass Co. in 1986. In a large excavation unit (2.5 x 2.5 m), Genheimer found sizeable quantities of broken glass discarded by the factory. Although 52.7% of the broken glass was colorless, only 0.9% was a solarized amethyst. This may suggest the beginning of manganese use as a decolorant by the company by 1893 (the date the factory moved and ceased production on the site). Alternatively, the small amount of manganese glass could be from *cullet* (broken glass used to "prime" the furnace) collected from other factories.

Despite the unsupported references to 1880 found in the early collectors' literature, documentary sources discuss the appearance of manganese-decolored glass as a part of a general trend toward technological improvement beginning about 1890. Although specific inventions were unmentioned, *Harpers* magazine (1889) touted the innovations and modern techniques then taking place within the glass industry. Biser ([1899]:86) noted, the "so-called 'lime flint' bottle glass" was becoming more common and "the past decade [since ca. 1889] has wrought a revolution in so far as to give flint glass bottles much prestige." Scholes (1935: 217) likewise stated: "From the first attempts to produce crystal glass in continuous tanks in the 1890's to the development of decolorizing by selenium twenty years later, glass makers struggled to maintain good color by manganese treatment." Zimmerman (1964:20–21) noticed the importance of the industrial development around 1890 but failed to link it to the early use of manganese in container glass. Although these sources are a bit unclear as to the date of entry of manganese-bearing glass, Gessner established the certainty that it was in use by 1891. In his *Glassmakers' Hand-Book*, Gessner (1891: 7) notes, "the use of manganese has, however, been largely abandoned in European factories during latter years, especially in the manufacture of window glass and fine flint ware" because it changed color. For bottle glass he included manganese in all of his "flint hollow-ware" recipes. Gessner (1891:54) also states:

> flint hollow-ware has grown to immense proportions during recent years, and in many cases has largely displaced green glass. Fruit jars, the use of which is growing more extensive each year, especially those of large size to displace the shape and color of the contents, are now, to a large extent, made of flint [manganese-decolored glass], which is preferred on account of its greater clearness and transparency.

This suggests that, by 1891, manganese-bearing glass had been in use for at least a few years and was growing in popularity.

Biser ([1899]:86) also noted another interesting development near the end of the 1880s, "For a long time flint glass bottles were regarded with disfavor, inasmuch as their cost alone excluded them from beer and soda trade, to say nothing of the current belief rife among the bottling fraternity that flint glass lacked the strength and resistance of green glass." The sentence implies that the resistance was by then no longer prevalent. Although this may suggest other new techniques as well, it seems to describe the process of conversion to manganese decolorization. The use of manganese as a decolorant would have left the glass as strong and resilient as its predecessor, green (or aqua) bottle glass.

Although developed by manufacturers of drug store bottles more than a decade earlier, use of the technique for manganese decolorization was therefore probably widely in use by the late 1880s. The actual dates of inception for the technique seem tied to container type. Three different methods, then, may be used for determining a beginning date for the use of manganese-decolored glass. First, the earliest known date for use in the United States is 1870 (at Whitall Tatum & Co.). Second, the most practical "general use" date is the late 1880s. Finally, more specific dates need to be researched for specific types of glass containers. Currently, that includes 1870 for drug store bottles (and probably other pharmaceuticals), the mid-1880s for milk bottles, and the mid-1890s for soft drink bottles.

A slight postscript about beginning dates must be added. In his excavation of the Johnson's Island Civil War Prison, David R. Bush (2004, pers. comm.) discovered "numerous examples of solarized glass from contexts that date from the Civil War." While this questions the veracity of the dates discussed above, there are two mitigating circumstances. First, manganese was used in tableware throughout much of the 19th century; second, manganese has also been used as a colorant. McKearin and Wilson (1978: 591) describe a style of flask that is found in both amethyst and deep amethyst (black) colors as well as various shades of green, blue, and yellow. A second style (McKearin and Wilson (1978:597) was colorless and "colorless, lavender tint." Although solarization is a possibility, the first bottle described was almost certainly made from amethyst glass intentionally, and the second probably obtained its tint accidentally through cullet or impurities. McKearin and Wilson (1978:592) also note a flask that is "amethyst and clear in striations, the overall effect being of brilliant amethyst." Other flasks are described as colorless, clear, or colorless with light shading of various colors ("clear light green" or "clear yellow green"). All of these are obviously not solarized. Future research should stress close observation of glass from the Civil War period for indications that might address solarization.

End Dates

As with a beginning date, the end date expresses a process. As noted above, the change from manganese dioxide to selenium and other decoloring agents was not caused by a shortage of manganese from Germany (although World War I did create a shortage of manganese, along with most other resources). The change was actually a result of technological improvements in the glass industry and is closely connected to the conversion to automatic bottle machines. McSwiney (1925b:53–57) and Miller and Pacey (1985:44–45) provide a concise summary of technological events that resulted in the transition to selenium usage, although they are vague as to the actual dating. Manganese dioxide performs best in crucibles, such as those used in the production of hand-blown glass, because of its need for an oxidizing environment. It is much less effective in open tanks, such as those required for the Owen Automatic Bottling Machine and others of its type. Even though manganese was more difficult to obtain during World War I, and selenium was cheaper to use, the improvement in technology (the popularity of semi-automatic and automatic bottle blowing machines) was the major reason for the change in decoloring agents. Because of the problem with manganese, many of the early machine-made bottles were aqua in color, a convenient way of avoiding the problem, as no decolorant was needed.

Scholes (1935:217) places the initial use of selenium about 1910. McSwiney (1925b: 53,55) suggests the earliest use of selenium at "a few years before the war" but adds, "up to ten years ago [1915] the only decolorizer used to any considerable extent for the production of colorless soda lime glass was manganese." Weyl (1959:283) contends that the use of selenium began in the early 1890s. Sources more contemporary with the change declared, "in 1917, selenium, a domestic by-product of copper, was substituted for manganese" (U.S. Tariff Commission 1918a:32) and "manganese is one of the important decolorizers employed by the glass manufacturer" (Fettke 1918:82). These sources indicate that selenium was in use by at least 1910 (possibly earlier) but did not become popular until about 1917.

The term *popular* needs to be clarified. Since the popularity of selenium use (and, therefore, the end of prominence for manganese) closely follows the development of the automatic bottle machine, the significance of the term concerning automation of the glass industry must be examined. The use of automatic bottle machines had increased in popularity to the point that, in 1917, approximately half of all bottles in the United States were made by the Owens Automatic Bottle Machine. Additional containers were made on a variety of semi-automatic machines. Although machine production increased in popularity, hand-blown bottles continued to be manufactured until the early 1930s (Miller and Sullivan 1984:86–89). Machines were more efficient for producing bottles in quantity, so the more popular container styles (beer, soda, and food bottles) were the earliest made by the new process. By approximately 1920, most of the popular types of bottles were machine made.

Also following the machine production trend, manganese use as a decolorant continued in the smaller, hand-production glasshouses and for specialty bottles in the larger plants. These small-run, specialty bottle producers still used crucibles and had no reason to make the transition to selenium. In 1926, Alexander Silverman (1926:897) commented, "selenium has also largely displaced manganese dioxide as a decolorizer." By 1933, Sharp (1933:763) noted, "selenium is almost invariably used as the decolorizer in bottle glass because of the relatively constant results to be obtained. Manganese is still employed for high-grade pot glass." Although manganese use continued past 1920, its widespread use had clearly come to an end.

End dating specific container types provides a postscript to the dating discussion. As with beginning dates, not all bottle types or glass houses adopted selenium or other decolorants at the same time. Drug store bottles (pharmaceutical bottles, usually oval in shape and containing embossed plate molds with the names of local druggists), probably the earliest to show the adoption of manganese as a decolorant, were also some of the last to abandon the technique. Whitall Tatum continued to make drug store bottles by hand blowing until about 1924 (beginning about 1924, all pharmaceutical bottles at Whitall Tatum were machine-made and embossed with a different logo) and therefore continued to use manganese as a decoloring agent until that time. Cost may have been a deciding factor for druggists. Machine manufacture required a minimum order. Often, that minimal requirement resulted in an order too large to fit the needs of most druggists (Miller and Pacey 1985:42). As a result, the machine manufacture of bottles created a cost beyond the practical reach of many businesses. The day of the individually marked drug store bottle was at an end.

Soft drink bottles rarely showed the presence of manganese after the advent of machine usage in that field, between about 1912 and 1915. Some of the pint- and fifth-size preprohibition liquor bottles with no manufacturer's mark and those with the *B* (with serifs) mark made by the Charles Boldt Glass Co. from 1910 to 1919 solarize to light amethyst color, indicating the use of manganese. Yet these same bottles have the distinctive Owens scars that indicate the use of the Owens Automatic Bottle Machine. According to Miller and McNichol (2002:3,6–7), only Boldt and the Illinois Glass Co. were issued licenses to make whiskey bottles prior to the cessation of the Owens patents in the mid-1920s. Because Boldt did not include date codes on his bottles, the date range when he discontinued the use of manganese is unknown. Many early milk bottles (ca. 1900–ca. 1912), including some made with Owens machines by the Thatcher Glass Manufacturing Co. as late as 1914 (by date code on the base), have solarized to varying shades up to a rich, dark purple.

Conclusion

Both historical and empirical evidence indicate that the previously accepted earlier date (1880) for the beginning of popularity of colorless glass container use in the United States as suggested by bottle collectors may be slightly incorrect. Popular use seems to have begun by at least the mid-1870s and was solidly in place by 1890. This dating cannot be generalized to all glass artifacts. Manganese was used in tableware by 1865 and in flat (window) glass in the U.S. long before 1880. A practical end date for manganese use in all but specialty bottles is about 1920, although some use continued until the early 1930s. The end of manganese use is generally concurrent with the end of mouth-blown bottle production.

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References

Angus-Butterworth, L. M.
1948 *The Manufacture of Glass*. Putnam, New York, NY.

Avery, S.
1905 Changes of Color Caused by the Action of Certain Rays on Glass. *Journal of the American Chemical Society* 27(7):909–910.

Baldwin, Rick
1985 Decolorizing Glass with Manganese. *Crown Jewels of the Wire* 17(7):23–25.

Bamford, C. R.
1977 *Colour Generation and Control in Glass*. Elsevice Scientific, New York, NY.

Biser, Benjamin F.
[1899] *Elements of Glass and Glassmaking: A Treatise Designed for the Practical Glassmaker, Comprising Facts, Figures, Recipes, and Formulas for the Manufacture of Glass, Plain and Colored*. Glass and Pottery, Pittsburgh, PA.

Douglas, R. W., and Susan Frank
1972 *A History of Glassmaking*. G. T. Foulis & Co., Henley-on-Thames, Oxfordshire, England.

Fettke, Charles Reinhard
1918 *Glass Manufacture and the Glass Sand Industry of Pennsylvania*. Report no. 12, Topographic and Geologic Survey of Pennsylvania, Harrisburg.

Fike, Richard E.
1987 *The Bottle Book: A Comprehensive Guide to Historic, Embossed Medicine Bottles*. Peregrine Smith, Salt Lake City, UT.

Fowler, Ron
1986 *Washington Sodas: The Illustrated History of Washington's Soft Drink Industry*. Dolphin Point Writing Works, Seattle, WA.

Gaffield, Thomas
1867 The Action of Sunlight on Glass. *American Journal of Science and Arts* 94:244–252.
1881 *The Action of Sunlight on Glass*. Salem Press, Salem, MA. [From a paper presented to the American Association for the Advancement of Science, Boston, 27 August 1880.]

Gessner, Frank M.
1891 *Glassmakers' Hand-Book: Containing Recipes for Making Flint, Bottle, Window, and Architectural Glass. Plain and in Colors: Plate Glass–American, French, Belgian, German, and Bohemian Formulas: Also Recipes for Strass and Artificial Gems.* George E. Williams, Pittsburgh, PA.

Gooding, E. J., and J. B. Murgatroyd
1935 An Investigation of Selenium Decolorising. *Journal of the Society of Glass Technology* 19:43–103.

Gortner, Ross Aiken
1908 Some Effects of Sunlight upon Colorless Glass. *American Chemical Journal* 34(2):158–162.

Griffenhagen, George, and Mary Bogard
1999 *History of Drug Containers and Their Labels*. American Institute of the History of Pharmacy, Madison, WI.

Harpers
1889 Great American Industries, VIII, A Piece of Glass. *Harpers* 79:245–264.

Harrington, J. C.
1952 *Glassmaking at Jamestown: America's First Industry*. Dietz Press, Richmond, VA.

Hodkin, F. W., and Cousen, A.
1925 *A Textbook of Glass Technology*. Constable & Company, London, England.

Horner, Roy
1969 *Tempo, the Glass Folks of South Jersey*. Reprinted in 1985 by Gloucester County Historical Society, Woodbury, NJ.

Hunt, Charles B.
1959 Dating of Mining Camps with Tin Cans and Bottles. *Geo Times* 3(8):8–10,34.

Jones, Olive, and Catherine Sullivan
1989 *The Parks Canada Glass Glossary for the Description of Containers, Tableware, Flat Glass, and Closures*. Parks Canada, Ottawa, Canada.

Kendrick, Grace
1963 *The Antique Bottle Collector*. Reprinted in 1971 by Old Time Bottle, Salem, OR.

McKearin, Helen, and George McKearin
1941 *American Glass*. Crown Publishers, New York, NY.

McKearin, Helen, and Kenneth M. Wilson
1978 *American Bottles & Flasks and Their Ancestry*. Crown Publishers, New York, NY.

McSwiney, D. J.
1925a The Decolorization of Glass. *The Glass Industry* 6(2): 23–26.
1925b The Decolorization of Glass. *The Glass Industry* 6(3): 53–57.

Miller, George L., and Tony McNichol
2002 Dates for Suction Scarred Bottoms: Chronological Changes in Owens Machine-Made Bottles. Paper presented at the 2002 Annual Meeting of The Society for Historical Archaeology, Mobile, AL.

Miller, George L., and Antony Pacey
1985 Impact of Mechanization in the Glass Container Industry: The Dominion Glass Company of Montreal, a Case Study. *Historical Archaeology* 19(1):38–50.

Miller, George L., and Catherine Sullivan
1984 Machine-Made Glass Containers and the End of Production for Mouth-Blown Bottles. *Historical Archaeology* 18(2):83–96.

Munsey, Cecil
1970 *The Illustrated Guide to Collecting Bottles*. Hawthorn, New York, NY.
1972 *The Illustrated Guide to the Collectibles of Coca-Cola*. Hawthorn, New York, NY.

Newman, T. Stell
1970 A Dating Key for Post-Eighteenth-Century Bottles. *Historical Archaeology* 4:70–75.

PAUL, A.
1982 *Chemistry of Glass*. Chapman and Hall, New York, NY.

PEPPER, ADELINE
1971 *Glass Gaffers of New Jersey*. Scribner's Sons, New York, NY.

ROSENHAIN, WALTER
1908 *Glass Manufacture*. Archibald Constable & Co., London, England.

RUEGER, CHARLES E.
1905 Changes of Color Caused by the Action of Certain Rays on Glass. *Journal of the American Chemical Society* 28(9):1206.

SCHOLES, SAMUEL R.
1935 *Modern Glass Practice*. Reprinted in 1952 by Industrial Publications, Ind., Chicago, IL.

SCOVILLE, WARREN C.
1948 *Revolution in Glassmaking: Entrpreneurship and Technological Change in the American Industry, 1880–1920*. Harvard University Press, Cambridge, MA.

SHARP, DONALD E.
1933 Chemical Composition of Commercial Glasses. *Industrial and Engineering Chemistry* 25(7):755–764.

SILVERMAN, ALEXANDER
1926 Fifty Years of Glass-Making. *Journal of Industrial and Engineering Chemistry* 18(9):896–899.

TOULOUSE, JULIAN HARRISON
1971 *Bottle Makers and Their Marks*. Thomas Nelson, New York, NY.

TUTTON, JOHN
[1996] *Udderly Beautiful: A Pictorial Guide to the Pyroglazed or Painted Milkbottle*. Privately Printed, Front Royal, VA.

UNITED STATES GEOLOGICAL SURVEY
1913 *Mineral Resources of the United States, Calendar Year 1912, Part 1—Metals*. U.S. Geological Survey, Washington, DC.
1919 *Mineral Resources of the United States, Calendar Year 1916, Part 1—Metals*. U.S. Geological Survey, Washington, DC.
1922 *Mineral Resources of the United States, Calendar Year 1920, Part 1—Metals*. U.S. Geological Survey, Washington, DC.

UNITED STATES TARIFF COMMISSION
1918a *The Glass Industry as Affected by the War*. Tariff Information Series, No. 4. U.S. Tariff Commission, Washington, DC.
1918b *The Glass Industry as Affected by the War*. Tariff Information Series, No. 5. U.S. Tariff Commission, Washington, DC.

WEEKS, JOSEPH D.
1883 Report on the Manufacture of Glass. *Report on the Manufactures of the United States at the Tenth Census (June 1, 1880), Embracing General Statistics and Monographs on Power used in Manufactures, the Factory System, Interchangeable Mechanism, Hardware, Cutlery, etc., Iron and Steel, Silk Manufacture, Cotton Manufacture, Woolen Manufacture, Chemical Products, Glass Manufacture.* Bureau of the Census, Washington, DC.

WERNER, A. E. A.
1968 Analytical Methods in Archaeology. *Analytical Chemistry* 40(2):28A–42A.

WEYL, WOLDEMAR
1959 *Coloured Glasses*. Dawson's of Pall Mall, London, England.

WHITE, J. F., AND W. B. SILVERMAN
1950 Some Studies on the Solarization of Glass. *Journal of the American Ceramic Society* 33(8):252–257.

ZIMMERMAN, MARY J.
1964 *Sun-Colored Glass: Its Lure and Lore*. "Ole" Empty Bottle House, Amadore City, CA.

ZUMWALT, BETTY
1980 *Ketchup Pickles Sauces: Nineteenth-Century Food in Glass*. Mark West Publications, Fulton, CA.

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