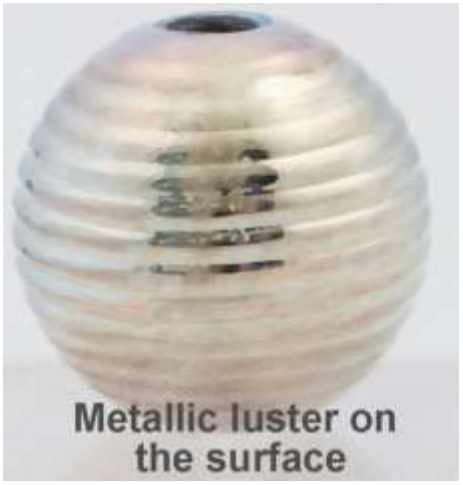
Working with

Colors

Jed Hannay

Working with Reducing Colors



The Reducing Process

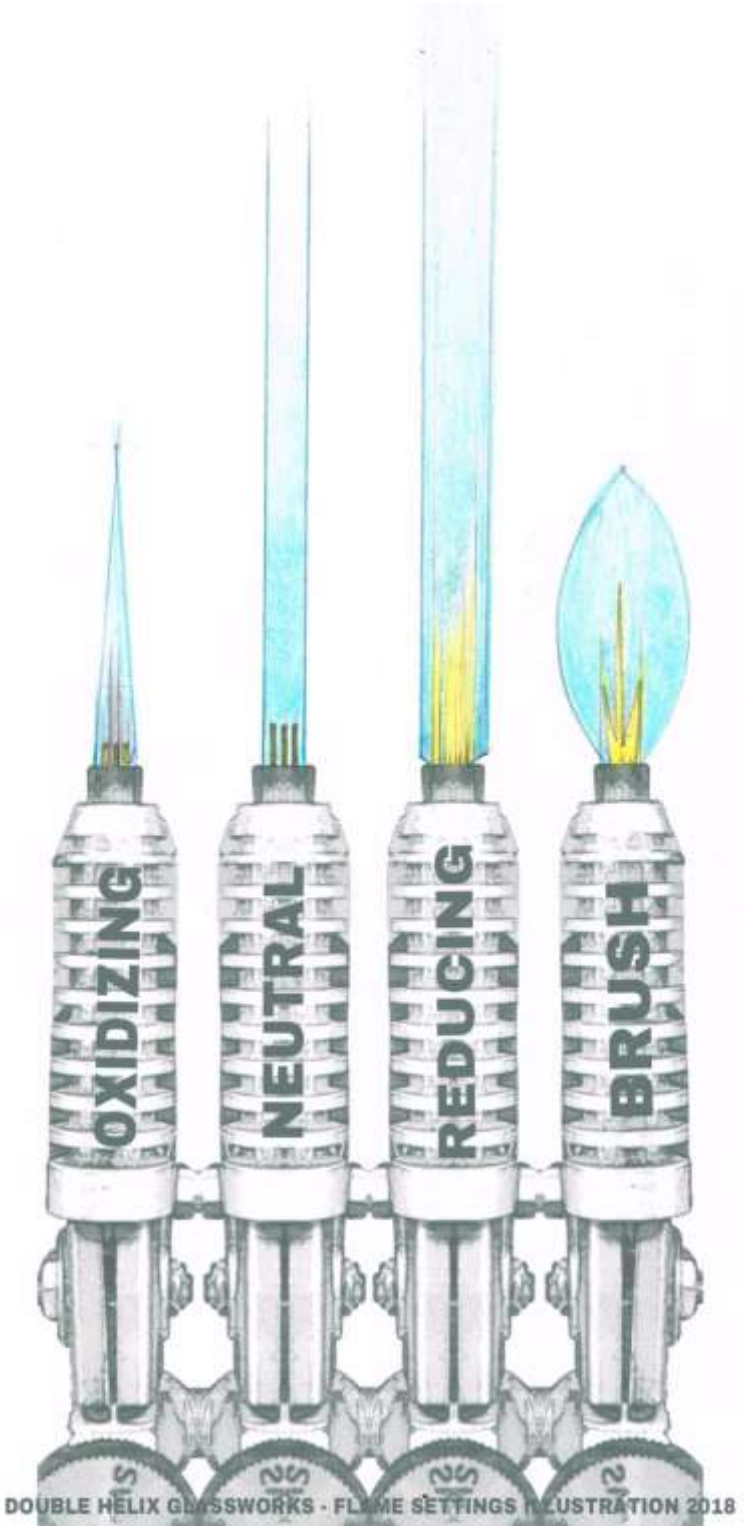
1. Work in a neutral flame.
2. Cool until the glow is gone.
3. Create a reduction flame; increase fuel or decrease oxygen.*
4. Briefly expose the glass to the reduction flame (5-10) seconds.
5. If more reduction is desired, repeat step 4, allowing the bead to cool between exposures.
6. For the pearlescent effect, encase the luster in clear without exposing the luster to the flame again.

*For some of the Dual Color Glasses, Reset before reducing.

Reduction Color Theory

Reduction colors contain silver dissolved in the glass matrix as Silver Oxide (Ag2O). Upon exposure to a flame deficient in oxygen, the Ag2O gives up its oxygen to the flame, leaving behind a thin layer of metallic silver. This metallic layer can be left on the surface or encased in clear glass.

A neutral or slightly oxidizing flame should be used during gathering, working, and shaping to preserve the silver in its oxide form. When the bead is ready to be reduced (after cooling) the flame is adjusted by increasing the fuel or decreasing the oxygen. The glass is then briefly exposed to this reducing flame.



Reduction Color Variables

Flame Chemistry

- An Oxidizing Flame will often display “hollow” areas inside the flame, where excess oxygen displaces fuel.
- A Reduction Flame will often have “stretched” candles.
- A Neutral Flame is somewhere in between the two, when there is an even balance of fuel and oxygen. Though a neutral flame is ideal, it is often simpler to adjust the torch to “slightly oxidizing”.
- A Brush Flame is a short, low velocity reduction flame.
- The chemistry of the flame also varies along the length of the flame, with areas closer to the fuel jets being generally more reducing than areas far out near the tip of the flame.

2. Heat

Though reduction is a chemical process, heat plays a role in developing the luster. The glass must be cooled before reducing or the luster can be muddy. Limiting the beads thermal gain during the reduction process will result in a cleaner luster. You can limit the heat by;

- Cooling the bead before reduction
- Using a cool reduction flame or
- Using repeated brief exposures to the reduction flame (5-10 seconds). Allowing the bead to cool for a few seconds between exposures.

3. Different Torches

Spend some time exploring the various flame settings. Different torches have a range of possible flame settings. See what your particular torch is capable of, and get use to dialing in your preferred flame settings. We do not recommend using a hothead. The more control you can have over your oxygen and your fuel, the better. We are usually using either Nortel's Arrow or GTT's Lynx with an oxygen concentrator and propane.

Trouble Shooting Reducing Glasses

1. No Reduction – usually caused by not cooling the glass for long enough before introducing it to the reducing flame. Can also be caused by too weak of a reduction flame.

2. Muddy colors- usually the result of too much reduction or too much heat.

a. Test your neutral flame. Hold a rod of reducing glass in it for a few seconds. If it develops a metallic sheen on the surface, then it's not neutral. Adjust by increasing your oxygen or decreasing your fuel.

b. Reduce for shorter periods, at the tip of a cool reducing flame.

3. Losing the luster in the kiln –annealing temperature is too high. We anneal at 950^{O}. You can also try putting activated charcoal in your kiln.

4. Erasing the luster – you can burn off the metals from the surface of the glass if it isn't muddy yet. Adjust your torch to an oxidizing flame and erase the luster.

Introduction to Striking Glasses

Striking Color Theory

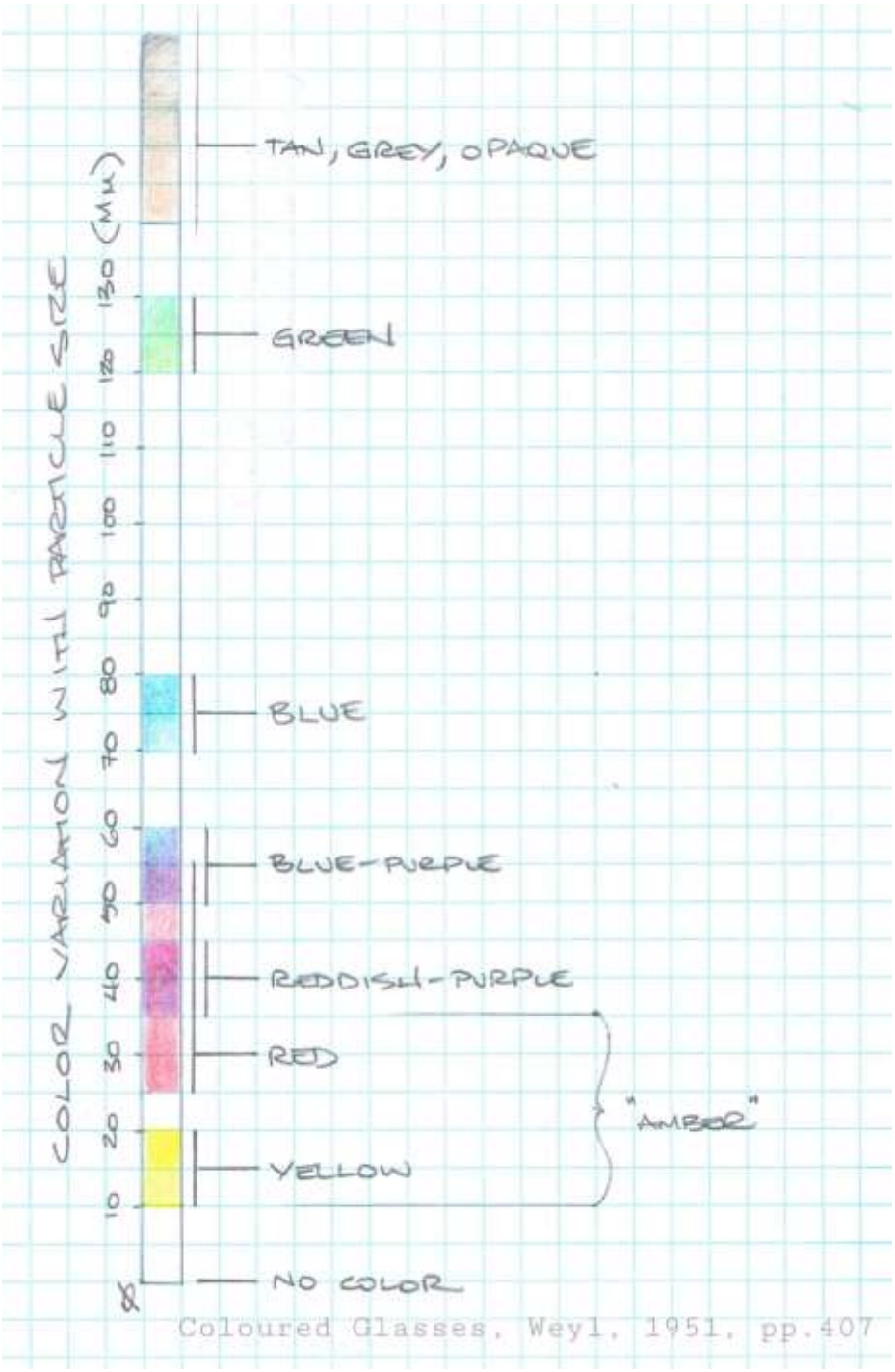
The theory of striking colors is that the metals; silver, gold and/or copper are growing crystals (or colloidal chains, depending on which theory you prefer). Silver, or other metals, are dissolved in the glass. When the glass is cooled, then

reheated, crystals form inside the glass. As these crystals grow, they cause the glass to transmit and reflect different wavelengths of light.

1. Crystal Growth & Nucleation

Crystal growth begins at a nucleation point. Striking colors can be homogeneously or heterogeneously nucleated. In homogeneously nucleated glasses, the metal itself forms aggregates that act as nucleation centers. In heterogeneously nucleated glasses, additional materials have been distributed throughout the glass. These materials act as nuclei, “seed” locations for crystal growth. All of our silver striking colors contain additional nucleating agents to affect a clean and complete strike.

2. <u>Crystal size and Color Transmission</u>



As the crystals grow, different colors are transmitted. For silver-based striking colors, the color sequence of lengthening crystals is; clear, yellow, red, red-purple, blue-purple, blue, green. The yellow and red stages usually occur together, resulting in amber or transparent brown. Variations in glass micro-composition, thermal history and heat application throughout the processes creates a polychromatic effect. Overstriking, the development of oversized or disorderly metal crystals tends to produce dull, muddied tones.

Striking Color Process

The process for developing desirable colors from silver striking colors has three distinct steps: Reset, Cool, and Strike (RCS)

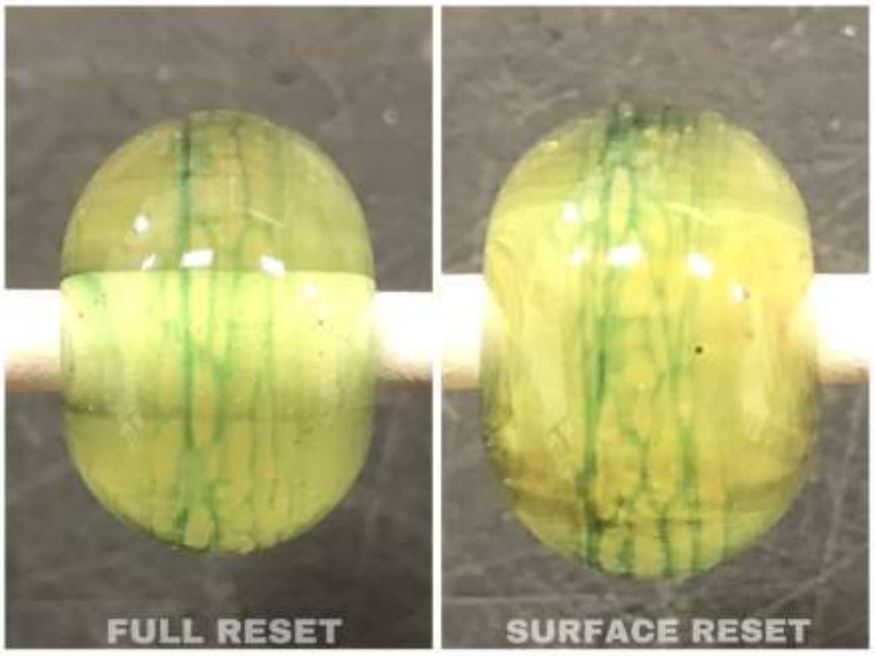
1. Reset

a. Erasing the Thermal History

During production, the glass has been held at striking temperatures for several hours, resulting in crystal growth. The rods are in an overstruck state looking opaque or misty. When the glass is heated above a certain temperature, the metals re-dissolve, yielding a clear glass. We refer to this process as the reset. The reset erases the thermal history of the glass, allowing the controlled intentional growth of the metal crystals. It's best to reset in a separate step. This eliminates variables and provides a more consistent outcome. At the temperatures that silver glasses reset, 104coe glass bases are soft enough to move. This does not mean the glass has to be "sloppy hot" to effectively reset the silver. A more judicious application of heat can reset while allowing the viscosity of the glass to remain controllable.

b. Surface or Full Reset

The visual cue for reset is transparency. In some colors this will be crystal clear, in others a clean transparent color, tinted by other metals in the glass. Skylla resets to a transparent light green. In a full reset, the mass of glass would be heated until the entirety of the glass was transparent and the mandrel is visible through the glass. In practice, we often end up with a surface reset, in which the transparent layer only extends to a certain depth, with the core of the bead remaining opaque, swirled, or dark colored. For some applications this is adequate.



c. Trouble Shooting the Reset
Inadequate reset can result in failure to strike (it didn't do anything) or muddy colors.

2. Cool

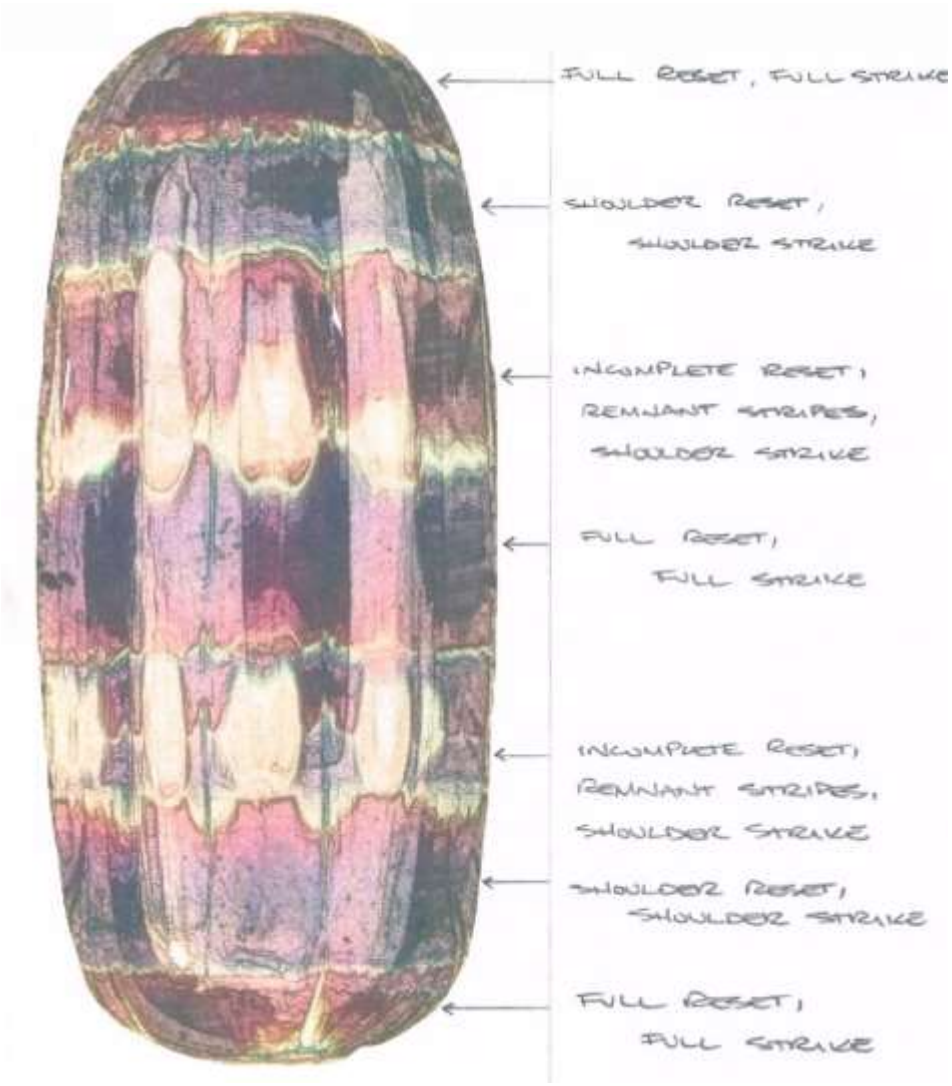
The cooling cycle is a critical step in achieving repeatable color outcomes. If the reset glass is not allowed to cool before striking, the process does not yield the desired crystal growth. There is a range of cooling times that produce desirable color outcomes. Generally, shorter cooling times will yield lighter pastel colors and longer cooling times will yield darker colors.

a. Determining Cooling Times
   I. The earliest appearance of light yellow or amber colors can be a cue that the cooling cycle is complete and the glass is ready to strike.
   II. Use known times (gained through experience) to count off the correct cooling time. A clock, stopwatch, metronome, or steady repeatable count can be useful.

b. Several variables can alter the cooling times of a striking color.

More Cooling	Variable	Less Cooling
the bigger the mass	Glass Mass	the smaller the mass
air cooling	Cooling method	use of heat sinks
encased	Depth of Application	surface
the hotter the glass	Temperature of glass at beginning of cooling	the cooler the glass

Trouble Shooting the Cooling Phase		
Stuck in Amber Phase	no cooling time	Your glass is being reset over and over
Light Pastel Colors	too short cooling time	
Dark Colors	too much cooling	may look deep amber with hints of blues and purples.



3. Strike

Once the bead has been reset and appropriately cooled, the glass is struck by gently heating in the furthest reaches of a neutral flame. The striking temperature needs to be cooler than the reset temperature. The glass may be hot enough to move under pressure, but does not flow in response to gravity.

Visual cues for striking include the faint orange glow indicating appropriate temperature as well as direct observation of the glass color. If the color appears too dark, additional strike time can be used. Longer strike times tend to produce lighter, more pastel colors. Excessive strike times can develop more opaque, neutral tones.

Trouble Shooting the Strike

Too hot of a strike will reset the glass again resulting in a continuous reset.

Introduction to Technical Glasses

- Technical Glasses, previously called Neutral Glasses, do not require the full reduction or striking processes but they do have other specific working characteristics.
- The Clears:
    - Aether is a reactive clear. It will interact with reducing glasses, usually by adding a yellow tint. Attractive over blues like Triton, but less attractive over pinks, like Clio.
    - Zephyr is non-reactive.
- The Gold Rubies:
    - Rhea and Lotis have been preset to strike red or pink during normal working conditions. Avoid overheating, which will reset them and result in undesirable colors. They can be used directly under or over our luster colors without a reaction.
- The Oracles: The Oracle project gives 104 flame workers the option to use low toxicity glasses in their work. They are made in the USA, without Antimony, Arsenic, Cadmium, Chromium, Lead, Nickel, or Selenium.

    - Oracle-Black appears as a dark blue rod, but strikes in the flame and in the kiln to produce a deep black. For best results, briefly flame strike before annealing. No reset or cooling is required. We anneal at 950F for 2+ hours. It has a relatively low colorant load, which improves working characteristics. There is a limit to how thin it can be applied and still read as black. It is somewhat reactive with our silver reducing glasses, but does not react with our silver striking glasses.

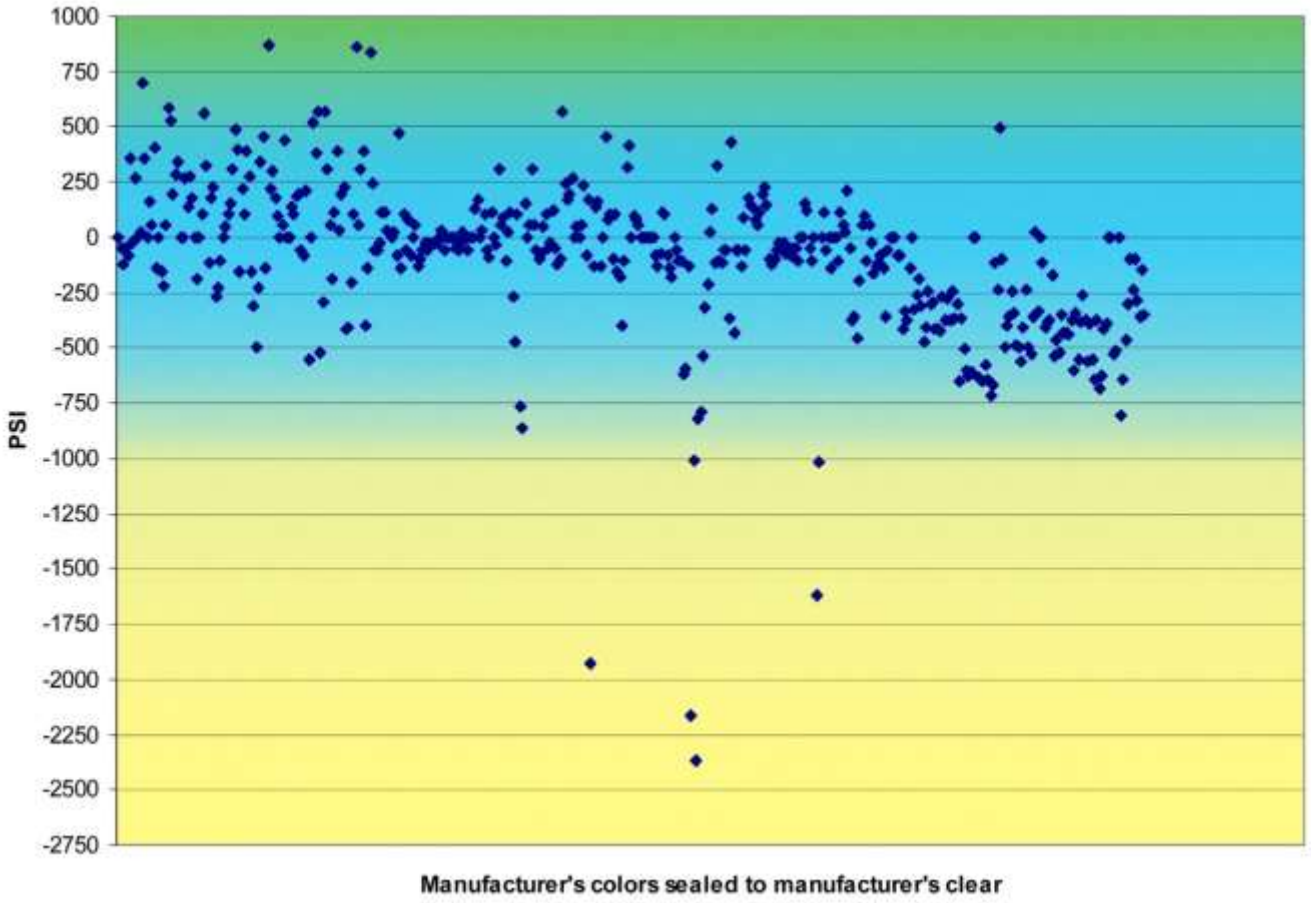
    - Oracle-White - has a nice viscosity curve, it allows for some light transmission which creates a brighter appearance. It's good as a base white, in thick stringer and in latticino.
    - Oracle-Ruby- kiln striking copper ruby, reset right before annealing. Anneal at 950 for 90 minutes.

Compatibility

Our philosophy on compatibility is to measure for strain between our glass and Effetre clear and to only sell those pots that are within a narrow span of strain. We test every pot at the top, middle and bottom. We keep records of these tests for every single pot of glass we've made.

We measure the stress by taking two sample rods of our glass and a rod of Effettre clear and sealing the three together in the kiln. This is called a Trident seal. After annealing the Trident seal, we read it in a polarimeter to measure the strain between the two glasses. The strain is expressed in pounds per square inch (PSI). The manufacturers of the polarimeter equipment and other respected glass companies state that 1000 PSI is a safe limit. Above this point breakage may occur. The glass being tested can be softer or stiffer than the control glass it is being tested against. This difference can be noted with the use of positive and negative PSIs. A positive PSI indicates the glass being tested is stiffer than the control glass, and a negative PSI that the test glass is softer than the control glass. The use of positive and negative PSIs splits the safe limit of 1,000 PSI into +/- 500 PSI. It is important to note whether the glass is softer or stiffer because different adjustments must be made to correct the next batch.

To understand how broad the tolerances of the 104-soft-glasses are, we tested several other manufacturers. We took samples of their available colors and tested them against their own clears. You can see the results in the following chart. The total readable spread of strain was 3,031 PSI (867 PSI to -2,164 PSI). The actual spread is greater because the 3 broken samples can't be read. With a spread this broad it is not feasible to manufacture a glass that would be compatible with all 104- soft-glass colors. The best any manufacture can do is maintain tight tolerances and apply them to every pot of glass they produce.



- 87% of the samples were well within safe limits of +/- 500 PSI.
- 13% were outside of safe limits, of those;
    - 9% were below -500 PSI
    - 2% were above 500 PSI
    - 1% were below -1000 PSI
    - 1% broke

Additionally though some colors were compatible with the manufacturer's clear they may not be compatible with other colors from the same manufacturer. For example, if you took a glass manufactured by company X that measured -760 PSI and used it with a glass also from company X that measured 700 PSI your total theoretical PSI would be 1,460 PSI. This is beyond the recommended limit of 1,000 PSI and may break.

We only sell glasses that have tested +/- 350 PSI, well below the safe limit of +/- 500 PSI. Having a tight tolerance is the best action we can take to solve for compatibility issues.

Glossary

Terms related to reducing

- **Reduction Glasses–** are exposed to a reducing flame to create a metallic luster.
- **Reducing Theory-** the process of exposing a silver or other metal glass to a reducing flame to develop the metallic luster. The glass is heated, cooled, and then placed in a reducing flame. Chemically, the exposure to a flame deficient in oxygen, forces the silver to give up its oxygen to the flame, leaving behind a thin layer of metallic silver.
- **Reducing Process-** Use a neutral or slightly oxidizing flame until ready for the reducing process. Then, cool the glass while setting a reduction flame. Briefly and repeatedly expose the glass to the reduction flame. (5-10 seconds). Allow the glass to cool for a few seconds between exposures.
- **Reducing flame –** created either by increasing the propane or other fuel in your torch or decreasing the oxygen. The candles should appear stretched.
- **Cool reduction flame –** usually the area at the tip of a reduction flame, farthest from the face of the torch.
- **Brush flame** – a short, low velocity reduction flame.
- **Neutral flame** - is neither reducing nor oxidizing. There is an even balance of fuel and oxygen. Though a neutral flame is ideal, it is often simpler to adjust the torch to “slightly oxidizing”
- **Oxidizing flame-** contains more oxygen than fuel. It will often display hollow areas inside the flame, where excess oxygen displaces fuel.
- **Luster –** the layer of silver or other metal that is developed to the surface of the glass.
- **Pearlescence-** the process of encasing the metallic luster in a clear or transparent layer of glass.
- **Muddy** – usually the result of a reducing glass being over reduced. Over reducing can happen when a slightly reducing flame is mistaken for a neutral flame or during the reduction process when reduced for too long, too hot or too close to the face of the torch.

Terms related to striking;

- **Striking Glasses -** are heated, cooled and struck to develop color.
- **Striking Color Theory-** the silver or other metals in the glass, when cooled, and then reheated, form crystals inside the glass. As these crystals grow, they cause the glass to transmit and reflect different wavelengths of light, which appear as different colors.
- **Striking Process-** The three steps required to develop multiple colors in striking glasses. They are reset, cool, and strike (RCS).
- **Strike:** the last step in a three part process for striking glasses. The glass is struck by gently heating in the furthest reaches of a neutral flame. The striking temperature is higher than the cooling temperature, but not as hot as the reset temperature. The glass may be hot enough to move under pressure, but does not flow in response to gravity.
- **Kiln Striking** – glasses that need to be reset and cooled but struck in the kiln. Flame striking will result in over striking.
- **Reset –** When the glass is heated above a certain temperature, the metals re-dissolve, yielding a clear glass. This erases the thermal history of the glass, allowing intentional metal crystal growth.
- **Full Reset -** the mass of glass is heated until the entirety of the glass is fully transparent.
- **Partial Reset -**only the surface of the glass has been reset.
- **Crystal growth -** When silver or other metal glass is cooled, then reheated, crystals form inside the glass. As these crystals grow, they cause the glass to transmit and reflect different wavelengths of light.
- **Nucleation –** can either be the aggregate that silver or metals form in the glass from which the crystal growth begins or additional materials can be added to act as attachment points for crystal growth.
- **Homogeneously Nucleated -**In homogenously nucleated glasses, the metal itself forms aggregates that act as nucleation centers.
- **Heterogeneously nucleated -**In heterogeneously nucleated glasses, additional materials have been distributed throughout the glass. These materials act as nuclei, “seed” locations for crystal growth.

- **Color Transmission –** the size of the grown crystals correspond to different color transmissions.
- **Over Striking -** the development of oversized or disorderly metal crystals tends to produce dull, muddied tones.
- **Thermal History –** The heat history of the glass. Resetting erases the heat history.

Other Terms

- **Cooling –** both reduction and striking colors require a cooling period before reducing or striking. Without a cooling period, reduction colors will be muddy or lusterless. In striking colors the cooling cycle is a critical step in achieving repeatable color outcomes. If the reset glass is not allowed to cool before striking, the process does not yield the desired crystal growth.
- **Compatibility** - the ability of two or more different glasses to seal together without causing so much stress between them that they break apart.
- **Neutral Glasses-** Neutral Glasses do not require special treatment or flames.
- **Technical Glasses –** do not require the full reduction or striking process but they do have other specific working characteristics.
- **Reactive –** some glasses have a chemical reaction with other glasses. For example, Aether reacts with silver glasses resulting in a green tint.
- **Test Batch-** a glass color that we are exploring. It will be labeled in the format XX-###
- **Production Color-** a glass color that has passed the testing phase and has been named. All of our colors use names from the Greco Roman pantheon.
- **Orphan Rod-** Orphan rods was either separated from the rest of its batch and we no longer know where it belongs or there was too little quantity of it to make a product. You can take some home by checking the box in your order.
- **Garage Sale-** a bundle of deeply discounted glass made mostly of redundant test batches and odd lots with a mix of; neutral, reduction, striking, dual colors and neutrals in first, second or third quality rods or frit.

Master Glass List

Color	Reducing	Pearlescent	Striking	Technical	Working Notes	Other Versions	Related Test
Aether	no	no	no	yes	reactive clear; reacts with silver colors. Do not pickle. Does not etch.	Aether 2	
Aion	yes	no	no	no	work in a neutral flame, cool, reduce	Aion 2	A-
Arke	yes	yes	no	no	work in a neutral flame, cool, reduce	3mm	IL-
Aurae	yes	yes	no	no	work in a neutral flame, cool, reduce	light, dark, gold	M-. AULTG-
Boreas	yes	yes	no	no	work in a neutral flame, cool, reduce		BE-
Chloe	yes	yes	no	no	speckled; work in a neutral flame, cool, reduce		TC-, TO-
Clio	yes	yes	yes	no	Reset, cool then reduce.	light, dark, odd	NE-, CA-, CE-, CL-
Ekho	yes	yes	yes	no	Reset, cool then reduce.	Ekho 2	EK-, TE-
Elektra	yes	yes	no	no	work in a neutral flame, cool, reduce	Elektra 2, 2.1, Lyte	E-. EL-, GR
Euros	yes	no	yes	yes	strike, reduce, or both. Reduce with a shorter cooling cycle for gold flakes.		EU-
Gaia	yes	no	no	no	work in a neutral flame, cool, then reduce.		
Helios	yes	no	no	no	work in a neutral flame, cool, reduce		HE-
Hyperion	yes	yes	yes	no	Reset, cool then reduce.	Light, Dark	CX-
Iaso	yes	yes	no	no	Best on the surface with a Brush Flame, copper reduction		AX-
Iris	yes	yes	no	no	Best on the surface with a Brush Flame, multi colored reduction		AX-
Kalypso	yes	yes	yes	no	Reset, cool then reduce.		KA-
Khaos	no	no	yes	no	Reset, cool, then strike.		KH-
Keto	yes	yes	no	no	speckled; work in a neutral flame, cool, reduce		TC-
Kronos	yes	no	no	no	work in a neutral flame, cool, reduce	Kronos 2, Super	
Lotis	no	no	no	yes	avoid overheating		
Luna	no	no	yes	no	reset, cool, strike	Luna 2, 2.1 & 3	L, LL
Melia	yes	yes	no	no	Best on the surface with a Brush Flame	Melia 2	CC-, EG-
Notos	yes	no	no	no	work in a neutral flame, cool, reduce		NO-
Nyx	yes	no	no	yes	work in a neutral flame, cool, reduce, also changes color in the kiln.	Nyx Odd	
Okeanos	yes	yes	yes	no	Either treat as a striking color or reducing color rather than combining.		OK-, TH-
Oracle-Black	no	no	yes	yes	no reset, no cooling, briefly strike before annealing, anneal @950 for 2+		ES-582
Oracle-White	no	no	no	yes	avoid overheating to prevent seperation		WH-
Oracle-Ruby	no	no	yes	no	kiln striking, reset before annealing at 950 for 90 minutes		RA-399, RE-695

Color	Reducing	Pearlescent	Striking	Technical	Working Notes	Other Versions	Related Test
Ossa	yes	yes	no	no	speckled; work in a neutral flame, cool, reduce	Light	OP-
Oxalis	yes	no	no	no	work in a neutral flame, cool, reduce		OX-, TO-
Pandora	yes	no	no	yes	strikes in the kiln	Pandora 2, Dark, Light,	PD-
Phoebe	yes	yes	no	no	work in a neutral flame, cool, reduce		ZL-
Phaeton	yes	yes	no	no	work in a neutral flame, cool, reduce		PK-, PL-
Psyche	yes	yes	no	no	work in a neutral flame, cool, reduce	Psyche Light, Dark	
Rhea	no	no	no	yes	avoid overheating	Rhea Light	RO-, RN
Skiron	no	no	yes	no	reset, cool, strike		SK-
Skylla	no	no	yes	no	reset, cool, strike		TK-
Terra	yes	yes	yes	no	Either treat as a striking color or reducing color rather than combining.	Terra 2, Fast Striking,	TE-, T-, G-
Terranova	no	no	yes	no	reset, cool, strike	Terranova 2, 2.1, Light,	TN-, Rh-, R-, H-
Thallo	yes	yes	no	no	work in a neutral flame, cool, reduce		OX-, TO-
Triton	yes	yes	no	no	work in a neutral flame, cool, reduce	Light	SL-
Zephyr	no	no	no	yes	Non-Reactive clear. Do not pickle, does not etch.	3mm, 5mm, 8mm, 12mm	ZE-
Experiments that aren't production colors, yet.							
Misc Striking			yes	no	Test batches with no production color match. Reset, cool, strike		AK-, HM-, OC-, VK-
Misc Reducing	yes	maybe	no	no	Test batches with no production color match. Work neutral, cool, reduce		CH-, OO-, SC- , TL-.EG
Catalyst	no	no	no	yes	Reacts with reduction colors, causing them to strike on contact.		RE-391, ES-404, ES-405
Opals	no	no	yes	yes	kiln striking; opacified at 950^{O} for 30 minutes		WO-733
Opaque Pink	no	no	yes	yes	apply hot, super heat, super chill, strike		SP-
Reverse Luster	yes	maybe	no	yes	Develops luster in oxidizing flame. Work neutral, cool, Oxidize		MX-, XX-
The very first Double Helix Glasswork's colors were handmade at the torch and sold on Ebay. These include, Dark Star, Emerald City, Kentucky Bourbon, Nebula, Northern Lights, Olympia Rain, Pacific Mist, Passion Flower, Purple Nebula, Rhubarb, River Rock and Sugar Plum.							

Words of Advice

1. **Use forced air ventilation when melting any glass at the torch.**
2. **Use proper protection when handling glass frit and powder.**
3. **Most of our glass does not etch.**
4. **Do not pickle.**
5. **We do not recommend using our glasses with a hothead. We recommend annealing at 950^{O}F.**