



**Tools and Resources**

***“How Glass Changed   
the World”***

October/November 2018

<http://www.acs.org/chemmatters>

**Teacher’s Guide:**



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**Tools and Resources**

***“How Glass Changed the World”***

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# Connections to Chemistry Concepts

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| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Covalent bonding** | In lessons about covalent bonding, students will find the properties of substances with network covalent bonds, like those in silicon dioxide used for glass manufacture, are different from most covalently bonded materials. |
| **Bond energy** | The high heat (sufficient kinetic energy) required to break the silicon-oxygen bond when sand is melted to make glass indicates the significant bond energy contained in the silicon-oxygen bond. |
| **States of matter** | While studying the states of matter, glass serves as an example of an amorphous solid—without a definite internal molecular structure—making it fall in between the categories of solids and liquids. |
| **Crystalline structures** | The amorphous structure of glass is often contrasted with crystalline structures. The use of crystalline compounds in glass can provide interesting comparisons between the properties compounds have in their crystalline state and in a molten, amorphous state. |
| **Mixtures** | Just as glass is hard to classify by the traditional chemical definitions of solids and liquids, it can prove as challenging to classify the type of mixture of various forms of glass. Some forms may be considered homogeneous solutions, while others could be seen as heterogeneous. Glass serves as an example of a material that defies being classified and challenges students’ thinking about a classification for this substance. |

# Teaching Strategies and Tools

## Standards

* Links to **Common Core Standards for Reading**:
  + **ELA-Literacy.RST.9-10.1:** Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
  + **ELA-Literacy.RST.9-10.5**: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).
  + **ELA-Literacy.RST.11-12.1**:Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
  + **ELA-Literacy.RST.11-12.4:** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
* Links to **Common Core Standards for Writing**:
  + **ELA-Literacy.WHST.9-10.2F**: Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
  + **ELA-Literacy.WHST.11-12.1E**: Provide a concluding statement or section that follows from or supports the argument presented.

## Vocabulary

* **Vocabulary** and **concepts** that are reinforced in the October/November 2018 issue:

Structural formulas

Amino acids

Chemical reactions

Equilibrium

Reaction rates

Oxidation & reduction

Electrochemistry

* Consider asking students to read “Open for Discussion: The Human Drive to Explore Space” to learn about the risks of space exploration prior to reading the article “Mars vs. Titan: A Showdown of Human Habitability.”
* Students may become interested in growing crystals to connect chemistry and art after reading the articles on pages 2 and 19.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles, and what they would like to explore further.
* Ask students if they have questions about some of the issues discussed in the articles.
* The *ChemMatters* Teacher’s Guide has suggestions for further research and activities.

# Possible Student Misconceptions

1. **“If a container is made of Pyrex, you can heat it and then pour cold water directly into it without damaging it.”** Some students think that because their lab glassware is Pyrex they can heat it directly over a Bunsen burner and then cool it off by placing it in a stream of cool water. They are somewhat surprised when it shatters. While Pyrex glass is able to withstand high temperatures, it does not tolerate sudden temperature changes, or thermal shock. Labels on Pyrex cookware state that the container can be frozen, microwaved, baked, and put in the dishwasher, but lots of caution directions are also provided in small print on the back. The back label cautions consumers to avoid severe hot and cold temperature changes, to use minimum amount of cooking time, to not use on any direct heat source, and to not add liquid to hot dishes or place hot dishes in the sink, immerse in water or place them on cold or wet surfaces. Pyrex dishes have been reported to explode, causing serious injuries. So, adhering to the safety precautions is very important. This list of Pyrex use restrictions can be found in the Epicurious article referenced here: <https://www.epicurious.com/expert-advice/pyrex-glassware-safety-shatter-exploding-tips-article>.
2. **“Glass flows very slowly, like a very thick liquid, and settles over time. That is why very old windows are thicker at the bottom.”** This is a myth that has been around for a long time. It is based on the observation that in antique windows the glass is often observed to be thicker at the bottom of the pane. Some have tried to explain this by stating that one of the properties of glass is that it will flow, like a liquid. The glass is thicker at the bottom of the pane because the glass continues to slowly flow, being pulled downward by gravity. In actuality, the windows are unevenly thick because of how they were manufactured. Antique glass was made by hand. Sometimes it was blown into a large cylinder and then cut down one side, allowing the molten glass to be laid flat. The glass often was wavy, bubbled, and uneven. Another early technique involved spinning molten glass on a round flat plate in order to force it to spread out like a large pizza crust. The edges turned out thicker than the middle. When the glass was cut for the window, often the thicker end was placed on the bottom for stability. Today window glass is made by floating the molten glass on top of molten tin. Tin has a lower melting point so, as the glass cools and hardens, the tin remains liquid with the hardened glass floating on top.
3. **“All compounds that are covalently bonded are supposed to have low melting points, like sugar.”** Most compounds that are covalently bonded **do** have low boiling points. This is because molecular solids, those with covalent bonds, are held together with intermolecular forces. These forces are relatively weak and, as a consequence, molecular solids are soft and have relatively low melting points (usually below 200 oC). Sand, however, is a **network** covalent solid, held together by a network of covalent bonds. Because covalent bonds are stronger than intermolecular forces, these solids are harder and have higher melting points.

# Anticipating Student Questions

1. **“What makes the silicon-oxygen bonds in sand so strong?”** The Silicon-oxygen bond is strong because the electrons between the two atoms are shared. The geometry of the bond is similar to the bent geometry found in water. What makes the silicon oxygen bond in sand itself so difficult to break is the giant network that is formed between the silicon and oxygen units. Essentially SiO2 is an **empirical** formula for sand. In reality, each silicon atom is covalently bonded to four oxygen atoms, and each of those oxygen atoms is bonded to another silicon atom. This tetrahedral structure around the silicon atom is similar to that of the arrangement of carbon atoms in diamonds, though not as symmetrical. The melting point of diamonds is over twice that of silica.
2. **“Does the flux chosen to be used when the sand is melted determine the properties of the glass product?** Fluxes lower the melting temperature of the silica but each one contributes slightly different properties to the glass. The three most common fluxes are sodium oxide (Na2O), lithium oxide (Li2O) or lithia, and potassium oxide (K2O). Na2O is most commonly used because it is both abundant and inexpensive. K2O can be used as a flux, and it creates a glass with a smaller expansion coefficient than sodium glass. Sometimes K2O will be used in conjunction with Na2O to modify the expansion properties of the glass product. Li2O lowers the melting temperature more than the other fluxes, and less of this compound is needed to get the right consistency for working with the glass. It also decreases the thermal expansion of the glass. However, due to its expense, it is reserved primarily for specialty glasses. Lead oxide (PbO) can be used as a flux as well. It provides low melting and working temperatures as well as contributes density to the glass, resulting in a glass with greater brilliance that is also easier to cut and polish. PbO also acts to stabilize the glass, preventing it from reacting with water or becoming cloudy. Na2O, K2O, and Li2O all require the use of a stabilizer that will make the glass harder and prevent it from dissolving in water. Calcium oxide or lime is the most common stabilizer.
3. **“What are the compounds used to make colored glass?”**

**Compound Color Compound Color**

Cadmium sulfide Yellow Gold chloride Red

Cobalt oxide Blue-violet Manganese Dioxide Purple

Nickel oxide Violet Sulfur Yellow-amber

Chromic oxide Emerald green Selenium oxide Reds

Carbon oxides Amber brown Antimony oxides White

Uranium oxide Fluorescent Iron oxides Greens &

yellow green browns

Copper compounds Blue, green, red Tin compounds White

Lead compounds Yellow

Manganese dioxide and sodium nitrate are used as decolorizing agents.

(<https://geology.com/articles/color-in-glass.shtml>)

1. **“When did they start using glass for windows?”** Glassstartedbeing usedin some windows shortly after A.D. 100 in Alexandria, Egypt, where a recipe for transparent glass was first created. Through experimentation with the ingredients added to the silica used to make glass, it was found that adding manganese oxide resulted in nearly transparent glass. This soon led to the use of glass for windows (although only in the most important buildings in the most important cities, like Rome and Alexandria). Early windows were usually cast, but some may have been made by rolling out the molten glass like dough. Both methods resulted in windows that were thick, cloudy, and uneven, but they let light in and kept the weather out.
2. **“How do they make Gorilla Glass®, used on cell phones, so strong?”** Gorilla glass is made so strong by an ion exchange process. A sheet of glass is placed in a bath of molten potassium salt at roughly 400° C. Smaller sodium ions leave the glass and are replaced with the larger potassium ions. The large potassium ions take up more room and get pressed together tightly when the glass cools. This creates a layer of compressive stress on the glass surface that makes it more resistant to damage. <http://www.corning.com/gorillaglass/worldwide/en/technology/how-it-s-made.html>
3. **“How is safety glass that is used in cars different from regular glass?”** Actually, there are two types of safety glass used in cars. The windshield is made by fusing a thin layer of the plastic polyvinyl butyral between two sheets of glass. The plastic holds the glass together even when it breaks, with the intent of keeping the passengers from flying out the windshield, being cut by flying glass, or being hit by an object that flies into the windshield from outside. The side and rear windows are made of tempered glass. Tempered glass is made using a process that heats the glass and then quickly cools it. The glass becomes harder and stronger. When it does break it does not break into large sharp shards like regular glass but breaks into small pebble-like pieces without sharp edges.
4. **“Where could I go to see (a) fulgurites, and (b) tektites?”**
5. Fulgurites, formed when lightning strikes the Earth melting the sand in its path, have been found all over the world wherever there is sand; however, they have also been found in rocks on the tops of mountains. Beaches and sand dunes are the most likely place to find fulgurites, as those that form in rocks are rare. Fulgurites often go undiscovered, because they form below the surface where the lightning has struck. Being fragile, when they do make it to the surface after the sand they are buried in erodes, they break up easily. Excavating the fragile fulgurites requires the skills of an archeologist. The longest excavated fulgurite on record was unearthed at a beach between Jacksonville, and Gainesville, Florida, by researchers from the University of Florida in 1997. It had two vertical branches that measured 16 ft. and 17 ft., respectively.
6. Tektites are found only where meteors have hit the Earth. They are located in broad swaths of land called strewnfields, named for how the glassy molten meteor pieces were strewn along the path of the meteor as it approached Earth. The strewnfields in North America are located in Georgia and southern Texas. The other fields are located in Australia, Ivory Coast, the Libyan Desert, central Europe, and Indochina.
7. **“Could sand recrystallize if glass were cooled very slowly after being melted?”** Complete recrystallization of glass into sand doesn’t happen but, in some glass, devitrification may occur. Devitrification is the conversion of glass material to crystallized material when the molecules in the glass change their structure into that of crystalline solids. This gives the glass a frosty or opaque appearance. When glass is held at a high temperature for too long, dust particles or other impurities can serve as nucleation points where crystals can start to form. The chemical composition of some types of glass makes them more vulnerable to devitrification than others. A high lime content can induce this condition. For some artistic applications, a degree of devitrification is desirable.

# Activities

**Labs and demos**

**“Prince Rupert’s Drops” demo:** Glass is melted and then dropped into cold water creating a teardrop shape hard enough to deflect a bullet at the rounded end but fragile enough to shatter if the tail of the drop is snapped.

Instructions for performing the demo can be found here: <https://www.youtube.com/watch?v=5zxZkK2aJig&feature=youtu.be>

A video taken by a high-speed camera of the Prince Rupert drop shattering can be found here: <https://www.youtube.com/watch?v=xe-f4gokRBs&feature=youtu.be>.

The story about the origin of Prince Rupert drops can be found here: <https://www.livescience.com/2720-secrets-prince-rupert-exploding-glass-drops.html>.

**“Glass Bead on a Wire” lab activity:** Students use borax and two different types of wire to see that glass is really a phase of matter rather than a particular material, and its color can be changed by other ions it absorbs when heated.

(<http://ceramics.org/wp-content/uploads/pcsa/Glass%20Bead%20on%20a%20Wire_Final.docx>)

**Simulations**

**“Glass Chemistry Game”:** In this online game, students listen to a narrator and then choose elements from the periodic table to make a specified color of glass.  
(<https://chemistry.cmog.org/>)

**Media**

**“How Glass is Made” video (6:37):** This video walks the viewer through each step of window-glass production, from the melting of sand to the stress testing of the final product. (<https://www.youtube.com/watch?v=IjNusHQOhTM>)

**“Glassblowing Science: How Does Glassblowing Work?” video (4:15):**  This “ACS Reactions” video takes the viewer on a trip to the McFadden Art Glass factory to watch glass objects being created, while also discussing the science involved in glassblowing. (<https://www.youtube.com/watch?v=HkLpAw9u-UU>)

**Lessons and lesson plans**

**“The Glass Age**”: In this two-part lesson plan with four activities, students learn about the history of glass and how glass technologies are changing our lives. Online resources are provided for the students to explore the science behind today’s glass engineering and to brainstorm future innovations. (<http://ymiclassroom.com/lesson-plans/glass-age/> )

**“Not Breaking Up is Hard to Do: The Properties of Glass”:** In this lesson, students will learn about the properties of glass, make sugar glass with a known recipe and test its properties, then choose a way to modify the recipe to see how the properties change. Activities where students learn about current glass innovations are also part of the lesson plan. (Access is restricted to AACT members, but the article will be available for free until December 1, 2018 at <https://teachchemistry.org/classroom-resources/not-breaking-up-is-hard-to-do>.)

**Projects and extension activities**

**“Forensic Glass Analysis”:** If you are teaching a unit on forensics, this lesson plan contains background information concerning glass making and the testing techniques used by forensic scientists to compare samples to determine the class or category of a glass sample or fragment. Students conduct an experiment that provides the student the opportunity to analyze fragments of glass for density, using a flotation method.

(<https://www.txcte.org/resource/lesson-plan-forensic-glass-analysis>)

**Glassblowing lab project:** Using glass tubing, students can make their own bud vase by melting the tubing closed and gently blowing into the tubing to create the bulb. Instructions for this activity can be found in Part B of Experiment 3, referenced here: <http://matse1.matse.illinois.edu/ceramics/c.html>.

# References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles published from the magazine’s inception in October 1983 through April 2013; all**

**available Teacher’s Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [***http://ww.acs.org/chemmatters***](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab to the left, directly under the “*ChemMatters Online"* logo and, on the new page, click on “Get 30 Years of *ChemMatters* Magazine!” (the icon on the right of the screen).**

**Selected articles and the complete set of Teacher’s Guides for all issues from the past three years are available free online at the same Web site, above. Click on the “Issues” tab just below the logo, *“ChemMatters Online”*.**



In “Glass: An Amorphous Solid”, author Baxter gives detailed information about how glass is manufactured, while also referencing the history of glass.

(Baxter, R. Glass: An Amorphous Solid. *ChemMatters*. 1998, *16* (3), pp 10–11)

“Glass: More Than Meets the Eye” discusses chemical composition, refractive index, density, and fracture patterns of glass and applies it to how forensic scientists test glass to determine the source of glass fragments found at a crime scene.

(Rohrig, B. Glass: More Than Meets the Eye. *ChemMatters*. 2006, *24* (3), pp 4–7)

“Try This: Forensic Identification of Glass Activity” in the October 2006 *ChemMatters* issue provides students with instructions on how to use density to identify glass fragments.

(Try This: Forensic Identification of Glass Activity. ChemMatters. 2006, *24* (3), p 8)

The Teacher’s Guide for the October 2006 *ChemMatters* Rohrig article above provides background information about glass history, manufacturing and forensics, and it provides links to student activities involving the forensics evaluation of glass for crime solving.

# Web Resources for More Information

**History of glass**

This excerpt from *Uncle John’s Fast Acting, Long Lasting Bathroom Reader* is a concisely-written, interesting history of glass.

(<https://www.neatorama.com/2012/09/10/The-History-of-Glass/>)

In “Glass of the Alchemists”, a tremendous amount of the history of glass is uncovered in the discussions of the alchemists and their experiments with glass.

(<https://www.cmog.org/article/glass-alchemists>)

**Glass information**

The Corning Museum of Glass Web site offers hundreds of videos and articles with information on all aspects of glass.

(<https://www.cmog.org/research/all-about-glass>)

This site contains information about the history of glass, plus links to information on how glass is made, glass blowing, stained glass, glass ingredients, and a glass historical timeline.

(<http://www.historyofglass.com/>)

**Gorilla Glass® used for electronics**

This site provides information about how Gorilla Glass**®** is made, including links to three videos that help explain the science behind this new glass.

(<http://www.corning.com/gorillaglass/worldwide/en/technology/how-it-s-made.html>)

**Making scientific glassware**

“The Scientific Glassblowing Learning Center” reports general information about scientific glassblowing, accompanied by several examples of glassware projects.

(<http://www.ilpi.com/glassblowing/glassblowing.html>)

**“**The Art of Scientific Glassblowing” is a 1-minute video showing the fabrication of a specialized piece of glassware for chemistry researchers at the University of Connecticut.

(<https://www.youtube.com/watch?v=0XOnl6YwT0M>)

**Glass blowing**

This site contains links to several videos about glass blowing, including scientific glassware, marbles, and a 1959 Oscar-winning documentary featuring glassblowers, set to jazz.

(<http://thekidshouldseethis.com/tagged/glass-blowing>)

**Glass cutting and bending techniques for the chemistry lab**

Written and illustrated instructions can be found at this site for cutting, bending, drawing down glass, as well as instructions for making closed tubes, bulb tubes, and fitting a wash bottle.

(<https://www.911metallurgist.com/blog/glass-working>)

This is a Flinn Scientific instructional video about cutting and bending glass tubing.

(<https://www.flinnsci.com/how-to-cut-fire-polish-bend-glass-tubing/vht0036>)

**Fulgurites and tektites**

This *Scientific American* article discusses fulgurites and dispels the myth behind a photo claimed to be of a fulgurite; it concludes with a precaution to be careful what you Tweet.

(<https://blogs.scientificamerican.com/but-not-simpler/what-really-happens-when-lightning-strikes-sand-the-science-behind-a-viral-photo/>)

A world map depicting the location of the tektite strewnfields, as well as pictures of the different types of tektites discovered there at this site.

(<https://www.meteorite.com/tektite-info-sales/tektite-information/>)