TEACHER INSTRUCTIONS

Candy Glass

Objective

To explore glass science through the creation and processing of "candy glass." To demonstrate the unique properties of glass by examining the solid-liquid and liquid-solid transitions of a glass-like system.

Background Information

Glass is an amorphous solid that is typically brittle and optically transparent. An amorphous solid is any material that has no long-range order of atoms. Crystalline materials (such as a metal) have an orderly arrangement of atoms, while amorphous materials do not (Figure 1).

Glass is a unique material because its viscosity slowly decreases as heat is applied until it flows in a similar fashion to water. The temperature at which it transitions from solid to liquid is often referred to as the glass-liquid transition temperature.

As the glass is cooled, the viscosity slowly increases. This property allows gaffers (people who "blow" glass) or machines to work with and shape the glass into products such as vases or bottles. If the glass is cooled too quickly, stresses will form in the glass causing it to crack. The glass-liquid reaction is typically reversible, meaning the solid can move to a liquid state and then back to a solid state.

The glass-liquid transition of a solid to a liquid state typically occurs due to heating, and the reverse reaction of a liquid to a solid state typically occurs due to cooling or compression.

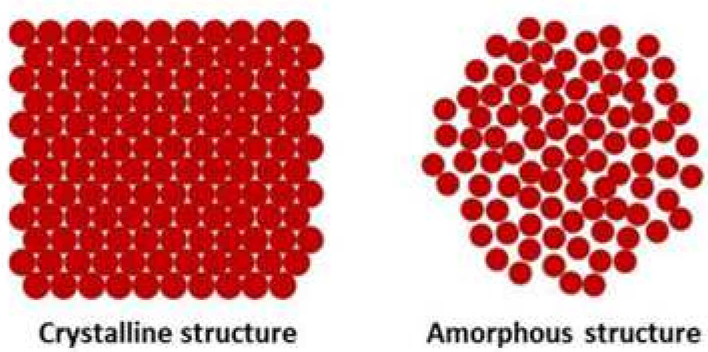

Figure 1. Crystalline vs. amorphous atomic structures

The term "glass" includes many different materials, some with which you are familiar. Soda-lime glass – composed primarily of silicon dioxide (sand) – is used in the production of windows and drinking glasses. Sugar glass – composed of a brittle transparent form of sugar – is used in movies, photographs, and plays to simulate soda-lime glass. It breaks very easily and is less likely to cause injuries, but still has the look and breaking patterns of soda lime glass. Cotton candy and lollipops are two glasses that are made from cane sugar.

Cotton candy is made by heating sugar until it reaches a molten state (liquid form) and squeezing it through small holes into a larger bowl that is spinning. The thin sugar fibers solidify almost immediately in the room temperature air and begin to collect on the outer edges of the bowl.

When you eat the cotton candy, the heat from your tongue causes the fibers to dissolve into a liquid form again. Other candies, such as lollipops and Jolly Ranchers, follow a similar process. Insulation used to keep your house warm in the winter is fiberglass, which is made in a similar fashion to cotton candy.

Using candy glass can provide a low-cost, hands-on approach to exploring aspects of real material science, focusing on glass science (Figure 2). Candy glass can be made from common kitchen ingredients including cane sugar (sucrose), corn syrup, and water. In this experiment, students will be introduced to common glass processing and characterizations including fiber pulling, composition, and refractive index.

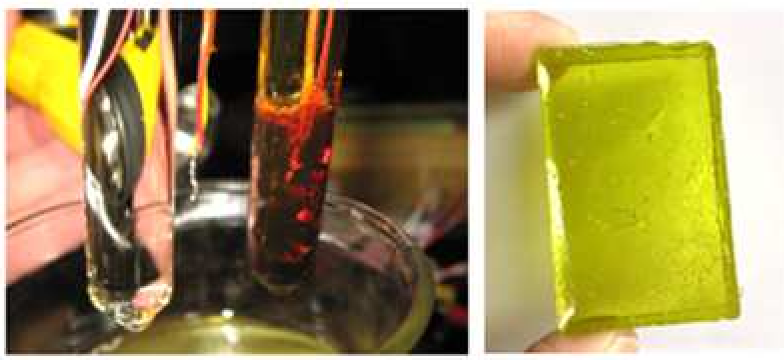

Figure 2. Candy glass examples.

(Left-Courtesy of Lehigh University Glass Laboratory, Right-Courtesy of Ursinus College)

Demo Description

During this demo, students will make their own candy sugar glass. Students will learn about common glass processing and characterizations including fiber pulling, composition, and refractive index. The creation of candy glass is essentially a mixture of sugar(s) and water heated to the right temperature to first dissolve the sugar and then boil off most of the water, stopping at the appropriate temperature to form a “glass” on cooling.

The temperature at which we stop boiling the mixture is directly linked to the residual water content which must be low enough to form the glass state of a hard candy. If the temperature is too low, a softer, non-glass, taffy-like candy will result instead (or even just a syrup).

In order for the highly concentrated sugar solution to remain in the "frozen liquid" state of the glass, we must avoid it from forming sugar crystals when cooling. Stirring too much can lead to this crystallization. The water and corn syrup are added as modifiers to help lower the melting point of the solution and limit crystallization. Alternatively, Jolly Ranchers® can also be melted in a beaker using a hot plate or in the silicon mold using a microwave.

Keywords

- Amorphous – non-crystalline materials that lack a long-range atomic order
- Glass – an amorphous, brittle solid which exhibits a glass-liquid transition when heated
- Liquid – fundamental state of matter characterized as having a definite volume, but no shape
- Solid – fundamental state of matter characterized by structural rigidity
- Viscosity – an internal property of a fluid that offers resistance to flow
- Glass transition temperature (T_g) – the transition in an amorphous material from a hard and relatively brittle "glassy" state into a viscous or rubbery state with an increase of temperature
- Fiberglass – a material fabricated from extremely fine fibers of glass and is used in a variety of applications ranging from household insulation to a reinforcing agent in ladders and automotive body panels

Materials List

Items Provided in the Kit:

- Silicon mold

Items Provided by Teacher/School:

- Water
- Cane sugar (sucrose)
- Corn syrup (Karo)
- 1 quart sauce pan (or 400 ml Pyrex beaker)
- Spoon (silicon recommended)
- Bowl for cold water
- Pan
- Aluminum foil

Optional Materials

- Candy thermometer (digital)
- Food coloring
- Hot plate
- Cooking spray
- Parchment paper
- Jolly Ranchers®
- Toothpick or Popsicle stick

Safety Precautions

Practice extreme caution while cooking and pouring the candy glass. The ingredients need to be brought to a very high temperature to form candy glass. To avoid burning yourself, use oven mitts while pouring and stirring. Instructors may wish to do the cooking part themselves as a demonstration for younger students. If you are using a hot plate and beaker they will get very hot. Caution should be used when handling the beaker during the demo. Allow the beaker and hot plate to cool before cleaning.

Figure 3. (Left) Candy glass ingredients.

(Right) measuring temperature.

(Courtesy of Lehigh University Glass Laboratory)

Instructions for making candy glass

1. Combine 4 teaspoons of the water (20 g), ½ cup cane sugar (120 g) and ¼ cup Corn syrup (Karo) in a 1qt saucepan or beaker. Mix and heat until the mixture boils (Figure 3). You can do this on a stovetop or hot plate. If you have a candy thermometer, insert it in the solution and note the temperature at which boiling occurs.

2. Dip your spoon into the solution and allow the liquid to drip back into the saucepan. It should drip back with a viscosity similar to liquid syrup. As you continue to heat your solution (temperatures above 250ºF (120ºC)) the solution will have an increase in viscosity and the drip from the spoon more slowly. Eventually you will see small threads forming from the ends of the drops as they fall from the spoon. As the boiling continues (and temperature rises), you should see more and more threadlike behavior. This indicates that a glass network is forming.

3. After the mixture has boiled for a while, notice when it becomes clear. Record the temperature at which the solution becomes clear. This is an approximate measure of the solubility temperature for this mixture.

4. **Testing for when your candy glass is done:** This can be accomplished two ways, by monitoring the temperature using a candy thermometer or by the "ball test."

- **Method One:** The temperature will rise as the water boils away. Once boiling begins, the temperature will rise slowly at first, but as the water boils away, the temperature increases at a faster rate. You will need to reach about 300ºF (150ºC) to get a good hard candy.

- **Method Two (The Ball Test):** The "ball test" is an old fashioned method to test if your candy is done. One you observe the threads beginning to form (see step #2), drop some of the hot syrup from the spoon into a dish of cold water. A "soft ball" will form when enough water has been removed to make a "taffy" 265ºF (130ºC). As you continue heating the drops falling in the cold water will become hard and crunch when bitten into. (Be careful to let it cool before putting it into your mouth.) As the candy approaches 300ºF (150ºC), you will be able to hear a distinct "crack" as the drop of hot mixture falls into the cold water. This is called the "crack" state and your syrup is ready to make a good hard candy (sugar glass) when cooled.

5. After you remove the saucepan from the stove, you can add food coloring if you choose. Only a few drops should be enough to change the color. The more drops you add, the darker your glass will be.

6. Pour the candy glass solution into the silicon mold or aluminum baking pan sprayed with cooking spray or covered in parchment paper.

Additional Demonstrations and Experiments

(1) Vary the water-sugar-corn syrup ratios in your starting solution and observe the results. If time permits, have students create a "sugar solution ternary diagrams" like Figure 4.

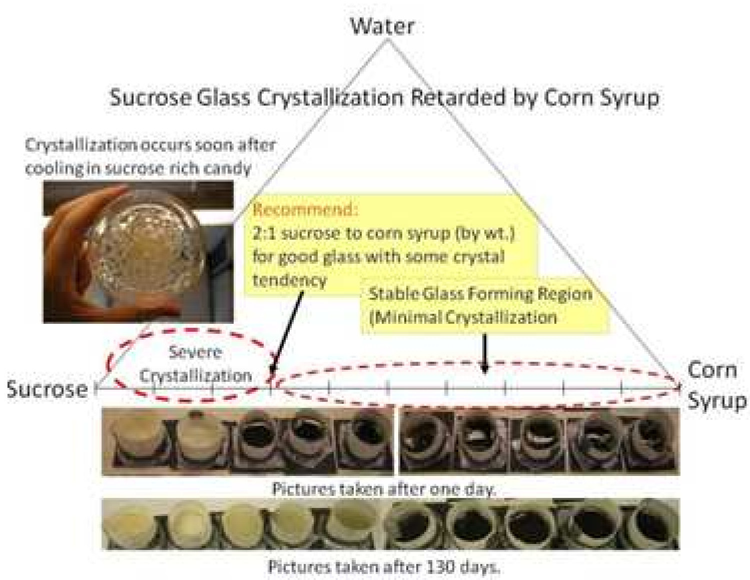

Figure 4. Water-Sugar-Syrup ternary diagram. (Courtesy of Lehigh University Glass Laboratory)

(2) Expose the candy glass to different environments and observe crystallization as a function of humidity and time. For example, you can create a dry jar by using desiccant or a high humidity jar using wet sponges.

(3) Measure the index of refraction for your candy glass. (See the Index of Refraction experiment from the Glass Science Kit Lessons for more details.)

(4) Instead of following step #6, dip a toothpick or popsicle stick to pull one fiber from the pan or beaker by removing it slowly. You must do this while the candy glass is still in a liquid state. Experiment with creating short fibers, long fibers, thin fibers and fat fibers. Have students compare how long they can pull the fiber before it breaks. (See the Candy Fiber Pull experiment from the Materials Science Kit Booklet Lessons for more details.)

Cleanup and Replacement Parts

Cleanup can be performed with standard dish soap and water once everything has cooled down. Replacement ingredients and candy thermometers can be purchased at most grocery stores. Beakers and hot plates can be purchased through online laboratory equipment supplies such as Fisher Scientific or VWR.

Acknowledgements

We thank the glass science team at Lehigh University for allowing us access and use of their extensive candy glass manufacturing and processing educational materials. A link to additional information including more candy recipes and candy glass experiments can be found here: https://www.lehigh.edu/imi/scied/libraryglassedu.html

TEACHER DISCUSSION QUESTIONS

Candy Glass

Questions for Before the Demonstration

1. Ask students if they can explain what an amorphous solid is and what a crystalline solid is?

Discussion: Crystalline solids have an orderly arrangement of atoms, while amorphous solids have no long-range order of atoms (*see Figure 1 in the Teacher Instructions*).

2. Ask students what they think will be some similarities and differences between real glass and candy glass?

Discussion: Processing will be different, and you need higher temperatures to melt most glasses compared to candy. Both real glass and candy glass can crystallize under certain conditions. They can both be made transparent or colored. Both break like real glass.

3. Ask students what do you think will happen once we add the ingredients and heat the solution? Will it boil? Will it become thick? Will everything dissolve?

Discussion: It will dissolve into a complete solution and become more viscous as it heats up.

Questions for During the Demonstration

1. Ask students what does the solution in the saucepan look like at different temperatures or times? How has it changed since you started heating it?

Discussion: Students should see the mixture dissolve and become clear with time.

2. If using a candy thermometer, ask the students to fill out Table I in the student handout. They should include the temperature in which the solution boiled and the temperature when the solution appeared clear. Ask the students if the boiling temperature was above the boiling temperature of water and why they think that is.

Discussion: Observations should include viscosity, clarity, appearance of crystallization, or changes in color and solubility. The boiling point will increase as water is boiled away from the solution leaving the sugar and syrup.

3. Ask students what happens to the water as the temperature increases.

Discussion: As you boil the solution the water disappears, this is evident as we observe an increase in boiling point.

Questions for After the Demonstration

1. Ask students how they determined when their solution was ready to pour. Which method did they use and how?

Discussion: Students should describe which method they used and how well it worked. They should hear a crack if using the "ball test." If their testing was not successful, what did they alter in order for it to work later?

2. Ask students to compare the melting behavior of ice to the way a glassy material, like hard candy, plastics or window (soda lime silica) glass melts.

Discussion: Students should talk about phase changes, viscosity, melting temperature, color and density.

STUDENT QUESTION HANDOUT

Candy Glass

1. Make a list of some examples of glass that you are familiar with.

2. Make a list of the properties of glass based on the list above and discussion.

3. What temperature did the mixture boil at? Was the temperature above 212ºF (100ºC)? Can you explain why?

4. What happens to the water as the temperature increases?

5. What temperature did the mixture become clear at?

6. Recall how a crystal, such as ice, melts. Compare its melting behavior to the way a glassy material, like hard candy, plastics or window (soda lime silica) glass melts.

7. What was the most interesting application of glass that you learned about today?

Table X. Observations during candy glass heating. Fill in intermediate temperatures. Include the temperatures where the solution boiled and when it became clear.

Temperature	Time	Observations
Room Temperature Starting		
230ºF		
300ºF		
Room Temperature Ending		