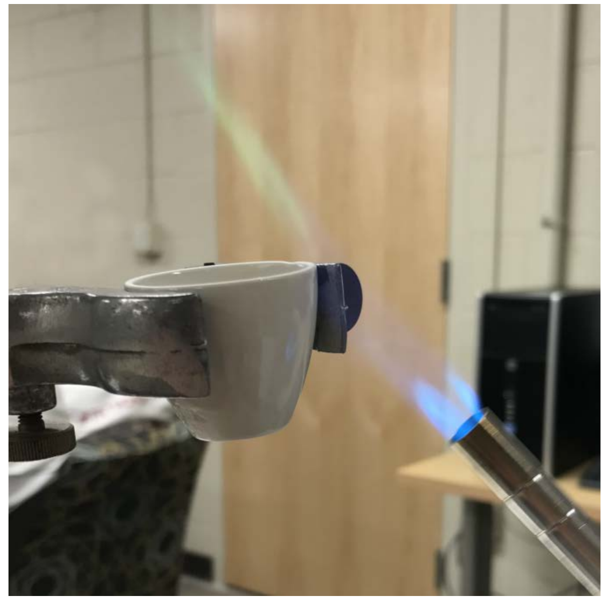
Your Very Own Borate Glass

Workshop

Students learn about glass, how glass is formed, and the conditions in which that occurs.

Glassy materials form a cornerstone of the study of material sciences—with leaps and bounds made in recent years, a full understanding of amorphous materials has never been so important. With this experiment, students learn about phase changes, atomic placement, and material properties.



Coe College

In this procedure, demonstrators create a simple glass that forms a pivotal point of the material science industry—borate glass, which is composed entirely of boron oxide.

Number of Participants: 2-20

Audience: Elementary (ages 5-10) and up

Duration: 30+ minutes

Difficulty: Level 4

Materials Required (Figure 1):

- 1 Double-ended bosshead clamp (1)
- 1 Extension clamp (slide-ended) (2)
- 1 Laboratory flask stand (52 cm) (3)
- 1 Ceramic crucible, 15-30 mL (4)
- Boric acid powder (5)
- 1 scoopula (6)
- 1 propane blowtorch (7)
- 1 pair of safety goggles (8)
- 1 pair of heat-proofed gloves (9)
- Heat-resistant material (ex. Bunsen burner pad, thin sheet of steel/iron)
- 1 timer
- Scientific measuring balance (only for High School section)

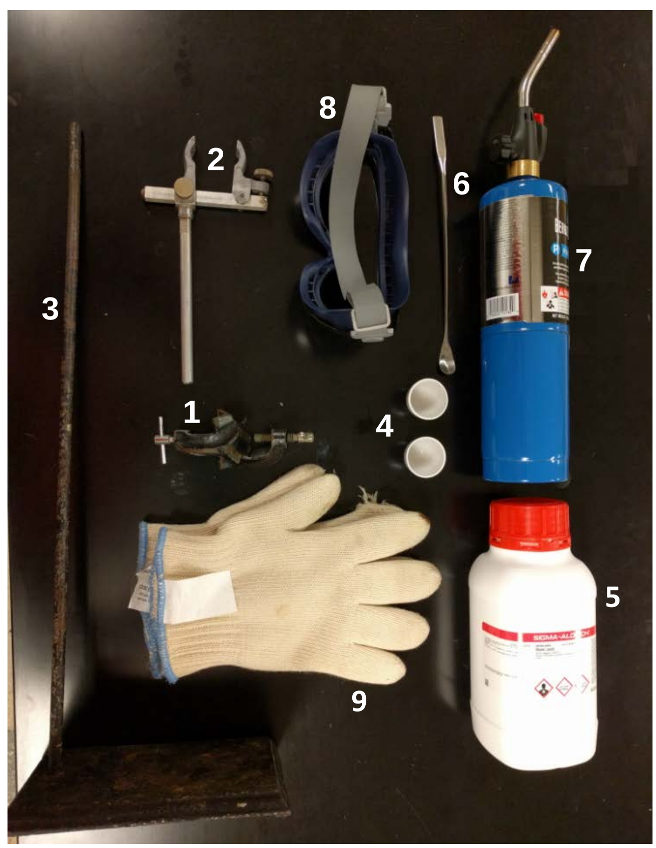


Figure 1

- *Optional* - Secondary compounds for colorization, such as:
    - CuO powder
    - Fe_2O_3 powder

See the "materials resource" document for suppliers of these items.

Setup:

1. Place the lab stand on a working surface and attach the bosshead clamp (double-ended clamp) three-fourths of the way up the lab stand (Figure 2).
2. Attach the extension clamp (slide end, much like a wrench) onto the open end of the bosshead so a 90° angle is formed between the lab stand and the extension clamp (Figure 3).
3. If the working surface is not heat resistant, position the desired heat-resistant material underneath the extension clamp, where the crucible will sit during the experiment.

Figure 2: Double-ended bosshead clamp

Figure 3: Extension clamp (slide-ended)

Experimental Procedure:

1. Take one ceramic crucible and inspect it for cracks/breaks. Once satisfactory, measure out 6 grams of boric acid powder using the scoopula and deposit in the crucible and mix for one minute. If a colored reaction is desired, measure out the necessary amount (see the table below) of secondary compound and deposit it in the crucible. Mix for an additional 3 minutes.

Secondary Compound	Weight (grams)	Resultant Color
CuO	0.01-0.005	Gray/Turquoise
Fe_2O_3	0.005	Dark Red

2. Insert the crucible into the extension clamp's grip, tightening the clamp's slide enough to hold the crucible tightly, but not enough to put too much stress on the crucible (Figure 4).
3. **PUT ON GOGGLES AND HEAT-PROOF GLOVES.**

Figure 4: Mounted ceramic crucible.

4. After testing the propane torch, begin to heat the base of the crucible. Heating the crucible too fast could cause it to break, as ceramics are sensitive to drastic temperature changes. Heating over a long period of time will not give the desired reaction. Turn the blowtorch's propane release a quarter turn, showing a bright blue flame. Pass the flame in a sweeping motion at the base of the crucible, keeping the nozzle of the blowtorch about three inches away from the crucible's base. Note, a demonstration video at spsnational.org/outreach for instructions on how to properly heat the crucible.
5. After one minute, move in closer to the crucible, making tight circular motions around the sides and base of the crucible. The nozzle of the blowtorch should now be one inch away from the crucible. Consult the video for an example. **DO NOT PUT YOUR FACE CLOSE TO THE CRUCIBLE.**
6. After another minute, steam should begin to release from the powder. This is the beginning of the decomposition of boric acid that will produce the boron oxide glass.
7. Continue to heat for another 6-10 minutes. Stop heating once steam stops releasing from the crucible, or the glass begins to boil over the top of the crucible. If this occurs, discontinue heat for one minute, then resume.
8. Once steam stops releasing, turn off the blowtorch and set aside. **DO NOT REMOVE PROTECTIVE EQUIPMENT.**
9. The crucible will take about 30 minutes to cool down. During this time, the glass will cool down, releasing the last bit of trapped air/steam. The glass may crack and eject small shards. **Do not get too close to the crucible until cool, and do not remove protective equipment.**
10. Once fully cooled, remove crucible from the extension clamp and admire your work. You have successfully made a borate glass!

Presenter Brief:

Familiarity of the basic boron oxide glass structure – trigonal borate and boroxol rings in this scenario is recommended. An overview of the states of matter and how temperature changes can elicit state changes is highly recommended for younger audiences. Be very familiar with the basic concepts of molecular bonding, arrangement, and organization.

Vocabulary:

- Amorphous solid (glass) – non-crystalline solids that do not display long-range organization, such as that of a crystal. Used as a term for glass.
- B_2O_3 – chemical formula for boron oxide. Also used as the chemical formula for glassy state borate. Composed of two boron atoms and three oxygen atoms in a zig-zag formation (in non-glassy state). In glassy state, arranges into the trigonal, tetrahedral, and boroxol ring formations while still retaining the chemical name. (Figure 5)
- Borate glass – a type of glass that has many practical applications in science and industry; produced by heating boric acid to above its melting temperature. Borate glass properties can wildly differ if a modifier element is added.
- Boroxol ring – the preferred structure that boron and oxygen will adhere to in a glassy structure. Composed of three boron atoms and six oxygen atoms in a hexagonal arrangement. (Figure 6)
- Glass transition temperature – known temperature at which glasses soften and atoms may move about, a defining aspect of all glasses.
- H_3BO_3 – chemical formula for boric acid. Composed of three hydrogen, one boron, and three oxygen atoms. (Figure 7)
- States of matter (phases) – three common existences: solid, liquid, gas.
- Tetrahedral borate – one of the atomic arrangements that borate molecules will adhere to. Composed of four oxygens arranged in a tetrahedron with a boron in the middle. (Figure 8)
- Trigonal borate – one of the atomic arrangements that borate molecules will adhere to. Composed of one boron and three oxygens in a triangular arrangement. (Figure 9)
- $2H_3BO_3 \xrightarrow{\Delta} B_2O_3 + 3H_2O$ – chemical equation detailing the reaction that boric acid undergoes to become glassy boron oxide. Pure boric acid has induced heat force it to undergo a chemical reaction that gives off water (H_2O) and boron oxide atoms, which arrange into a glassy borate structure.

Figure 5

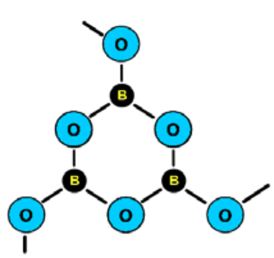


Figure 6

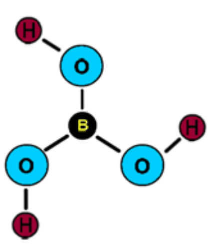


Figure 7

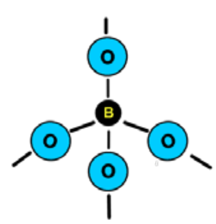


Figure 8

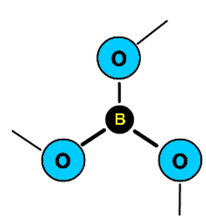


Figure 9

Physics & Explanation:

Elementary (ages 5-10):

This demo serves as a great introduction to the three states of matter.

> Ask participants what they know about states of matter. Lead the discussion towards the solid state, and show the participants an example of a glassy material. Ask about what they know is made of glass (and what they think might be).

We suggest creating a barrier of some kind between the experiment and the audience—chairs will do. It is also suggested to mix the compounds ahead of time—perhaps allow the participants to look at the powders and make predictions about what the final glass will look like. Also, if possible, pass out shaded glasses/goggles for the participants before starting, as they may be startled by the bare flame. Don't forget to put on your own safety equipment.

> While heating, ask the participants about what they know about state changes according to heat. When the compounds begin to liquefy and bubble up, invite students to look, while not getting too close. It can be nice to have a glass of ice water present to explain the process of a solid turning into a liquid.

The powder starts the process as a solid (powder), and when heat is added the powder turns into a liquid, with trapped water/air being released as a gas. As heat is added, the boric acid powder will bubble up and completely liquify. Upon removing the heat source, the now liquid compound will cool and solidify into the final product: glass.

> After the full heating cycle, while the glass is cooling down, explain to students what they just witnessed. Start the conversation with states of matter, and how different objects can exist in different states of matter. An infrared thermometer can be used to know when the crucible has cooled sufficiently.

> If the crucible has cooled enough to handle, show the participants the final product.

🔑 Solids are composed of tightly-packed atoms which hold their shape at room temperature. Solids can undergo a phase change into a liquid if heat or pressure is added. By increasing the temperature of an object, the atoms in the material can move around more.

Middle (ages 11-13) and general public:

Unlike solids, liquids do not hold their shape at room temperature because the atoms can move past each other. Once again, liquids can undergo a phase change into a gas.

Gasses take the shape of their container and the atoms move even more freely than in a liquid.

> Begin by explaining the three common states of matter. Point out that a substance can undergo a phase change and remain the same substance. An example is ice: Ice has several different solid forms yet all are solid. Carbon can also form different phases: graphite and diamond. These are physical changes. Sometimes, by adding heat or pressure, chemical changes can occur causing the substance to change.
>
> Use a reproduction of Figures 10-13 to explain how boric acid changes into borate glass. Have a few examples prepared ahead of time to display the difference between these two solids (powder and glass).
>
> Encourage some comparison and contrasting—what makes both materials, which appear so different, both solids? Refer to the definition of solid matter.
>
> After discussion, begin performing the experiment. Encourage students to observe the transition from a solid to liquid.

When the heat is introduced, the bonds in the powder break and atoms begin to move around, causing steam to form, be released, and allows the formation of borate glass.

> After the glass is finished forming, lead a discussion about the molecular bonds, the state changes, and the chemical reaction. If the crucible is cool, allow participants to observe the glass (while still wearing goggles).
>
> Encourage students to research ways glass is used in modern society, as some of the applications may surprise them.

Introducing heat or pressure to a substance can cause a physical change (like a state change) or a chemical change (like a chemical reaction).

High School (14 +):

Interactions on the molecular level usually need some energy to start the process (or they would have happened already). The elements that compose the powders will not interact with one another just by proximity due to their stable condition in the powder form at room temperature.

Before mixing, the compound’s molecules are randomly jumbled together without any interaction present. After mixing the powder thoroughly, the particles are distributed in a more uniform manner. With a better distribution of compounds, the material will melt and mix more evenly and produce a better material.

Mix the powder and begin heating.

With the introduction of heat (induced by the blowtorch’s flame), the stable bonds created by the compounds will begin to break apart and atoms will begin to move about—this is the start of the glass formation.

Show or reproduce the chemical equation for this process:

$$2H_3BO_3 \overset{\Delta}{\rightarrow} B_2O_3 + 3H_2O$$

At this transition, the powder has turned fully to a liquid. At the molecular level, many of the boric acid molecular bonds are broken at this time, and the free-moving boroxol rings and triangles are moving about in the liquid. The boron and oxygen is in a molecular formation called a trigonal borate, composed of one boron and three oxygens.

Figures 10 - 13 illustrate this transformation.

As this occurs, the hydrogen and unbounded oxygen bond together to form water, released in the form of steam.

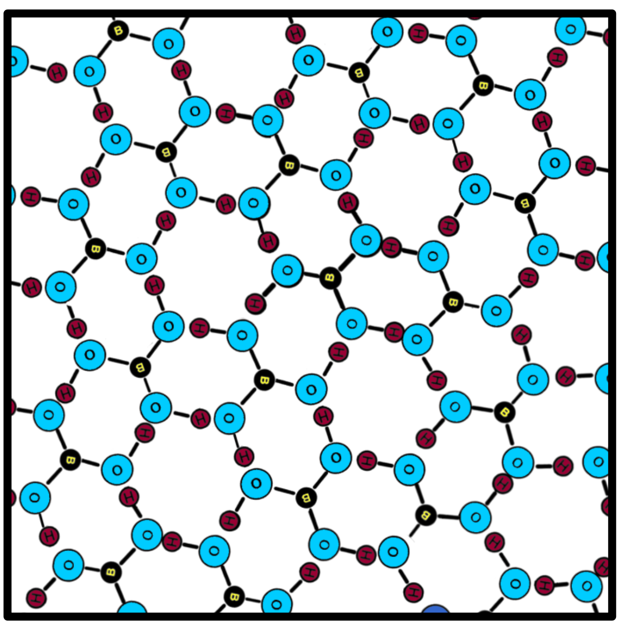


Figure 10: The H_3BO_3 structure before heating. All molecules are stably bonded and immobile.

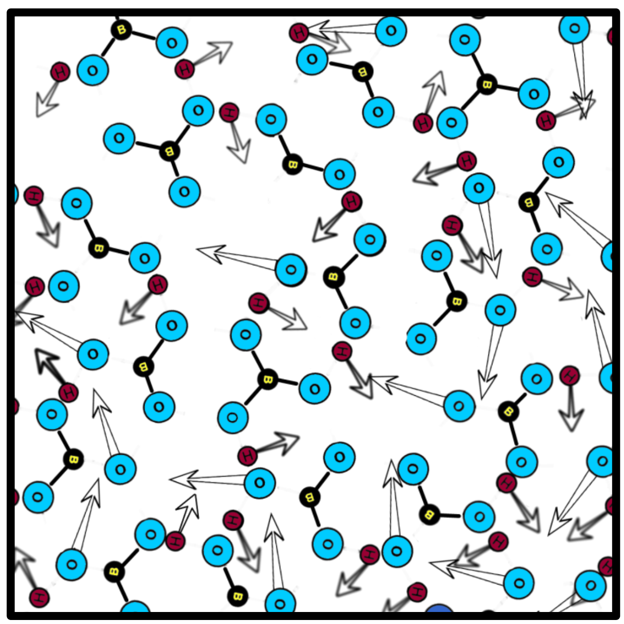


Figure 11: With the addition of heat, bonds between the hydrogen and some oxygen break, forcing the hydrogen and oxygen to move around. Boroxol rings and trigonal borate are freed move around.

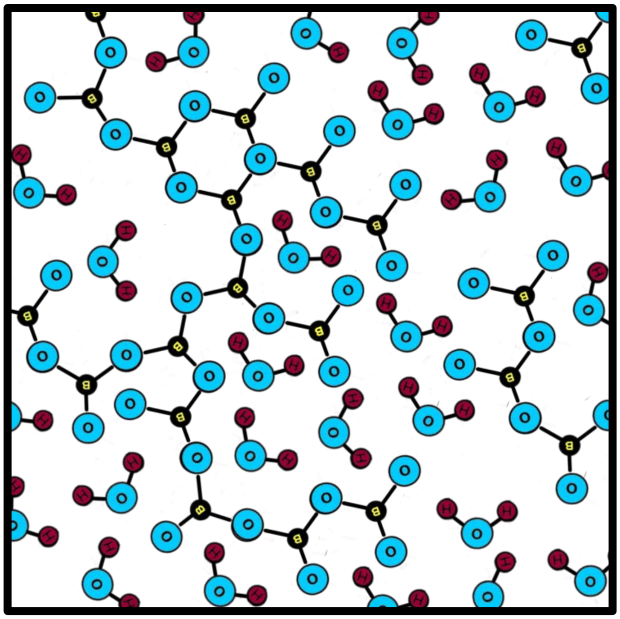


Figure 12: All hydrogen will bond in pairs to free oxygens, creating water molecules, while the trigonal borate and boroxol rings bond to one another forming the final glass network.

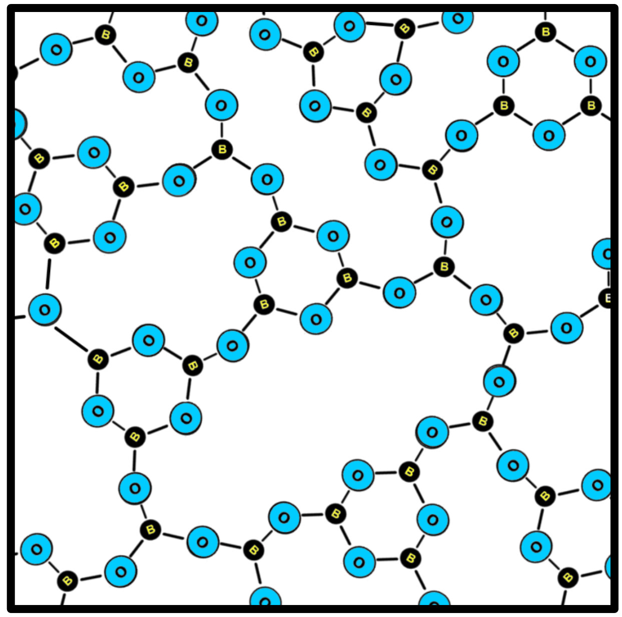


Figure 13: All the water has now evaporated and the borate glass has fully formed. Note the presence of both boroxol rings and trigonal borate in the network.

Transition to a discussion of glass and crystal structures. Glass differs from crystal; it is not a rigid, organized atomic network, but a much looser arrangement (Figures 13 & 14).

Encourage students to research ways glass is used in modern society, as some of the applications may surprise them.

If using this experiment as a high school lab assignment, the attached worksheet may be helpful.

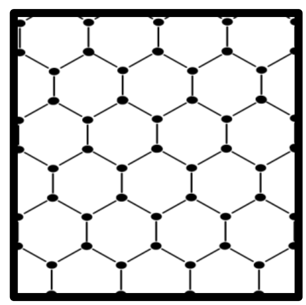


Figure 14: Typical arrangement of a hexagonal crystal structure.

Additional Resources:

- *IMI Lehigh Glass Demonstrations:* an excellent resource stocked with plenty of additional glass/material science demonstrations and resources: http://www.lehigh.edu/imi/scied/libraryglassedu.html
- *Corning Museum of Glass:* everything from the history of glassworking to current endeavors in glasswork can be found here: http://www.cmog.org/