
TEACHER INSTRUCTIONS

Thermal Shock

Objective: To illustrate thermal expansion and thermal shock.

Background Information: In physics, thermal expansion is the tendency of matter to increase in volume or pressure when heated. For liquids and solids, the amount of expansion will normally vary depending on the material's coefficient of thermal expansion. When materials contract, tensile forces are created. When things expand, compressive forces are created. Thermal shock is the name given to cracking as a result of rapid temperature change.

From the laboratory standpoint, there are three main types of glass used today: borosilicate, quartz, and soda lime or flint glass. Borosilicate glass is made to withstand thermal shock better than most other glass through a combination of reduced expansion coefficient and greater strength, though fused quartz outperforms it in both respects. Some glass-ceramic materials include a controlled proportion of material with a negative expansion coefficient, so that the overall coefficient can be reduced to almost exactly zero over a reasonably wide range of temperatures.

Improving the shock resistance of glass and ceramics can be achieved by improving the strength of the materials or by reducing its tendency to uneven expansion. One example of success in this area is Pyrex, the brand name that is well known to most consumers as cookware, but which is also used to manufacture laboratory glassware. Pyrex traditionally is made with a borosilicate glass with the addition of boron, which prevents shock by reducing the tendency of glass to expand.

Demo description: Three different types of glass rods will be heated so that students can observe the amount of thermal shock that occurs. Different formulas of glass affect the mechanical, electrical, chemical, optical, and thermal properties of the glasses that are produced.

Keywords:

- sodium flare – a bright yellow flame caused by the reaction of an oxygen-rich flame with glass containing sodium.
- coefficient – the coefficient of thermal expansion is used to determine the rate at which a material expands as a function of temperature.
- thermal conductivity – the property of a material that describes its ability to conduct heat.

- thermal shock – the way in which some materials are prone to damage if they are exposed to a sudden change in temperature.
- thermal expansion – the tendency of matter to change in shape, area, and volume in response to a change in temperature through heat transfer.

Materials List:

Items provided in the kit:

- three soda-lime (flint) glass rods
- three borosilicate glass rods
- three fused silica (quartz) glass rods
- glass beaker
- torch head

Items to be provided by the teacher/school:

- propane
- strike lighter or matches
- ice water

Safety Precautions: It is possible for small pieces of glass to become airborne during the quenching of the rod in ice water, so don't allow students to hover over the demo area.

Instructions:

Prior to starting the demonstration, discuss with the students the process of determining thermal shock by explaining that the two most important properties that determine resistance to thermal shock in glass are thermal conductivity and coefficient of thermal expansion.

Thermal conductivity, which refers to how well heat is conducted, is hard to measure and has a low variability in glass. The better the conductivity, the more rapidly and evenly heat is distributed. The better the conductivity, the less chance there is of thermal shock (inversely proportional).

The coefficient of thermal expansion refers to the amount of expansion per unit of length per °C. It is easy to measure and varies greatly in glass. The lower the coefficient, the less stress caused by a sudden temperature change. The lower the coefficient, the less chance of thermal shock (directly proportional).

The general guideline for determining thermal shock probability in glass is:

$$\frac{\text{coefficient of thermal expansion}}{\text{thermal conductivity}}$$

The larger the value of the ratio, the more likely damage will occur due to thermal shock. The value for thermal conductivity stays about the same for all glass. The, the coefficient of thermal expansion has the most effect (see chart below).

Material	Coefficient of Thermal Expansion (cm/cm x °C)
Fused silica glass	6 x 10 ⁻⁷
Borosilicate glass	33 x 10 ⁻⁷
Aluminosilicate glass	44 x 10 ⁻⁷
Porcelain	60 x 10 ⁻⁷
Soda-lime glass	85 x 10 ⁻⁷
Mild steel	110 x 10 ⁻⁷
Aluminum	250 x 10 ⁻⁷

A “modifier” is used to lower the melt temperature of the glass and increases the workability of the glass. Soda-lime has a high percentage of modifier. Fused silica glass has no modifier—it is pure silica. Borosilicate glass has an intermediate amount of modifier. The chart below shows the differences in glass depending upon the amount of modifier.

Lower	% of Silica in Glass	Higher
Soft	Type of glass	Hard
Lower	Melting temperature	Higher
Higher	Coefficient of expansion	Lower

1. Have the students journal their observations during the demonstration.
2. Show students the difference in color of the three types of glass rods by looking at the ends. The soda-lime glass will have a definite green color (think Coke bottle green). The fused silica will be white if unpolished, and the borosilicate will be in-between. The higher the percentage of silica content, the less color the glass will have. The greenish tint is due to iron oxide impurities in the silica.
3. Attach the torch head to the propane and turn on.
4. Heat one end (1- 1.5 inches) of the soda-lime glass rod in the flame. Try to hold the glass rod so that the same length of glass is in the flame throughout the heating. Point out the “sodium flare” that occurs as the glass heats up. Allow the glass to sag or slump to show softening.

5. Remove from the flame and quench in the ice water. Thermal shock will occur and pieces of glass will break off onto the bottom of the beaker. There will be many fractures throughout the portion that was heated.
6. Heat one end of the borosilicate glass rod in the flame. Have the students note that there is less sodium flare. Sagging or slumping should be harder to achieve but the end should fire polish (become smooth or “polished”).
7. Remove from the flame and quench in the ice water. Some thermal shock will occur, but there should be fewer overall cracks than with the soda-lime glass. There should be one or two cracks at the interface between where the glass rod was in the flame and where it was not.
8. Heat one end of the fused silica glass rod in the flame. There should be no sodium flare, and no sagging, slumping, or fire polishing will occur. Remove from the flame and quench. The rod will not thermal shock and no cracks should occur.

Additional demonstration using the three different glass rods involves the index of refraction. Borosilicate glass has about the same index of refraction as vegetable oil. Immerse the three rods in a beaker or clear plastic cup containing an inch or two of vegetable oil. Only two rods should be visible in the oil. The third one, the borosilicate rod “disappears”.

Cleanup/Replacement Parts: Make sure propane torch is turned off and allow it, the beaker, and the water to cool down. Pour out the water. Using a paper towel, carefully wipe the broken glass pieces into a trash can or broken glass container. To reuse the soda lime and borosilicate rods, use a triangular file to score and break off the cracked end. (Use gloves and remove about one inch of rod.)

Sources of glass rods:

Pyrex and Quartz (borosilicate and fused silica)

- National Scientific Company - Quakertown, PA – www.quartz.com
- Phone: 215-536-2577
- 5 mm diameter Pyrex Rod x 8" long - saw cut ends - \$.80 each
- GE 214 Quartz Rod 5mm x 8" long - saw cut ends - \$2.16 each
- \$50 minimum order required

Soda-lime (flint)

- Flinn Scientific – www.flinnsci.com
- stirring rods, soft glass, 5 mm x 24" - pkg/10 – item# GP9035 - \$15.80

TEACHER DISCUSSION QUESTIONS

Thermal Shock

Discussion Questions to Ask Before the Demo

Before heating and quenching the first glass rod, ask students what they think will happen when you do that to the soda-lime glass rod.

Discussion: Emphasize the fact that the soda-glass rod has a higher coefficient of thermal expansion ratio, which increases the risk of thermal shock.

Discussion Questions to Ask During the Demo

Following the soda-lime glass rod and prior to heating and quenching the borosilicate glass rod, ask the students if they think thermal shock will occur in this rod.

Discussion: Refer to the charts and ask them to support their predictions of what will happen.

Discussion Questions to Ask After

Ask the students about any other observations they made about how the different glasses reacted to the heat.

Discussion: Discuss the differences they should have noticed regarding sodium flare and any slagging or slumping that occurred.

STUDENT QUESTION HANDOUT

Thermal Shock

1. What is meant by the term “thermal conductivity”?
2. What is meant by the term “thermal expansion”?
3. What is the “coefficient of thermal expansion” refer to?
4. Why does thermal shock occur?
5. Of the three types of glass used in the demonstration (soda-lime, borosilicate, and fused silica), which would be the best for the following uses:
 - solar panels:
 - everyday drinking glasses:
 - cookware: