Advanced Materials: Thermal Shock in Glass

Grade/ Grade Band: Middle and High school	**Topic:** Physical Science and Engineering

Brief Lesson Description:
In this lesson, students explore the effects of thermal shock on different types of glass, including soda-lime, borosilicate, and tempered glass. Using Prince Rupert's Drop as an engaging demonstration, they experiment with glass rods under rapid temperature changes and learn how heat treatments improve material strength and resistance. The lesson connects these concepts to real-world engineering applications.

Performance Expectation(s):
MS-PS1-1: Develop models to describe the atomic composition of simple molecules and extended structures.

HS-PS2-6: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

Specific Learning Outcomes:
Students will be able to:
- investigate the concept of thermal shock and the properties of glass under extreme conditions
- describe the molecular structure of these materials
- explore how heat treatments like tempering improve the material's resistance to thermal stress
- explore real-world applications

Narrative / Background Information

Prior Student Knowledge:
Students should have a basic understanding of the following concepts:
Prior Knowledge for Middle School (MS):
- Atoms and Molecules (MS-PS1-1): Basic understanding that matter is composed of atoms, with molecules being made up of combinations of atoms.
- States of Matter and Material Properties: Familiarity with solids, liquids, and gasses, and their distinct properties (e.g., hardness, flexibility). Awareness of how materials like glass and metals respond to heat and pressure.
- Energy and Heat Transfer: Basic knowledge of heat transfer methods (conduction, convection, radiation) and material responses to heating, such as expansion. Familiarity with concepts like thermal conductivity and insulation.
- Engineering and Design (MS-ETS1-2): Awareness that engineers use material properties to design solutions for practical problems.

Prior Knowledge for High School (HS):
- Atomic and Molecular Structure (HS-PS1-1, HS-PS2-6): Detailed understanding of atomic structure, subatomic particles, and bonding (ionic, covalent, metallic) and their impact on material properties.
- Material Properties: Knowledge of metals, ceramics, polymers, and glass, focusing on mechanical, thermal, and electrical properties, such as tensile strength and thermal expansion.
- Energy and Thermodynamics: Advanced understanding of heat transfer, thermal conductivity, and specific heat, with knowledge of how energy is stored and transferred in materials.
- Problem-Solving and Engineering Design (HS-ETS1-2): Experience in applying scientific knowledge to solve engineering challenges, optimizing material choices, and using the engineering design process (defining, developing, and testing solutions).

Science & Engineering Practices:	**Disciplinary Core Ideas:**	**Crosscutting Concepts:**
Planning and Carrying Out Investigations: Students conduct hands-on experiments with different types of glass rods to observe the effects of thermal shock. Constructing Explanations and Designing Solutions: Students apply their knowledge to select appropriate types of glass for specific applications. They explain their choices based on their observations of thermal properties and material performance.	PS1.A: Structure and Properties of Matter. - MS: Different substances have different physical and chemical properties. - HS: The structure and properties of matter determine their use, and the behavior of materials under different conditions can be predicted. PS2.B: Types of Interactions - HS: Forces at the molecular level are essential to understanding	Structure and Function: Students learn that specific structural properties, like molecular composition, lead to unique behaviors in response to heating and cooling. Cause and Effect: Students explore the cause-and-effect relationship between the thermal treatment of glass (heating and cooling) and the resulting changes in material strength, internal stresses, and thermal resistance. Energy and Matter: Students Investigate thermal shock and material behavior when

	how materials like glass behave under stress, especially during heating and cooling, which leads to internal stresses and affects the material's durability.	subjected to changes in thermal energy, emphasizing the conservation of energy and how energy transfer affects matter at the molecular level.

Possible Preconceptions/Misconceptions:

Glass is uniformly fragile:
Students may think all glass is equally fragile and prone to breaking, not realizing that tempered and treated glass can be much stronger and more resistant to impact and thermal stress.

All types of glass behave the same way under heat:
Students may believe that all glass types react the same to heating and cooling, not understanding how different compositions (e.g., soda-lime vs. borosilicate) result in varied thermal and mechanical properties.

Heating always weakens materials:
Some students might assume that heating a material always weakens it, unaware that processes like annealing or tempering can increase a material's strength or durability by altering its internal structure.

Thermal shock is purely a temperature issue:
Students might think thermal shock is only caused by extreme temperatures, without understanding that the uneven expansion and contraction due to rapid temperature change that causes cracking or breaking.

Tempered glass is unbreakable:
Students may believe tempered glass is indestructible when in reality it's designed to resist certain forces and shatter in a specific, safer way under extreme stress.

Thermal expansion happens evenly across all materials:
Some students might assume all materials expand and contract evenly when heated or cooled, not realizing that different materials and even parts of the same object can expand at different rates, leading to stress and failure.

LESSON PLAN – 5-E Model

ENGAGE: Opening Activity – Access Prior Learning / Stimulate Interest / Generate Questions:
Objective: Capture student interest using the fascinating properties of Prince Rupert's Drop.

Demonstration of Prince Rupert's Drop:
Begin by showing a video (NOVA Beyond the Elements: Indestructible from 10:44 to 12:25 - then pause) or live demonstration of a Prince Rupert's Drop (a teardrop-shaped piece of glass formed by dripping molten glass into cold water). Emphasize how the drop is nearly unbreakable at its bulbous end but shatters instantly if its tail is damaged.

Discussion Points:
Ask, ***"Why do you think the glass behaves this way?"***
Gather ideas and then unpause the video (continue playing the video NOVA Beyond the Elements: Indestructible from 12:25 to 15:49) or briefly explain that the internal stresses created by rapid cooling make the glass extremely strong in certain parts but very weak in others.

Real-World Connections:
Tie this phenomenon to tempered glass used in everyday objects like smartphone screens and car windows. Explain how the controlled cooling process creates internal stresses that enhance the material's durability and safety.

EXPLORE: Lesson Description – Materials Needed / Probing or Clarifying Questions:
Teacher Note: This Exploration is based on the Thermal Shock! Lesson from the Ceramic & Glass Industry Foundation (CGIF). Please read the background information before diving into this lesson. It may also be supportive to watch this video demonstration before conducting the demo with students.

Objective: Students will conduct experiments to observe how different types of glass respond to thermal shock and explore methods for improving glass strength.

Demonstration: Three different types of glass rods will be heated so students can observe the amount of thermal shock that occurs. The composition of each glass affects its mechanical, electrical, chemical, optical, and thermal properties, leading to varying reactions when exposed to rapid temperature changes. This demonstrates how different glass formulas influence their overall behavior and performance in practical applications.
Keywords:

- **sodium flare** – a bright yellow flame caused by the reaction of an oxygen-rich flame with glass containing sodium.
- **coefficient of thermal expansion** – the amount of expansion (or contraction) per unit length of a material resulting from one degree change in 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.

Before the Demo: Before heating and quenching the first glass rod, ask students what they think will happen to the glass rods as they are heated and then submerged in the cold water.

Step 1: Heat the soda lime glass rod uniformly using the small propane tank and torch head. Have students make observations about the appearance of the glass, flame, and whether or not there is any sagging or slumping occurring as the glass rod is heated.
Step 2: Quickly immerse the soda lime rod in cold water to create a thermal shock.
Step 3: Observe and record the results for the soda lime glass. Does the glass crack, shatter, or remain intact?
Step 4: Repeat steps 1-3 for the borosilicate glass, followed by the fused silica (quartz) glass.
(Notes: The soda lime glass will produce a sodium flare as well as sag. The borosilicate glass will not produce a sodium flare and may not sag, however, the end should fire polish. The fused silica will not produce sodium flare, will not sag, and does not fire polish)

Expected Observations: Soda-lime glass may crack or shatter due to its low resistance to thermal shock.
Borosilicate glass, with its lower coefficient of thermal expansion, may withstand the shock better. Fused silica glass should remain fully intact due to the fact that it has no modifier added (to reduce the melting temperature) and silica has a very low coefficient of thermal expansion.

Discussion:
Students should record and compare how each type of glass responds to thermal shock and relate this to the material's molecular structure and thermal properties in order to discuss the following questions:

1. ***What did you notice about how each type of glass responded to rapid cooling? Based on your observations, which type of glass seemed most resistant to thermal shock, and why do you think that is?***
2. ***How did the appearance or structure of each glass rod change after the thermal shock test? What might these changes indicate about the internal stresses in the material?***
3. ***If you were to choose one type of glass for a product that experiences frequent temperature changes, which would you pick based on today's demonstration? What factors would you consider in making this choice?***

EXPLAIN:
Objective: Guide students to connect the results of the glass experiments to the scientific concepts of thermal shock, material strength, and thermal expansion.

Utilize the data tables and background information found in the Thermal Shock! Lesson from the Ceramic & Glass Industry Foundation (CGIF) to explain the following:

Thermal Shock and Coefficient of Thermal Expansion:
Thermal shock occurs when a material is exposed to sudden changes in temperature, causing rapid expansion or contraction. If the material expands or contracts unevenly, internal stresses lead to cracks or breaks.
Discuss the coefficient of thermal expansion and how fused silica glass and borosilicate glass, with their lower coefficients, resist thermal shock better than soda-lime glass.

Tempering Process:
Utilize the Tempered Glass video to explain how tempering strengthens glass by inducing internal compressive stresses that help it resist external forces. Use Prince Rupert's Drop as an example of how tempered glass behaves under stress.

Discussion:
What did you notice about how each type of glass responded to rapid cooling? Based on your observations, which type of glass seemed most resistant to thermal shock, and why do you think that is?

- This question encourages students to reflect on the differences they observed in the glass rods and consider why certain types might be better at resisting thermal shock.

How did the appearance or structure of each glass rod change after the thermal shock test? What might these changes indicate about the internal stresses in the material?

- This question prompts students to think about visual and structural clues that reveal internal stresses caused by thermal shock, laying the groundwork for discussing molecular structure in the Explain section.

If you were to choose one type of glass for a product that experiences frequent temperature changes, which would you pick based on today's demonstration? What factors would you consider in making this choice?

- This question helps students apply their observations to practical decision-making, encouraging them to think critically about the properties required for different applications.

ELABORATE: Applications and Extensions:
Students will apply their understanding of the glass properties demonstrated in the lab by selecting the most suitable type of glass—soda-lime, borosilicate, or fused silica—for various applications. They will consider factors like thermal shock resistance, durability, and temperature tolerance and explain their reasoning for each choice.

1. **Task:** For each of the following uses, choose the best type of glass and explain your thinking:
    - **Solar Panels-** Consider the need for weather resistance, UV stability, and moderate thermal stability.
    - **Everyday Drinking Glasses-** Consider affordability, clarity, and whether high thermal resistance is necessary.
    - **Cookware-** Account for exposure to high temperatures and rapid cooling in cooking and washing.
    - **Bathroom Mirrors-** Consider clarity, cost-effectiveness, and the thermal demands of a bathroom environment.
    - **High-Temperature Furnace Windows-** Consider extreme heat resistance, transparency, and thermal shock resistance.

Students should present their selections or designs with justifications, highlighting how each glass type's properties align with the needs of each application. This activity reinforces their understanding of material selection in real-world contexts.

EVALUATE:

Formative Monitoring (Questioning / Discussion):
Questions throughout the lesson in ***bold and italics*** can be used to check students' understanding throughout the lesson.

Summative Assessment (Quiz / Project / Report):
Students will complete a reflection answering the following questions:
- How does thermal shock affect glass and ceramics?
- How can we improve the resistance of materials to thermal shock?
- Why is tempered glass used in high-stress applications?

Constructed Response Rubric

Elaborate Further / Reflect: Enrichment:
1. **Research Project on Glass Types:** Have students select a specific type of glass (e.g., borosilicate, tempered, laminated) and research its properties, manufacturing process, and applications. They can present their findings through a poster, presentation, or infographic, highlighting their advantages and disadvantages to the class .
2. **Design a Glass Product**: Students can work in small groups to design a product that utilizes glass effectively, considering the properties discussed in the lesson (e.g., thermal shock resistance, durability). They should present their design with sketches and rationale for material choices, explaining how their design meets specific needs (e.g., safety, aesthetics, functionality).
3. **Guest Speaker or Virtual Tour**: Invite a guest speaker from a local glass manufacturer, artist, or engineer to discuss the importance of material properties in their work. Alternatively, organize a virtual tour of a glass factory or a museum specializing in glass art and technology, allowing students to see practical applications of what they learned.
4. **Create a Video or Podcast**: Have students create a short video or podcast episode discussing what they learned about thermal shock, glass properties, and resilience. They can interview classmates, include demonstrations, and share insights on how these concepts relate to everyday life and technology.

SOCIAL EMOTIONAL LEARNING ACTIVITY

CASEL Competencies Addressed:
- Self-Awareness: Understanding personal responses to stress and recognizing internal strengths.
- Self-Management: Developing strategies to cope with stress and manage emotions.
- Social Awareness: Recognizing how stress affects others and practicing empathy and supportive communication.

Objective: Students will explore resilience and adaptability by reflecting on personal experiences of stress, identifying ways to respond effectively, and understanding how to support others in challenging situations.

Lesson Sequence:
1. **Engage**
    - Start with a class discussion: "What does it mean to be resilient?" and "What helps someone 'bounce back' from a tough situation?"
    - Ask students to think of objects or situations that endure stress or pressure. Examples could be rubber bands stretching, clay molding, or a bridge holding weight.
    - Explain that just like these objects, people also respond differently to challenges, and building resilience helps us handle stress and bounce back stronger.
2. **Opening Reflection**

- Reflection Activity: Have students think of a specific time when they felt "stressed out" or under pressure. Ask them to jot down responses to these prompts:
    - What was the situation?
    - How did you feel at the time?
    - What did you do to cope, or what could have helped you cope better?
- Group Sharing: In pairs or small groups, invite students to share their experiences. Encourage active listening and supportive feedback, highlighting that everyone experiences stress differently.

3. **Explaining Resilience**
    - Discuss resilience as the ability to adapt and recover from difficulties, much like materials or structures designed to withstand pressure.
    - Introduce coping strategies that can help build resilience, such as:
        - Taking a few deep breaths or stepping away momentarily
        - Seeking help or talking to a friend
        - Changing perspective to see challenges as chances to grow
    - Explain that just as materials can be strengthened for durability, we can also strengthen our resilience with these strategies.
4. **Role Play**
    - Scenario Role-Play: Present students with scenarios involving common stressors (e.g., preparing for a big test, handling a disagreement with a friend, feeling nervous about a presentation).
    - In small groups, students discuss how they might approach each scenario using coping strategies. After discussion, they can role-play their responses.
    - After each role-play, discuss which strategies were helpful and why, emphasizing resilience and effective communication.
5. **Setting goals**
    - Have each student set a personal goal to strengthen their resilience in a specific area (e.g., managing anxiety before exams, handling frustration with friends).
    - Encourage them to choose one coping strategy they will try in the coming weeks and write down a specific plan for how and when they'll use it.
6. **Reflection Questions**:
    - What does resilience mean to you, and why is it important?
    - What strategy do you find most helpful when you're stressed, and why?
    - How can you support others who may be going through a tough time?

INTERDISCIPLINARY CONNECTIONS/IDEAS

Mathematics:

- **Data Analysis and Measurement:** Students can engage in mathematical concepts by measuring temperature changes, calculating thermal expansion, or analyzing the data collected from their experiments. They can use statistics to interpret results, such as comparing the strength of different glass types and determining averages, ranges, and variances in performance under thermal stress.

Technology:

- **Applications of Glass in Modern Innovations:** Discussion about the various applications of glass in contemporary society, such as in electronics (smartphones, screens), architecture (energy-efficient windows), and renewable energy (solar panels). Students can explore how materials science advancements drive innovations in technology and sustainability, fostering discussions on the future of glass technology and its potential impacts on society.

Social Studies:

- **The Development of Glassmaking Techniques:** A historical perspective can be integrated by exploring the history of glassmaking, including ancient techniques and the evolution of glass production. Discussions can cover how innovations in glass technology (like the creation of tempered glass) have influenced art, architecture, and everyday life throughout different cultures and time periods, such as the significance of glass in Renaissance art.

Art:

- **The Aesthetics of Glass**: Glass is often used in art and design, from stained glass windows to modern glass sculptures. Students can explore the artistic elements of glass, examining how different properties (like transparency, color, and texture) can affect artistic expression. This connection allows for discussions on the intersection of science and art, particularly how material properties influence artistic techniques.

Materials Required for This Lesson/Activity	
Quantity	**Description**
Items provided in the [Materials Science Classroom Kit] from the Ceramics and Glass Industry Foundation:	
3	soda-lime (flint) glass rods
3	borosilicate glass rods
3	fused silica (quartz) glass rods
1	glass beaker
1	torch head
Items not found in the Materials Science Classroom Kit:	
1	small propane tank
150 mL	water and ice (enough to fill beaker most of the way)

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