Lab: Chemistry is Cooler Stress Test Challenge

FOR THE TEACHER

Summary
In this lab, students will design and build a device capable of insulating an ice cube submerged in boiling water for two minutes. In this open-ended inquiry based activity, students will be required to critically think about structure and function of the materials they wish to use to build a device to solve a complex real-world problem. Students must consider the thermal properties of the materials, density, and the need to form a non-permeable barrier between the ice cube and the boiling water.

Grade Level
High School

NGSS Alignment
This lab will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS3-1**: Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
- **HS-PS3-2**: Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).
- **HS-ETS1-2**: Design a solution to a complex real-world problem by breaking it down into small, more manageable problems that can be solved through engineering.
- **HS-ETS1-3**: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
- **Scientific and Engineering Practices**:
  - Developing and Using Models
  - Planning and Carrying Out Investigations
  - Constructing Explanations and Designing Solutions

Objectives
By the end of this lab, students should be able to

- Compare and contrast the insulating properties of various materials.
- Discuss the thermal flow in a system.
- Apply the thermal properties of the materials to predict and control the thermal flow of energy in a system.

Chemistry Topics
This lab supports students’ understanding of

- Energy & Thermodynamics
- Endothermic and Exothermic processes
- Density
- Thermal properties related to structure
- Specific heat capacity
- Phase changes

Time
**Teacher Preparation**: 10 minutes
Lesson: ~165 minutes total
- 15 minutes to introduce challenge
- 40 minutes to build in class (optional)
- ~80 minutes to test devices (dependent on class size)
- 30 minutes for post lab discussion.

Materials
- Hot plate
- Large pot filled with water (approximately 8 quart)
- Scale
- Ice cubes (1 per group)
- Timer (clock, stopwatch, cell phone)
- Tongs
- Option 1 (recommended): Student are required to select and acquire their own materials outside of school. The materials can be found at home, borrowed from a friend, or purchased at a hardware store (spending limit $10 per group).
- Option 2 (If policy or circumstances do not allow for students to supply their own materials): Teacher supplies students with a variety of materials to build the device. Suggested materials may include; rubber gloves, PVC pipe, Styrofoam, duct tape, cloth, cotton, rubber bands, balloons, aluminum foil, plastic wrap, bolts, nuts, sand, wire, string, and other possible distractors.

Safety
- Always wear safety goggles when handling chemicals in the lab.
- Students should wash their hands thoroughly before leaving the lab.
- When students complete the lab, instruct them how to clean up their materials and dispose of any chemicals.
- Exercise caution when using a heat source. Hot plates should be turned off and unplugged as soon as they are no longer needed.

Teacher Notes
- This challenge can be used to introduce thermochemistry. Students should have prior experience and understanding of the concepts of density and phase changes. Alternatively, this activity could also be used as a capstone assessment at the end of thermochemistry unit. This activity is recommended for students to work in pairs but could work having students work individually or in larger group if needed.
- Prior to activity: Distribute the Challenge Activity Sheet to each group. It is recommended that students work in pairs. To introduce activity, have student observe a large pot of boiling water and ask them to predict verbally how long it would take for an ice cube to melt once placed in the water. After observing the melting ice cube (typically takes about 20 seconds for a normal sized ice cube to melt), inform the students that the goal of the activity is to engineer a device that can preserve an ice cube in the boiling water for 2 minutes.
- Option 1:
  - Inform students that they may use any materials they find at home or outside of school to build their device. Require students to keep a log of materials used and how they acquired the material (found at home, borrowed, and/or purchased).
  - Students may spend a maximum of $10 and must produce receipts for purchased items. Give the students 2 days to acquire materials. For example, if the activity is introduced on Monday, give students until Thursday to bring in materials (if building devices in class).
  - If students are building the devices in class (recommended), allow approximately 40 minutes (one class period).
- Students may run small scale tests without using an ice cube on the materials to test the properties of the materials.
- If students are building devices at home, allow an extra day. If the students are building devices at home, they may also test materials. Teacher may determine if they wish to allow students to conduct practice test at home with ice cubes.
- Restrictions will rely on the honor system for enforcement which is why building in class is recommended.

**Option 2:** "You must adjust the materials section of the student document if option 2 is selected.
- If school policy or circumstances prevent students from acquiring their own supplies, the teacher may provide the necessary materials (suggestions and options listed in materials section).
- The materials should be randomly scattered around the room to add to the inquiry and investigatory nature of the activity.
- Resist assisting students in selecting materials.
- The goal of the activity is to have the students explore and critically think about the materials they choose to complete the lab.

- Students must complete pre-lab questions prior to building day, or testing day if building outside of class.
- Prior to Testing: Take a picture of the outside and inside of each device and post the pictures to Google classroom, Edmodo, Google slides, or a PowerPoint presentation for post lab analysis and discussion.
- Testing: Teacher will be responsible for facilitating testing. Randomly select an order for the groups to be tested. For each test:
  1. Have the students weigh the initial mass of the ice cube and record on their lab report and on the board (Have a data table on the board which displays group name, initial mass, final mass, and change for each test to add to the competitive nature of the challenge).
  2. Students have a maximum of one minute to secure the ice cube in the device.
  3. Immediately after the students have secured the ice cube in their device, use tongs to carefully place the device in the boiling water. Remember, the device must be completely submerged in the water. If the device does not submerge, hold the device under the water using tongs and assess a penalty for not meeting that criteria (recommended 10% of total grade).
  4. Start time immediately after the device is placed in water. It is recommended to request a student to assist you in timing.
  5. After two minutes, remove the device from the water and allow the device to cool for 2 minutes. The cooling time must be standard for each group. Assign another student to time the cooling time.
  6. After the two minute cooling period, students should immediately remove the ice cube and record the mass in their lab report and on the board.
  7. After the first device is removed from the water, the next group should be ready to put their device into the boiling water. Make sure students are aware of the testing order and remind students to be ready when it is their turn to complete the test.

- After testing: Post the pictures of the student devices using a classroom projector. If a projector is not available, use student electronic devices or printed pictures. Use student results to drive discussion on what materials and designs worked the best. Discuss reasons why certain materials worked better than others based on the thermal properties and molecular structure of the materials.
- The lab could also be used to introduce and discuss phase changes, endothermic and exothermic reactions, heat capacity, and energy flow. Students should have supporting evidence for their claims when discussing the results.
- Hints: Dependent on student ability, hints can be given to guide the inquiry process.
1. Remind students that research can be conducted to determine what materials will make the best insulators.
2. Teachers may need to give multiple reminders that their device must be completely submerged under water and be water tight.
3. Teacher may put all available materials on a central desk instead of having students search for the materials in the room.
4. Teacher can circulate room and use questioning to guide students in a more successful path.
5. If multiple groups are unsuccessful in preserving the ice cube, the teacher could allow students to alter their device, and retest.

- **Answers to pre-lab questions**
  1. Add mass to the cork by attaching some form of additional matter (i.e. weight) to the point where the cork and added mass has a mass to volume ratio greater than water (\( \text{DH}_2\text{O} = 1.0 \text{ g/mL} \))
  2. The table has higher thermal energy (enthalpy) than the ice cube. In this system, the energy from the table will flow into the ice cube causing a phase change.

- **Topics for post activity discussion:**
  - Students will hopefully recognize the materials that were more effective (i.e. rubber, PVC, Styrofoam) and offer evidence for their claim based on data from the activity.
  - Classify materials as good conductors and poor conductors of thermal energy based on the results of the activity and the chemical concepts present in lab. For example, energy needed to be transferred to the ice cube in order for it to melt into a liquid. Good conductors would transfer large amounts of energy from the boiling water to the ice cube causing it to melt while poor conductors would not transfer significant amounts of energy from the boiling water preserving the ice cube.
  - Depending on level of student, interests of teacher, and time available this lesson could expand with a discussion on the structure of the materials and the impact of the structure on thermal properties. For example, air entrapment in Styrofoam. This lesson could also be used to generate thought and a discussion on how igloos keep individuals warm in cold climates or how thermoses work.

- **Grading Recommendation:**
  - Example grading breakdown based on a 50 point assignment:
    - 5 pts Pre-lab questions
    - 25 pts for bringing in materials on time, completing build on time, and staying on task
    - 5 pts for materials chart and submission of receipts if applicable
    - 5 pts for students successfully building a device that submerges in water
  - This breakdown will allow students to potentially earn a grade of 40 out 50 pts from meeting the requirements above before testing.

- **Suggested point allocation from testing:**
  - 1st place: 15 pts (total 55 out of 50 pts)
  - 2nd place: 12 pts (52 out of 50 pts)
  - 3rd place: 10 pts (50 out of 50 pts)
  - 4th through 7th place: 5 pts (45 out of 50 points)
  - 8th place to 12th place: remove one point from the previous total until you reach zero (i.e. 8th place 4pts, 9th place 3pts...)
  - 13th place or lower: 0 pts
FOR THE STUDENT
Lesson

Chemistry is Cooler Stress Test Challenge

Background
Companies must diligently and rigorously test their products before mass production can occur and the product is sold on the open market. A critical part of the testing process is stress testing in which the minimum and maximum capabilities of the product are tested in extreme conditions often to the point of failure. Stress tests simulate conditions which far exceed the normal conditions of operation or use of the product. The Chemistry is Cooler company is attempting to design a new camping cooler which can keep products cool in the warmest of climates. As the lead research and development engineer, you have been assigned to develop a prototype for the cooler and subject the device to a stress test.

Prelab Questions
1. A normal cork floats on water. What alterations could be made to cause the cork to sink?
2. An ice cube is sitting on a table at room temperature. Describe the flow of energy in the system.

Objective
Design a device that can preserve an ice cube in boiling water for 2 minutes. Your device must be completely submerged in the boiling water for the entire 2 minutes.

Materials
You may use any materials you find at home or outside of school to build your device. You must keep a log of materials used and how you acquired the material (found at home, borrowed, and/or purchased). You may spend a maximum of $10 per group and must produce receipts for purchased items.

Safety
- Always wear safety goggles when handling chemicals in the lab.
- Wash your hands thoroughly before leaving the lab.
- Follow the teacher’s instructions for cleanup of materials and disposal of chemicals.
- Exercise caution when using a heat source. Hot plates should be turned off and unplugged as soon as they are no longer needed.

Procedure
1. You must acquire the materials you will use to build your device by the assigned building day.
2. You will have 40 minutes to build your device on the building day.
3. During building, you may conduct teacher approved small scale tests.
4. On testing day, your teacher will facilitate the testing of the devices.

*Note: If your device does not fully submerge on its own during testing, there will be a penalty!
**Data**
List all items used in your device, and total all costs. Remember that the cost must not exceed $10. *Attach receipts if material was purchased.*

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<th>Materials Log</th>
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**Total Cost:**

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<th>Ice Cube Test</th>
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<td>Mass of ice cube before heating (g)</td>
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<td>Mass of ice cube after heating (g)</td>
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<td>Change in mass (g)</td>
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**Post activity discussion**
Meet with another group and analyze the results of the lab. Observe the pictures of devices created by other groups. Discuss what materials seemed to be the most effective in preserving the ice cube. Your discussion should include the differences between the materials based on the arrangement of the particles on the molecular level and their impact on the thermal properties of the material. For example, explaining reasons why Styrofoam is a more effective insulator than metal.