ENGINEERING DESIGN

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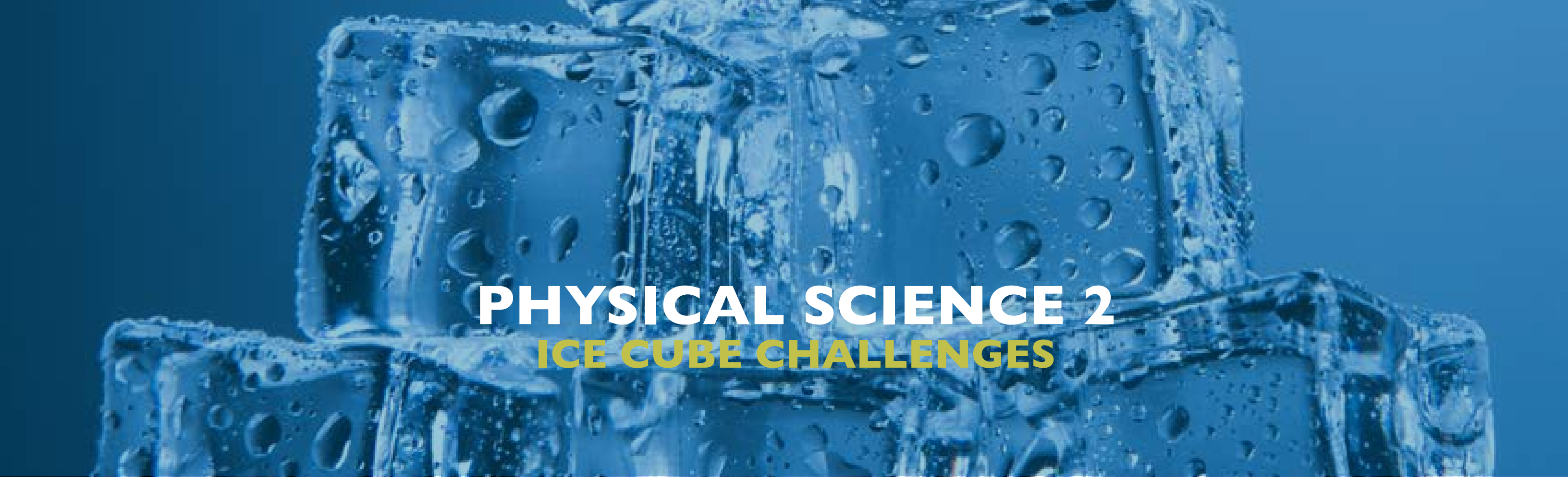

PHYSICAL SCIENCE 2
ICE CUBE CHALLENGES

Next Generation Science Standards Addressed

MS-PS3 Energy
PERFORMANCE EXPECTATION MS-PS3-3

Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.

Disciplinary Core Idea PS3.A: Definitions of Energy

- Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.

Disciplinary Core Idea PS3.B: Conservation of Energy and Energy Transfer

- Energy is spontaneously transferred out of hotter regions or objects and into colder ones.

MS-PS1 Matter and Its Interactions
PERFORMANCE EXPECTATION MS-PS1-6

Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes.

Disciplinary Core Idea PS1.B: Chemical Reactions

- Some chemical reactions release energy, others store energy.

MS-ETS1 Engineering Design
PERFORMANCE EXPECTATION MS-ETS1-4

Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Disciplinary Core Idea ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.

Science and Engineering Practices: Developing and Using Models, Analyzing and Interpreting Data

Links to IQWST Unit PS2: "How Can I Make New Stuff from Old Stuff?"

IQWST Unit PS2 Scientific Principles addressed:

- Any moving object has kinetic energy.
- Energy can be converted/transformed from one type to another.
- Energy can be transferred between systems.
- Energy cannot be created or destroyed. If some energy appears to be missing, it has either been transformed to a type that is not readily apparent or has been transferred to another system.
- Every object has thermal energy.
- An object's thermal energy increases as its temperature and/or its mass increases.
- An object's temperature increases as the nanoscopic particles of which it is composed move faster.
- Chemical energy is transformed into other types of energy during a chemical reaction.
- An object's chemical energy increases as its mass increases. The type of substance an object is made of influences the amount of chemical energy it has.

If this activity is being used in conjunction with IQWST's PS2 unit, then the activity is best done any time after Lesson 8. Part 1 uses thermal energy concepts, which students explore in Lesson 6, and Parts 2 and 3 cover energy associated with chemical reactions, which students investigate in Lesson 8.

Teacher Preparation

Background Knowledge

Chemical Reactions in this Activity

During Parts 2 and 3 of this activity, students will carry out three chemical reactions. Two of these reactions are endothermic. That means they transfer energy from the surroundings to the products, thereby transforming thermal energy into chemical energy. During these two reactions, the temperature of the surroundings decreases.

Reaction 1 (citric acid + sodium bicarbonate):
(In the presence of water)

$$C_6H_8O_7 + 3NaHCO_3 + \text{energy} \rightarrow Na_3C_6H_5O_7 + 3H_2O + 3CO_2$$

citric acid + sodium bicarbonate → sodium citrate + water + carbon dioxide

Reaction 3 (acetic acid + sodium bicarbonate):

$$C_2H_4O_2 + NaHCO_3 + \text{energy} \rightarrow NaC_2H_3O_2 + H_2O + CO_2$$

acetic acid + sodium bicarbonate → sodium acetate + water + carbon dioxide

One of these reactions is exothermic. It transfers energy from the reactants to the surroundings, thereby transforming chemical energy into thermal energy. During this reaction, the temperature of the surroundings increases.

Reaction 2 (calcium chloride + sodium bicarbonate):
(In the presence of water)

$$CaCl_2 + 2NaHCO_3 \rightarrow CaCO_3 + 2NaCl + H_2O + CO_2 + \text{energy}$$

calcium chloride + sodium bicarbonate →
calcium carbonate + sodium chloride + water + carbon dioxide

Set-Up

Part 1

Before students can perform this activity, purchase or prepare enough ice cubes for each group. Ideally, the ice cubes would be uniform in size and shape because both factors contribute to the rate at which an ice cube melts. Having ice cubes of comparable size and shape will help produce controlled conditions and generate data that is easier to compare from one trial to the next and across groups. Therefore, the best ice cubes for this activity will come either from an ice machine that produces uniform pieces of ice or from manually filling an ice tray with equal amounts of liquid water in each receptacle before freezing.

Furthermore, ice cubes should be large enough so as not to melt completely when exposed to control conditions (open air, no wrapping, and no surrounding chemical reactions) for ten minutes.

Before having students carry out the activity, perform a trial run on at least one ice cube to confirm that it will not melt completely within 10 minutes. Shorten each trial to less than 10 minutes, if necessary.

- water
- ice cubes (from tray or purchased)
- freezer
- cooler for storing ice in classroom
- stopwatch

 

Clean-Up

If purchased from a grocery store or specialty food store, all of the substances used in this activity are safe for disposal in a sink or wastebasket. Place any excess unreacted dry ingredients into separate plastic bags and dispose of in a wastebasket. Pour aqueous reaction mixtures (the liquid mixtures that result from Parts 2 and 3) down the sink with plenty of water. If purchased from a scientific supply store, follow the directions for proper disposal according to the accompanying materials safety data sheets.

Safety Guidelines

- Have students wipe up ice or water spilled during Part 1 of this investigation.
- Students should wear safety goggles and gloves (and aprons, if available) during Parts 2 and 3 of the activity.
- Clean up spilled chemicals with paper towels before continuing on to the next step.
- Instruct students never to taste, touch, or inhale any substances in the science lab. Even if a substance is familiar and edible, the equipment and surfaces may be contaminated, and reactions may generate unanticipated products.

Differentiation Opportunities

In Part 1, students may work individually, in pairs, or in small groups to do this activity, as appropriate for their abilities and depending on time allotted and supplies available. To extend the self-guided inquiry, you could provide students with additional ice cubes and encourage them to perform more trials with the materials available. You (or students) could also bring in other materials to test and compare with their original data. Students could also expand this activity by testing other materials at home and reporting their study design, data, and results to the class.

In Part 2, to accommodate a shorter class period or to use fewer supplies, you could have each group perform only one chemical reaction and then share their observations with the class. To simplify the activity for some students or to accommodate a shorter class period, you could omit Part 3.

To accommodate a classroom with a limited number of balances, students could use measuring spoons instead of a balance to measure the dry reactants. A mass of 4 g of citric acid is about 1 teaspoon. A mass of 5 g of sodium bicarbonate is about 1 teaspoon. A mass of 5 g of calcium chloride is about 1 teaspoon. You might also use measuring spoons if some students struggle significantly with all of the measurements needed in this activity, and you wish to make some aspect of the work easier for them. They can still use balances for the components of the activity that are not the dry reactants.

Timeframe
2 Class Periods

Activity

ICE CUBE CHALLENGES

Materials

For each group of students, for Part 1:

- ice cubes, 2
- sheets of aluminum foil, 2 (about 13 cm × 13 cm [5" × 5"] each)
- sheets of felt, 2 (about 13 cm × 13 cm [5" × 5"] each)
- sheets of bubble wrap, 2 (about 13 cm × 13 cm [5" × 5"] each)
- sheets of newsprint, 2 (about 13 cm × 13 cm [5" × 5"] each)
- rubber bands, 2
- stopwatch
- paper plates, 2
- paper towels

For each group of students, for Parts 2 and 3:

- graduated cylinder
- clear plastic cups, 2
- beakers or small bowls, 2 (each large enough to hold a plastic cup)
- thermometer
- citric acid, 4–8 g
- baking soda (sodium bicarbonate), 20 g
- vinegar (acetic acid), 15–30 mL
- water, 45–60 mL
- calcium chloride (pickle crisp), 5–10 g
- ice cubes, 2
- stopwatch
- paper towels

For the teacher/class:

- electronic balances
- plastic spoons for measuring out dry ingredients
- water
- ice cube tray
- freezer
- cooler for storing ice in classroom

Learning Goal/Purpose
Analyze data from tests of thermal conductivity of different materials to design a way to keep frozen items from melting. Conversely, analyze data from tests of thermal energy production in different chemical reactions to design a way to speed up the melting of ice.

Introduction

Help students think about everyday experiences that involve the transfer of thermal energy.

- **What makes you decide to put on a jacket or a sweatshirt?** *(I feel cold; I want to keep warm)*
- **When do you cover up with a blanket?** *(When the weather turns cold; when I feel cold)*
- **Each of your responses was related to temperature. What does it mean to "keep warm" in terms of what we have learned about thermal energy?** *(A blanket or sweatshirt keeps thermal energy from transferring from a person's body to the surroundings.)*
- **What kinds of materials are used to make sweatshirts and blankets? Why do you suppose those materials are chosen?** *(Materials include fabrics like fleece and wool, and fabric layers stuffed with down feathers. Something about those fabrics keeps me warmer than other materials do.)*
- **Let's review what we know about thermal energy transfer. What happens when you put a cold spoon into a hot beverage or you use a cold utensil to stir something you're cooking on the stove?** *(The utensil gets hot.)* **What does that mean in terms of energy transfer?** *(Thermal energy transfers from the hot material you're stirring to the cooler utensil, causing the utensil to get hot.)*
- When we say that we are "heating" something, what we mean—in scientific language—is that we are transferring thermal energy to an object. **How do we typically do that?** *(By turning up the burner on the stove, using a fire or space heater, turning up the thermostat in the car or in the house, or leaving something in the hot sun)*
- We've learned that thermal energy always transfers from warmer objects to cooler objects. **So, what happens when you crawl into bed into cold sheets? What kind of energy transfer takes place?** *(Thermal energy transfers from my warm body to the cold sheets, and the sheets warm up until after a while, they don't feel cold anymore.)*
- **We have learned that thermal energy transfers from warmer to cooler objects—the hot pan to the cold metal spoon, your warm body to cold sheets. What other examples can you think of?** *(Responses will vary. Prepare other examples that will be familiar to your students, in case additional ideas would help them understand the concept.)*

Guiding the Activity

Read the "What Will We Do?" section aloud with students.

Let's think about the first task for a moment. You are going to use what you know about energy transfer and apply it to ice because ice is so easy for us to work with.

Given the conversation we just had, what are some materials that you think you could use to keep an ice cube from melting so quickly? Record your ideas in the Prediction section.

Procedure

Part 1:

Note: In the reading that follows Part 1, students will learn about thermal insulators that slow the transfer of thermal energy. This reading will *follow* their exploration of various materials.

- **What kinds of objects are used to keep ice from melting quickly? What kinds of materials are these objects made of?** *(An ice chest, or cooler, is used to keep ice from melting. Lunch bags or containers to bring frozen foods home from the grocery store are lined with shiny, silvery material. Some ice chests are made of Styrofoam. Some are made of plastic that has air between layers of plastic. Wraps for cans and bottles are made of metal, or Styrofoam, or layers of fabrics designed to keep things cool. These materials are all lightweight, yet they keep things cool.)*
- **What kinds of objects do you know of that are used to heat things up quickly? What kinds of materials are these objects made of?** *(Sample responses: A pan is used to heat things up on the stove. Pans are usually made of metal. The aluminum foil is a metal.)*

Provide students with the materials for the investigation. They should then follow the procedure, designing, collecting data, and explaining results. If you prefer to be the timer for the entire class, do that instead of having each group keep track of their own time. If time permits, allow students to re-design a wrap and model and test their new design a second time.

Collect data as a whole class, or jigsaw groups (create groups made up of 4 students, 1 to represent each of the 4 previous groups). Then discuss students' conclusions.

Part 2:

In the first ice cube task, students investigated thermal energy transfer using a variety of materials. In the next task, they will investigate thermal energy transfer again, but this time using chemical reactions that involve energy transformations. Not all chemical reactions involve the same kinds of energy transformations.

- **What type of energy does a fuel like gasoline have?** *(Fuels have potential energy—specifically, chemical energy.)*
- **What type of energy is produced when the fuel burns?** *(When fuel burns, chemical energy is transformed into kinetic and thermal energy.)*
- **What evidence do we have of this—of kinetic and thermal energy being produced when fuel burns?** *(Examples include: Vehicles and other transportation devices move, fires give off thermal energy, grills/BBQs give off thermal energy while burning gas or charcoal.)*
- **And what makes that happen? What is the process by which the energy transformation takes place?** *(A chemical reaction)*

Some chemical reactions, like the burning of a fuel, release thermal energy. In these exothermic reactions, the surroundings get warmer as thermal energy transfers from the reacting substances to the surroundings—to a pan, to the air, to water, etc.

Other chemical reactions, like the reactions that take place in cake batter when you bake it, store energy. Thermal energy transfers from the surroundings to the reacting substances. The energy gets stored as chemical energy in the products. In these endothermic reactions, the surroundings get cooler as thermal energy transfers from the surroundings to the reacting substances.

Students will need to pay attention to the change in temperature that occurs as each chemical reaction takes place. As they carry out each test, they will be looking for a *very quick* cooling or a *very quick* warming as measured by the thermometer.

Part 3:
Before students proceed with Part 3 of the activity, confirm that they are carrying out *one* of the three reactions described in Part 2. ***They must not carry out other random chemical reactions.*** They should also use only the amounts described in the procedure and not more. Explain that some combinations of reactants can lead to dangerous chemical reactions. They can produce gases that can cause illness or injury.

Discussion

Explain that the class has just used controlled tests to evaluate the effectiveness of two different design solutions. In both cases, their design involved transfers of energy.

- **What was the purpose of observing an ice cube that was not wrapped in Part 1, and an ice cube that was not surrounded by a chemical reaction in Part 3? Hint: How did the change in mass of that ice cube help you analyze your data?** *(Sample answer: In each case, the second ice cube was a control that let us compare our data and draw a conclusion. Without having the ice cube as a control, we would not know how effective our design solution was. We also would not know if other factors were causing the results we were observing.)*
- **In both designs, thermal energy was transferring to an ice cube and causing it to melt. How did your two designs differ in terms of the goal associated with that energy transfer? In other words, how did you want your designs to affect the transfer of thermal energy to the ice cube?** *(Sample answer: In Part 1, I wanted to slow down the transfer of energy to the ice cube. In Part 3, I wanted to speed up the transfer of energy to the ice cube.)*
- **How could you combine aspects of the design in Part 1 to improve the design in Part 3?** *(Sample answer: We could wrap the beakers that hold the chemical reaction in Part 3 with the materials we used in Part 1 so that the thermal energy generated in the reaction does not get wasted to the surroundings. More of the thermal energy will transfer to the ice cube and cause it to melt.)*

Reading

Introducing the Reading
Begin with a discussion about which objects in a hot car feel the hottest. Explain that objects feel hot when thermal energy transfers from an object to your skin. Ask students:

- **Which is at a higher temperature: your skin or an object resting inside a car on a hot summer day?** *(An object inside the car is at a higher temperature than your skin.)*
- **In which direction does thermal energy transfer when you touch an object in a hot car?** *(Thermal energy transfers from the object in the car, which is at a higher temperature, to your skin, which is at a lower temperature.)*

Explain that all the objects inside a car that has been sitting in the sun for hours are probably at the same high temperature. The metal objects only *feel* different from the cloth objects because those materials transfer thermal energy differently.

Reading Follow-Up

- **Think about the cloth of a seat belt and the metal of its latch. Which material do you think is a good thermal conductor and which is a poor thermal conductor? Why?** *(Sample answer: The metal is a good thermal conductor because it transfers thermal energy easily to my skin. The cloth is a poor thermal conductor—a thermal insulator—because it doesn't transfer thermal energy as easily to my skin.)*
- **Which kind of material would be most effective for preventing a frozen item from melting: a thermal insulator or a thermal conductor? Explain your ideas.** *(A thermal insulator would be most effective for preventing a frozen item from melting, because it would slow the transfer of heat from the surroundings to the frozen item.)*
- **Think about the materials that you were given to wrap around the ice cube in Part 1 of the activity. Which kind of material would be most effective for preventing a frozen item from melting? Were any of those materials effective thermal insulators? Why do you think so?** *(Sample answer: The felt and the bubble wrap would be effective thermal insulators. They slowed down the transfer of thermal energy from the surroundings to the ice cube and thus slowed the melting process.)*

Wrap-up

As you ask questions to bring this lesson to a close, prompt students to refer to the activities they did in class, the readings, or other resources you may have used as support for their ideas or evidence for the claims they make. An easy way to do this is to follow up their statements with a question such as: "How do you/we/scientists know that?"

- **In which direction did thermal energy transfer in this activity: from the ice cubes to the surroundings, or from the surroundings to the ice cubes? Use evidence to explain your answer.** *(Thermal energy always transferred from the surroundings to the ice cubes. The ice cubes melted, which showed that thermal energy was transferring to them and causing them to get warmer.)*
- **During this activity, why did thermal energy always spontaneously transfer to the ice cubes from the surroundings?** *(Thermal energy always transfers from warmer objects to cooler objects. The ice cubes were always at a cooler temperature than the surroundings, so energy always transferred to them.)*
- **In this activity, what kind of chemical reaction did you use to melt an ice cube: a reaction that released energy, or a reaction that stored energy? How do you know?** *(We used a reaction that released energy to melt the ice cube. We know it released thermal energy because it caused the surroundings to increase in temperature.)*
- **In this activity, how did you modify or improve a design solution based on test results?** *(Sample answer: I looked at the data my classmates and I collected and changed my idea about how to keep an ice cube from melting. I improved my design by adding layers and using the materials that worked best for other groups.)*