

PhysicsQuest 2019

Science Kits for Middle School Classrooms

Dr. Wu's Secret Project



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Coordination, Research, Text, and Editorial Review

Jon Anderson, Isabel Bishop, Randie Hovatter,
Jamie Liu, Leah Poffenberger, James Roche,
Natalie Ruiz, Laurie Tangren, Rose Villatoro, David Voss

Graphic Design and Production

Meghan White

Illustration of Experiment Guides

Isabel Bishop

Illustration of Dr. Chien-Shiung Wu

Annamaria Ward

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Welcome to PhysicsQuest 2019!

PhysicsQuest experiment kits demonstrate the fun and relevance of science to middle school students as they learn more about the physical world. Each kit offers a series of activities to build enthusiasm for science and encourage active participation. This year, we distributed 20,000 kits to 6th through 9th-grade physical science classes, home school groups, science clubs, and after-school programs across the United States.

The aim of PhysicsQuest is to introduce students to the basic concepts of physics, but the overarching goal is to give them a positive experience that will sustain their interest in math and science. Each kit includes a user's manual and materials for four physics experiments designed to provide fun and accessible lessons at the middle school level.

About the American Physical Society (APS):

The American Physical Society is the premier professional society for physicists in the United States. APS shares the knowledge of physics by publishing journals, hosting scientific meetings, reaching out to the public, and promoting physics education.

PhysicsQuest is brought to you by PhysicsCentral, an APS program that communicates the excitement and importance of physics to people of all ages.

Learn How Your World Works

Watch cool physics experiment videos, read PhysicsQuest books and comics, or ask a physicist your toughest science questions at physicscentral.com.

Share Your Results!

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Materials List

The PhysicsQuest activities directly correspond to many of the Next Generation Science Standards (see page 50). The experiments are designed with flexibility in mind—they can be done in one continuous session or split up over a number of weeks. The activities can be completed in any order as a regular classroom exercise, extra credit, or science club activity.

The PhysicsQuest kit includes this manual and most of the materials you need to complete the activities. This manual includes a Teacher Guide and Student Guide for each of the four experiments. For additional details, visit physicscentral.com/physicsquest.

Included in this Kit:

- Dye tablets (4)
 - Plastic tube
 - Clay
 - Packets of vinegar (2)
 - Steel wool
 - Clear plastic bag
 - Liquid crystal thermometers (2)
 - Self-inflating balloon
 - Felt
 - Aluminum
 - Silver insulation bubble material
 - Packets of sugar (9)
 - Table salt
 - Thermal paper
 - Rock salt
- If your kit is missing any of the materials listed above, please contact info@teachersource.com

Not Included in this Kit:

- 20 oz. soda bottles (2)
- Hot water
- Cardboard (use the PhysicsQuest box)
- Cold water
- Cups
- Paper towels
- Scissors
- Timer / Stopwatch
- Ice
- Freezer

Overview: Teacher & Student Guides

Each activity includes a Teacher Guide and a Student Guide. These sections are included in each guide. You will need to copy the Student Guide and distribute it to students before they can begin the activity.

Teacher Guide

- **Key Question**
Highlights the goal of the activity.
- **Key Terms**
Terms related to the activity.
- **Materials**
List of what materials are needed to perform the experiment.
- **Before the Activity**
Concepts and skills that students should be familiar with before starting the activity. It helps to review these as a group before getting to work.
- **After the Activity**
By completing the experiment, students are developing the skills listed in this section.
- **The Science Behind:**
Science related to the activity that you can share with your students.
- **Suggested Resources**
List of sources used to create the activity. Use these resources to find more information.
- **Next Generation Science Standards (NGSS)**
These K–12 content standards were developed to improve science education for all students (see more on pages 50-51).

Student Guide

- **Key Terms**
Terms related to the activity.
- **Getting Started**
Questions to help students reflect on the key question and how they might find an answer with the materials provided.
- **Setting Up the Experiment**
Step-by-step instructions to help students set up the activity.
- **Collecting Data**
Step-by-step instructions to guide students through the data collection process.
- **Analyzing Your Results**
Multiple questions help guide students through data analysis and discussion of their results.

Using PhysicsQuest in Your Classroom

Since logistics and goals may vary across schools, we encourage you to read through these suggestions and then decide how best to use PhysicsQuest.

Time Allotment

The time required to complete the PhysicsQuest activities will depend on the skill level of your class and how much lab experience they have had. Most groups will be able to complete one activity in a 45-minute class period. Please note that Activity Four has a longer setup time and may require a longer class time allotment.

Safety Notice

While following the precautions in this guide can help teachers foster inquiry in a safe way, no manual could ever predict all of the problems that might occur. Good supervision and common sense are always needed. Activity-specific safety notices are included in the Teacher Guide when appropriate.

Creating Cooperative Groups

Working effectively in a group is one of the most important parts of scientific inquiry. To help you create the structured, cooperative environment necessary for PhysicsQuest, one example of a successful group work model is given below.

Group Work Model

Give each student one of the following roles. You may want to have them rotate roles for each activity so they can try different jobs.

Lab Director

Coordinates the group and keeps students on task.

Chief Experimenter

Sets up the equipment and makes sure the procedures are carried out correctly.

Measurement Officer

Monitors data collection and determines the values for each measurement.

Report Writer

Records the results and makes sure all of the questions in the Student Guide are answered.

Equipment Manager

Collects all equipment needed for the experiment. Makes sure equipment is returned at the end of the class period and that the lab space is clean before group members leave.

Integrating PhysicsQuest with Your Curriculum

PhysicsQuest can be integrated with your school's standard curriculum in a variety of ways. Some of the most popular methods are:

As a stand-alone class activity

PhysicsQuest is self-contained and serves well as a special project on the day following a test, immediately preceding/following winter break, or other such times. PhysicsQuest also works well as a science club activity or as an extra credit opportunity.

As a fully integrated part of required curriculum

The topics covered in PhysicsQuest are covered in many physical science classes, so another option is to have students do each activity during the corresponding unit.

As an all-school activity

Several schools have found it worthwhile to set up PhysicsQuest activity stations around the gym for an afternoon and have small groups of students work through the stations at assigned times.

As a mentoring activity

Some teachers have used PhysicsQuest as an opportunity for older students to mentor younger students. In this case, 8th or 9th grade classes first complete the activities themselves, and then visit 6th grade classrooms to assist younger students.

Implementing PhysicsQuest with Small Groups

Each PhysicsQuest kit includes one set of materials. This means that if your students are working in small groups (as recommended), all groups should work on different activities simultaneously (Option 1) or you will need to buy supplemental materials (Option 2).

Option 1: Small groups work on different activities simultaneously

Divide students into four groups and have each group work on a different challenge at the same time. Have the student groups discuss their findings and come to a consensus.

Option 2: All students work on the same activity at the same time

Divide the class into small groups and devote one class period to each activity. Have each group complete the experiment independently. Near the end of each period, have all of the students come together and discuss their results as a class.

About Dr. Chien-Shiung Wu

The Path to a Science Degree

When she arrived in California in 1936, Chien-Shiung Wu was fighting an uphill battle—one she'd been fighting her whole life. A young Chinese woman going to school would have been completely unheard of in her mother's lifetime, and now she was abroad in pursuit of a PhD! Wu had traveled to the United States with hopes of starting graduate school at the University of Michigan, but she soon discovered that U-M did not even allow women past the front gates. This was a major road block, but Wu never let anything stop her from a career in science.

Despite the setback with U-M, and the fact that the academic year had already begun, Wu enrolled at the University of California, Berkeley. At Berkeley, Wu met her future husband, Luke Chia-Liu Yuan, and was introduced to Ernest O. Lawrence at the Radiation Laboratory, who would soon win the 1939 Nobel Prize in Physics for his invention of the cyclotron particle accelerator. She joined Lawrence's lab and did research alongside Emilio Segrè, another soon-to-be Nobel Prize winner. Wu worked at the Radiation Laboratory while completing her PhD and returned as a post-doctoral fellow after discrimination against her race and gender made it difficult for her to secure a position elsewhere.

A Secret Project

In 1944, Wu joined the Manhattan Project, a top-secret research project to develop nuclear weapons during World War II before Nazi Germany could do so. She did meticulous work in experimental nuclear physics, and it wasn't long before her reputation grew. The saying was, "if the experiment was done by Wu, it must be correct."

One of the experiments she would work on was called the B Reactor, which was built to create plutonium by bombarding uranium with neutrons. Inexplicably, the reactor shut down at regular intervals. Its designer, physicist and Nobel Laureate Enrico Fermi, was stumped until he received this piece of advice: "Ask Mrs. Wu."

Wu discovered that the reactor was also making something else besides plutonium. A different element, xenon, was being created in the reactor and absorbing all the neutrons, making plutonium production impossible. Thus, when the reactor was powered up, it worked until there was too much xenon and then shut down until the xenon decayed away.

Wu's Parity Breakthrough

After the war, Wu continued her physics research by studying beta decay, in which a radioactive element emits an electron and, inside the nucleus, a neutron turns into a proton. Physicists had thought that nuclear reactions obeyed certain laws like conservation of energy and another law called conservation of parity. Conservation of parity is the idea that an object behaves exactly the same as a mirror-image copy of itself.

Some theorists had predicted that in certain particle interactions, parity is not conserved, but Wu was able to prove it experimentally. She found that the electrons emitted in beta decay traveled in a preferred

direction relative to the orientation of the nucleus; in other words, the atom and its mirror image would behave differently.

This was a huge breakthrough in physics. However, Wu's contributions went unacknowledged when her colleagues won the Nobel Prize in 1954. It wasn't until 1978 that Wu was publicly acknowledged for her work: she was the first scientist awarded the Wolf Prize, which is considered to be the second most prestigious prize in science, after the Nobel.

Life After the Lab

Dr. Wu continued to make significant contributions to science throughout her career. She became the first female president of the American Physical Society (APS), and her 1965 book *Beta Decay* is still a reference for nuclear physicists. Wu retired in 1981 but continued to have a great impact on the science community. She was dubbed "the First Lady of Physics," and even has an asteroid named after her! In 1998, she was honored posthumously for her pioneering work in nuclear physics with an induction into the National Women's Hall of Fame.

Background Reading

1. Tsjeng, Zing. *Forgotten Women: The Scientists*. s.l. : Hachette, Australia , 2018.
2. Chiang, Tsai-Chien. *Madame Chien-Shiung Wu: The First Lady of Physics Research*. Singapore : World Scientific, 2014.
3. Dicke, William. *Chien-Shiung Wu, 84, Top Experimental Physicist*. New York : New York Times, 1997.
4. Wang, Zuoyue. *Wu Chien-Shiung*. *Dictionary of Scientific Biography*. New York : Charles Scribner's Sons.
5. Hammond, Richard. *Chien-Shiung Wu: Pioneering Nuclear Physicist*. s.l. : Chelsea House Publishers, 2007.
6. Associated Press. *21 Inducted into Women's Hall of Fame*. Seneca Falls, N.Y. : Los Angeles Times, 1998.

ACTIVITY

1

Turning Thermal Tides

In this activity, students will experiment with the movement of hot and cold water. Through the experiment, students will observe how heat moves from hot areas to cold areas. They will also experience thermal equilibrium by watching two colored liquids slowly mix between two soda bottles. **Note:** You can use a baking sheet to protect surfaces from spills or perform the steps over a bucket or sink as you tilt the bottles.

Before the activity students should know:

- Water is made of molecules.
- Molecules move at different speeds based on their temperature.
- Objects have density, which will affect where they settle relative to other substances.

After the activity students should be able to:

- Describe how thermal energy moves from places of warmer temperatures to places of colder temperatures.
- Understand that temperatures eventually stabilize as time goes by.
- Conclude that thermal equilibrium happens faster with convection currents than with conduction.
- Determine that hot water is less dense than cold water based on where the water layers.
- Comprehend that temperature can affect the density of an object.

Key Question

How will hot and cold water move when they are placed together?

Materials

- Dye tablets (4)
- Plastic tube
- Clay
- 20 oz. soda bottles (2)*
- Hot water*
- Cold water*

**Not included in the PhysicsQuest kit*

Key Terms

Conduction

Transfer of heat energy through contact

Convection

Transfer of heat energy through currents

Density

The mass of a substance per unit volume

Molecules

The smallest particle of a substance that retains all the properties of the substance and is composed of one or more atoms

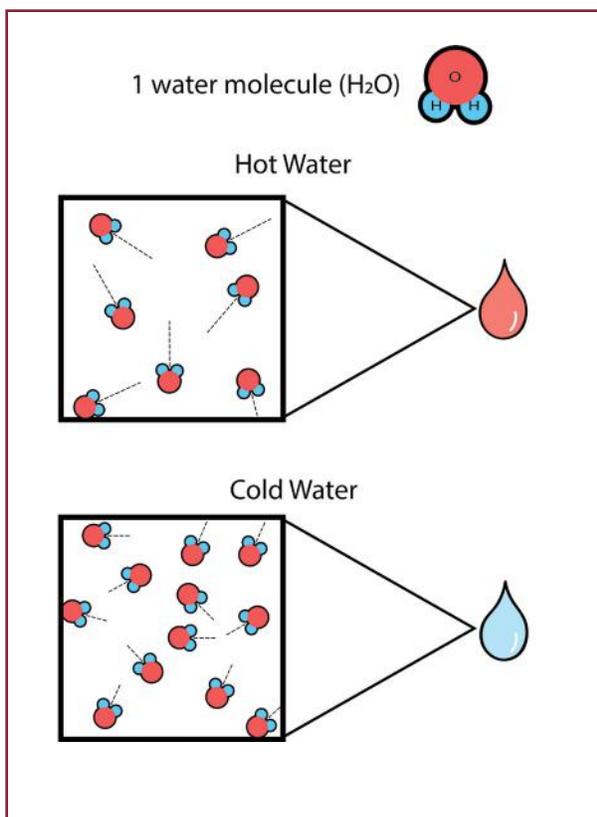
Thermal Energy

Energy in the form of heat

Thermal Equilibrium

A state of a system in which all parts are at the same temperature

The Science Behind Heat Transfer, Temperature, and Density



The water in the bottles is made of molecules of hydrogen and oxygen (H_2O). Water at room temperature has a density of one g/mL. When water is hot, the molecules move quickly, bumping against one another and spreading out. The further apart the molecules move, the less dense the material. This causes the hot water to be less dense than room temperature water. Hot water will have a density of less than one.

In cold water, the molecules move slowly and are able to pack more densely. Because the molecules are closer together, the cold water will have a higher density. There are more molecules in the space, causing the water to have higher density. The cold water will have a density greater than one g/mL.

When substances have different densities, they will settle and move within a container based on their relative densities. Less dense substances will rise and more dense substances will sink. This happens when liquids, solids, and gases interact.

If you look at an oil and vinegar salad dressing, you will see that the oil has risen to the top of the bottle and the vinegar mixture has sunk to the bottom. What you are observing is the separation of two liquids based on their densities. The oil, which is less dense, rises. The vinegar mixture, which is more dense, sinks. Even if you shake the bottle, eventually they will settle back into these original positions.

In this experiment, when the bottle of hot water is placed on top of the bottle of cold water, the hotter (and therefore less dense) liquid does not need to move anywhere. The cold water with the higher density will stay in its bottle at the bottom. The two will mix slowly where they meet as thermal energy transfers from one liquid to the other.

When the hot water bottle is placed on the bottom, the water will rise toward the top of the container because its density is lower than the cold water. The hot and cold waters will mix quickly because the hot water will rise to the top, passing through the cold water on its way.

Eventually, the water in both bottles will mix together to reach thermal equilibrium. This happens because the higher temperature water is in contact with the lower temperature water. While they are in contact, they are transferring thermal energy. This will continue until both liquids are the same temperature.

Thermal equilibrium will occur in less time when the hot water is on the bottom than when it is placed on top. This is because the transfer of heat happens through a current, or convection, when the hot water passes through the cold. When the hot water bottle is the one on top, the transfer of energy is mostly through conduction—the transfer of heat by contact—and happens more slowly.

Suggested Resources

Learn an amazing water trick:

go.aps.org/watertrick

Find out what makes hot water hot, and cold water cold:

go.aps.org/racingmolecules

Discover different water densities:

go.aps.org/densityvideo

Marvel at this animation of a molecular model:

go.aps.org/tempdensity

Learn what makes ice float in water:

go.aps.org/icefloat

Next Generation Science Standards (NGSS)

This activity addresses the following standards:

MS-PS1-4 Matter and its Interactions

Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

MS-PS3-3 Energy

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

MS-PS3-4 Energy

Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

MS-PS3-5 Energy

Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

ACTIVITY

1

Turning Thermal Tides

Density of an object is what determines whether it will float, like ice in your drink, or sink, like dropping a rock in a pond. Density is based on the mass and volume of an object. Floating and sinking doesn't just happen with solid objects: It can happen with other substances. Liquids and gases can sink and float too.

Getting Started

Have you ever had a drink that recommended you shake it before you drink it? Why did you have to shake it? What did that have to do with the densities of the different ingredients in the drink?

Have you ever noticed that the air is warmer in a room the higher up you move? Have you noticed it is colder near the floor? What does that tell you about the densities of the warm and cold air?

Key Terms

Conduction

Transfer of heat energy through contact

Convection

Transfer of heat energy through currents

Density

The mass of a substance per unit volume

Molecules

The smallest particle of a substance that retains all the properties of the substance and is composed of one or more atoms

Thermal Energy

Energy in the form of heat

Thermal Equilibrium

A state of a system in which all parts are at the same temperature

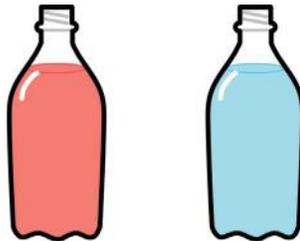
How do you predict the hot and cold water will move when they are placed together?

How will the placement of the different temperature waters affect the mixing of the two colors?

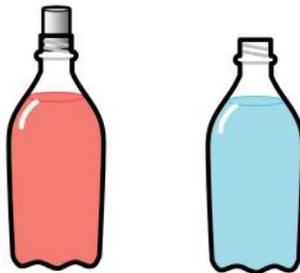
Can two containers of the same substance have different densities? Why or why not?

Setting Up the Experiment

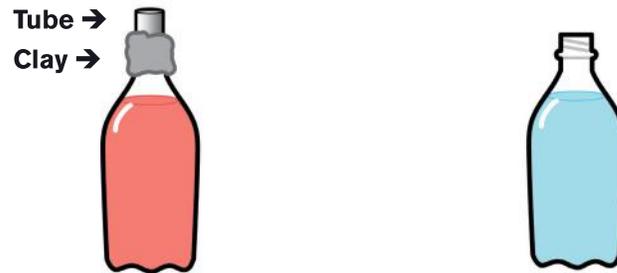
1. Fill the first 20 oz. bottle two-thirds of the way full with very hot water. **Use caution: This needs to be done carefully to avoid getting burned!** Fill the second 20 oz. bottle two-thirds of the way full with very cold water.
2. Place one dye tablet in each bottle. Make sure the dye tablets are different colors.



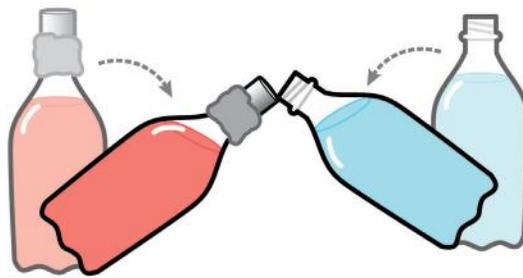
3. Place one end of the clear plastic tube into one of the bottles. The middle of the tube should be at the top of the bottle.



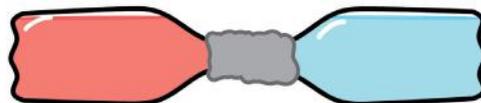
4. Use the clay to secure the tube and seal the gap between the opening of the bottle and the sides of the tube.



5. This next step will be slightly difficult so you may want to do it over a baking sheet, sink, or bucket. Tip the bottles, and very carefully slide the other end of the tube into the second bottle. Try not to let the water in the two bottles mix.



6. Seal the second bottle securely with clay. You should now have two bottles, attached with a plastic tube and clay, laying on their sides. Hot water of one color should be in one bottle and cold water of another color should be in the other.



Collecting Data

Hot on Top:

Carefully turn the bottles so that the bottle with the **hot water is on top** of the bottle with cold water. If you've sealed it well, there should be very little spillage. Now watch for a full 2 minutes and record everything that is happening:

1. What do you notice?

2. How is the water on the bottom behaving?

3. Can you tell if it's moving? How?

Cold on Top:

Set up the experiment again exactly as described in the "Setting Up the Experiment" section. This time, turn the bottles so that the **cold water is on top** of the bottle with the hot water. Watch again for two minutes.

1. What do you notice?

2. How is the water on the bottom behaving?

3. Can you tell if it's moving? How?

Analyzing Your Results:

1. What did you observe when you put the hot water bottle on top of the cold water?

2. What difference did you observe when you reversed the order of the bottles to put the cold water on top?

3. In which order did you see the water mixing together the fastest? Why do you think this happened?

4. Describe an instance in your daily life where you observed a similar phenomenon.

ACTIVITY
2

Getting Warmer / Getting Colder

As we go through our day, we touch many different objects. Some feel cool to the touch while others feel warm. Our ability to sense temperature can vary. An object that feels cool to us one day might feel warm the next without its temperature actually changing.

On a cold day, we choose to wear certain types of clothing to keep us warm. A cozy wool sweater is a better choice for cold weather than a cotton t-shirt. This is because different materials have different insulating properties.

In this **two-part activity**, students will test their ability to rank temperatures by touch. By comparing how different surfaces feel to the touch compared to their actual temperatures, students will realize that their sense of touch isn't always accurate. Students will also compare the thermal insulating properties of the same objects using thermal paper.

Before the activity, students should know:

- That materials in contact with each other will come to thermal equilibrium.
- That heat energy moves from places of hot to places of cold.
- How to read a liquid crystal thermometer (see illustration on page 23).

After the activity, students should be able to:

- Recognize the need for objective measuring tools, such as a thermometer.
- Qualitatively estimate the thermal conductivity of different materials.
- Understand that some materials can insulate better than others.

Key Questions

Can you trust your sense of touch? Do different objects have different thermal insulating properties?

Materials

- Liquid crystal thermometer (10°C to 32°C/50°F to 90°F)
- Thermal paper
- Silver insulation bubble material
- Aluminum
- Felt
- Cardboard (you can use the PhysicsQuest box)*
- Small ice cubes, similar in size (4)*
- Warm water (6 fl oz. per cup, 24 fl oz. total)*
- Cups for water (4)*
- Paper towels*
- Timer*
- Scissors*

**Not included in the PhysicsQuest kit*

Key Terms

Thermal Conductivity

The thermal conductivity of a material indicates how quickly heat energy travels through the material

Thermal Equilibrium

A state of a system in which all parts are at the same temperature

Thermal Insulation

The process where the transfer of heat energy is slowed

The Science Behind Thermal Conductivity and Thermal Insulation

The five human senses—sight, smell, touch, taste, and hearing—tell people a lot about their world, but sometimes tools (such as x-rays, microscopes, and thermometers) can provide much more accurate information.

Human senses are limited in scope and sensitivity and many times aren't as objective as they initially seem. Use your hand to touch a piece of metal and a piece of wood. Which one feels warmer?

Assuming that you are not near a direct heat source, all of the objects around you should be at thermal equilibrium, including the metal and the wood. If you measure the temperature of the metal and wood with a thermometer, you'll find that both read about 24°C (about 75°F), which is room temperature. So why does the metal feel colder?

When two objects are in thermal contact—meaning they can exchange heat energy—heat energy will always flow from the warmer object to the cooler object until the two reach thermal equilibrium. Skin temperature is roughly 34°C (about 93°F), almost 20 degrees Fahrenheit higher than room temperature. When you touch something at room temperature, heat energy flows from your fingers into the object. The rate at which the heat energy travels from your hand through a material depends on the material's thermal conductivity. Metals have higher thermal conductivities than wood, so heat energy flows more quickly through metals than wood. The metal feels colder because heat energy leaves your fingers faster.

An object with high thermal conductivity will heat up and cool off more quickly than an object with low thermal conductivity. Imagine putting a metal spoon and a plastic spoon into a cup of hot coffee. The metal spoon will get hot much faster than the plastic spoon, since metal has higher thermal conductivity than plastic. Both will eventually come to equilibrium with the temperature of the coffee and each other.

Thermal insulation is the process where the heat energy is slowed or blocked from moving from one place or object to another place or object. The heat energy can be reflected, absorbed, or slowed based on the materials involved.

Materials with high thermal conductivity will generally make poor insulators since heat flows through them quickly. A good insulator will have low thermal conductivity, making heat energy flow through them more slowly. A block of ice will melt more quickly when sitting on a material with high thermal conductivity, like metal, than when sitting on a material with low thermal conductivity, like wood. Metal is a poor insulator and it allows heat to reach the block of ice faster than the wood, which is a good insulator, does.

Suggested Resources

Find more information about heat and insulation:

go.aps.org/heatinsulation

Learn how to stay warm with thermal insulation:

go.aps.org/staywarm

View thermal camera pictures by Paul Falstad:

go.aps.org/thermalpics

Enjoy a bite-size lesson about energy transfers and efficiency:

go.aps.org/bitesizeenergy

Next Generation Science Standards (NGSS)

This activity addresses the following standards:

MS-PS1-4 Matter and its Interactions

Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

MS-PS3-3 Energy

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

MS-PS3-4 Energy

Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

Part One: Getting Warmer

Key Terms

Thermal Conductivity

The thermal conductivity of material indicates how quickly heat energy travels through the material

Thermal Equilibrium

A state of a system in which all parts are at the same temperature

Thermal Insulation

The process where the transfer of heat energy is slowed

Heat Transfer

Start this activity by touching some of the things around you, such as your desk, your skin, and the classroom door. Which feels the warmest? Which feels the coolest? People often judge the temperature of something by touch, like when you stick your toe into a swimming pool to make sure the water isn't too cold.

Getting Started

On a scale of one to ten (ten being the best), how would you rank the reliability of your sense of touch?

1 2 3 4 5 6 7 8 9 10

Considering the materials you will use in this activity (silver insulation bubble material, aluminum, felt, and cardboard), which do you think will be the best and worst at transferring heat energy? Rank the materials in order of best to worst thermal conductors.

1. _____ (best)
2. _____
3. _____
4. _____ (worst)

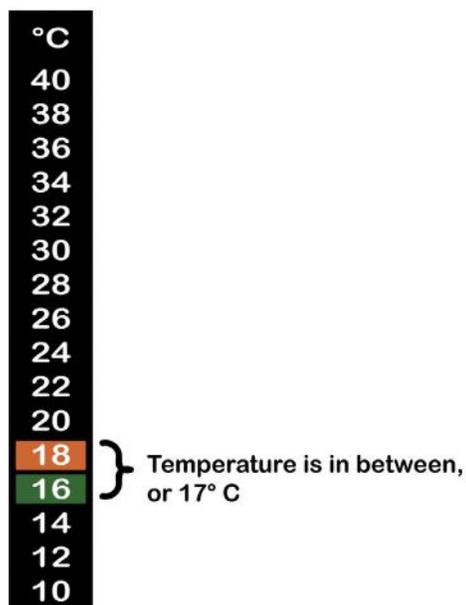
Imagine placing a piece of ice on top of each type of material. Which material do you think would melt the ice the fastest?

Using a Liquid Crystal Thermometer

Liquid crystal thermometers are made from a material that changes color based on its temperature. To measure the temperature of a surface, peel the backing off of the thermometer and stick it to the object whose temperature you want to measure.

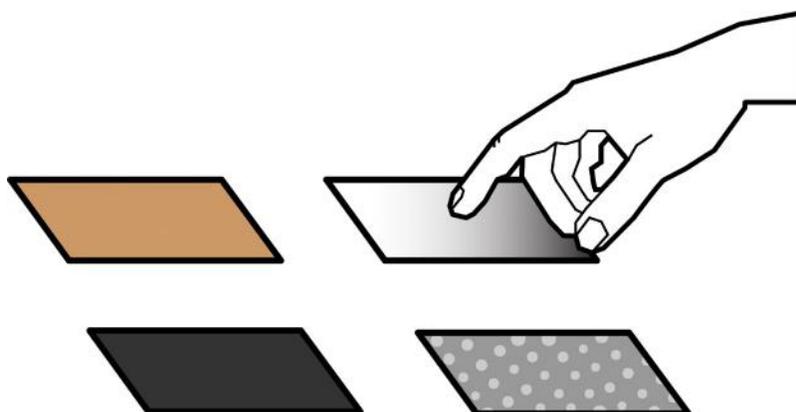
Within a few seconds, you will see a color appear next to one of the numbers. This is the temperature of the object's surface. If two different colors appear next to each other, the temperature is between the two numbers.

You can reuse the thermometer—just peel it off of one surface and stick it to another!



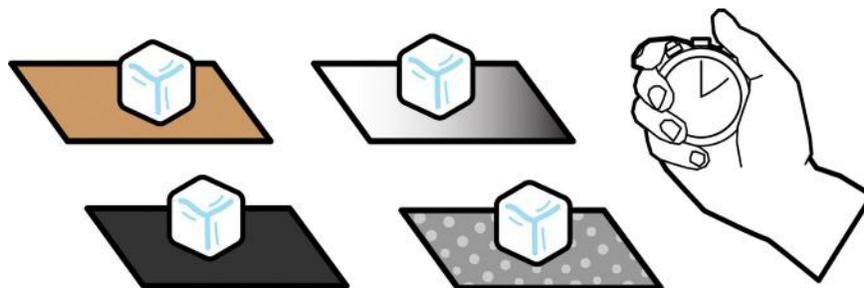
Setting Up the Experiment

1. Put a layer of paper towels on top of the table.
2. Cut out a 3x3" square of cardboard.
3. Lay the cardboard on top of the paper towels. Then lay the silver insulation bubble material, felt, and aluminum on the paper towels, each an inch or two apart.



Collecting Data

1. Use your pointer finger to touch each piece of material, one by one, for about two seconds. Only one person should touch each piece of material at a time. Then, rank them from coldest to warmest.
 1. _____ (coldest)
 2. _____
 3. _____
 4. _____ (warmest)
2. Measure the temperature of the cardboard, felt, aluminum, and silver insulation bubble material using the liquid crystal thermometer. Record the temperatures in **Chart A** (page 25). Remove the thermometer once you are finished recording the temperatures.
3. Pick out four ice cubes that are all the same size and place one in the middle of each of the four materials. Set your timer for five minutes.



4. At one, three, and five minutes, draw a picture of what is happening to each ice cube in **Chart B** (page 25).
5. After five minutes, rank the materials in order of how quickly they melted the ice. If it is hard to tell the order, wait a few more minutes.
 1. _____ (Melted ice the slowest)
 2. _____
 3. _____
 4. _____ (Melted ice the fastest)

Chart A: Measured Temperatures

Item	Temperature
Aluminum	
Cardboard	
Felt	
Silver Insulation Bubble Material	

Chart B: Drawings

Item	At 1 minute	At 3 minutes	At 5 minutes
Aluminum			
Cardboard			
Felt			
Silver Insulation Bubble Material			

Analyzing Your Results

1. Was your sense of touch as accurate as you predicted? Why or why not?

2. Choose the word in parentheses that best completes each sentence.

When at room temperature, a material with high thermal conductivity will feel (warmer / colder) than a material with low thermal conductivity.

When at room temperature, a material with high thermal conductivity will melt ice (faster / slower) than a material with low thermal conductivity.

3. Based on the results of your tests, rank the four materials in order from lowest to highest thermal conductivity.

1. _____ (Lowest thermal conductivity)

2. _____

3. _____

4. _____ (Highest thermal conductivity)

ACTIVITY 2

Part Two: Getting Colder

Thermal Insulation

If you have ever stepped outside in the morning and noticed that you were very cold while waiting for the school bus, you have experienced a lack of thermal insulation.

Getting Started

Imagine a time it was cold outside. What helped keep you warm?

Considering the materials you will be using (silver insulation bubble material, aluminum, felt, and cardboard), which do you think will be the best and worst at stopping the transfer of heat energy?

Key Terms

Thermal Conductivity

The thermal conductivity of material indicates how quickly heat energy travels through the material

Thermal Equilibrium

A state of a system in which all parts are at the same temperature

Thermal Insulation

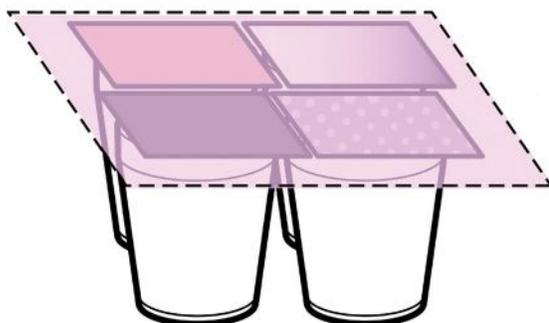
The process where the transfer of heat energy is slowed

Use your best guess to rank the four objects from lowest to highest thermal insulation.

1. _____ (Lowest thermal insulation)
2. _____
3. _____
4. _____ (Highest thermal insulation)

Setting Up the Experiment

1. Cut the thermal paper to the same size as all of the four materials combined (silver insulation bubble material, aluminum, felt, and cardboard).
2. Fill each of the containers with 6 fl. oz. of hot water.
3. Put the four containers of hot water close together.
4. Place each of the four materials over a different container.
5. Place the thermal paper on top of the four materials.



Collecting Data

Watch to see which material changes color first, second, third and fourth. Write your results below in **Chart C**.

Chart C: Color Change Rates

Item	Order in Which the Paper Changed Color (1, 2, 3, 4)
Aluminum	
Cardboard	
Felt	
Silver Insulation Bubble Material	

Analyzing Your Results

1. Which materials were the best thermal insulators? How did this compare to your predictions?

2. What other observations can you make about the four materials and how quickly they each turned the thermal paper's color?

3. Which material was the worst thermal insulator? Why do you think it was the worst?

4. Now that you have completed both parts of the activity, describe the relationship between thermal conduction properties and thermal insulation properties.

ACTIVITY
3

Rusted Out & Blown Up

Everyone has seen something rust: a nail, a bike, or even a car. Rusting is a long process and may not seem very interesting, but there is a lot of physics going on as a salt-covered car turns from blue to an unfortunate orange. Rusting is an exothermic reaction, meaning heat is given off as something rusts. Because the reaction usually happens so slowly, the heat often goes unnoticed. In this experiment, we will make steel wool rust extremely quickly. The speed will allow us to explore this chemical reaction. We will also be exploring what happens during an endothermic reaction, when heat is absorbed instead of expelled.

Before the activity, students should know:

- That some chemical reactions absorb heat energy, which makes the temperature drop.
- That some chemical reactions produce heat energy, which makes the temperature increase.
- How to read a liquid crystal thermometer (see illustration on page 23).

After the activity, students should be able to:

- Understand and explain the difference between exothermic and endothermic reactions.
- Compare the temperature changes of both reaction types using a student-created graph.

Key Question

What's the difference between an exothermic reaction and an endothermic reaction?

Materials

- Packets of vinegar (2)
- Steel wool
- Clear plastic bag
- Liquid crystal thermometers (2)
- Self inflating balloon
- Cup*
- Paper towels*
- Timer*

**Not included in the PhysicsQuest kit*

Key Terms

Chemical Reaction

In a chemical reaction molecules interact to create a new substance. They can combine, separate or change the way they are bound together.

Endothermic

Meaning “inside heating,” this type of chemical reaction absorbs heat. It is the opposite of exothermic.

Exothermic

Meaning “outside heating,” an exothermic reaction is one that releases energy. In this experiment, the energy is released in the form of heat.

Kinetic Energy

Kinetic energy is the energy of motion. When things move they have kinetic energy.

The Science Behind Rusting and Science Fair Volcanoes

Every one of us has seen something rust. If asked to describe the rusting process, you might say something like, “metal left outside turns brownish and falls apart. Oxygen from the air combines with the metal and causes it to rust.” This is what happens, but there is a little more going on: the rusting reaction also gives off heat.

Chemical reactions can be either endothermic or exothermic. In an endothermic reaction, heat energy is absorbed by a material to make the reaction go, and the surrounding temperature drops. In an exothermic reaction, heat energy is released by a material, making it feel hot. If this reaction happens quickly, the heat energy released can be easily felt. If a reaction occurs slowly, not enough heat energy is produced at one time to be felt. Rusting is usually a very slow reaction.

Rusting Reaction



Rust is formed when three oxygen atoms bind with two iron atoms. There are a lot of steps in between and the reaction needs water to help it out, but the end result is three oxygen atoms bonded with two iron atoms. This reaction is exothermic, so heat energy is released during the rusting process. However, there is too little to be felt by us since this reaction happens so slowly. By making the rusting reaction happen very fast in this experiment, we make it possible to feel the heat energy.

Steel is made of iron with some carbon atoms thrown in the mix. If you use steel wool at home, you know that it doesn't usually rust, but that after using it for a long time, it will. Steel wool has a coating on it that makes it difficult for oxygen atoms to get to the iron to start the rusting process. Since steel wool is made of many fine strands of steel, there is a lot of surface area that can be exposed to air. If the coating wasn't there, the steel wool would rust extremely quickly.

In this experiment, students will speed up the rusting process of steel wool by using vinegar to remove the coating and then watch as the steel wool quickly rusts. Because it will rust so fast, it will be possible to feel the heat energy released from the reaction.

Inside the self-inflating balloon are loose baking soda (NaHCO_3) and a packet of vinegar (CH_3COOH). When the packet is popped, a reaction begins between the baking soda and the vinegar and carbon dioxide (CO_2) gas is released. This reaction is most commonly seen in science project volcanoes. This experiment is usually too messy and uncontained for students to feel the temperature change indicating that it is an endothermic reaction.

When sodium bicarbonate (baking soda) mixes with vinegar, the hydrogen atoms in the vinegar react with the baking soda. This creates an unstable chemical called carbonic acid (H_2CO_3) that quickly decomposes into carbon dioxide. Carbon dioxide gas creates the famous bubbles that come oozing out of volcanoes in science classrooms all over the country. This reaction absorbs energy for the atoms to rearrange during the reactions, and the temperature will decrease (making this an endothermic reaction).

Suggested Resources:

Watch a video of flaming steel:

go.aps.org/bluesteel

See examples of exothermic and endothermic reactions:

go.aps.org/endoexo

Explore the science behind baking soda and vinegar:

go.aps.org/balloon

Solve the formula of baking soda plus vinegar:

go.aps.org/equation

Next Generation Science Standards (NGSS)

This activity addresses the following standards:

MS-PS1-2 Matter and its Interactions

Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

MS-PS1-6 Matter and its Interactions

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

*Integrates traditional science content with engineering through a Practice or Disciplinary Core Idea.

Rusted Out and Blown Up

ACTIVITY 3

Key Terms

Chemical Reaction

In a chemical reaction molecules interact to create a new substance. They can combine, separate or change the way they are bound together.

Endothermic

Meaning “inside heating,” this type of chemical reaction absorbs heat. It is the opposite of exothermic.

Exothermic

Meaning “outside heating,” an exothermic reaction is one that releases energy. In this experiment, the energy is released in the form of heat.

Kinetic Energy

Kinetic energy is the energy of motion. When things move they have kinetic energy.

We’ve all seen something that has rusted. Usually, it’s something old that has been outside for a very long period of time. But what would happen if you could make something rust very quickly? How would it feel to be able to touch the object while the rust reaction was happening? If you have ever made a homemade volcano, you know that it’s exciting and messy. Do you think a homemade volcano could ever give off heat like a real volcano?

Getting Started

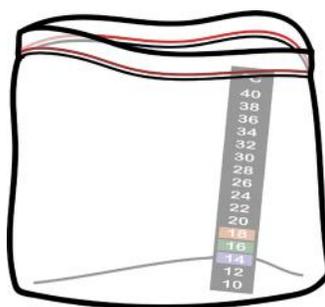
When have you seen things rust? What changes happen when something rusts?

Predict three things that you might see when you watch something rust quickly.

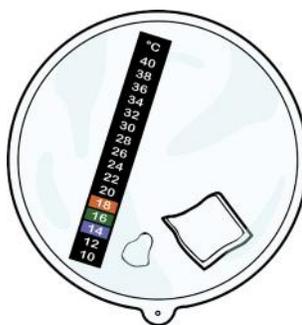
What happens when baking soda mixes with vinegar? How do you think this reaction compares to rusting?

Setting up the Experiment

1. Open the clear plastic bag.
2. Stick the liquid crystal thermometer for measuring higher temperatures inside of the bag so that:
 - a. You can see it through the bag.
 - b. The thermometer touches where the steel wool will sit.



3. Pour both of the vinegar packets into a cup.
4. Stick the second liquid crystal thermometer for measuring cooler temperatures on the outside of the self-inflating balloon where the liquid will collect.

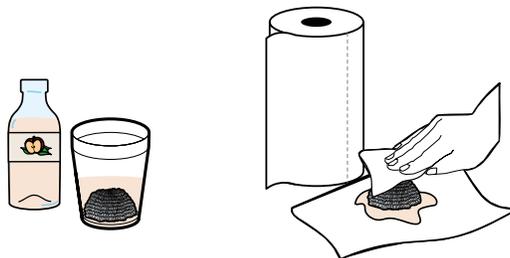


5. Make a chart to collect your data in the Collecting Data section on page 36.

Collecting Data

Rust:

1. Place the steel wool in the vinegar cup and make sure it is completely covered.
2. Let the steel wool soak in the vinegar for five minutes.
3. Pull the steel wool from the cup and immediately blot the vinegar off with a paper towel.



4. Quickly place the steel wool in the plastic bag and seal it.
5. Make sure you also have a hand on the bag for the first few moments so that you can feel the temperature change.
6. Record the temperature of the thermometer every five seconds for one minute.

Balloon:

1. Squeeze the self-inflating balloon until the packet inside pops. You might have to put the balloon on a table and lean on it.
2. Make sure you have a hand on the balloon for the first few moments so that you can feel the temperature change.
3. Record the temperature of the thermometer every five seconds for one minute.

Chart

--

Analyzing Your Results

1. How did the appearance of the steel wool change?

2. What happened to the temperature of the steel wool?

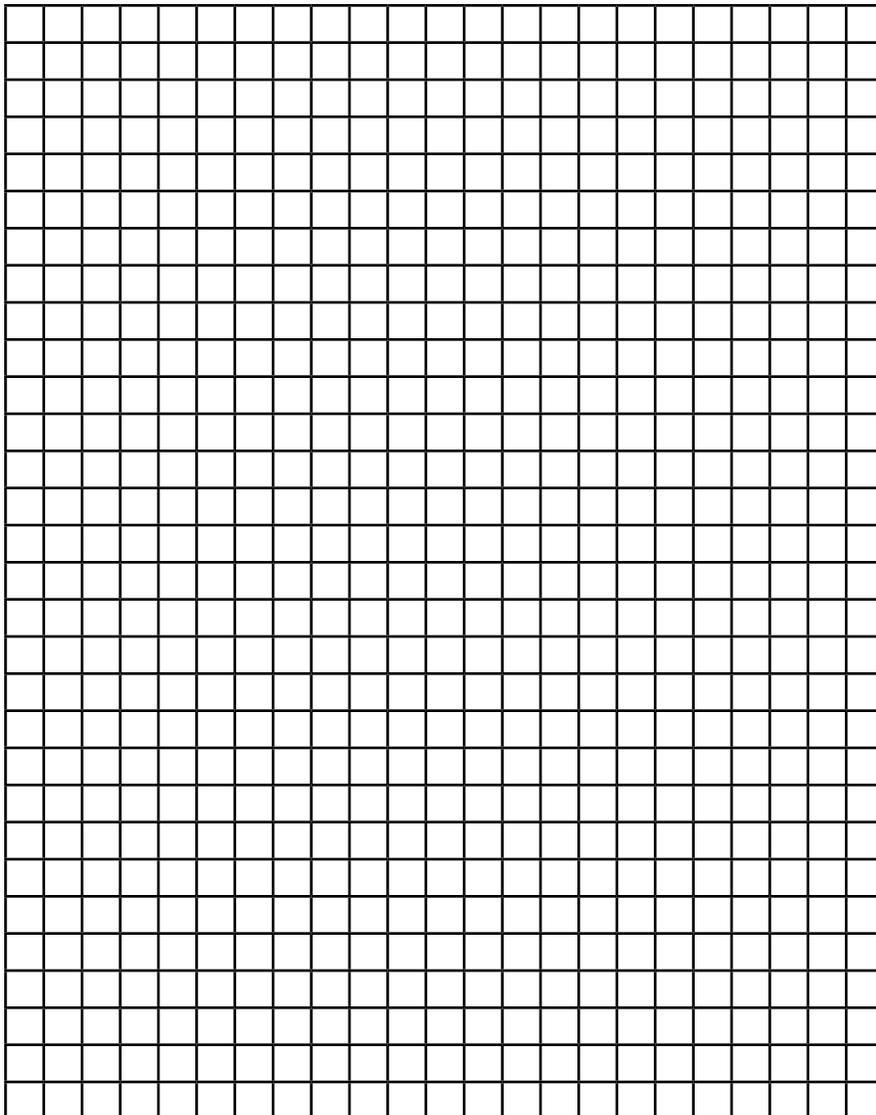
3. Why did you need to soak the steel wool in vinegar?

4. How did the temperature change as the balloon inflated?

5. Compare this to what happened with the steel wool. What was the same? What was different?

6. Look back at your predictions. How does what you saw compare with what you thought you would see?

7. Make a graph of temperature vs. time for both the balloon and the steel wool.



ACTIVITY

4

Getting Salty

This activity demonstrates the different effects that table salt, rock salt, and sugar have on the temperature at which ice melts. Salt is used on icy roadways because it lowers the melting point of ice, making it melt away even if it's freezing outside. Through this activity, students will investigate the effects of different substances on changing the melting temperature of ice. **Note:** This activity requires the freezing of 7 cups of water filled with 8 fluid oz. each. You may need to modify the timing of this activity to fit the class time allotted, such as freezing the cups overnight.

Before the activity, students should know:

- Pure substances are made up of only one type of molecule.
- Mixtures are made up of two or more types of molecules.
- As a pure substance, water has a freezing/melting point of 0°C (32°F).

After the activity, students should be able to:

- Determine that mixtures have different melting points than pure substances.
- Understand that you can identify if a substance is pure based on its melting point.

Key Question

When different substances (table salt, rock salt, and sugar) are added to ice, which one will lower the melting point of the ice the most?

Materials

- Table salt
- Rock salt
- Sugar
- Cups for making ice (7)*
- Stopwatch*
- Freezer*

**Not included in the PhysicsQuest kit*

Key Terms

Compound

A substance that is composed of two or more separate elements chemically bonded together.

Element

A simple substance that cannot be broken down using a chemical reaction.

Mixture

Combination of two or more substances that are not chemically bonded together.

Molecule

Combination of one or two atoms that are chemically bonded together.

Pure Substance

A substance made up of only one type of molecule.

The Science Behind Mixtures

Pure substances are substances that contain molecules of only one type. The molecules in a pure substance can be either elements or compounds. Elements are one type of atom, like oxygen. A compound is made up of two or more elements that are chemically bonded together to make a new substance, like hydrogen and oxygen combining to make water.

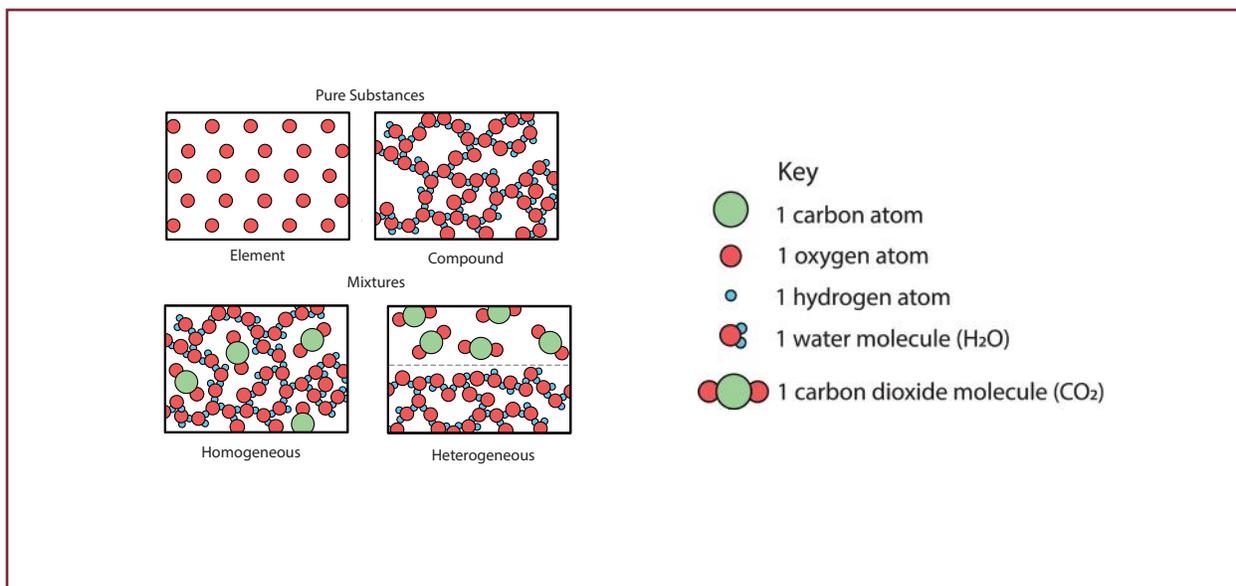
Mixtures are a combination of two or more substances that are not chemically bonded together, like salt in water or raisins in your trail mix. Since these substances don't react chemically, it's possible to separate a mixture back to its original parts. Adding something to a pure substance to make it a mixture will change how that substance behaves.

There are two basic types of mixtures: homogeneous and heterogeneous. Homogeneous mixtures are evenly mixed and appear the same throughout like saltwater. If properly dissolved, you wouldn't be able to see the salt grains in a bucket of saltwater. In heterogeneous mixtures you can see the different substances making up the mixture, like in a trail mix, and they can easily be separated back into their original parts.

Water is a pure substance when it contains only molecules of H_2O . Pure water has a freezing point of 0°C , which means the melting point of ice made with pure water is also 0°C . When other substances like sugar or salt, are added to water, it becomes a mixture, and its freezing/melting point will change.

When salt (NaCl , sodium chloride) is added to water, it becomes a mixture, which changes the melting/freezing point and the boiling point of the water. While water is freezing, the salt molecules disrupt the formation of ice crystals. This causes the liquid (saltwater) to drop to a temperature lower than 0°C before it reaches its freezing point and changes into a solid (ice). This also means that ice made with saltwater will melt at that same lower temperature.

Other substances will have similar effects on water's freezing/melting point. Some chemicals, such as ethylene glycol, a compound in antifreeze, can drop the freezing point much lower than salt. It is commonly used to help de-ice planes or prevent freezing of pipes in RVs or boats. However, this chemical is poisonous to animals and humans.



Suggested Resources

Learn more about what occurs when you mix salt and ice:

go.aps.org/freezingpoint

Discover why adding salt to water makes it colder:

go.aps.org/saltwater

Enjoy an ice melting science experiment using food coloring:

go.aps.org/meltingice

Make ice cream(!) using ice and salt:

go.aps.org/icecream

Next Generation Science Standards (NGSS)

This activity addresses the following standards:

MS-PS1-2 Matter and its Interactions

Analyze and interpret data on the properties of substances (before and after the substances interact) to determine if a chemical reaction has occurred.

MS-PS1-4 Matter and its Interactions

Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

Getting Salty

Key Terms

Compound

A substance that is composed of two or more separate elements chemically bonded together.

Element

A simple substance that cannot be broken down using a chemical reaction.

Mixture

Combination of two or more substances that are not chemically bonded together.

Molecule

Combination of one or two atoms that are chemically bonded together.

Pure Substance

A substance made up of only one type of molecule.

Have you ever slipped on an icy surface or seen a video of someone slipping on ice? Have you ever been in a car that has slipped on an icy road? To keep this from happening, salt is sometimes put down on icy roads and sidewalks to help the ice melt faster, even if it's still cold outside. In this experiment, you will explore how to lower the melting point of ice to make it melt quicker.

Getting Started

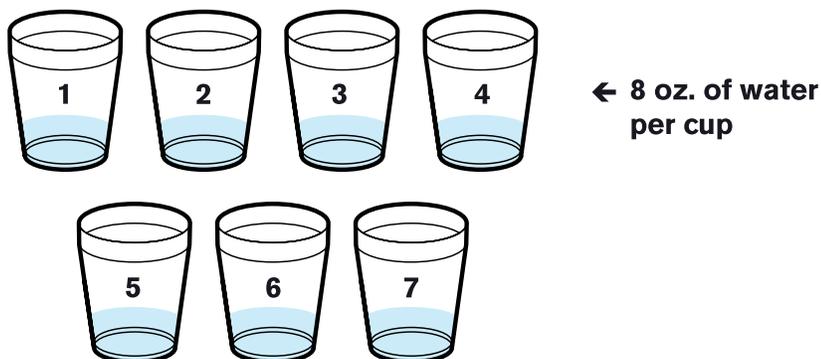
How do you think the substances (table salt, rock salt, and sugar) will change the melting point of the ice?

Predict the order in which ice containing each of these substances will melt from fastest to slowest.

1. _____ (melts fastest)
2. _____
3. _____ (melts slowest)

Setting Up the Experiment

1. Fill the smaller cups with the substances as follows and label as follows:
 - Cup 1 – $\frac{1}{3}$ of the total table salt
 - Cup 2 – $\frac{2}{3}$ of the total table salt
 - Cup 3 – $\frac{1}{3}$ of the total rock salt
 - Cup 4 – $\frac{2}{3}$ of the total rock salt
 - Cup 5 – 3 packets of sugar
 - Cup 6 – 6 packets of sugar
2. Label Cup 7 – water only (this cup will be your baseline)
3. Carefully pour 8 oz. (one cup) of water into each cup for the substances to dissolve. Make sure each cup is filled to the same level.

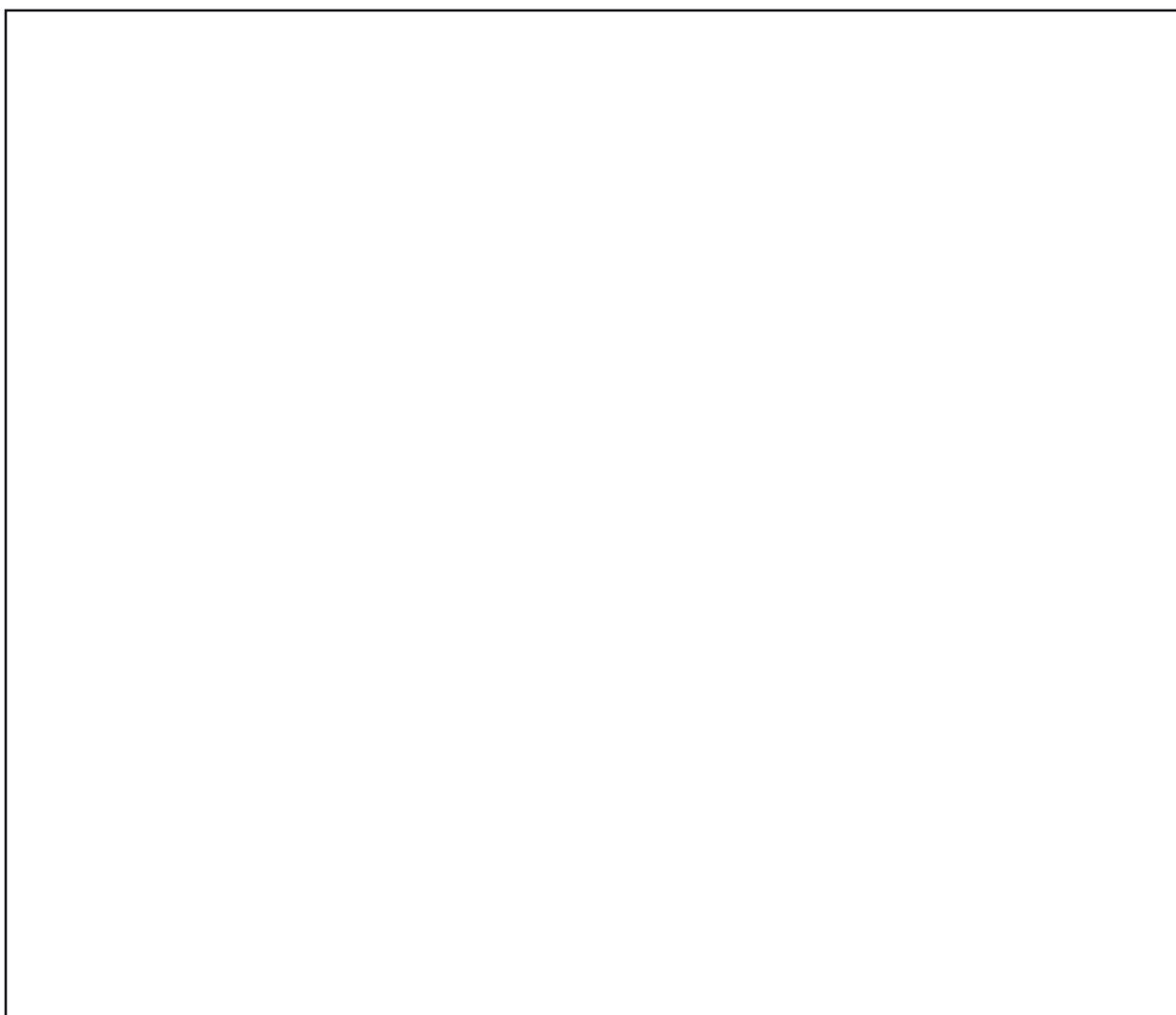


4. Place all seven cups in the freezer for at least two hours, or until the water has frozen.
5. Make a chart for recording the time it will take each cup of ice to melt in the Collecting Data Section on page 44.

Collecting Data

1. Remove the ice cups from the freezer.
2. Place the cups somewhere warm—the warmer, the better.
3. Start the stopwatch to keep track of how long it takes each cup of ice to melt.
4. Record how much time it takes for each cup of ice to melt completely.

Chart



Analyzing Your Results:

1. How did the order of the ice melting compare to your predictions? Which cup of ice melted first?

2. Compare the time it took for ice made with just water to melt compared to the other cups. Did it melt faster or slower?

3. Did ice made from water mixed with different amounts of the same substance melt at the same time? Why or why not?

4. List the substances from the least effective to most effective at lowering the melting point of ice.

1. _____ (least effective)

2. _____

3. _____ (most effective)

5. Now that you have determined which substance works the best at lowering the melting temperature of the ice, how would you explain to a school that they should use it on icy sidewalks to keep people safe?

Crossword Puzzle: Dr. Wu's "Aha!" Moment

Once students are able to solve the secret message, expand on it with the full quote from Chien-Shiung Wu: "These were moments of exhilaration and ecstasy! A glimpse of this wonder can be the reward of a lifetime. Could it be that excitement and ennobling feelings like these have kept us scientists marching forward forever?"

Sometimes, science takes a lot of time and hard work before getting to that "Aha!" moment. Chien-Shiung Wu worked the majority of her life with very little recognition for her contributions to physics, but the moments of discovery and inspiration along the way kept her going.

Suggested Resources

Channeling Ada Lovelace: Chien-Shiung Wu, Courageous Hero of Physics

go.aps.org/physicsherowu

Profile of Chien-Shiung Wu

go.aps.org/profilewu

Bertsch McGrayne, Sharon. Nobel Prize Women in Science : Their Lives, Struggles, and Momentous Discoveries. Washington, DC. 2006

Chiang, Tsai-Chien. Madame Chien-Shiung Wu: The First Lady of Physics Research. Singapore: World Scientific, 2014.

Tsjeng, Zing. Forgotten Women: The Scientists. Hachette, Australia , 2018.

Answer Key

				¹ E	Q	U	I	L	I	B	R	I	U	M						
				N																
				D									² D							
				O		³ C			⁴ T	H	E	R	M	A	L					
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A **G L I M P S E**
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10D 12A 11A 10A 8D 12A 1A 10A

Crossword Puzzle: Dr. Wu's "Aha!" Moment

Wherever she went, Dr. Wu became known for her amazing attention to detail. Test your skills by completing the crossword puzzle below. If there's a clue that stumps you, remember you can always "Ask Dr. Wu" by looking back through your experiment guides!

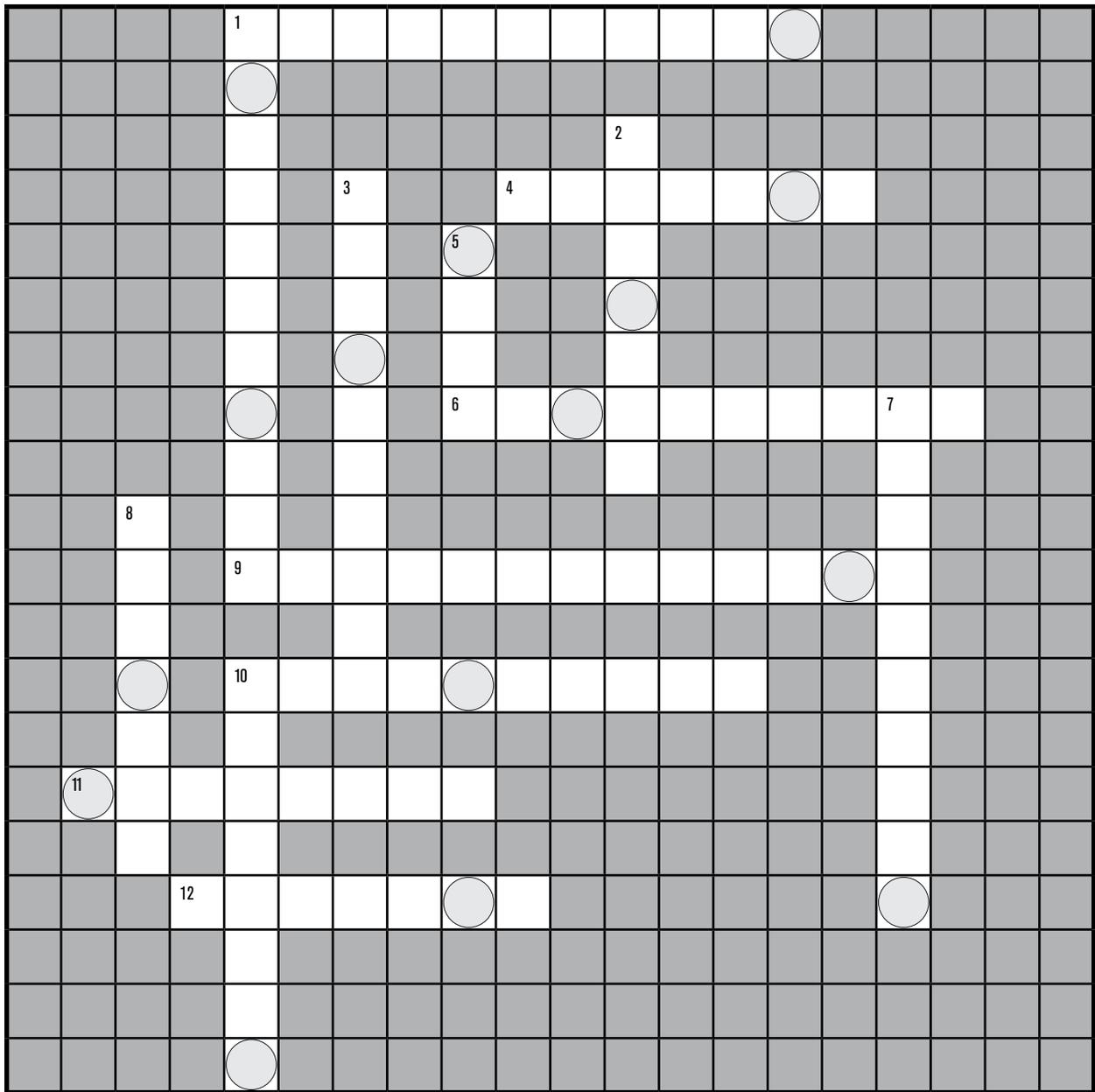
If you are especially careful, you can use the crossword to decrypt a message from Dr. Wu herself!

ACROSS

1. The state of a system in which all parts are the same temperature (Thermal _____).
4. Energy in the form of heat (_____ Energy).
6. "Outside heating." A reaction that releases energy, sometimes in the form of heat.
9. The first scientist to win the Wolf Prize.
10. Transfer of heat through currents.
11. 0 degrees Celsius is the _____ point of water.
12. Energy in the form of motion (_____ Energy).

DOWN

1. "Inside heating." A reaction which absorbs energy, usually in the form of heat.
2. The amount of mass per volume of an object.
3. Transfer of heat through touch.
5. A substance made up of any one molecule.
7. A _____ material slows the transfer of heat.
8. A combination of two or more substances, not chemically bonded together.
10. A type of reaction where molecules interact to form a new substance.



A
 7D 10D 12A 1A 5D 2D 10A

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Next Generation Science Standards (NGSS)

PhysicsQuest activities directly correspond to many of the Next Generation Science Standards (see nextgenscience.org). NGSS benchmarks addressed by each of the activities are listed below.

Activity 1: Turning Thermal Tides

MS-PS1-4 Matter and its Interactions

Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

MS-PS3-3 Energy

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

MS-PS3-4 Energy

Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

MS-PS3-5 Energy

Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

Activity 2: Rusted Out & Blown Up

MS-PS1-2 Matter and its Interactions

Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

MS-PS1-6 Matter and its Interactions

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

Activity 3: Getting Warmer / Getting Colder

MS-PS1-4 Matter and its Interactions

Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

MS-PS3-3 Energy

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

MS-PS3-4 Energy

Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

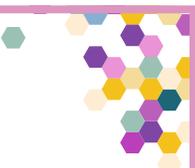
Activity 4: Getting Salty

MS-PS1-2 Matter and its Interactions

Analyze and interpret data on the properties of substances, before and after the substances interact, to determine if a chemical reaction has occurred.

MS-PS1-4 Matter and its Interactions

Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.



STEP UP



PHYSICS TOGETHER

STEP UP is a national community of physics teachers, researchers, and professional societies.

If half of the high school physics teachers encourage just one more female student to pursue physics as a major, a historic shift will be initiated — female students will make up 50% of incoming physics majors.

Do you know a high school physics teacher? Visit our website to help recruit teachers to the movement.

STEPUPphysics.org



PhysTEC: Transforming Physics Teacher Education Programs



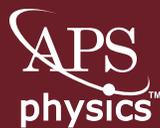
Physics
Teacher
Education

Coalition

The Physics Teacher Education Coalition (PhysTEC) provides direct support and resources to improve physics teacher preparation programs at colleges and universities across the United States. PhysTEC's primary goal is to address the national shortage of high school physics teachers.

If you know of a physics or physical science education program at your local campus, encourage them to join PhysTEC!

Learn More: phystec.org



American Physical Society

One Physics Ellipse
College Park, MD 20740
aps.org

Continue the Quest:



physicscentral.com/physicsquest