2007 Resource for Middle School Classrooms

PhysicsQuest

Marie Curie's Floating Classes

Distributed by the
American Physical Society

APS physics

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www.physicscentral.com/physicsquest

Table of Contents

Welcome to PhysicsQuest 2007!

History of the PhysicsQuest Program

As part of the World Year of Physics 2005 celebration, the American Physical Society produced PhysicsQuest: The Search for Albert Einstein's Hidden Treasure. Designed as a resource for middle school science classrooms and clubs, the quest was received enthusiastically by nearly 10,000 classes during the course of 2005. Feedback indicated that this activity met a need within the middle school science community for fun and accessible physics material, so the American Physical Society (APS) has decided to continue this program. APS is pleased to present this third kit, *PhysicsQuest 2007: Marie Curie's Floating Classes.*

Each PhysicsQuest kit follows a mystery-based storyline and requires students to correctly complete four activities in order to solve the mystery and be eligible for a prize drawing. We hope this goal will entice students to actively participate — and that once students begin participating they find that physics is interesting and fun!

About the American Physical Society (APS)

APS is the professional society for physicists in the United States. APS works to advance and disseminate the knowledge of physics through its journals, meetings, public affairs efforts, and educational programs. Information about APS and its services can be found at www.aps.org.

APS also runs PhysicsCentral, an award-winning website aimed at communicating the excitement and importance of physics to the general public. At this site, www.physicscentral.com, you can find out about APS educational programs, current physics research, people in physics, and more.

PhysicsQuest 2007 Competition

About PhysicsQuest

PhysicsQuest is a set of four activities designed to engage students in scientific inquiry. The 2007-08 activities are linked together via a storyline that follows the underground university that Marie Sklodowska Curie attended when women were not allowed to study at her local university in Poland. As students perform the experiments, they will be collecting information that will help them determine the secret location of her class.

PhysicsQuest is designed with flexibility in mind — it can be done in one continuous session or split up over a number of weeks. The activities can be conducted in the classroom or as an extra credit or science club activity. The challenges can be completed in any order, but to get the correct final result all of the challenges must be completed correctly.

About the PhysicsQuest Competition

APS sponsors an optional PhysicsQuest competition designed to encourage students to invest in the project. If you choose to participate in the competition, your class must complete the four activities and you must submit their answers online by April 14, 2008. All classes that submit answers online will receive a certificate of completion and those that complete the activities correctly will be entered into a prize drawing. Details on the prizes will be posted on the PhysicsQuest website as they become available.

The online results submission form requires the answers to all of the questions on the Final Report. Each step must be correct in order for classes to qualify for prizes. Each class can only submit one entry form, so class discussions of results are encouraged.

Answers can be submitted online through the PhysicsQuest website beginning December 1, 2007: www.physicscentral.com/physicsquest. If you have questions about any activity, please contact physicsquest@aps.org.

Included in this kit

This PhysicsQuest manual
1 page inserts (7)
Piece of aluminum
Piece of glass
Piece of felt
Liquid crystal thermometers (4)
Dye tablets (16)
Bulb thermometers (3)
Small glass vial
Clear drinking straw (4)
Modeling clay
Yeast
Hydrogen peroxide
Rubber band
Film canister

For more information on these items and where they can be purchased, please visit the PhysicsQuest website.

If your kit is missing any of these materials, please contact the kit vendor according to the directions on the PhysicsQuest website.

Not included in this kit

Corrugated cardboard
(at least 3″x3″)
Transparent cups (3)
Styrofoam cups (3)
Small ice cubes (4)
Warm and cold water
Paper towels
Stopwatch
(or clock with second hand)
Scissors
Ruler
Calculator
Scotch tape

The PhysicsQuest Materials

The PhysicsQuest kit includes this manual, seven inserts, and most of the hardware your students need to complete the activities. There is also a corresponding website, www.physicscentral.com/physicsquest, which has supplemental material such as extension activities.

The Teacher Guide

The Teacher Guide for each activity includes:

Key Question This question highlights the goal of the activity.

Key Terms This section lists terms related to the activity that the students will encounter in the Student Guide.

Before the Activity... Students should be familiar with these concepts and skills before tackling the activity.

After the Activity... By participating in the activity, students are practicing the skills and studying the concepts listed in this section.

The Science Behind... This section includes the science behind the activity, and some historical background. The Student Guide does not include most of this information; it is left to you to decide what to discuss with your students.

Safety This section highlights potential hazards and safety precautions.

Materials This section lists the materials needed for the activity. Materials that are provided in the kit are in bold type; you will need to provide the rest.

Extension Activities

Extension activities related to each activity can be found on the PhysicsQuest website. This section gives a brief description of those related to the activity.

Bibliography and Suggested Resources

This section lists the books and other resources used to create this activity and recommended resources for more information on the topics covered.

The Student Guide

Each activity has a Student Guide that you will need to copy and hand out to all of the students. In addition, you will need to copy the PhysicsQuest Challenge/Final Report and the map of Warsaw inserts and hand them out to your students when you first start the PhysicsQuest activities. The Student Guide includes:

Key Question This question highlights the goal of the activity.

Materials This section lists the materials students will need for the activity.

Getting Started This section includes discussion questions designed to get students thinking about the key question, why it's important, and how they might find an answer.

The Experiment This section leads students step-by-step through the set-up and data collection process.

Analyzing your Results This section leads students through data analysis and has questions for them to answer based on their results.

Using Your Results to Find Marie's Class In this section students turn their results into information that will help them determine the secret location.

Inserts

Included with this kit are seven, 1-page inserts that students will need in order to locate Marie's classroom.

PhysicsQuest Challenge / Final Report The PhysicsQuest Challenge introduces students to the project and their mission. Students should fill out the opposite side of this handout, the Final Report, as they complete each activity. Although groups may fill out the form independently, each class can only submit one answer to the online competition.

Ruler Template During Activity 3: Measuring Change, students will need to cut out one of these rulers.

Map of Warsaw and Grid Overlay (4) The clues that students will uncover by solving the four activities will show them how to find the location of Marie's classroom on this map. We have included four grid overlays for you to distribute to your classroom groups.

Activity Hardware

The hardware included in the kit is listed on page 3. Enough materials are included for four groups to perform each activity, but only one group at a time. For specific information on these items and where they can be purchased, see the Materials List on the PhysicsQuest website. Please note that some of these activities require water of varying temperatures or ice. Please prepare accordingly.

PhysicsQuest Website

The PhysicsQuest website, www.physicscentral.com/physicsquest, has supplemental material for teachers, such as extension activities. Periodic updates on the program will also be posted on this site.

PhysicsQuest Logistics

Materials

The PhysicsQuest kit comes with only one set of materials. This means that if your students are working in four small groups (recommended), all groups should work simultaneously on different activities and then rotate activities, unless you provide additional materials. The Materials List on the PhysicsQuest website includes specific descriptions of the materials and where they can be purchased.

Safety

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.

Time Required

The time required to complete the PhysicsQuest activities will depend on your students and their lab experience. Most groups will be able to complete one activity in less than 45 minutes.

Small Groups

Working effectively in a group is one of the most important parts of scientific inquiry. If working in small groups is challenging for your students, you might consider adopting a group work model such as the one presented here.

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 many 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.

Using PhysicsQuest in the Classroom

This section suggests ways to use PhysicsQuest in the classroom. Since logistics and goals vary across schools, please read through the suggestions and then decide how best to use PhysicsQuest. Feel free to be creative!

PhysicsQuest as a stand-alone activity

PhysicsQuest is designed to be self-contained — it can be done easily as a special project during the day(s) following a test, immediately preceding/following winter break, or other such times. PhysicsQuest also works well as a science club activity and extra credit opportunity.

PhysicsQuest as a fully integrated part of regular curriculum

The topics covered in PhysicsQuest are covered in many physical science classes, so you might have students do the PhysicsQuest activities during the corresponding units.

PhysicsQuest as an all-school activity

Some schools set up PhysicsQuest activity stations around the school gym for one afternoon. Then small groups of students work through the stations at assigned times.

PhysicsQuest 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 go into 6th or 7th grade classrooms and help students with the activities.

The PhysicsQuest Challenge

A Floating University

Marie Sklodowska Curie and her family lived double-lives. They were Polish and lived in Warsaw during the late 1800s. Warsaw had been the capital of Poland. However, as a result of various wars, Poland was split apart and Warsaw was controlled by Russia when Marie was born.

The leader of Russia made it illegal for people to speak Polish and teach Polish history. People could lose their jobs, go to jail, or even be killed for being loyal to Poland.

Marie's family believed that Poland should be its own country again. They resisted the Russian authorities in secret.

During elementary school Marie's class followed a coded schedule. For example, a class on Polish geography might be called "Russian Language" on the schedule. When Russian inspectors came to check on the school the students would hide their Polish books and pretend they were learning Russian instead.

Marie was a very good student. She wanted to study math and science in a university, but the university in Warsaw didn't let females study there. Marie didn't have enough money to go to another university. Luckily, Marie had another option.

There was a secret university in Warsaw run by Polish professors. The professors taught groups of students in their homes. The classes had to be kept secret because the police could arrest the teachers for teaching Polish history and culture. This school was called the Floating University because the classes "floated" around to different houses. This kept the police from finding out about the classes.

Your Mission

Find the secret location of Marie's next class. Be careful — you don't want to end up at the Police Station or the Courthouse with your Polish books!

The location of the Floating University has to be kept very secret. If the police find out everyone will be in trouble! To find the secret location you will need to solve four challenges. Each one will get you a step closer to finding the secret location.

Good luck!

Activity 1 Checking Temperatures

In this activity students test their ability to rank temperatures by touch. By comparing how different surfaces feel to their actual temperatures, students should come to the realization that they can't always trust their senses. This is one of the reasons why objective measuring tools are so important.

Key Question

Can you trust your sense of touch?

Before the activity students should know...

- How to read a liquid crystal thermometer
- That materials in thermal contact will come to thermal equilibrium

After the activity students should be able to...

- Recognize the need for objective measuring tools
- Qualitatively estimate the heat conductivity of different materials

Key Terms

Liquid Crystal Thermometer
Liquid crystal thermometers contain liquid crystals, a unique material whose color depends on temperature.

Heat Conductivity
The heat conductivity of a material describes how quickly heat travels through the material.

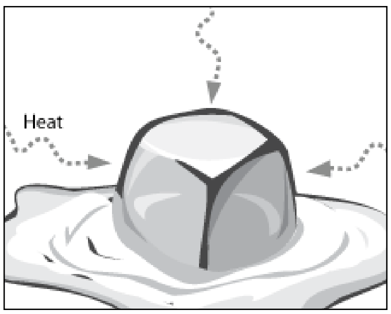
The science behind heat conduction

In 1895 Wilhelm Röntgen discovered X-rays. For the first time people could see inside the human body without cutting it open. It didn't take long for scientists to realize how valuable this technology was, particularly in medicine — doctors could see broken bones, bullets, and other metal objects inside bodies without cutting them open.

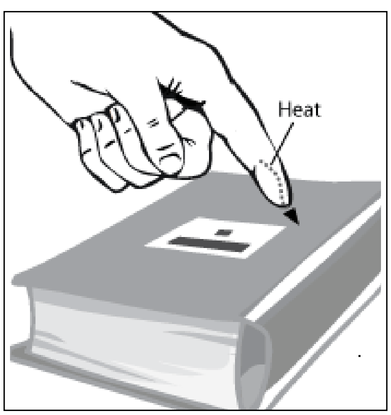
During her research Marie learned how to create X-rays. When World War I started, she decided to use her knowledge to help wounded soldiers. Marie and one of her daughters created a set of mobile X-ray units that were driven to army camps at or near the front lines. These machines enabled doctors to better diagnose wounded soldiers and likely saved many of them from unnecessary operations (and therefore possible infections) and amputations. The right tool enabled scientists and doctors to see things in a whole new way.

The five human senses — sound, sight, touch, taste, and hearing — tell people a lot about their world, but sometimes different tools (like X-rays, microscopes, and thermometers) can provide much more information. Human senses are limited in scope and in sensitivity and many times aren't as objective as they initially seem.

The heat flows from the warmer object (coffee) to the cooler object (air) causing the coffee to cool.



The heat flows from the warmer object (air) to the cooler object (ice), causing the ice to melt.



When you touch something at room temperature, heat flows from your fingers into the object.

Touch a piece of metal and a piece of wood. Which one feels warmer?

When two objects are in thermal contact — meaning they can exchange heat — heat will always flow from the warmer object to the cooler object until the two reach thermal equilibrium. This is why coffee cools down to room temperature if you don't drink it right away and ice melts if it's not in a freezer.

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, which is room temperature.

So why does the metal feel colder?

Skin temperature is about 34°C, on average 10 degrees higher than room temperature. When you touch something at room temperature, heat flows from your fingers into the object.

The rate at which the heat travels through a material depends on the material's heat conductivity (also called thermal conductivity). Metals have higher heat conductivities than wood, so heat flows more quickly through metals than through wood.

This means that the metal feels colder because heat leaves your fingers faster. At a given time, the temperature difference between your fingers and the surface of the wood is smaller than the temperature difference between your fingers and the surface of the metal.

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

A block of ice will melt more quickly when sitting on a material with high heat conductivity, even though such a material feels colder to the touch than a material at the same temperature with low heat conductivity. This is because the heat from the material will flow more quickly through the material and into the ice.

Corresponding Extension Activities

1. **Visualizing Conduction:** Watch as heat travels along a piece of metal.
2. **Visualizing Convection:** Watch convection take place using liquid crystal paper.
3. **Visualizing Thermal Radiation from the Sun:** Warm up liquid crystal paper with energy from the sun.

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McCamish, Erin. *Cold Floors.* PhysicsQuest 2006 Extension Activities. http://www.physicscentral.com/physicsquest/pq06/Extensions_All.pdf.

University of Virginia Physics Department. *Phun Physics: Thermal Conductivity.* http://phun.physics.virginia.edu/topics/thermal.html.

Suggested Resources

California Energy Commission. *Energy Story.* http://www.energyquest.ca.gov/story/chapter01.html.

Falstad, Paul. *Thermal Camera Pictures.* http://www.falstad.com/thermal.

GSCE Bitesize. *Forms of Energy.* http://www.bbc.co.uk/schools/gcsebitesize/physics/energy/energy_transfer_and_efficiencyrev2.shtml. British Broadcasting Corporation.

Materials

Glass

Aluminum

Felt

Liquid crystal thermometer

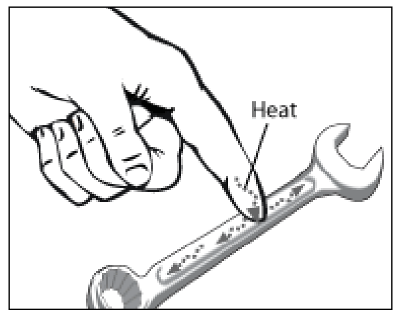
4 small ice cubes, all about the same size

Corrugated cardboard (at least 3″x3″)

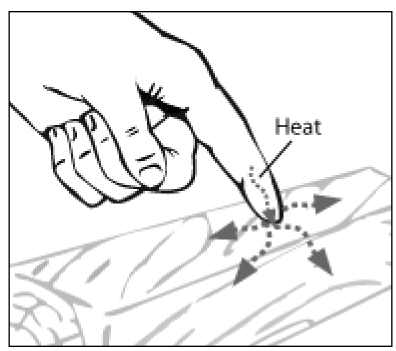
Paper towels

Stopwatch (or clock with second hand)

Scissors



When you touch a metal object, the heat from your fingers is carried away from the surface and quickly disperses throughout the object.



When you touch wood, the heat disperses from the surface at a slower rate.

Activity 1 Checking Temperatures

With the discovery of X-rays in 1895, people could see inside the human body without cutting it open. For the first time, doctors could see broken bones, bullets, and other metal objects inside bodies without cutting them open.

During World War I, Marie and one of her daughters created mobile X-ray machines. Doctors on the front lines used these machines to diagnose wounded soldiers. Having the right tool helped doctors save many soldiers.

An important part of science is using the right tool in an investigation. In this activity you will investigate whether your sense of touch is a good tool for judging temperature. Your results will give you the first clue you need to find the secret location of Marie's class.

Key Question

Can you trust your sense of touch?

Materials

- Glass
- Aluminum
- Felt
- Liquid crystal thermometer
- 4 small ice cubes, all about the same size
- Cardboard
- Paper towels
- Stopwatch (or clock with second hand)
- Scissors

Getting Started

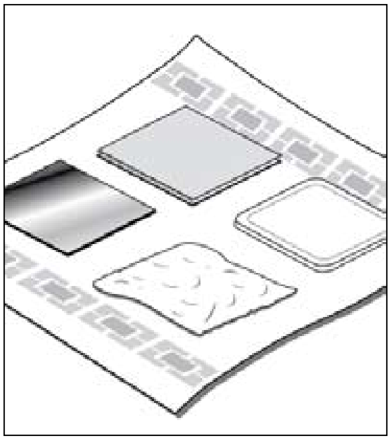
Touch some of the things around you— like your desk, your skin, and the classroom window. Which feels the warmest? Which feels the coolest?

People often judge the temperature of something by touch.

- Parents squirt the milk from a baby bottle on the inside of their wrists to make sure it's not too hot.
- People cautiously dip a finger in their soup to make sure it won't burn their tongues.
- Kids stick their toes into the pool to make sure the water isn't too cold.

When do you use your sense of touch to measure the temperature of something?

- On a scale of 1-10, how much do you trust your ability to tell the difference between hot and cold objects?



Using a Liquid Crystal Thermometer

These thermometers are made from a material whose color depends on 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 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 one surface and stick it to another!

The Experiment

1. Put a layer of paper towels on top of the table.
2. Cut out a 3x3-inch square of cardboard.
3. Lay the cardboard on top of the paper towels. Then lay the glass, felt, and aluminum on the paper towels, each an inch or two apart.
4. One-by-one, touch each piece of material for about 2-seconds*. Then rank them from coldest to warmest.

   **It's best to touch each material with one finger at a time. Only one person should touch each material at a time.*

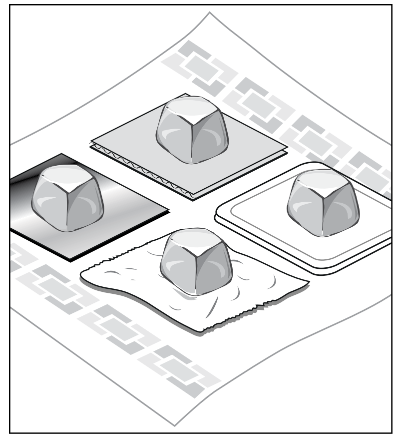
   1. ____________________ (coldest)
   2. ____________________
   3. ____________________
   4. ____________________ (warmest)

5. Imagine placing a piece of ice on top of each type of material. Based on your results, which material do you think would melt the ice the fastest?
6. Measure the temperature of the cardboard, felt, aluminum, and glass using the liquid crystal thermometer. (See "Using a Liquid Crystal Thermometer" on the left side of this page). Record the temperatures in Chart A. Remove the thermometers once you are finished recording the temperatures.

Chart A

	Measured Temperature
Cardboard	
Felt	
Aluminum	
Glass	

7. Pick out 4 ice cubes that are all the same size and place one in the middle of each of the four materials. Start the stopwatch.
8. After 1, 3, and 5 minutes, draw a picture of what is happening to each ice cube in Chart B.
9. After 5 minutes, rank the materials in order of how quickly they melted the ice — 1 for the slowest and 4 for the fastest. 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)

10. Do your results match your prediction from Step 5?

Chart B

	Cardboard	Felt	Aluminum	Glass
1 minute				
3 minutes				
5 minutes				

Analyzing your Results

1. How did your ranking from coldest to warmest (step 4) compare to the actual temperature of each of the materials (step 6)?

   Is this what you expected? Why or why not?

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

   A material with high heat conductivity will feel (warmer / colder) than a material at room temperature with low heat conductivity.

   A material with high heat conductivity will melt ice (faster / slower) than a material at room temperature with low heat conductivity.

What is going on?

All materials have a property called *heat conductivity*. Heat conductivity describes how quickly heat travels through a material.

When you touch a material that has high heat conductivity, the heat from your fingers travels through the material quickly. This makes your fingers feel cold.

When you touch a material with low heat conductivity, it takes a long time for the heat from your fingers to leave. This means your fingers will stay warm longer.

3. Based on the results of your tests, rank the four materials in order from lowest heat conductivity (1) to highest heat conductivity (4).

   1. ____________________ (Lowest heat conductivity)
   2. ____________________
   3. ____________________
   4. ____________________ (Highest heat conductivity)

Using Your Results to Find Marie's Class

In question three you ranked the four materials in order from lowest heat conductivity to highest heat conductivity. Did you rank cardboard 1st, 2nd, 3rd, or 4th? ________

Activity 2 Racing Molecules

In this activity students explore the fundamental difference between hot and cold water. An important part of science is learning to identify what you don't understand — even if it is something you encounter every day — and asking questions about it. Isaac Asimov, a biochemist and popular science fiction writer is quoted as saying, "The most exciting phrase to hear in science, the one that heralds the new discoveries, is not 'Eureka!' (I found it!) but 'That's funny...'"

Key Question

What is the difference between hot and cold water?

Key Terms

Atom
An atom is the smallest particle you can have that defines an element. For example, hydrogen is made up of hydrogen atoms and oxygen is made up of oxygen atoms.

Molecule
A molecule is a group of atoms held together by chemical bonds. For example, a water molecule is formed when two hydrogen atoms and one oxygen atom are chemically bound together.

Before the activity students should know...

- All matter is made up of small particles called atoms.
- All atoms have energy and are constantly in motion.

After the activity students should know...

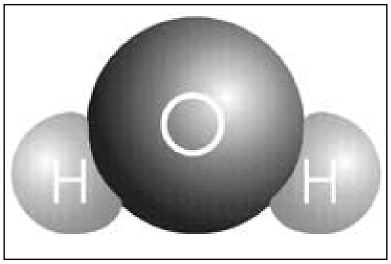
- Heat is associated with the motion of atoms.
- Temperature is a measure of the average energy of the particles in the system.
- About how fast water molecules are moving and have a sense of how this compares to speeds they are familiar with.

The science behind hot and cold...

During 1896 the French scientist Henri Becquerel made a startling discovery that changed the course of Marie's life – he found that uranium spontaneously emitted radiation.

Marie was immediately drawn in by the mysterious uranium rays and chose them as the subject of her doctoral thesis. She dedicated the rest of her life to understanding radioactivity, eventually identifying other radioactive elements and even discovering new elements based on their high levels of radioactivity (polonium and radium). Her work led to a modern-day understanding of how radioactive elements decay and release energy, and earned her two Nobel Prizes.

Many discoveries in science result from people seeking to explain what they don't understand — such as the discoveries of polonium and



A water molecule.

the radioactive decay process. Successful scientists observe what happens around them and wonder why. Why does uranium spontaneously emit radiation? Why do liquids flow but solids keep their shape? Why is hot water different from cold water?

A water molecule is made of two hydrogen atoms and one oxygen atom chemically bound together.

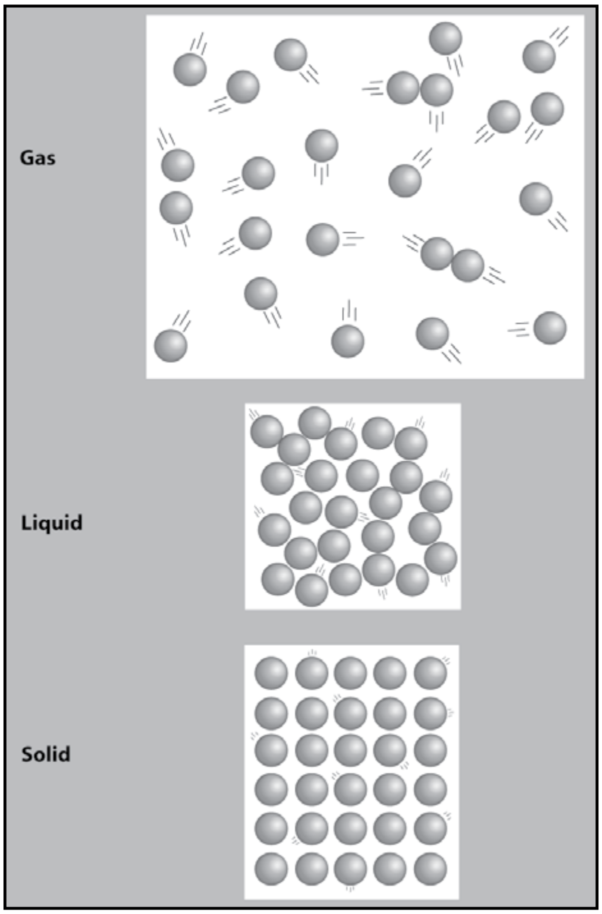
The molecules in water, like in all substances, are constantly moving around — this means that they have kinetic energy. Molecules with more kinetic energy move around faster than molecules with less kinetic energy. The temperature of a substance is the average amount of kinetic energy its molecules have.

Molecules in a liquid have enough energy to move around and pass each other. This is why water can flow around a rock and take the shape of the glass you pour it into. Molecules in solids, like ice, are packed together closely and don't have the energy it takes to move around very much, so solids keep their shape. Molecules in a gas have lots of energy and spread out even more than molecules in a liquid.

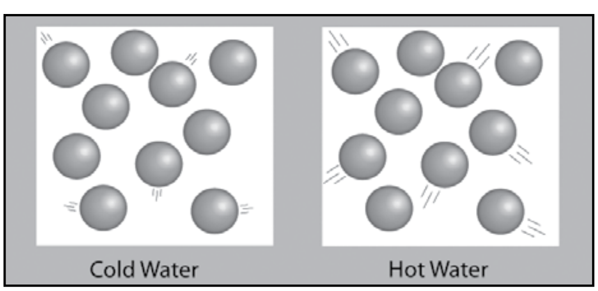
Because warm water has a higher temperature than cold water, its molecules have a higher average kinetic energy than cold water. You can see this by adding food coloring to the water.

Like water, food coloring is made of molecules. The food coloring molecules in a glass of water are pushed around by the water molecules and eventually spread throughout the entire glass, even if you don't stir the water.

Since molecules of warm water move around faster than molecules of cold water, they spread the food coloring out more quickly. This difference is measurable, as students will see in this experiment.



A depiction of the relative amounts of energy in the molecules of a gas, liquid, and solid.



Water molecules of warm water move around faster than molecules of cold water.

Safety

This activity requires students to work with a plastic cup full of warm water. Students should not use hot water because it could burn them if spilled and could burn them through the cup if very hot water is used.

Materials

3 dye tablets

Bulb thermometer

3 transparent cups

Warm and cold water

Stop watch
(or clock with a second hand)

Calculator

Corresponding Extension Activities

1. **Hot Leaks:** Investigate why hot water leaks more than cold water.
2. **Full of Hot Air:** Watch a balloon expand as the air inside is heated.
3. **Molecular Motion:** Make a model of the way molecules move in different states.
4. **Float or Sink:** Watch water's strange behavior in a container with oil.

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http://pubs.acs.org/cen/whatstuff/stuff/813foodcoloring.html.

Kurtus, Ron. *Heat.* School for Champions, 2003.
http://www.school-for-champions.com/science/heat.htm.

Rader's ChemKids.com. *States of Matter*.
http://www.chem4kids.com/files/matter_intro.html.

Sweet Briar College. *H_2O: The Mystery, Art, & Science of Water*.
http://witcombe.sbc.edu/water.RacingMolecules.

Activity 2 Racing Molecules

Marie had a challenging childhood. She was brought up resisting the Russian authorities, but in school she had to speak Russian and hide her love for Poland. Marie's mother and an older sister died when Marie was young. Still, Marie was curious and wanted to know how things worked. She asked a lot of questions and studied hard to find the answers. This was one of the reasons she became a very successful scientist.

In this activity you will study something you encounter every day — hot and cold water. Determining the difference between hot and cold water will bring you one step closer to finding Marie's classroom!

Key Question

What is the difference between hot and cold water?

Materials

3 dye tablets

3 transparent cups

Bulb thermometer

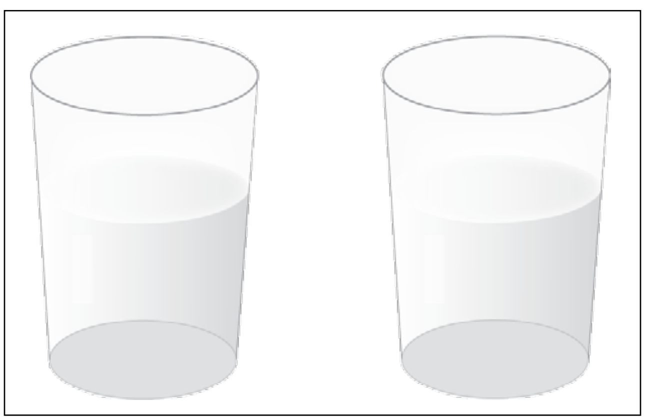
Warm and cold water

Stopwatch
(or clock with a second hand)

Calculator

Getting Started

- Put some warm water in one cup and cold water in another. By looking at the cups can you tell which one is filled with the warm water?



- How might you figure out which cup had warm water in it without touching the water?
- What do you think is going on inside the warm water that makes it different from the cold water?

Taking the Temperature

When you measure the temperature of water, put the thermometer in the cup and let it sit for one minute before you read the temperature. This will give it time to adjust to the temperature of the water.

The Experiment

1. Empty the cups and label them "1", "2", and "3".
2. Fill the "1" cup with very cold water.
3. Fill the "2" cup with lukewarm water.
4. Fill the "3" cup with very warm water.
5. Measure the temperature of the water in each of the cups and record the temperatures on Chart A.

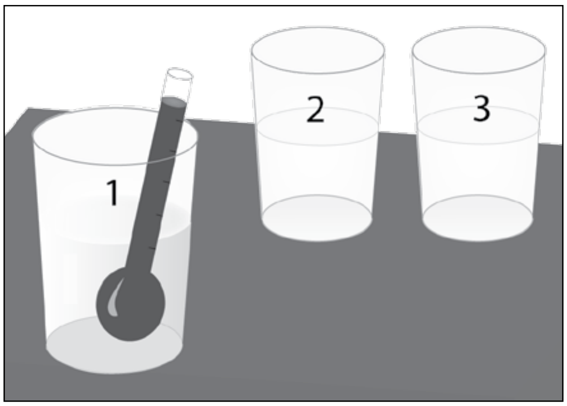
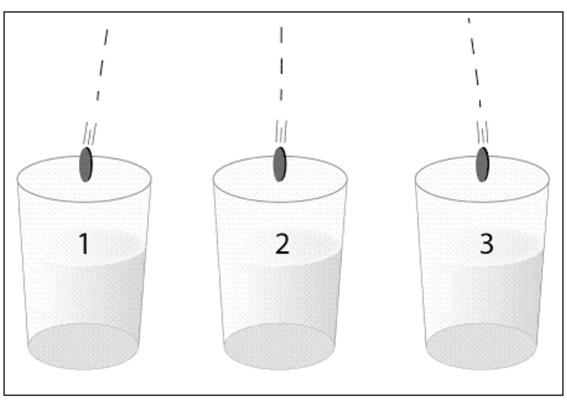


Chart A

Cup	Temperature of water (°C)
1	
2	
3	

6. Get your stopwatch ready. At the same time, drop one tablet of food coloring into each of the cups and immediately start the stopwatch.



7. Watch the food coloring spread out in the water and write down your observations after 30 seconds, 1 minute, and 2 minutes in Chart B. Pay special attention to how streaky the food coloring is and whether it is spread out evenly within the water.

Chart B

30 Seconds

Cup	Observations	Sketch
1		
2		
3		

1 Minute

Cup	Observations	Sketch
1		
2		
3		

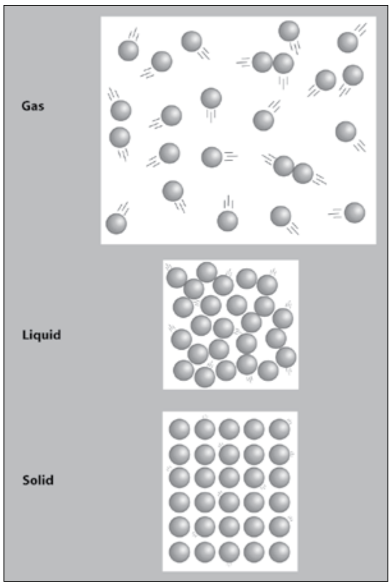
2 Minutes

Cup	Observations	Sketch
1		
2		
3		

Analyzing your Results

1. How did the temperature of the water affect the time it took for the food coloring to spread out?

2. Temperature is a measure of how fast the molecules are moving within the cup of water. How does this help explain what you observed in this experiment?



3. Using a mathematical relationship determined by scientists, you can calculate approximately how fast the water molecules are moving within each cup of water. $\boxed{\text{speed} = 37\sqrt{(T + 273)}}$

   where T is the water temperature in degrees Celsius. This relationship gives you an answer in meters per second.

   Use the equation to calculate the average speed of the water molecules at the three different temperatures of water that you measured. Record the speeds on Chart C.

Chart C

Cup	Temperature of water (°C)	Speed (in meters per second)
1		
2		
3		

4. As the temperature of water increases, does the speed of its molecules increase or decrease?

5. As the speed of water molecules increases, does the time it takes for the food coloring to spread out increase or decrease?

   Why do you think that is?

6. How do these speeds compare to the speed of a car? The speed of light? The speed of sound? (**Reminder: pay attention to the units of your speeds!**)

Using Your Results to Find Marie's Class

On a molecular level, what do you think is the main difference between hot and cold water? (Circle one)

1. Cold water molecules are bigger
2. Hot water molecules are bigger
3. Cold water molecules move faster
4. Hot water molecules move faster

Activity 3 Measuring Change

In this activity students investigate one of the manifestations of a change in temperature — a change in volume. "Temperature" can seem like a mysterious concept because it can't be directly measured like mass or volume. Instead, temperature has to be inferred from measurements of other physical changes in a material. Scientists use indirect measurements like this to make observations of situations that are difficult to study.

Key Question

How is temperature measured?

Key Terms

Thermal Expansion
Thermal expansion is the tendency of matter to change in volume in response to a change in temperature.

Bulb Thermometer
A bulb thermometer uses the property of thermal expansion to indirectly measure the temperature of a material.

Before the activity students should know...

- How to read a metric ruler
- How to read a bulb thermometer

After the activity students should be able to...

- Give examples of how the physical properties of substances can change with temperature
- Explain how bulb thermometers work

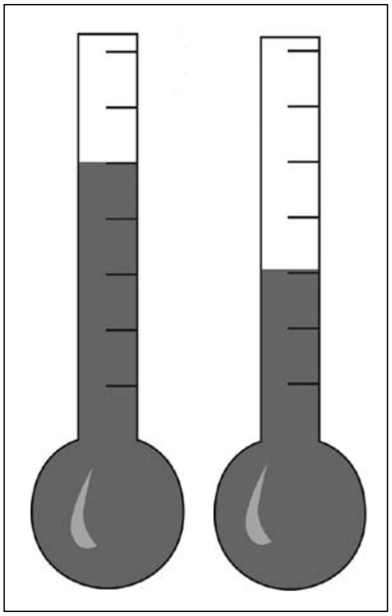
The science behind heat and change in volume

One of the challenges of science research is that sometimes you have to deal with things that are difficult to directly observe because they are too small (atoms), too big (the universe), too bright (the sun), or too extreme in another way. In these cases scientists have to use what they can measure to infer the information they need.

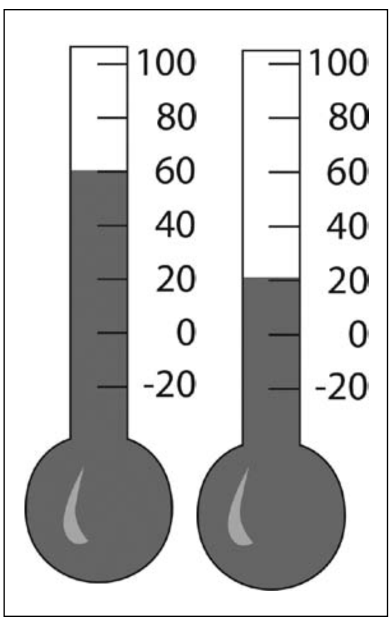
Marie Sklodowska Curie knew this well — her research required years of tedious work isolating radium in quantities too small to see. Barbara Goldsmith writes in her biography of Marie Curie, Obsessive Genius:

> *In the numbing years of measuring and remeasuring, of thousands of fractionations, of tons of processed pitchblende residue, [Marie] had produced an amount of pure radium so small that it resembled a few grains of sand.*

But this tiny quantity allowed Marie to prove to the academic world that she had identified a new element — radium.



Picture A



Picture B
The numbers along the outside of the tube indicate what temperature corresponds to a given volume.

In this experiment students will learn one way that the temperature of a substance can be measured. As shown in Activity 2, heat is associated with the motion of atoms. However, it is not realistic or necessary to measure the energy of individual atoms. Instead, scientists use properties that they can measure to infer the temperature of a substance.

In Picture A, which thermometer is reading a higher temperature? How do you know?

The temperature of a substance is a measure of the average kinetic energy (or energy of motion) of its molecules. But a thermometer doesn't measure the kinetic energy of each molecule and take the average — this would be very difficult. Instead, thermometers use what we know about how the physical properties of a substance change with temperature to infer temperature.

For instance, common bulb thermometers measure changes in volume. Most substances expand when their temperature increases and contract when their temperature decreases. The extent of the change in volume for a given temperature difference varies by substance.

The dark liquid substance in a bulb thermometer is usually alcohol or mercury. Bulb thermometers are designed so that when the temperature of the liquid increases, it expands up into the tube. The volume change per change in temperature is well-known for these substances and the numbers along the outside of the tube indicate what temperature corresponds to a given volume.

The glass or plastic that encases the liquid in a bulb thermometer also expands or contracts in response to a temperature change, but at a much lower rate than the encased liquid.

There are thermometers that rely on other kinds of temperature-dependent properties of materials. For example,

- Digital thermometers that you stick under your tongue usually measure a change in electrical resistance;
- Ear thermometers usually measure the thermal radiation coming from your body; and
- Liquid crystal thermometers reflect different colors of light at different temperatures.

In this activity, students will create their own bulb thermometer and investigate how the volume of fluid insde the bulb changes with temperature.

Safety

This activity requires students to work with very warm water. Students should not use hot water because it could burn them if spilled.

Students should handle the glass vial with care and follow proper disposal guidelines if the glass is broken.

Materials

Glass vial

Modeling clay

Clear drinking straw

Bulb thermometer

Dye tablet

Ruler template

Warm and cold water

3 styrofoam cups

Tape

Corresponding Extension Activities

1. **Happy / Unhappy Spheres:** Observe the effect of temperature on two similar, but not exactly alike, spheres.
2. **Soda Bottle Collapse:** Watch what happens as a soda bottle cools.
3. **Greenhouse Effect:** Observe how the atmosphere keeps the Earth warm using household materials.

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Suggested Resources

California Energy Commission. *Energy Quest. How Things Work: How Does the Thermometer Work?* 2002. http://www.energyquest.ca.gov/how_it_works/thermometer.html.

Henderson, Tom. *Kinetic Energy*. The Physics Classroom. http://www.glenbrook.k12il.us/gbssci/phys/Class/energy/u511c.html.

Lynds, Beverly T. *About Temperature*. Project Skymath. http://eo.ucar.edu/skymath/tmp2.html.

Editor's Note: In the interest of providing "dramatic results," the thermometer created by your students in this activity differs in one important way from a bulb thermometer. Since the vial is only 3/4 filled with water, air remains in the vial after it is sealed with the clay and straw. When heated, air expands more than water, so when the thermometer is placed in warm water, most of the observed effect on the height of the water in the straw is due to the higher air pressure pushing on the water in the vial. However, this effect is still due to the principle that substances expand when heated due to increased motion of the molecules within the substance, and the thermometer legitimately measures the increase in temperature. You are welcome to modify this activity to make it closer to a model of a bulb thermometer by using either rubbing alcohol in place of the water or using a much thinner straw (not included in the kit). Both of these changes produce noticeable height changes even when the vial is completely filled with liquid.

Activity 3 Measuring Change

One of the challenges of being a scientist is working with things that are hard to measure because they are too small (like atoms), too big (like the universe), or too bright (like the sun). In these cases scientists have to use what they can measure to figure out the information they need. Marie faced this challenge in her Nobel Prize-winning work. She often had to work with amounts of materials too small to see.

In this activity you'll look at how to measure temperature and make a thermometer of your own. What you learn will get you one step closer to finding Marie's classroom!

Key Question

How is temperature measured?

Materials

Glass vial

Modeling clay

Clear drinking straw

Bulb thermometer

Dye tablet

Warm and cold water

3 transparent cups

Ruler template

Tape

Getting Started

Discuss the following questions with your group.

- Thermometers are useful in many situations:

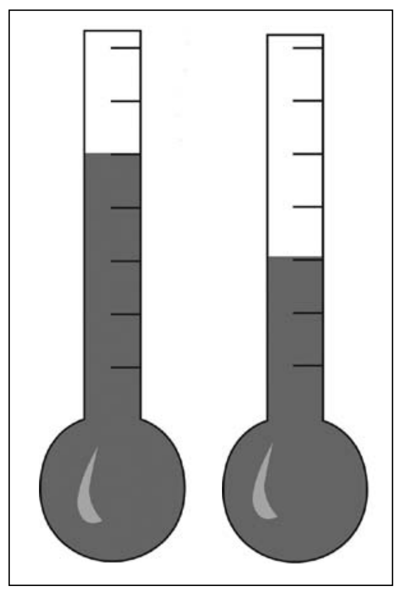
  Knowing the temperature outside can help you decide whether to dress for the pool or a chilly walk in the park.

  Knowing the temperature inside of a turkey lets you know if Thanksgiving dinner is ready.

When else do people use thermometers?

- In Picture A, which thermometer is recording a higher temperature? How can you tell?

- Why does the height of the line change when the temperature changes?



Picture A

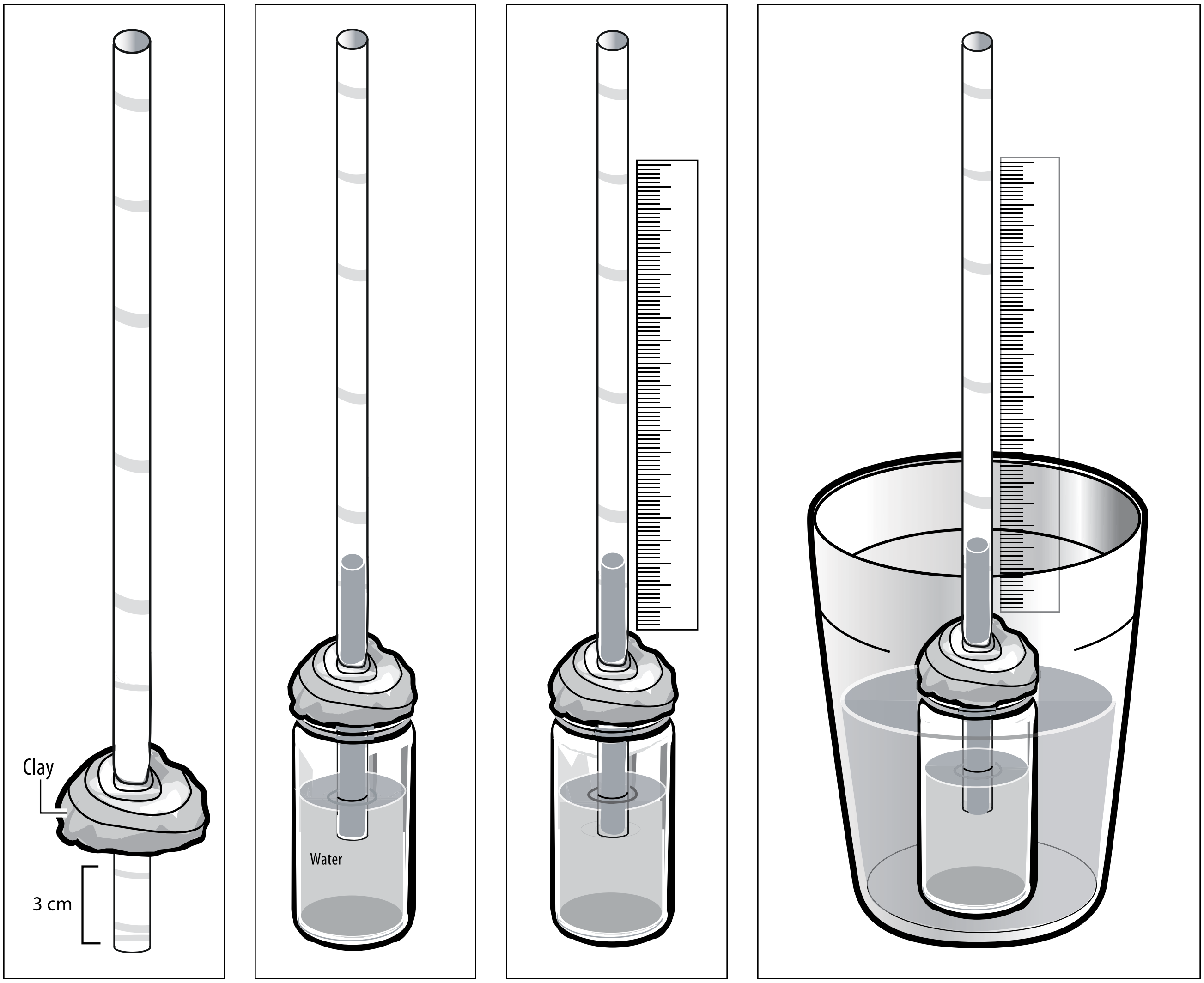


Figure B1 Figure B2 Figure B3 Figure B4

The Experiment

1. Fill the glass vial 3/4 full with room temperature water.

2. Break one of the dye tablets into pieces and add a small piece to the vial. Coloring the water will make your measurements easier. Set the vial aside.

3. Take a small blob of clay (about the size of a “tootsie roll”) and roll it into a cylinder about 12-cm long. Flatten out the cylinder so you have a ribbon-shaped piece of clay.

4. Roll the ribbon around your straw, about 3-cm from one of its ends, as in Figure B1.

5. Put the short end of your straw into the vial and use the clay to seal the straw in place, making an air-tight seal in the neck of the vial. One end of the straw should be sticking up and the other should reach at least half way down into the vial. (Make sure your staw reaches the colored water).

6. Forcefully push the clay into the neck of the vial until the water level in the straw rises a few centimeters above the clay, as in Figure B2. (This may take some fiddling to make it work. The idea is to push the clay so that the air pressure increases in the vial and sends water up the straw. However, be careful not to fill the vial with clay).

7. Cut out one of the rulers on the Ruler Template. Tape the ruler to the vial so the zero mark lines up with the top of the clay, as in Figure B3.

8. Fill a cup approximately 3-cm deep with room temperature water, as in Figure B4.

9. Put your homemade thermometer in the cup. Leave your thermometer in the cup for 3 minutes. **Caution: Always pick up your thermometer by the rim of the vial!**

10. Use your attached ruler to measure the height of the water level in the straw. Record this height in Chart A.

11. Remove your homemade thermometer and use the commercial bulb thermometer to measure the actual temperature of the water in the cup. Record this temperature in Chart A.

12. Repeat steps 8-11 replacing room temperature water with warm water (at least 10° C warmer than the room temperature water you used).

13. Repeat steps 8-11 replacing the warm water with very warm water (at least 10° C warmer than the warm water you used).

Chart A	Water height (cm)	Measured Temperature (°C)
Room temperature water		
Warm water		
Very warm water		

Analyzing your Results

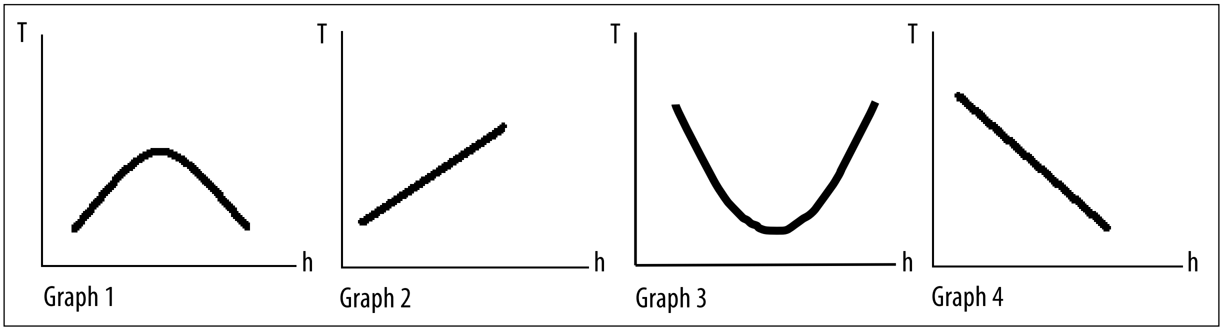
1. Using the grid below, graph temperature of water versus the height of water in the straw from Chart A. The horizontal axis should be “height of water in the straw (in cm)” and the vertical axis should be “Temperature (in ° C).” Draw a line through your data points that best fits your data (do not “connect the dots”).

2. What does your graph show about how the volume of the fluid in the vial changes with temperature?

3. Based on the results of Activity 2 (Racing Molecules), why do you think the volume changes?

Using Your Results to Find Marie's Class

Choose the graph below that most looks like the graph you created in Question 1.



What number graph did you choose? _________

Activity 4 Creating Heat

Although they may not realize it, students observe energy changing from one form into another all the time – from the dropping of a pencil to the melting of ice. In this activity students explore heat as a form of energy that can change from one type into another. In particular, they will use yeast to create a reaction that releases chemical energy as heat energy.

Key Question

How is heat related to energy?

Key Terms

Exothermic Reaction
An exothermic reaction releases heat into its environment.

Endothermic Reaction
An endothermic reaction absorbs heat from its environment.

Before the activity students should know...

- There are many forms of energy, including sound, mechanical, chemical, heat, and electrical energy
- One form of energy can change into another
- The atoms in a molecule are held together by chemical bonds

After the activity students should be able to...

- Talk about heat as a form of energy that can change into other forms
- Recognize when heat is being added to a system

The science behind heat energy

The word "energy" has lots of uses.

- Marie Sklodowska Curie studied radioactive elements – unstable elements that release energy as they decay. This energy can leave an atom as elementary particles (such as alpha or beta particles or neutrons) or gamma rays (high energy light waves).
- The word "energy" is often in news stories about reducing dependence on fossil fuels and other sources traditionally used to power cars and lights.
- Sportscasters often talk about athletes using energy-enhancing drugs that give them an edge over the competition.

In all of these cases "energy" refers to the ability of something to perform work. This is what defines energy. Although there are many different types of energy, they all fit nicely into one of two categories – kinetic energy or potential energy.

Kinetic energy is motion. The energy in an electrical current and sound are both types of kinetic energy because they deal with the movement of electrons and compression waves respectively. Likewise, mechanical energy and heat are other types of kinetic energy.

Potential energy is stored energy, like the energy in chemical bonds. Potential energy also includes the energy an object has due to its position, like the gravitational energy of a rock at the top of a hill.

One of the fundamental properties of energy is that it can change from one form into another, although the total amount of energy in a closed system always remains the same. For example, a windmill turns wind energy into mechanical energy and a crash turns the energy of a car's motion into sound, heat, and mechanical energy.

In this activity students will investigate how mechanical energy can be turned into heat (by stretching a rubber band or rubbing their hands together) and how chemical energy can be turned into heat (by breaking apart hydrogen peroxide).

In order to turn chemical energy into heat, students will add yeast to hydrogen peroxide. Yeast catalyzes the breakdown of hydrogen peroxide (H_2O_2) into water (H_2O) and oxygen, as shown below.

$$\boxed{2H_2O_2 \rightarrow 2H_2O + O_2}$$

In other words, the yeast breaks apart the chemical bonds that hold the water and oxygen together. The free oxygen bubbles up to the surface and floats away, leaving a mixture of yeast and water behind. As the bonds break they release energy in the form of heat. The additional heat can be observed by measuring the temperature of the solution in the canister before and after the yeast is added.

When a reaction gives off heat it is called an exothermic reaction. Other examples of exothermic reactions include freezing water and the formation of snow in clouds. A reaction that absorbs heat is called an endothermic reaction. Examples of endothermic reactions include melting ice and photosynthesis.

Safety

During the hydrogen peroxide experiment oxygen gas is released. Because oxygen enhances combustion, no open flames or sparks should be near this experiment. The solution may reach high temperatures so students should not handle the solution until the oxygen has stopped bubbling and the solution has had time to cool.

Materials

Rubber band

Film canister

Bulb thermometer

Yeast

Hydrogen peroxide

Styrofoam cup

Corresponding Extension Activities

1. **Smashing Spheres:** Observe energy conversion using steel spheres.
2. **Cold Wave:** Observe a chemical reaction that lowers the temperature of water.

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The NEED Project. *Intro to Energy*. http://www.need.org/needpdf/infobook_activities/IntInfo/IntroI.pdf.

Suggested Resources

HowStuffWorks. Why does hydrogen peroxide foam when you put it on a cut? http://www.howstuffworks.com/question115.htm.

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Activity 4 Creating Heat

The word "energy" has lots of uses. Politicians talk about renewable energy sources, sportscasters talk about energy-enhancing drugs used by athletes, and car manufacturers talk about energy-efficient cars. Marie also studied energy. She studied radioactivity, a type of energy given off by some elements.

In this activity you will look at some of the many forms of energy and how energy can turn from one form into another. Your results will give you the final clue you need to locate Marie's class!

Key Question

How is heat related to energy?

Materials

Rubber band

Film canister

Bulb thermometer

Yeast

Hydrogen peroxide

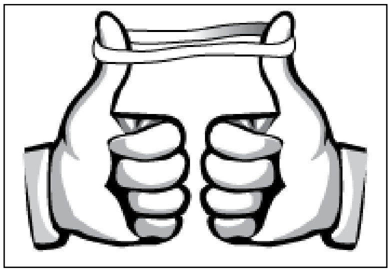
Styrofoam cup

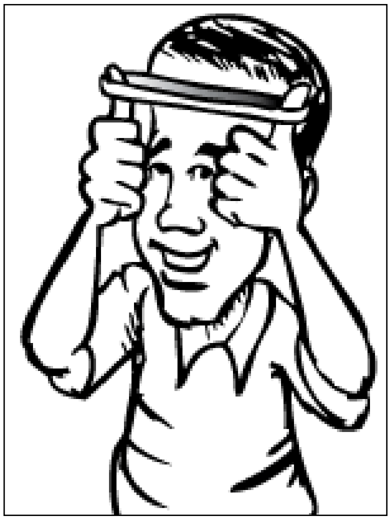
Getting Started

- Look around the room, what kinds of energy are in the room?

- One of the cool things about energy is that it can turn from one form into another. For example, cars turn the chemical energy in gas into mechanical energy that powers them. The speakers in your stereo turn the energy in an electric current into sound — another form of energy.

  Give some other examples of energy changing from one form to another.





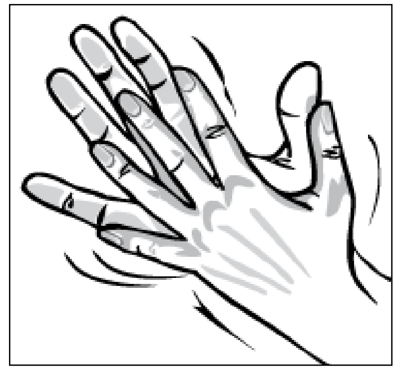
Experiment 1

1. Hook the rubber band around your thumbs and hold it so that is it taut, but not stretched.
2. Touch the rubber band to your forehead and pay attention to its temperature.
3. Stretch the rubber band out about 20-cm or so and then immediately touch it to your forehead. Does the rubber band feel colder or warmer? Record your answer in Chart A.
4. Let the rubber band return to its normal size.
5. Have each person in your group do this experiment at least 3 times so that you can be sure of your result.

Chart A

Group Member	Trial 1 warmer or colder?	Trial 2 warmer or colder?	Trial 3 warmer or colder?

Experiment 2



1. Assign one person in your group to be the judge and one person to be the volunteer.

2. The judge should put his or her fingers on the volunteer's palms for about 3 seconds, paying attention to their temperature.

3. The judge should remove his or her fingers from the volunteer's palms.

4. The volunteer should then rub his or her hands together for 15 seconds.

5. After the 15 seconds are over, the judge should put his or her fingers on the volunteer's palms again and record whether they feel warmer or colder on Chart B.

6. Repeat this experiment until everyone in your group has been the judge and the volunteer.

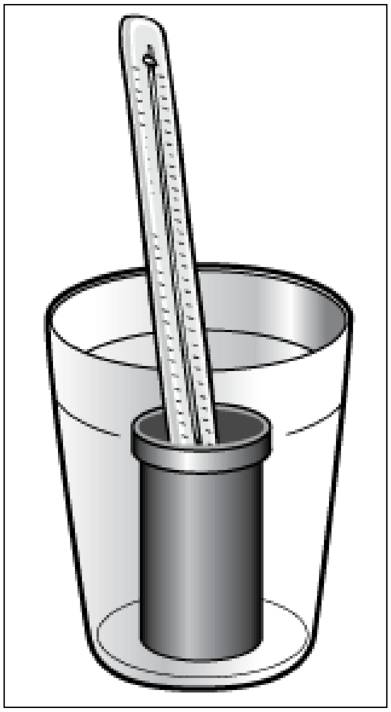
Chart B

Judge	Were the palms warmer or colder?

Experiment 3

Taking the Temperature

When you measure the temperature of hydrogen peroxide, put the thermometer in the cup and let it sit for about 1 minute before you read the temperature. This will give it time to adjust to the temperature of the hydrogen peroxide.



1. Fill the canister half full of hydrogen peroxide.

2. Carefully place the canister inside the Styrofoam cup.

3. Put the thermometer inside the canister and record the temperature of the hydrogen peroxide below.

Starting temperature of the solution in the canister: ________ °C

4. Remove the thermometer.

5. Add about 1/4 of a teaspoon of yeast to the canister and mix the solution with the end of the thermometer. Then leave the thermometer in the canister.

6. Draw a picture of what happens after you add the yeast.

7. After the solution stops foaming, record its temperature below.

Final temperature of the solution in the canister: ________ °C

What's going on in Experiment 3?

When you add yeast to hydrogen peroxide, the hydrogen peroxide breaks apart into water and oxygen. The oxygen bubbles up to the surface and floats away, leaving a mixture of yeast and water behind.

The yeast causes the hydrogen peroxide to break apart. When this happens, some of the chemical energy that held the hydrogen peroxide together is released in the form of heat energy.

Analyzing your Results

1. In the first two experiments, you did something to increase the temperature of what you were studying. For each experiment, write what you did to increase the temperature.

   Experiment 1: ____

   Experiment 2: ____

   Heat is a form of energy. Both of these actions turned other types of energy into heat energy.

2. For each case listed below, give one example for each energy transformation. The first one is done for you as an example.
   a. Heat energy turning into chemical energy

      Heat from the sun is absorbed by plants and turned into chemical energy during photosynthesis.
   b. Electrical energy turning into heat energy

      ____
   c. Mechanical energy turning into sound energy

      ____
   d. Chemical energy turning into mechanical energy

      ____

3. In Experiment 3, what happened to the temperature of the solution in the canister after you added the yeast?

   What do you think caused this to happen?

4. What type of energy was turned into heat energy in Experiment 3?

Using Your Results to Find Marie's Class

A reaction that gives off heat it is called an exothermic reaction. A reaction that absorbs heat is called an endothermic reaction.

Was the reaction in Experiment 3 an endothermic reaction or an exothermic reaction?

National Science Education Standards

The PhysicsQuest activities directly correspond to many of the National Science Education Standards (http://newton.nap.edu/html/nses/). Standards addressed by each of the PhysicsQuest activities are listed below.

Activities 1-4

5-8 Science as Inquiry: Use Appropriate Tools and Techniques to Gather, Analyze, and Interpret Data. The use of tools and techniques, including mathematics, will be guided by the question asked and the investigations students design.

5-8 Science as Inquiry: Think Critically and Logically to Make the Relationship Between Evidence and Explanations.

5-8 Science as Inquiry: Develop descriptions, explanations, predictions, and models using evidence. Students should base their explanation on what they observed, and as they develop cognitive skills, they should be able to differentiate explanation from description…

5-8 Science as Inquiry: Design and Conduct a Scientific Investigation. Students should develop general abilities, such as systematic observation, making accurate measurements, and identifying and controlling variables.

5-8 History and Nature of Science: Nature of Science. Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.

K-12 Unifying Concepts and Processes: Systems, Order, and Organization. There are physical laws governing the behavior of nature that exemplify its order, predictability, and regularity.

K-12 Unifying Concepts and Processes: Evidence, Models, and Explanation. Scientific explanations incorporate existing scientific knowledge and new evidence from observations, experiments, or models into internally consistent, logical statements.

Activity 1: Checking Temperatures

5-8 Physical Science: Transfer of Energy. Heat moves in predictable ways, flowing from warmer objects to cooler ones, until both reach the same temperature.

5-8 Science and Technology: Understandings about Science and Technology. Science and Technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technology.

5-8 Science in Personal and Social Perspectives: Science and Technology in Society. Technology influences society through its products and processes. Technology influences the quality of life and the ways people act and interact.

Activity 2: Racing Molecules

5-8 Physical Science: Transfer of Energy. Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.

5-8 Science as Inquiry: Use Mathematics in all Aspects of Scientific Inquiry. Mathematics can be used to ask questions; to gather, organize, and present data; and to structure convincing explanations.

5-8 Nature of Science: Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.

Activity 3: Measuring Change

5-8 Physical Science: Transfer of Energy. Heat moves in predictable ways, flowing from warmer objects to cooler ones, until both reach the same temperature.

5-8 Science as Inquiry: Use Mathematics in all Aspects of Scientific Inquiry. Mathematics can be used to ask questions; to gather, organize, and present data; and to structure convincing explanations.

K-12 Unifying Concepts and Processes: Constancy, Change, and Measurement. Knowledge of mathematics is essential for accurate and communicable measurement. Changes in systems can be quantified. Mathematics is essential for accurately measuring change.

Activity 4: Creating Heat

5-8 Physical Science: Transfer of Energy. Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.

5-8 Physical Science: Properties and Changes of Properties of Matter. A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample. A mixture of substances often can be separated into the original substances using one or more of the characteristic properties.

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