Original broadcast: January 8 & 15, 2008

Absolute Zero

PROGRAM OVERVIEW

NOVA brings the history of cold to life with historical recreations of great moments in low-temperature research and interviews with historians and scientists to reveal how civilization has been profoundly affected by the mastery of cold.

Hour one of the program (The Conquest of Cold):

- reports on the pioneering experiments done by Robert Boyle to understand what cold was.
- presents how the first temperature scales were determined by Daniel Fahrenheit and Anders Celsius.
- recounts how Guillaume Amontons first came to speculate that cold had an absolute limit.
- explains how scientists came to understand what heat and cold actually were, including the incorrect caloric theory proposed by Antoine Lavoisier.
- reports on the first industrialization of cold through ice sales.
- details how experiments on the steam engine led to the development of artificial refrigeration.
- profiles how Clarence Birdseye and Willis Carrier harnessed the cold to create frozen foods and air conditioning.

Hour two of the program (The Race for Absolute Zero):

- features the race between nineteenth-century scientists James Dewar and Heike Kamerlingh Onnes to become the first to liquefy hydrogen, the last of the so-called permanent gases.
- notes how unexpected events in the study of cold led to new areas of research, including superconductivity and superfluids.
- details how Albert Einstein came to predict that a new state of matter—one that behaved according to quantum mechanical rules—could be produced at temperatures just above absolute zero.
- shows how particles would change into overlapping waves in this state of matter, known as the Bose-Einstein condensate.
- details the race among scientists to create this condensate.
- describes how one scientist found a way to slow down the speed of light.
- reports on research being done to develop quantum computers.
- shows how far down the scale scientists have traveled and explains why reaching absolute zero is not possible.

BEFORE WATCHING

1 Have students brainstorm all the things and places they can think of that are cold. List these on the board. Assign groups to research temperatures of some of these items, including the coldest place on Earth. When they are done, create a temperature line that spans 25 degrees C to -273.16 degrees C (absolute zero). Have students put their items on the temperature line and note how far their items are from absolute zero.

2 Science is a human endeavor undertaken by many individuals of various backgrounds. Organize students into seven groups. As they watch the program, have each group take notes on the following scientists: a) Robert Boyle and Guillaume Amontons; b) Antoine Lavoisier and Benjamin Thompson (Count Rumford); c) Michael Faraday; d) Sadi Carnot, James Joule, and William Thompson (Lord Kelvin); e) James Dewar and Heike Kamerlingh Onnes; and f) Eric Cornell, Carl Wieman, Wolfgang Ketterle, and Daniel Kleppner. Students should record each scientist's nationality, whether the scientist worked alone or with others, what each did to further the science of cold, and the tools each used.

AFTER WATCHING

1 Have each group present information about its scientist(s). What did each scientist learn? What tools were available to each scientist? How did scientists share information in each time period? What role did competition play in advancing science?

2 Ask students what they would do if they did not have refrigerators. How has refrigeration changed people's lives? In what other ways has the ability to control cold been important to society?

CLASSROOM ACTIVITY

Activity Summary
Students build and calibrate their own bulb thermometers.

Materials for Teacher
- various thermometers and temperature probes for display (do not use mercury thermometers)
- nail and hammer
- ballpoint pen or pencil
- 3 hot plates
- 3 large containers (for warm water)
- paper towels

Materials for Each Team
- copy of "Building a Bulb Thermometer" student handout
- copy of "Calibrating Your Thermometer" student handout
- 170 g (6 oz) baby food jar
- clear straw
- room-temperature water
- 1000 ml beaker
- water
- crushed ice
- plasticene or modeling clay
- food coloring
- plastic pipette
- 8-cm x 13-cm (3-in x 5-in) index card
- tape
- ballpoint pen
- thermometer (to measure water temperature)

Background
While humans have always wondered about cold, the earliest known studies about cold began in the 1600s. One of the first steps toward understanding cold was to determine how to measure it. Grand Duke Ferdinand de Medici invented the first accurate thermometer in 1657. Now thermometers are everywhere.

Three main scales are in use today: Fahrenheit, Celsius, and Kelvin. A pioneer in developing alcohol and mercury thermometers, Daniel Fahrenheit devised a scale in the early 1700s where he marked zero to represent the temperature of equal parts of ice, water, and salt. On this scale, the freezing point of water is 32 degrees, and the boiling point is 212 degrees. In 1742, Anders Celsius developed a scale where he labeled the freezing point of water as 100 degrees and the boiling point of water as 0 degrees, and marked off 100 equal degrees between them. (Today's Celsius scale reverses the 0 and the 100.) The third type of scale is named after Lord Kelvin, who proposed the Kelvin scale in the mid-1800s. The Kelvin scale—which is based on the Celsius scale, but has no negative

LEARNING OBJECTIVES

Students will be able to:

- understand how a bulb thermometer works.
- create a temperature scale for their thermometer.
- convert between Fahrenheit and Celsius temperature scales.

STANDARDS CONNECTION

The "Building a Bulb Thermometer" activity meets the following National Science Education Standards (see books.nap.edu/html/nses).

GRADES 5–8
Physical Science
- Properties of matter
- Transfer of energy

History and Nature of Science
- Science as a human endeavor
- History of science

Video is not required for this activity.

INTERACTIVE ACTIVITIES

Learn your way around a refrigerator, design a thermometer online, conduct your own experiment in cold research, play an ice trade game, and more in the interactives found at www.pbs.org/nova/zero

CLASSROOM ACTIVITY (CONT.)

numbers—is widely used by scientists. The Kelvin scale uses the triple point of water (the temperature at which water exists simultaneously as a solid, liquid, and gas, 273.16 K) and the boiling point of water (373 K) as its fixed points. Zero on the Kelvin scale is considered to be absolute zero, the point at which all molecular motion stops.

In this activity, students build and calibrate a simple bulb thermometer.

Procedure

Part I

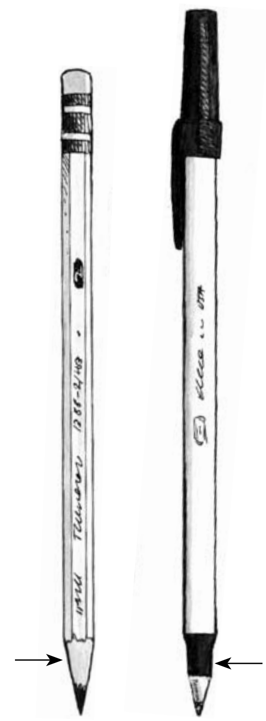
1 Prepare the container tops for students' bulb thermometers prior to the activity. While the lid is still on the jar, tap the nail into the middle of the jar lid. Use the hammer to tap the top of a ballpoint pen or pencil so that the tip is inserted to the point shown (see illustration). This will open the hole just enough so the straw will go through. While a larger hole can be plugged with clay, there is a much higher chance of the liquid leaking out during the experiment if the hole is even a bit wider than the straw. Remove the jar labels (otherwise they will fall off while in the warm water bath).

2 Ask students to brainstorm all the thermometers that can be found in their homes. *(Some examples include thermometers to measure outside temperatures, thermometers to measure body temperatures, and kitchen thermometers used to measure food temperatures in meat and candy.)* Ask students to find as many types of thermometers as they can in their homes and record the range of temperatures on each and the temperature that the thermometer reads when found.

3 Display the thermometers you brought in. Make a list on the board of all the thermometers students found, and show a sample of each if you have one. Have each student report temperature ranges and the temperature reading of the thermometer. Which temperature scale does each use (Fahrenheit or Celsius)? What are the similarities and differences in the temperature ranges on each instrument? How similar were their temperature readings when they were found? What would explain any differences?

4 Explain to students that all thermometers depend on some material that changes their properties when their temperatures change. A liquid bulb thermometer, such as the classic mercury thermometer, relies on the fact that liquids expand as they get warmer and contract as they get colder. Students will make a homemade liquid bulb thermometer in this activity.

5 Organize students into teams. Provide each team with the handouts and materials listed. Have students make their thermometers. Before students calibrate their thermometers, check each team's thermometer to make sure that the clay is well sealed around the straw, that the jars are as tightly sealed as possible, and that the water levels are at about halfway up the straw.



Insert pen or pencil into the jar lid to the point shown to create a hole with the proper diameter.

CLASSROOM ACTIVITY (CONT.)

Part II

1 Create three warm water baths at a station in the room for students to use to calibrate their thermometers; the water should reach at least halfway up the jar but not go over the top (remember to take into account how many students may be using the warm water bath at once as this will raise the water level). Use a hot plate to keep the warm water bath between 45 and 50 degrees C. Keep an eye on the warm water bath during the activity to ensure it is maintaining its temperature (using as large a container as possible will help keep the bath a constant temperature).

2 Have students make their own ice water baths in beakers. Provide paper towels near each bath for cleanup. Students should do the ice water baths first; if they do the warm water bath first, it will take a long time for the liquid in the jars to cool enough to show a noticeable decrease in volume.

3 After students have used their reference thermometers to calibrate their homemade thermometers, review answers to the questions on the student handout. Explain the three most typical temperature scales used (see Background on page 2 for more information). What would each of the three different scales be good for measuring? What would their homemade thermometers be good for measuring? *(Their thermometers would be best for measuring a very narrow temperature range, such as how the temperature in the classroom changes throughout the year.)*

4 To illustrate how the first universally accepted temperature scales were invented, show students the portion of the program that presents how Daniel Fahrenheit and Anders Celsius came up with their scales. www.pbs.org/nova/teachers/activities/3501_zero.html#video (QuickTime or Windows Media plug-in required.)
After students have viewed the video, ask them what the value is in having everyone agree to use a specific scale. *(A universally accepted scale means that the thermometer can serve as a common reference point for temperature measurements, thus providing a standard "language" for temperature.)*

5 As an extension, work with the students to research how other types of thermometers—like turkey pop-ups, Galileo thermometers, and digital thermometers—work.

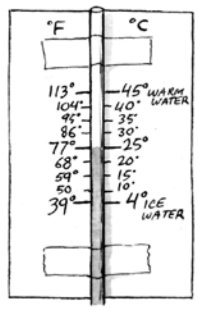
Classroom Activity Author

This activity was adapted with permission from the "Absolute Zero Community Education Outreach Guide," written by Karen C. Fox in collaboration with Devillier Communications, Inc. The guide, as well as the companion "Absolute Zero Science Educator's Guide" with classroom teaching strategies, was designed for middle school teachers and informal educators. They can be found at **www.absolutezerocampaign.org/get_involved/community_education.htm**

ACTIVITY ANSWER

Water expands as it gets warmer, and contracts as it gets colder. As the water in the jar of the thermometer got warmer, it expanded and had nowhere to go but up through the straw. Then, when the thermometer was used to measure something colder, the water in the jar got colder and contracted and sank down in the straw. This principle of volume change can be used to measure temperature.

While thermometers measure a change in temperature, the numbers used to describe that temperature are arbitrary. The numbers are simply a scale that a set of people agree to use; different scales are useful for different situations. The United States, for example, uses the Fahrenheit scale, while much of the rest of the world uses the Celsius scale.



The scale at right was created for a thermometer built using a 170 gram (6-ounce) baby food jar. The thermometer took about five minutes to come to temperature in the ice water bath (4 degrees C) and about ten minutes to come to temperature in the warm water bath (45 degrees C).

Student Handout Questions

1 What happened when you placed your thermometer in the warm water bath? The ice water bath? What caused the changes you observed? *The liquid rose when the thermometer was placed in the warm water bath and fell when placed in the ice water bath. The changes were caused by the water increasing in volume when it was heated and decreasing in volume when cooled.*

2 What are the limitations of your thermometer? *Some limitations include that the thermometer is slow to adjust to temperature because of the large amount of liquid in the "bulb" portion, that it could not measure below 32 degrees F (0 degrees C) or above 212 degrees F (100 degrees C) because the liquid being used would freeze or boil at those temperatures, and that because it is open at the top, water could evaporate (thus rendering the scale inaccurate).*

3 What other scales could you use to represent the different temperatures you measured? *Temperature scales are arbitrary; just about anything can be used to represent calibration points as long as everyone in the group using the thermometer agrees on the proposed scale. Students may suggest various number ranges, birthdates of class members, names of scientists, or class members' initials.*

4 Which of the following temperatures would you prefer outside: 24 degrees Celsius or 70 degrees Celsius? Why? *The best temperature for being outside would be 24 degrees C, a comfortable outdoor temperature (equivalent to 75 degrees F). Seventy degrees C would be scorching hot (equivalent to 158 degrees F).*

LINKS AND BOOKS

Links

NOVA—Absolute Zero
www.pbs.org/nova/zero
Considers whether there is an absolute hot, explores the impact of refrigeration on society, and provides student interactives related to the science of cold.

Absolute Zero and the Conquest of Cold
www.absolutezerocampaign.org
Features a variety of educational resources, including historical biographies, a time line of low-temperature physics, and companion teaching guides.

Book

Absolute Zero and the Conquest of Cold
by Tom Shachtman.
Boston: Houghton Mifflin, 1999.
Features the struggles of philosophers, scientists, and engineers over four centuries as they attempt to understand the nature of cold. Served as the basis for NOVA's "Absolute Cold" program.

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David H. Koch
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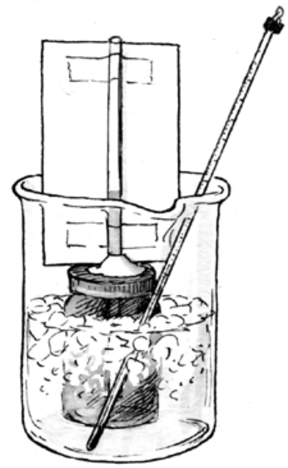
Building a Bulb Thermometer

Thermometers measure temperature. The first known accurate thermometer was invented about 350 years ago. In this activity, you will be building and calibrating your own bulb thermometer.



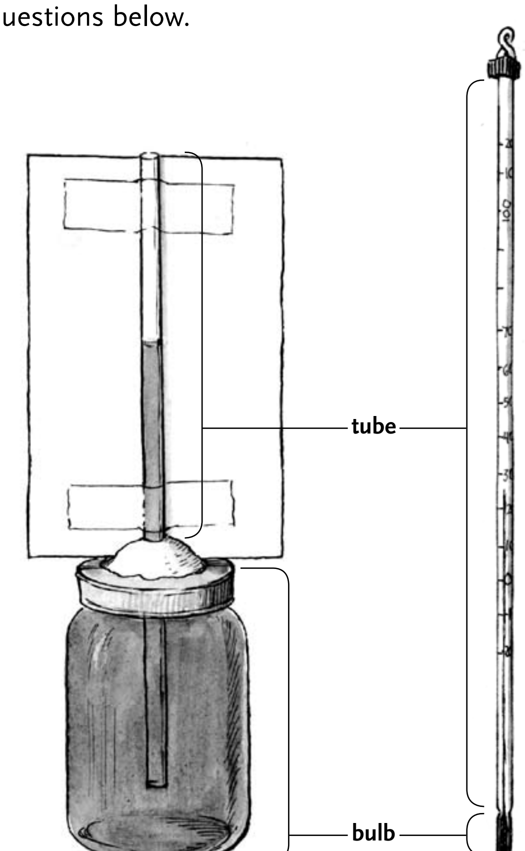
Procedure

1 Make your thermometer. Place the straw through the hole in the drink lid and pull it down far enough so that the portion at the top of the lid extends to the height of an index card (see illustration).
2 Mold the clay around the bottom of the straw to seal any gaps in the lid around the straw so no air can escape from the "bulb" of your thermometer. Make sure the clay is molded tightly around the straw.
3 Set the lid and straw aside. Fill the drink jar to the *very* top with room-temperature water. Place four to six drops of food coloring in the water.
4 Put the lid back on the jar and make sure it is screwed on *as tightly as possible.*
5 Push the edge of the index card into the clay and tape it to the straw as shown.
6 Using the pipette, add more water until the height of liquid in the straw is about halfway up the index card (if you add to much water, you can use the pipette to take some out). Then add another drop of food coloring.
7 Use the "Calibrating Your Thermometer" handout to calibrate your thermometer. Then answer the questions below.

Questions

Write your answers on a separate sheet of paper.

1 What happened when you placed your thermometer in the warm water bath? The ice water bath? What caused the changes you observed?
2 What are the limitations of your thermometer?
3 What other scales could you use to represent the different temperatures you measured?
4 Which of the following temperatures would you prefer outside: 24 degrees Celsius or 70 degrees Celsius? Why?



Calibrating Your Thermometer

Now that you have made your thermometer, it's time to calibrate it with a thermometer that includes a scale. The two most commonly used scales are Fahrenheit and Celsius, which were invented in the early to mid-1700s by scientists named Daniel Fahrenheit and Anders Celsius.

Procedure

1 Create your ice-water bath by filling half your beaker with water and crushed ice. Make sure that there is enough ice in the beaker to chill the water but not so much that you cannot set your thermometer in the beaker.

2 Put your bulb thermometer and reference thermometer in the container of ice water so that it is mostly—but not fully—submerged in the ice water. When the liquid in the your thermometer stabilizes (it takes about five minutes), mark the index card next to the height of the liquid and label it "ice water." Write the temperature on the reference thermometer next to this mark.

3 Move both thermometers to the warm water bath. Once again mark the appropriate spot on the index card when the liquid in your thermometer stops moving (it takes about ten minutes). Write down "warm water" and the temperature from the reference thermometer next to this mark.

4 Draw a line halfway between the two spots and label it with the number halfway between your high number and low number. Continue to add a few extra lines in this way: Mark a spot halfway between two other lines, and label it with a number halfway between those two numbers.

5 Look at the scale that your reference thermometer uses and mark the card above your measurements with that scale (°C for Celsius and °F for Fahrenheit). Convert the temperatures you measured from one scale to the other using one of the formulas in the "Conversion Formulas" sidebar. Write the second set of temperatures on the opposite side of the index card and label that scale.

Conversion Formulas

Celsius to Fahrenheit
Multiply the Celsius temperature by 9. Divide the answer by 5. Add 32.

Fahrenheit to Celsius
Subtract 32 from the Fahrenheit number. Divide the answer by 9. Multiply by 5.