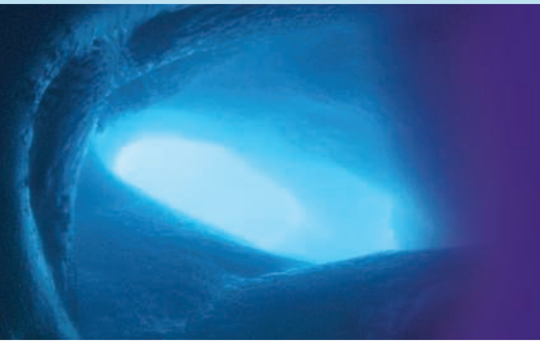
ABSOLUTE ZERO



Community Education Outreach Guide

A Resource for Teachers and Informal Educators of Middle School Students

About the Guide

The Absolute Zero Community Education Outreach Guide is a resource for teachers and informal educators of middle school students. Drawing from the history of the human quest to explore the cold, this guide focuses on topics — from historical attempts to understand the physics of heat to modern day magnetically levitating trains — that are covered in the two-part public broadcasting special, *Absolute Zero*, produced by Meridian Productions and Windfall Films.

Watching *Absolute Zero* would certainly enhance any of the presentations described in this guide, but it is by no means required. Instead, this guide offers a road map for comprehensive presentations including hands-on demonstrations, questions to encourage student participation, suggestions for how to lead the class, and ways to encourage the students to continue studying the science topic at hand.

This is not intended to be a comprehensive science curriculum. However each module does relate to the science standards for middle schools, as detailed at the end of the guide.

Absolute Zero

Absolute Zero demonstrates how civilization has been profoundly affected by the mastery of cold. The documentaries, which are a unique blend of science, cultural history and adventure story, explore key concepts, significant individuals and events in the field of low-temperature physics and the enormous impact that the mastery of cold has had on society through such technologies as air conditioning, refrigeration and liquefied gases.

Absolute Zero is underwritten by the National Science Foundation and the Alfred P. Sloan Foundation and is based largely on Tom Shachtman's acclaimed book, *Absolute Zero and the Conquest of Cold*. It features the struggles of philosophers, scientists and engineers over four centuries as they attempt to understand the nature of cold, to explore its deepest reaches, to create the "cold technologies" that have transformed society and to seek a deeper understanding of matter itself.

Absolutezerocampaign.org

The *Absolute Zero* Campaign Web site (www.absolutezerocampaign.org) is intended to be a place where students, teachers, parents and others can find out about the field of low-temperature physics. The site is a place where teachers can download ideas for teaching physics in the classroom; where students can learn about the "cool" things happening in the field; and where physicists, engineers and other scientists can become a part of teaching the next generation of physicists.

The site also contains additional educational material and resources including graphics, biographies of historical figures, games, a time line of low-temperature physics history and additional topics and experiments beyond those in this guide.

National Partnership Program

National Partners serve as an essential building block for the outreach campaign and provide strategic guidance, support and in-kind institutional resources.

NATIONAL PARTNERS

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NATIONAL PARTICIPANTS

National Institute of Standards and Technology

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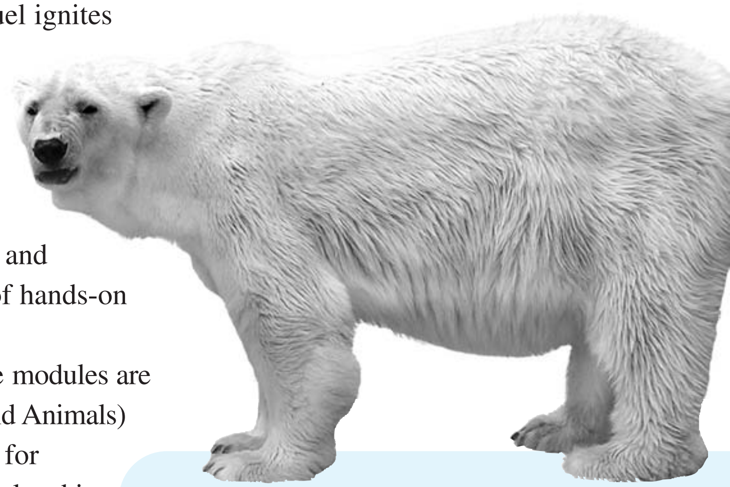
Funding for the *Absolute Zero* series, outreach campaign and this guide is made possible in part by Grant No. ESI-0532536 from the National Science Foundation.

Any opinions, findings, and conclusions or recommendations expressed in this guide are those of the authors and do not necessarily reflect the views of the Foundation.

Introduction

The study of low-temperature physics is one of the largest scientific fields today. Cold liquid oxygen is stored in hospitals, cold rocket fuel ignites the space shuttle's engines, cold superconductors in cell phone towers help boost reception. Not to mention the fact that the air-conditioning and refrigeration in our homes got their start from early innovators in cold research. This guide presents both the modern technologies that rely on low-temperature science as well as the basic physics behind understanding heat and cold, while grabbing the students' attention through a variety of hands-on demonstrations.

The guide is aimed at students in Grades 5 - 8, though some modules are certainly more suited to younger students (Thermometers and Cold Animals) and some to older ones (Cryogenics, Superconductivity, Quest for Absolute Zero). Each module can stand alone. If they are completed in order, they will build on each other — but that's certainly not necessary. As the demonstrator, please pick the modules and the order that seem most appropriate.



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A Note for Informal Educators

While this guide would certainly be helpful in a traditional classroom, we hope to encourage others — parents, museum educators, scout troop leaders, after school caretakers, scientists, engineers, university students — to do community educational outreach as well. With simple demonstrations, suggestions on how to guide the conversation and cool topics, this guide should help even a first-timer jump into informal education. Organize within your community, have fun, and put on a show!

Since these are informal education demonstrations, they are meant to be flexible and participatory — not a lecture at the front of the room. Here are a few suggestions:

- ✓ Don't do all the talking yourself. Leave the group lots of time to watch and think.
- ✓ Encourage students to predict what will happen before you begin the demonstration. Making predictions and comparing them to actual outcomes are important parts of the scientific process. Afterwards, have them discuss why they think something happened a certain way, even before you offer the official explanation.
- ✓ Stop regularly to make sure the group understands and to let them ask questions. If you don't know an answer, simply suggest that someone research the answer and report back to the rest of the group.
- ✓ If the group is small enough, ask them to gather around you to encourage more involvement.
- ✓ Any excuse for group work, small discussions, or individual writing activities that allow students the opportunity to make sense of these ideas for themselves is time well spent.

✓ If you must do all the demonstrations at the front of the room, call up a volunteer or two to help. Continue to ask questions, but encourage people to call out the answers rather than raise a hand. In this way, you can keep the group moving, by saying "I heard the right answer over there!" and then giving a detailed explanation.

Materials Needed

The demonstrations require a minimum of specialized or expensive tools. A few need some advance preparation on your part, and one section requires liquid nitrogen, which can be ordered from a liquid gas supply store or a welding store. (Better yet, liquid nitrogen can often be charmed from a university physics department, a hospital, or a science lab.) In all cases, please read the module through completely from beginning to end so you know what you will need.

Safety Rules

All schools have rules about what may be done in their science labs. (Some schools insist on no food in the labs, for example, and liquid nitrogen should only be used with a mature group.) If you are an experienced teacher you know the rules for your own school, and you also have a sense of how your specific group of students will behave. Please use common sense, or skip a demonstration altogether, if it's not appropriate.

If you are a guest demonstrator, make sure you check with the administrators about the appropriate safety rules, and make sure you have access to the right arena. An exhibition hall or kitchen may suit your needs better than a standard science lab. Remember that these are for middle school children, and are not safe for elementary school groups.

The federal government requires the filing of a Material Safety Data Sheet for certain materials, including rubbing alcohol and liquid nitrogen, if stored on site at a school. Such materials need to be securely stored — locked away from curious students — at all times.

Modules that use liquid nitrogen should only be demonstrated by those who have the protective equipment, the background and the means to ensure secure storage of the liquid nitrogen.

Thermometers

MATERIALS

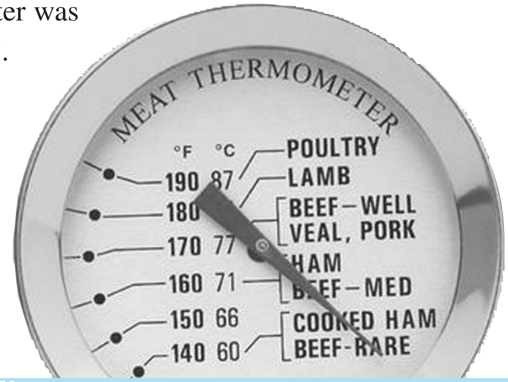
- various thermometers and temperature probes for display — as many different types with as many different scales as possible (do not use mercury thermometers — these are illegal in many districts)
- a small jar with a metal top
- a nail and hammer
- a straw, preferably clear
- water
- play dough or chewing gum
- food coloring
- magic marker

Get Students Involved

Show the students a variety of different thermometers — those for the weather; for cooking; for fevers; pop-up turkey thermometers; oven thermometers that measure high temperatures; freezer thermometers that measure low ones; and thermometers that show Fahrenheit, Celsius and Kelvin scales. As you pass these around the room, tell the group that while humans have always wondered about the cold, they only began to study it in the 1600s.

One of the first steps toward understanding the cold was to figure out how to even measure it. The first accurate thermometer was invented by Grand Duke Ferdinand de Medici in 1657.

Now thermometers are everywhere. Ask the group to brainstorm on all the thermometers that can be found in their homes. For example: the thermometer in the backyard to measure the temperature outside, the fever thermometer in the medicine cabinet to measure body temperature, and the meat and candy thermometers in the kitchen that measure the temperature of food. Ask the group what ranges of temperatures they think each thermometer needs to measure to successfully do its job.



The Main Show

1. A Bulb Thermometer

Explain that all thermometers depend on some material that changes its properties when its temperature changes. A liquid bulb thermometer, such as the classic mercury thermometer, relies on the fact that liquids expand when they get hot and contract when they get cold. To illustrate this, the class will build a bulb thermometer using water. Proceed with the **Bulb Thermometer Demonstration**. The thermometer may be built with a few student assistants at the front of the class or teams of students may each make their own.

DEMONSTRATION

Build a Bulb Thermometer

Use the hammer and nail to make a hole in the metal top of a small jar. (Students should have the help of an adult throughout this process. Alternatively, you could put holes in the lids before the demonstration.) Thread the bottom of a straw through the hole, and then seal the hole completely with play dough or chewing gum, so no air can escape around the outside of the straw. Fill the jar with cold water up to the very, very top — add a few drops of food coloring — and tightly screw on the metal top. Add a bit more water to the jar through the straw, until the colored water fills the bottom of the straw. Set the jar in a large bowl filled with very hot water. Watch how the colored water in the jar goes up the straw, just like mercury goes up the tube in a conventional thermometer. Now place the jar in a bowl of ice cold water and watch how the colored water drops back down.

What happened? Water — and any material — changes if it's heated or cooled. Water expands when it gets hot, and contracts when it gets cold. As the water in the jar of the thermometer got warmer, it expanded. It 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, so it contracted and sank down in the straw.

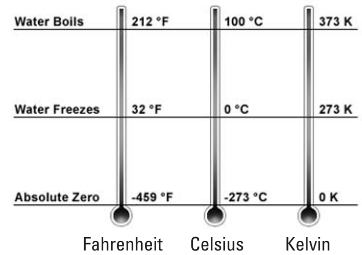
The point: All materials change if they get hot or cold, and you can use this fact to measure temperature. Of course measuring just how much the temperature has changed is a different story…

Thermometer Scales

Put the bulb thermometer in the bowl of ice cold water once again. When the colored liquid in the thermometer reaches a stable point, make a mark on the straw with the magic marker. Ask the students what number they would like to label this point. Suggestions might be the number zero, the number 100, someone's age, the date, the actual temperature of the water bath as measured by another thermometer — it doesn't matter! Once you've picked a number, or each student team has picked a number, it can be carefully written onto the straw. Next use the thermometer to measure the hot water bath. Once again mark the appropriate spot on the straw, and pick a number for that temperature. (Again the number doesn't matter. It can be lower or higher than the original number.) Next, 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 half way between two other lines, and label it with a number halfway between those two numbers. Let the water come to room temperature and measure the room temperature. According to your scale what temperature is the room? Next use a standard thermometer to measure the two water baths and the room temperature. What temperatures are they according to the Fahrenheit or Celsius scale?

The point: While thermometers accurately measure a change in temperature, the numbers we use to describe that temperature are arbitrary. It's simply a scale that everyone in a group agrees to use, and different ones are more useful for different situations. The U.S., for example, has agreed to use Fahrenheit, while much of the rest of the world uses Celsius. Your group of students could all agree to use their own if that's what makes sense to them!


Anders Celsius



2. Thermometer Scales

Now that the students have seen how a thermometer works, ask what the difference is between this and a commercial thermometer. Standard thermometers, of course, have numbers on them. Have them imagine what it would be like if they were creating the very first thermometer — it's totally up to them to assign a scale to their new invention. Have them make suggestions on how to do this. Perform the **Thermometer Scales Demonstration**.

After the students have marked a scale on their thermometers and compared their scale to the standard scales, ask them what the value is in having everyone agree to use a specific scale.

Tell the students about the three most common scales. *Daniel Fahrenheit* devised a scale where he marked zero as the temperature of equal parts of ice, water and salt. On this scale, the freezing point of water is 32°, and the boiling point is 212°. *Anders Celsius* devised a scale where he labeled the freezing point of water as 100° and the boiling point of water as 0°, and marked off 100 equal degrees between them. (Today, our Celsius scale is similar but reverses the 0 and the 100.) The last scale is named after *Lord Kelvin*. It labels "absolute zero" — the coldest any material in the universe can get — as zero. The freezing point of water on this scale is much warmer than that: 273, and the boiling point of water is 373. Ask the students what kinds of things each scale is good for measuring. Ask them what they think their homemade thermometer is best for measuring, too!

Additional Ideas:

- With careful adult supervision, perform some cooking experiment such as making caramel or other candy that depends exactly on bringing the food to the perfect temperature. Have students purposely bring the food to the wrong temperature and see what happens.
- Tell students about (or have them prepare short reports on) the lives of Daniel Fahrenheit, Anders Celsius, and Lord Kelvin.
- Work with the students to research how other types of thermometers, like turkey pop-ups and digital thermometers, work.

MATERIALS

- ice (in fun shapes, if possible)
- copy of the solid, liquid, gas chart below — in handout form, or on chalkboard
- syringe
- balloon
- small pebble
- food dye
- matches
- large glass bowl
- a small coffee cup
- two small bottles — empty pill jars will work in a pinch
- popcorn kernels
- a pot (glass, if possible) or a beaker
- a stove (or a hotplate if using a beaker)
- plastic wrap
- a pin

States of Matter

Get Students Involved

Holding ice in your hand — or even passing some around the room — encourage the students to talk about what's happening as the ice begins to melt. (You might freeze water in fun ice-cube shapes or in plastic cups or even in a disposable rubber glove over night, so that you're handing around a frozen hand-shaped piece of ice.) Ask them what it feels like as ice — solid, cold, slippery — and then what the melting water feels like — warmer, wet, liquid. Ask them what the difference is between the liquid and the ice: are they both still water? What makes them different? Why does the ice melt and why does warm ice turn into a liquid? Explain to the group that today you are going to explore the details of solids, liquids and gases.

Solids are made of atoms that are packed tightly together and don't move much; solids generally hold their shape. Liquids are made of atoms that are more loosely connected, and can move around; liquids will fit the shape of whatever container they're in. Gases are made of atoms that aren't bound to each other at all, and can move as far away from each other as they want; a gas will expand to fit whatever space is available to it.

The Main Show

1. The Properties of Different States of Matter

Shape is a concept your students will be familiar with: different objects have different shapes. They also have different sizes, or volume. Tell them that materials have other measurable properties depending on what they're made of: density, temperature, compressibility, diffusion. You have already told the students that different atomic configurations make up different states of matter — now you will explore these other properties and how they differ between solids, liquids and gases. Hand out the **Properties of Matter** sheets, or else draw up the table on a chalkboard. The students may answer the question in groups or everyone may work together. Ask them to fill out the chart.

DEMONSTRATION

Students can have their own printouts of the following chart, or the group may work together on a chalkboard.

Properties of Matter

			SOLID	LIQUID	GAS
Shape	Does a substance maintain its shape without a container?	Yes or No			
Volume	Does the amount of space a substance takes up stay the same whether it's inside or outside a container?	Yes or No			
Compressibility	How easily can the particles of a substance be forced into a smaller volume?	Low to High			
Diffusion	How quickly do the particles move from an area of high concentration to an area of low concentration?	Very Slow to Fast			
Density	How does the concentration of particles in a given volume compare to that of other substances?	Low to High			

Some answers will be quick and easy — they will probably know whether solids and liquids keep their shape, for example. Lead them through experiments on any of the subjects they don't know — being careful to explain what the words mean if necessary.

- ***Volume:*** Measure a cup of water and pour it into a variety of containers — ask the students every time the water is transferred to a new container how much water there is. Blow up a small balloon and ask them to hold their hands to describe the volume of the air in the balloon. Now release the air into the room. How big do they think that volume of air is now?

- ***Compressibility:*** Put a finger tip over the end of a syringe that is filled with air, liquid, and then a small pebble. How far can each material be compressed by the syringe?

- ***Diffusion:*** Drop a pebble, and some colored water (dyed with food dye) into a glass of water to compare solid and liquid diffusion. To get a sense of gas diffusion, light a match or a piece of paper, and ask how long it takes for the smoky smell to get to a student at the front and then the back of the room.

- ***Density:*** Since denser objects sink below lighter objects, you can test for density this way: drop the pebble into a glass of water, and then squirt a syringe full of air into the water.

DEMONSTRATION

Light and Dense Water

Set up a large glass bowl of room-temperature water, with a small overturned coffee cup on the bottom to serve as a platform. Fill a small bottle with hot water dyed red, and another small bottle with very cold water dyed blue. Gently place each bottle on its side on the coffee cup — the hot water will flow upwards and diffuse faster than the cold water, which will flow downwards. (A quick student might wonder if the dyes themselves affect the density — switch the dyes to prove it's solely the temperature at work.)

The point: Heat affects the properties of any given substance.

2. Temperature and States of Matter

Once the students have a good idea of the properties of the different states, explain that almost every material in the universe can exist in any state as long as it's at the right temperature and pressure. Water is the most obvious example — in our everyday lives we regularly see it in solid (ice), liquid (water) and gaseous (steam) form. Of course, all materials have different temperatures at which they turn from solid to liquid or from liquid to gas. Ask the students to give examples of materials that are solid, liquid, or gas at room temperature, and let them brainstorm on examples of places these materials exist in other forms (for example, lava is hot, liquid rock; dry ice is cold, solid carbon dioxide; and melted butter is hot, liquid butter.) Explain that heating and cooling a substance is one way of changing its state, and that heating a liquid will usually begin to make it less dense and more diffusible. That is, it usually begins to have properties more like a gas — even before it actually turns into a gas. To illustrate this concept perform the **Light and Dense Water Demonstration**.

Having demonstrated that temperature changes the liquid's density and diffusion, ask the students what they think happened to the other properties of heated water — like volume and compressibility.

Next you're going to show the students how the volume of liquid changes as it heats and turns into a gas. Ask the group for some help preparing the popcorn. Hand out a handful of kernels to each student and have them put a hole in the hull with a pin. Then start the **Steamin' Popcorn Demonstration.**

DEMONSTRATION

Steamin' Popcorn

Collect the popcorn with all the holes and put it into the beaker or glass pot, cover it with plastic wrap and poke a hole with the pin in the plastic wrap. Put the pot on the stove, or on a hotplate if using a beaker. If you have two setups, start a second pot with normal popcorn in it.

The popcorn with holes will not pop. Ask the students if they can figure out why. Tell them there is a tiny drop of water inside each popcorn kernel and encourage them to figure out how normally that water increases in volume as it gets heated — causing pressure that explodes out of the popcorn, making it to pop. Next walk them through how the hole lets the steam escape, keeping the kernel from popping.

If you only were able to pop the popcorn with no holes —- and you are in a room where students are allowed to eat — make a real batch now!

The point: Heat affects the properties of any given substance. In this case, water changes in volume as it gets hotter and turns into a gas. This volume change is what pops popcorn. Since gas diffuses so easily, if you give the steam a hole to run out of, it will escape — the extra volume no longer has enough pressure to pop the popcorn.

Additional Ideas:

- Give the students a list of materials and have them guess — and then find the accurate — boiling points and freezing points for each.
- Teach the group the words for changing states of matter: boiling, melting, freezing, condensation, sublimation and deposition. Provide illustrations of each.
- Younger children may act out the way atoms move in different substances. Have some "assistants" act like a solid by sitting close together and wiggling in their chairs. Have a few stand up and move around, sticking close together, to be a liquid. Let everyone roam free around the room to be a gas.

MATERIALS

- various objects to help demonstrate energy such as: a pencil, two magnets, a toy car, flashlight, two tuning forks, lamp, radiometer
- cups of hot, cold and room temperature water
- thermometer or temperature probe
- a bowl of water
- steel shot
- cardboard tube (like the core of a roll of paper towels)
- duct tape, or similarly strong tape
- ice
- scale

Understanding Heat and Energy

Get Students Involved

Ask the students to define "energy." Don't lead them, but let them throw out whatever ideas they have. Talk them through — or better yet, demonstrate — a variety of different kinds of energy. Pick up a pencil and drop it onto the table — there is stored energy *(potential energy)* at the top and movement energy *(kinetic energy)* as it drops. Pull two magnets apart and let them slap back together — describe the stored energy and movement energy here. Turn on a toy car (chemical energy of the battery turned into mechanical energy) and a flashlight (chemical energy of the battery turned into radiation energy). Set a tuning fork ringing and watch a second one start up in sympathy (mechanical energy of the sound wave). Put a radiometer near a light bulb and watch the wheels turning (radiation energy turned into mechanical energy). Plug in a lamp (electrical energy turned into radiation energy). Ask the students again if they can come up with a definition for energy that encompasses all of these types. Explain that while there are many different kinds of energy, in general, energy is something which can change something else (often, but by no means exclusively, by making it move). In science, the definition is quite precise — energy is something which can perform work on something else. Tell the group that the feeling of heat also results from energy in one object causing a change in another.

The Main Show

1. Some History

It has been a little more than 100 years since scientists have understood that the feeling of heat comes from a transfer of energy. Explain to the children that in the late 1700s, heat was thought to be an actual material, called caloric, that could seep from one object to the next and make it hot. The more caloric in a substance, they thought, the hotter it was. This was consistent with the fact that liquids expand when they warm up. It made sense to early scientists that heated things swelled because a big dose of

DEMONSTRATION

Heat Flow

Set up four cups of water on a table: two with room temperature water, one with very warm tap water, and one with ice water. (Preferably without letting the students know which temperature of water is where.) Have a student put two fingers in the hot cup and two fingers from the other hand in the cold cup and report which cup feels hotter. Meanwhile have another student measure the temperature in each cup and report the temperature aloud. After 15 seconds, the first student should quickly dry his fingers, and stick them into the two room temperature cups — and again report which one feels warmer. (It should be the cup with the fingers that had previously been in cold water.) The second student now measures the temperature of the water in the two cups and reports that temperature to the class — unlike what the first student felt, the temperatures should be equal. Remind the students that today you are talking about energy and the way energy moves from one object to another . . . then ask the group if they can figure out why one cup felt warmer even though both cups were the same temperature.

What happened? In the case of the cold fingers, the water was warmer than the fingers, and so the fast-moving molecules in the water encouraged the molecules in the fingers to move more quickly, heating the fingers — thus giving the sensation that the water was warm. In the case of the warm fingers, the water was colder with more sluggish molecules. The faster-moving molecules in the fingers transferred their energy to the slower molecules in the water. Since the water "stole" heat from the fingers, it gave the sensation that the water was cold.

The point: "Heat" is more of a sensation than a true measurement of temperature. We feel "heat" and "cold" simply based on whether the internal energy from our body flows toward the object, or the internal energy from the object flows toward our body. Heat is, in essence, simply energy on the move.

hot caloric had just been added. Because they thought caloric was a physical substance, they also thought it couldn't be created or destroyed, and the amount of heat in any system would always stay the same, or that heat is always *conserved*.

The caloric theory isn't true. In the late 1800s, scientists realized that heat isn't some kind of material you can touch. Instead the temperature is a property of matter that depends on how fast the atoms or molecules inside are moving — the faster they move, the more energy they have and the higher the temperature. Perform the **Heat Flow Demonstration** (this is the same demonstration, with a slightly different emphasis, as is in the Refrigeration module, so if you chose to do that section first, you can speed through this quickly!)

The concepts of "heat" and "temperature" are tricky ones — even for professional physicists — and worth hammering home after the demonstration. "Temperature" is the measurement of internal energy, i.e., how fast the particles inside the material are moving. The feeling of "heat," on the other hand, is very specifically the transfer of internal energy from one material to another — it is not an instrinsic property of the material.

DEMONSTRATION

The Mechanical Equivalent of Heat

Fill a large bowl with water and measure the temperature. Place some steel shot into a cardboard cylinder. Seal off both ends firmly with the duct tape and shake the tube vigorously for several minutes. Remove the shot and pour it into water. Measure the change in water temperature. Challenge the group to think of other tools for making the water hotter using only mechanical energy. (Students might even be divided into teams and asked to race against each other to reach a given temperature most quickly.) Ask the group if they can describe the transfer of energy from start to finish.

The point: Mechanical energy adds internal energy — increased motion of molecules — to any given object. That internal energy is then transferred to the water, causing its molecules to move more quickly, and raising its temperature.

2. Internal Energy in More Detail

We call the energy of those atoms and molecules moving inside any given body *internal energy*. The internal energy of a material can be changed in two ways: by adding internal energy from another body or by doing *work* on it. Work includes things like rubbing, which requires mechanical energy. For example, drilling a hole in a piece of wood will add internal energy to the wood. In this way, mechanical energy can be used to create higher temperatures. Perform the **Mechanical Equivalent of Heat Demonstration**.

Remind the students that in the 1700s, when scientists thought heat was created by something called *caloric*, they thought heat was always conserved. The discovery that mechanical energy (something like drilling) could be used to increase internal energy (which is perceived by us as an increase in temperature) taught everyone that heat isn't conserved at all — but energy is. Energy can change into different kinds of energy, and it can be transferred from object to object, but nevertheless the total amount of energy always remains the same.

3. Making Things Cold

The insight that you can change energy into other kinds of energy turned out to be crucial in the quest to make things colder and colder — if you can transfer the internal energy of an object into another body or into another kind of energy, then you've lowered the temperature! Perform the **Making Things Cold Demonstration**.

Tell the students, that using internal energy to do work is what makes refrigerators cold! Inside a refrigerator, a liquid refrigerant is turned into a gas. Turning a liquid into a gas requires energy. Where does that energy come from? The refrigerator steals energy from the internal energy inside the refrigerator — and that lowers its temperature and makes it colder.

DEMONSTRATION

Making Things Cold

(This is an experiment that many scientists repeated over and over in the early 1800s, when they were trying to understand how heat and cold worked.)

Bring 1/2 kilogram of water to boiling, and measure its temperature — it should be about 212° F or 100° C. Now take 1/2 kilogram of very cold water — as close to 34° F, or 1° C as you can get it — and mix the two together. Now measure the temperature of the mixture. You should get 1 kilogram of water at a temperature somewhere very close to the middle — around 123° F or 50° C. Ask the group to explain why this happened. (The internal energy of the hot water increased the internal energy of the cold water, and the resulting water had an internal energy — and a temperature — half way between the two original ones.)

Next, combine 1/2 kilogram of boiling water and 1/2 kilogram of ice (which is 32° F or 0° C). Mix the two together until the ice melts and then measure the resulting temperature. This time you will get a kilogram of water — but the temperature won't be the halfway point. Instead it will be much colder, closer to 51° F and 11° C. Remind the students that energy is always conserved — not heat — and ask the students to explain what happened. Where did the extra energy go? This time the internal energy of the water had to be used for two things: First it melted the ice — that is, it did work on the ice by pushing the molecules further apart to make liquid water. This used up part of the internal energy, meaning that just by melting the ice, the hot water was cooled down. But there was still some internal energy left over. The hot water is cooler than it was, but still warmer than the cold water. So, the second use for its internal energy goes toward warming up the cooler water. The resulting water temperature is the average of the ice's temperature and the cooler water. (As opposed to the first example, where all the internal energy went towards only one use — heating the cooler water.)

The point: Internal energy can simply flow to another substance, thus increasing the temperature of that substance, OR it can be put to use to do work causing change in another substance. In the second case, internal energy — and temperature — is therefore decreased, which makes things colder.

Additional Ideas:

- For homework before this module, ask the children to bring an ice cube to class. Don't give them any instructions on how to do so. What worked and what didn't? What were the kinds of energy that affected whether the ice melted or not?
- Challenge students to identify ways heat turns into mechanical energy and vice versa. (The engine of your car with its pistons pumping away gets hot. Hot steam on a tea kettle will move through the whistle on the spout to let you know your water has boiled.)
- Have students research historical scientists who helped devise the theories of caloric and the theories of thermodynamics.

MATERIALS

- thermometer or temperature probe
- glasses of warm, room temperature and ice water
- aerosol deodorant can
- rubbing alcohol (use caution with rubbing alcohol as it is flammable)
- paper and magic marker to make signs

Refrigeration

Get Students Involved

Explain to the students they will study how a refrigerator works and how it depends on some very basic laws of physics. Ask what life would be like without a refrigerator. Explain that the first home refrigerator was only invented in 1911 and that very few homes had refrigerators until the1940s.

The Main Show

1. Heat Flow

Three things help keep your fridge running: heat flow, evaporation and compression. The first thing to understand about a refrigerator is how on earth anything gets cold anyway. Ask the students to imagine stepping outside on a cold day — why do they get cold? What is their mental model for this process? Do they think the cold seeps into their body, or that the air takes the heat out, or something else entirely? Don't tell them right away that the surrounding cold air lowers the temperature of their bodies — let them debate and discuss it for a few minutes. If you have done any of the first three modules, then the students already know that the feeling of heat comes from the rapid movement of atoms transferring energy to another substance. Explain that when you put a hot thing like your face next to something cold like wintry air, the molecules in each substance want to move at the same speed. In order to speed up, the molecules in the air take some of the internal energy from the molecules in your face — thus making the air molecules move faster and feel warmer, while the molecules in your face slow down and feel colder.

After you have reviewed the principles of heat flow, pick two "assistants" from the group and proceed with the **Heat Flow Demonstration**. (If you have already done this demonstration in the "Understanding Heat and Energy" module, simply review it, emphasizing that heat flows in only one direction.)

DEMONSTRATION

Heat Flow

Set up four cups of water on a table: two with room temperature water, one with very warm tap water, and one with ice water. (Preferably without letting the students know which temperature of water is where.) Have one assistant put two fingers in the hot cup and two fingers from the other hand in the cold cup. This assistant should report which cup feels hotter. Meanwhile have the other assistant measure the temperature in each cup and report the temperature aloud. After 15 seconds, the first assistant should quickly dry his fingers, and stick his fingers into the two room temperature cups — and again report which one feels warmer. (It should be the cup with the fingers that had previously been in cold water.) The second student now measures the temperature of the water in the two cups and reports that temperature to the class — unlike what the first student felt, the temperature should be equal. Ask the students if they can figure out why one cup felt warmer even though both cups were the same temperature.

What happened? In the case of the cold fingers, the water was warmer than the fingers, and so the fast-moving molecules in the water encouraged the molecules in the fingers to move more quickly, heating the fingers — thus giving the sensation that the water was warm. In the case of the warm fingers, the water was colder with more sluggish molecules. The faster-moving molecules in the fingers transferred their energy to the slower molecules in the water. Since the water "stole" heat from the fingers, it gave the sensation that the water was cold.

The point: Heat energy only ever moves from a hotter substance to a colder one.

DEMONSTRATION

Evaporation

This demonstration can be done with several student assistants at the front of the room, or if the group is small enough, water and rubbing alcohol may be passed around to everyone. Have the students put a few drops of water on one arm — wipe the water around and then discuss how it makes their skin feel cold. Remind the students that their arm feels cold because as the water evaporates, changing from a liquid into a gas, it steals heat energy from their arm.

Next have the students put a few drops of rubbing alcohol on the other arm and wipe them around. How does that feel? Rubbing alcohol should make their arm feel much colder.

What happened? The rubbing alcohol evaporated also, but its molecules are easier to evaporate than those of water at the temperature of your arm. This means that the molecules of alcohol can take away more energy. And where does that extra energy come from? From the body heat in their arm! The rubbing alcohol steals a lot more heat than the water, which made their arm feel much colder.

The point: Evaporation can make something feel colder. Different liquids evaporate at different rates and the rates tend to depend on how low their boiling points are. So certain liquids — like the ones inside your refrigerator, which evaporate at temperatures even lower than rubbing alcohol — can make things extremely cold.

2. Compression and Evaporation

Now that everyone understands that to make something colder requires slowing down its molecules, tell the students you will show them two ways to do just that. The first is through compression and expansion. Pass around a can or two of aerosol deodorant to the class. Have the students spray the can and feel how cold the deodorant is. Ask the students if they have any idea why. Explain that inside the can the contents are under a lot of pressure, compressing all the molecules in on themselves. Once the contents get out of the can and expand, the molecules slow down — and slower molecules always mean a colder substance.

Another way to make things cold is through evaporation. Ask the students to remember how cold they feel when they step out of a shower. Explain that the water on their body evaporates into the air and turns into a gas. The act of evaporation transforms a liquid into a gas and this requires energy. The water gets this energy by stealing the heat energy from your body — which makes you feel colder. Begin the **Evaporation Demonstration**.

3. How a Refrigerator Works

Tell the students that a refrigerator uses compression and evaporation to take the heat out of your food and transport it to the outside. Ask for three assistants, and give each of them a piece of paper to hold — one should say "Evaporator Coil," one should say "Compressor" and one should say "Condenser Coil." Explain that the refrigerant is the liquid which makes your refrigerator cold by traveling through a closed loop over and over and over — the students are going to act out the journey of the refrigerant. Now pick a fourth assistant to be the Refrigerant and give that student four pieces of paper that say: "refrigerant — liquid," "refrigerant — cold gas," "refrigerant — warm gas" and "refrigerant — hot gas" which can be held up at the appropriate point along the way. Now teach the students how the refrigerator works — encouraging the students to hold up the appropriate signs at the right times.

The refrigerant is a liquid that evaporates at a temperature even lower than rubbing alcohol, so when it evaporates, it can make something even colder. The refrigerant starts its journey going through an expansion valve (remember the valve on the aerosol can?) into the *evaporator coil*. Here the liquid expands dramatically and evaporates into a gas, becoming icy cold. This cold refrigerant then travels through a set of coils at the back of the refrigerator. Heat from the inside of the fridge travels into the cold coils, which makes the refrigerator — and the food — colder, and the refrigerant gas warmer.

Now the refrigerant needs to expel its heat into the outside air, but that's a problem, since even though the gas is now warmer than the inside of the refrigerator, it's still colder than room temperature. We have seen that heat only travels toward an area that's colder. So there's no way for the refrigerant at this stage to transfer its heat to the outside, warmer world. However the *compressor* now rapidly compresses the gas and its internal energy increases, making it even hotter. Last, the hot, compressed gas funnels its way to a *condenser coil* which is in the back of the refrigerator and in contact with the outside air. Here, finally, the heat flows away from the refrigerator into the surrounding room. (This explains why the back of the refrigerator always feels warm!) When the refrigerant gas loses heat, it becomes cold again, condensing back into a liquid. Once in liquid form, it moves back to the expansion valve and starts the whole process over again.

After you have walked the group through the whole process, have the students recite it all themselves — explaining what happens in each stage. Help them out where appropriate!

Additional Ideas:

- Invite a refrigerator repairman to class. Invite a doctor, a grocer, a farmer, a chef, or a mortician to class to describe how refrigerators and freezers are used in their work.
- Have students find photos of old refrigerators.
- Have students write an article for a 1911 newspaper about this new "refrigerator" and what it can do.

Teacher's Note:
The demonstrations for this section require time to freeze food samples and to let them thaw. If it's not possible to do this module over the course of one or two days, the freezing may be done ahead of time. In this case, show the class fresh samples as described below, and then — taking a cue from cooking shows – ta da! present the frozen samples directly afterwards. Also, pay attention to school rules about food/eating in the lab — this whole module may be done in a kitchen.

MATERIALS

- pictures of the various animals mentioned below — pictures can be found on the Internet
- a freezer
- various foods, such as fresh berries, celery, lettuce, cooked ground beef, cooked macaroni, slices of hard boiled egg
- juice
- two ice cube trays
- toothpicks or popsicle sticks

Cold Animals

Get Students Involved

Ask the students to imagine the feeling of being cold, and what kinds of things they do — such as bundle up — to keep themselves warm. Do they know how animals survive a cold winter? Some students will know that bears hibernate, or that snakes curl up in caves, or even that the blubber on a polar bear helps it stay warm. Now ask if they know how frogs or insects keep warm through the winter. Tell them you are going to study all the unique ways that animals keep themselves from freezing.

The Main Show

1. Freezing Problems

Explain to the group that the coldest environment on earth is in Antarctica. In the winter of 1989, Vostock, Antarctica reached -128.6° F (-89.2° C) — so cold that hot water poured onto the snow would freeze before it even hits the ground. When living creatures are exposed to below-freezing temperatures like this, ice can form in their blood vessels, causing the vessels to stretch or even burst. Frozen ice in the blood stream also steals water from blood cells, killing them. Without water, and with sharp points on the ice crystals all around, frozen cells can be broken and destroyed. (Have you seen a contact lens that's been left out to dry? It often rips in half — that's what can happen to cells when they lose their water.) Perform the **Freezing Fun Demonstration** in order to show what can happen to cells.

DEMONSTRATION

Freezing Fun

Hand out the various foods, and have the group examine them — have them describe their color, shape, texture, smell and taste.

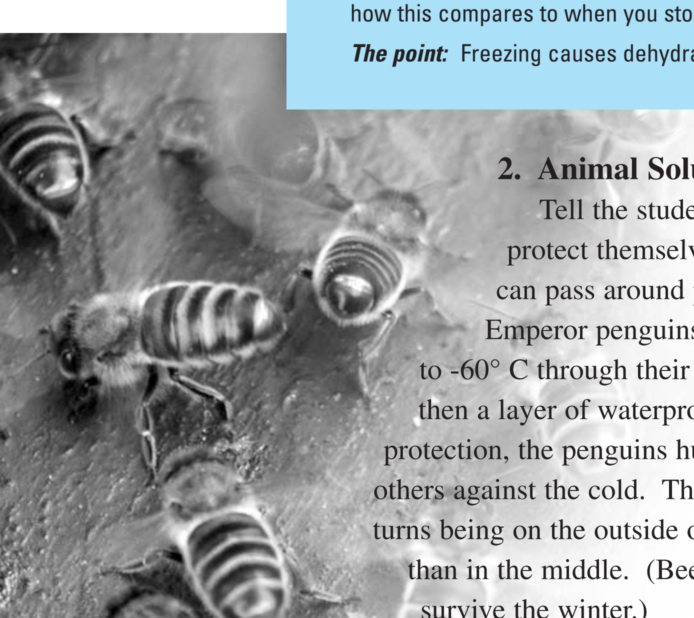
Next, place bits of each food in the wells of an ice cube tray. Without covering the tray, put it in the freezer. Let the ice cube tray sit in the freezer for several hours — or better yet overnight — until everything is well-frozen.

Take a look at the tray of foods. Compare their color, shape, texture, smell, etc. to how they looked before. Are water crystals formed around the outside? Since you have told the students how ice pulls water from inside blood cells, encourage them to describe what they think happened to these foods. Set food aside to thaw.

Once the foods thaw, describe them again. How do these compare to the originals? Do they look like something the group would still want to eat? Taste them. (They will all be perfectly safe to eat, whether or not they look pretty or taste good.) How do the tastes compare to the previous tastes?

Because the frozen foods weren't covered in the ice tray, they lost a lot of water to evaporation. Ask the group how this compares to when you store food in the freezer in an air-tight container.

The point: Freezing causes dehydration and destruction of cells, which in turn can cause animals to die.



2. Animal Solutions

Tell the students that you are going to discuss the different ways animals protect themselves from getting ice in their blood streams. As you do this, you can pass around pictures of the various animals.

Emperor penguins spend the winter in Antarctica, surviving temperatures down to -60° C through their bodies' amazing insulation. They have a layer of blubber and then a layer of waterproof feathers that help trap their body heat inside. For even more protection, the penguins huddle together during the winter, each one helping insulate the others against the cold. The hundreds of penguins in the giant huddle shuffle around, taking turns being on the outside of the group — where the temperature can be up to 20° C lower than in the middle. (Bees, too, form the same kind of constantly moving huddle to survive the winter.)

Other animals have even more complicated ways of protecting their cells. Some insects — Antarctica houses little arthropods called springtails, for example — produce glycerol in their cells. Glycerol acts as antifreeze that will completely stop ice crystals from forming. In this way, these creatures prevent freezing altogether and can survive down to -40° C.

Instead of preventing freezing, some animals survive cold temperatures by simply letting themselves freeze solid — while herding any ice crystals in their bodies to spots where they can't do damage. Some varieties of North American turtles and frogs can do this, and near the North Pole, the Arctic woolly bear caterpillar can too. These animals create extra glucose (blood sugar) in their livers and pump the glucose into their cells. Water has a hard time freezing with all that glucose in it and so the only water that freezes is between the cells. A frozen wood frog can survive with a layer of ice right under its skin, but that ice doesn't get into its cells, so the frog will thaw in the summer and return to its normal life.

Perform the **Making Popsicles Demonstration**.

3. Human Applications

One of the reasons scientists study how animals survive the winter is to see if they can successfully preserve animal and human cells for medical reasons. Ask the students for their ideas on why this might be useful. Some possibilities: organs must be carefully preserved through cold temperatures, but not in such a way that the cells are destroyed; veterinarians freeze animal eggs and sperm in order to help endangered animals survive. (The students may have even heard about attempts to freeze whole human bodies to bring them back to life — a field called "cryonics." Explain that while there are indeed people who study this, no one is sure it will ever be possible!)

DEMONSTRATION

Making Popsicles

Pour juice into the wells of an ice cube tray. Put this in the freezer, and after 30 minutes or so, take it out to see if the juice is frozen just enough for you to stick a toothpick or popsicle stick into each well. Replace the tray in the freezer.

Let the ice cube tray sit in the freezer for several hours — or overnight — until everything is well frozen.

Twist the ice cube tray until you can wiggle out the popsicles. Ask the students how the popsicles look. Was there any unfrozen syrup left over in the bottom of the tray? Have the group eat the popsicles — can they suck the juice out and leave a crystal lattice of ice behind? The water froze into ice, but the sugary juice remained liquid. Remind the students that the wood frog uses sugar to keep its own cells from freezing — can they figure out why the water froze in their popsicles, but the juice didn't?

The point: Sugar water doesn't freeze as quickly as regular water, and so cells filled with sugar water will stay liquid even in freezing temperatures.

Additional Ideas:

- This module could be combined with a study of the terrain and ecosystem of Antarctica.
- Have students create posters, each with a drawing of a cold-weather animal and a description — with diagrams — of how it survives harsh winters.
- Have students research the applications of cryopreservation in medicine.
- Have students research animals — like mastodons — or even people, that have been frozen in ice for millennia.

Safety Rules:

This module is best-suited for those who already have easy access to, and experience with, liquid nitrogen. Do the following section only if you have the protective equipment, the background and the means to ensure security. (Or else you could invite a well-prepared expert to do the demonstration!)

While liquid nitrogen is not dangerous if handled correctly, it is only appropriate for a mature, well-behaved group as it does require special care: it should be handled only by adults; use thick leather or nylon-coated fabric gloves at all times and wear goggles; be careful not to spill any on your body; don't store it on site at a school or where children can access it; and read liquid nitrogen safety rules online ahead of time at http://webs.wichita.edu/facsme/nitro/safe.htm. Essentially it should be treated the way you might treat a vat of boiling water — with respect!

MATERIALS

- liquid nitrogen
- a ladle
- safety goggles and safety gloves
- images, perhaps printed from the Internet, of frozen vegetables, MRI images, oxygen tanks, maglev trains, etc.
- several flowers
- 10-20 balloons
- a Styrofoam container with a mouth smaller than an inflated balloon
- plastic film canisters
- modeling clay or play dough
- 2 quarts (1.9 liters) of Half and Half
- 1 cup (237 ml) of sugar
- 4 teaspoons (20 ml) of vanilla (optional)
- 2 cups (473 ml) of mashed strawberries (or other fruits or some chocolate syrup or any flavoring you'd like!)
- wooden spoon
- wire whisk
- large plastic punch bowl

Cryogenics and Technology

Get Students Involved

Explain that you are going to explore all the ways low-temperature science affects our lives. Ask for examples — possible answers might be refrigeration, air conditioning, ice cream, or frozen food. Tell the group that the bulk of low-temperature science technologies — known as "cryogenics"— require temperatures much colder than a simple freezer. Cryogenics makes use of all sorts of liquid gases like hydrogen, nitrogen and oxygen, to keep things at temperatures hundreds of degrees below zero. Pass out some images of cryogenic technologies and tell everyone they may be surprised at how many modern conveniences require such extreme cold: flash freezing vegetables, high-temperature superconductors in cell phone towers, MRIs and storing liquefied natural gas for energy — to name a few.

The Main Show

1. Liquid Nitrogen

Liquid nitrogen should be treated with respect. If it stays in contact with the body for long, it will freeze your skin. The fact is that liquid nitrogen evaporates so quickly that it will usually disappear into the air long before it has the chance to hurt you, so as the showman you don't need to be paranoid — however the first step in this module is to instill a healthy caution in the children in front of you. (In a small, unventilated room, liquid nitrogen can also reduce the oxygen to dangerous levels, so do work in an open area!) Perform the **Brittle Flowers Demonstration**. When you're finished, explain to the students that you want them to stay eight feet away from the nitrogen at all times. Any assistants you call on for help will have to wear goggles and gloves.

DEMONSTRATION

Brittle Flowers

Ask for two to three student assistants. Show them the canister of liquid nitrogen and explain that the liquid is at -320° F (-196° C). Ask what they think would happen if they put their hands in it. (DON'T LET THEM!) Outfit each student with goggles and gloves, and give each one a flower.

Have the students dip their flowers into the nitrogen and hold them there for a few moments until the nitrogen stops bubbling. (In a small enough room, all the students will hear a hiss — this is the sound of the nitrogen boiling when in contact with the warm flower.) Remove the flowers and have the group guess what they think has happened to them. Then have the students grab the flowers with their gloves — crumbling the flower into dust. What happened? What might happen to their hands in the canister? You can also crash the flower onto the table to demolish it, to be dramatic if you wish.

The point: Liquid nitrogen is so cold it will freeze the water molecules inside something living. If you froze your hand down to -320° F, it would break too!

DEMONSTRATION

Liquid Air

Use the ladle to fill the Styrofoam container about one-quarter full with liquid nitrogen. Ask two assistants, outfitted with goggles and gloves, to help you blow up a number of balloons. As the balloons are being blown up, ask how many they think would fit inside the container. Set one of the balloons directly on top of the Styrofoam container, where it should balance, unable to fit through the hole. The liquid nitrogen will chill the air inside the balloon. The balloon will get smaller and eventually fall into the container. Act surprised. You might even ask the students if they tied the knot tightly. Put another balloon on top of the container. Watch the same thing happen again. Remind them that liquid air will have a much smaller volume than gaseous air. Ask again how many balloons they think would fit inside.

Once you've put a fair number of balloons in the container, ask everyone what will happen when the balloons come out. Have an assistant pull out a balloon and describe it to the group — there will be liquid inside. Warn the students that sometimes the balloons pop when they get pulled out. Ask them where the liquid came from. It's liquid air! Quickly the liquid will evaporate back into gas, and the balloon will re-inflate. Ask the students to explain why if a hospital wanted to store large amounts of oxygen, it would make more sense to store it cold.

The point: Liquid oxygen takes up almost 900 times less space than gaseous oxygen, so storing cold oxygen saves on containers and space. (Gaseous oxygen is also highly flammable, unlike liquid oxygen.)

2. Medicine

When might freezing part of someone's body be a *good* thing? What if something growing on the body was harmful? Doctors sometimes use liquid nitrogen to freeze off warts or skin cancer — and even scars on the heart that cause irregular heartbeats. Doctors also use cryogenics for oxygen storage. Remind the students that — as they learned in the States of Matter module — liquid takes up less space than gas and then perform the **Liquid Air Demonstration**.

When you've finished the demonstration, tell the students that a single liter of liquid oxygen (around three soda cans' worth) will expand 862 times when allowed to come to room temperature — and that will fill five oxygen tanks.

3. Space Flight

Another place where storage space is at a premium is on spacecraft like the space shuttle. Explain to the group how rocket engines work. They are, at their most basic, fairly simple: by throwing something backwards with extreme force, the rocket goes forward. This happens due to the principle of conservation of momentum. You can see it if you sit on a twisting stool and throw your arms to the right; the rest of your body sitting on the stool will twist to the left. Or if you stand still on ice skates and throw a baseball to someone, you will start sliding in the opposite direction.

In the case of a rocket engine you need a big enough push to send the rocket moving so fast that it can rise off the surface of the Earth. The solution lies in creating an explosive, but controlled, burn that fires gases out the back of the engine. In the case of the space shuttle the explosion is made from a fuel, liquid hydrogen, and an oxidizer, liquid oxygen. And liquid gases, with temperatures near absolute zero, are an example of cryogenics at work. Perform the **Rockets Demonstration**.

DEMONSTRATION

Rockets

Wedge a film canister into a large piece of play dough, so that it sits upright on a table. Ladle a small amount of liquid nitrogen into the canister. Wait a few moments until the liquid stops bubbling and then snap the plastic cover into place. After a few seconds, pop, the cover will speed up toward the ceiling. Ask the group to describe what happened.

The point: As the liquid in the film canister evaporated into gas, its volume expanded. It got so big that it popped the cover off. See if the students can understand how this is both similar to and not exactly like a rocket. This is an upside-down rocket. If it were just like a rocket, the cap would go down, but the film canister would speed upwards in the other direction due to conservation of momentum. So this is an upside-down rocket and you used the play dough to keep the canister from falling over or hitting anyone.

After the demonstration, tell the students that the space shuttle's main external tank has two huge tanks of its own. One tank holds 1,500,000 liters of liquid hydrogen and the other holds 550,000 liters of liquid oxygen. Together they weigh about 1.6 million pounds (719,000 kg). The two liquids are funneled together at an amazing rate — the equivalent of emptying an Olympic-size swimming pool once every 25 seconds. They are burned in the main combustion chamber to produce exhaust that shoots out the bottom of the space shuttle at approximately 6,000 mph (10,000 km/h) — thus sending the space shuttle into orbit.

4. Frozen Foods

Another area where liquid nitrogen has affected our daily lives is in the food we eat. Frozen vegetables save much more of their flavor and texture if frozen quickly. Remember how fast the flowers froze? Liquid nitrogen is a great way to protect food — it helps prevent damage, discoloration and degradation. If students may eat in the demonstration room you are in, perform the **Ice Cream Demonstration**.

When you're finished, explain that while flash freezing does use liquid nitrogen, most ice cream manufacturers don't actually use nitrogen to make their products — but it certainly works well for freezing, doesn't it?

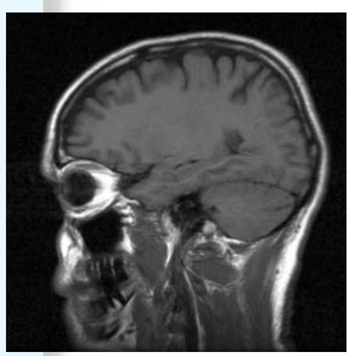
DEMONSTRATION

Ice Cream

Ask for two assistants and outfit them with gloves and goggles. Have the students help measure and mix the ingredients as you make the ice cream. Mix the Half and Half, sugar, and vanilla in a large plastic punch bowl with a wire whisk. Add the strawberries (or other flavoring) and whisk it all together. Pour a small amount (about 250 ml) of liquid nitrogen directly into the bowl. Stir the mixture with a wooden spoon, being careful not to splash. Keep adding small amounts of liquid nitrogen until the mixture becomes too thick to stir. Allow any excess liquid nitrogen to boil off. Give the ice cream a moment to warm up — test it before giving it to the group — and eat!

Additional Ideas:

- There are hundreds of other ideas for demonstrations with liquid nitrogen — search the Internet and have fun!
- Describe how liquid nitrogen is made.
- Ask the students to research other technologies that rely on cryogenics, for example, MRIs, superconductors, cryopreservation of seeds, magnetic levitating trains, linear accelerators and infrared telescopes.
- Explain the difference, or have the students research the difference, between "cryogenics" and "cryonics" — the attempt to freeze human bodies. Make sure to discuss which goals of cryonics are currently scientifically feasible and which aren't.



Educators Note:
This section requires some specialized — though not too expensive — materials, and some advance work building part of the demonstration. Materials can be bought online. Having the children help with building the Ring Flinger Device is one way to get them involved — though it will certainly take time, and require oversight. Also, there are online videos of both the "Ring Flinger" and the "Meissner effect" which can be substituted for doing the demonstrations in class if necessary.

Read the liquid nitrogen safety rules in the cryogenics section before working with liquid nitrogen!

MATERIALS

- images of models of atoms
- images of the various people involved with early superconductivity work
- liquid nitrogen
- copper ring
- superconducting disk
- neodymium-iron-boron (or other strong) magnet
- Petri dish
- Styrofoam cup
- non-magnetic tweezers
- gloves
- Ring Flinger Device as built according to instructions here: http://education.jlab.org/workbench/lenz/index.html

Superconductivity

Get Students Involved

Show the group images of models of atoms with a nucleus in the middle and electrons orbiting around it. Ask the students to name the parts, making sure to discuss that the neutrons are electrically neutral, the protons are positive, and the electrons are negative. Tell them that what they're viewing isn't to scale — have them guess how far away the electrons should be from the nucleus if the atoms were to scale. The answer is about a mile away! The atom is mostly made up of empty space. Even solid objects like their bodies and their chairs are empty space. Ask them why they think that with all that empty space, they don't fall through their chairs. It's because the electrons in your body repel the electrons in the chair — they're held up by an electromagnetic force. Explain to the students that all objects have electrons in them, but electrons flow differently in different materials and depending on how they move, the object can allow more or less electricity to flow. In *insulators*, the electrons don't move around much, so they don't allow electrical current to flow, but electrons flow easily in *conductors*, so they allow electrical current to travel through. Today you are going to examine a special kind of conductor called a *superconductor*, which let much more electricity flow through than normal.

The Main Show

1. Cooling Down a Conductor

The first thing you're going to do today is simply to show how all conductors conduct electricity even better when they are cold. To demonstrate this, explain to the group that they first need to understand that given the right conditions, a changing magnetic field will produce electrical current, and that the electrical current in turn, produces a magnetic field in opposition to the original one. This is called Lenz's Law. Begin the **Ring Flinger Demonstration**.

Walk the group through the explanation of why the ring flew up into the air, making sure to mention that the effect depended on the fact that current formed in the ring. Current doesn't run through metal unimpeded of course, it experiences *resistance*, much like a sled will eventually slow

DEMONSTRATION

Ring Flinger

Turn the Ring Flinger on, and then drop a copper ring onto it. Instead of falling, the ring will hover about halfway down the tube. Now turn the Ring Flinger off — the copper ring will drop. Turn it back on and watch the ring fly a short way up into the air. Because the Ring Flinger uses alternating current (AC), the magnetic field that it produces is constantly changing, flipping its north and south poles while it is switched on.

The point: The changing magnetic field in the Ring Flinger caused a current to form in the copper ring. In turn this current in the ring created opposing magnetic fields, also changing all the time. In the first example, these opposing fields gently balanced each other, and the ring hovered. In the second case, the turning on of the Ring Flinger created such a large change in the magnetic field that the result was much larger, and the ring flew off.

DEMONSTRATION

Cold Ring Flinger

Safety Note: The Ring Flinger will send its ring straight up into the air — however, please have the students stand eight feet back, and caution them not to touch the cold ring when it lands on the floor.

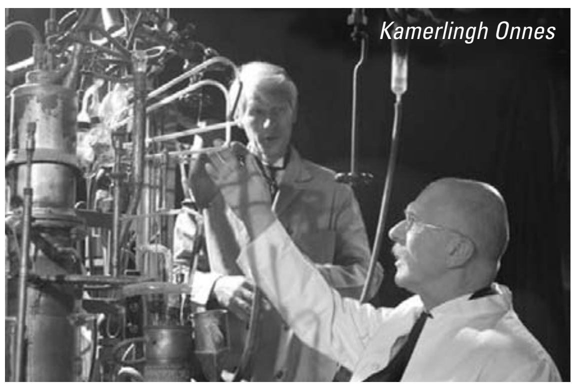
Using gloves and tongs, dip the copper ring into a thermos of liquid nitrogen. Hold it until the bubbling stops, and then — still wearing gloves — repeat the original Ring Flinger experiment. Watch the ring fly much higher than it did before. (It's worthwhile to practice this before demonstrating it, just to get a sense of how high it will in fact go — short ceilings, beware!)

The point: Cooling a conductor decreases its resistance and increases its conductivity — electrical current becomes much stronger.

down at the bottom of a hill due to the friction of the runners on the snow. Different materials have different amounts of resistance, and therefore electrical current moves through at different levels of efficiency. Ask the students what they think would happen if you could make the ring experience even less resistance, and therefore greater current. How high would the ring fly then? Tell them that you can make the ring less resistant — by making it much, much colder. Perform the **Cold Ring Flinger Demonstration**.

2. History of Superconductors

Using images of the various scientists, describe the history of superconductivity. At the beginning of the 1900s, scientists understood that cold decreased resistance and improved conductivity, but they weren't sure what would happen if they took a conductor into the extremes of freezing temperatures. Some people, such as Lord William Thomson Kelvin, believed that current would stop altogether. Heike Kamerlingh Onnes thought the resistance to the current in the material would gradually drop off and current might increase. Kamerlingh Onnes, a Dutch physicist at Leiden University, was the first to liquefy helium in 1908, bringing the record man-made temperature down to -452° F (-269° C). He decided to test how well metals conducted electricity at extremely cold temperatures.



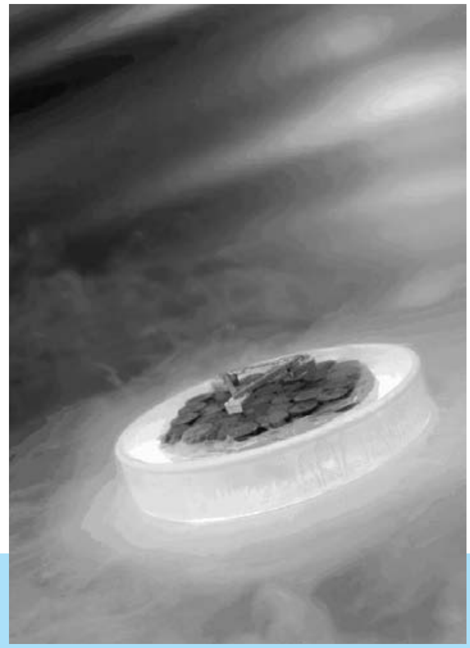
Kamerlingh Onnes

Kamerlingh Onnes studied a wire made of mercury. Initially, he noticed only the steady decrease of resistance as the wire got colder and colder. But then, all of the sudden, once the wire hit 4.5 K (-451.57° F or -268.65° C), all resistance disappeared. Current flowed through the wire and it didn't need any voltage to keep moving. It would be as if someone gave you a push on a sled, and even though you were on flat ground, the sled just kept going and going, never slowing down — you could travel around the whole world without ever getting another push.

3. The Meissner Effect

While superconductors are fascinating for this power to conduct electricity so efficiently, they have fascinating magnetic properties, too. In 1933, Karl Wilhelm Meissner and R. Oschenfeld discovered that superconductors are repelled by magnetic fields — scientists say they are diamagnetic. Two normal magnets cause each other to move — you can feel a strong magnet practically jump out of your hand when you put it on the refrigerator. But a superconductor produces a stable magnetic effect — a bar magnet will levitate easily and steadily over a superconductor, something which is called the Meissner effect to this day. Perform the **Meissner Effect Demonstration**.

Ask the students what kinds of things they would like to see levitate. You might suggest skateboards and trains. Imagine ice hockey played with levitating skates, or sleeping on a levitating bed. The first superconductors had to be kept so cold in order to function that these kinds of technologies just weren't practical. In the 1980s, scientists discovered materials that were superconducting at higher temperatures (77 K / - 196° C / -321° F) — though still incredibly cold by human standards. These materials can be cooled by liquid nitrogen, which is far easier to work with and much less expensive. Talk about the technologies that exist today — such as MRIs and magnetic levitating trains — that make use of superconductors.



Additional Ideas:

- Assign each student a currently available superconductor technology to research and describe to the class. You might suggest magnetic levitating trains, MRIs, cell phone towers, particle accelerators, electric generators.
- Discuss how life might be different if these superconductor technologies didn't exist.
- Superconductors can be made of different combinations of different atoms — give a small chemistry lesson on these interesting elements.

DEMONSTRATION

The Meissner Effect

First take two bar magnets and demonstrate how they naturally repel or attract each other depending on how you hold them. Try to levitate one above the other to show that it can't be done.

Next, fill the Styrofoam cup with liquid nitrogen. (This will help to keep the liquid nitrogen in the Petri dish from boiling away too fast.) Place the Petri dish on top of the Styrofoam cup and carefully pour in enough liquid nitrogen until the liquid is about a quarter inch deep. The liquid will boil rapidly for a short time. Wait until the boiling subsides.

Using non-metallic tweezers, carefully place the superconducting disk in the liquid nitrogen in the Petri dish. Wait until the boiling subsides.

Using non-metallic tweezers, carefully place a small magnet about 2 mm above the center of the superconductor. Upon releasing the magnet it should levitate at some 3 mm above the superconductor. The magnet should remain suspended until the superconducting disk warms to above its critical temperature, at which time the magnet will no longer levitate. It may either settle down onto the disk or "jump" away.

The point: While two normal magnets always repel or attract each other to their maximum capacity, a superconducting magnet (which requires incredibly cold temperatures) allows a bar magnet to simply levitate. Also, once the superconductor gets warm, it loses its special magnetic properties.

The Quest for Absolute Zero

MATERIALS

- images of and temperatures for some very cold and very hot objects.
- images of Amontons, Bose and Einstein
- at least 10 small pipettes with bulbs on them
- at least two beakers
- hot plate
- thermometer or temperature probe with Celsius scale
- water
- ice
- an Internet-connected computer

Get Students Involved

Ask the students to name the coldest things they can think of — they might name a freezer or Antarctica or even the vacuums of space. Ask them to describe what happens to things that get cold — and push them beyond the concepts of "they freeze." If the students have already done the States of Matter module, you can remind them how as things get colder, atoms slow down, gases become liquids and liquids become solids, and various other changes happen. Go through the same procedure for hot things — what are the hottest things in the universe? What physical changes happen when things get very hot? Pass around images of particularly hot and cold objects in the universe, with their average temperatures labeled. Finally, ask the students if they think there's a limit to how hot an object can get. How about how cold something can get? There is no limit to the highest possible temperature of an object, but there is a limit to the coldest temperature. We call that temperature *absolute zero* — on a thermometer it measures 0 K, -459.67° F, or -273.15° C. The group will explore this incredibly cold temperature and what happens to atoms when they get that cold.

The Main Show

1. Why Does Absolute Zero Exist?

This concept of a "limit" on the cold end of the temperature scale is a subtle and interesting one. Challenge the students to try to figure out why there would be a limit on one side, but not the other. After they've called out a few possibilities, tell them that a similar example is the light scale. There is no limit to how bright something can be, but there is a limit to how dark it can be. Perform the **Absolute Dark Demonstration**.

Explain that when something is absolutely dark, there is not one speck of light left. There is no way to remove *more* light, and make it darker. Remind the group that an object changes temperature through the exchange of heat — there is no way to make something cold by adding "cold." Instead, objects only get colder when heat is removed. When an object reaches absolute zero, it has lost all its internal (or *thermal*) energy. Much like an absolutely dark room, there is no way to remove any more internal energy and make the object colder.

DEMONSTRATION

Absolute Dark

Ask the students how you would go about making the room you're in darker and follow their instructions for as long as is reasonable — turn off the lights, close the shades, duct tape off the cracks of light around the door. If you have a small enough crowd and enough inclination, you could get your group into a very dark room indeed — a windowless closet off a darkened corridor for example — but you can perform this in an average room as well, asking the students to imagine what is impossible to actually change. (Destroying the sun and stars, for example!) At a certain point they will run out of possibilities. You have removed all the light (or they can imagine all the light has been removed) and there is no way to make the room any darker.

The point: Much like absolute zero on the cold end of the temperature scale, there is a limit to how dark a room can be.

2. Finding Absolute Zero

Tell the group some history behind absolute zero, handing around any images you've brought. In 1703, Guillaume Amontons realized there was a limit to how much heat could be removed from an object, and that there must therefore be a limit to coldness. Amontons didn't know exactly why, since nobody understood at the time exactly what made something hot. Today we know that increased temperature is caused by movement of atoms inside a material. Faster atoms mean hotter matter; slower atoms mean colder matter. Absolute zero, therefore, is the point at which all atoms stop moving. To make atoms stop moving altogether is impossible, and it is only recently that scientists have even gotten close to absolute zero. It is possible, however, to determine the temperature of absolute zero without having to make anything that cold. Remind the group that volume is one of the things that changes with temperature. By measuring how volume changes as air gets hotter or colder, you will determine the temperature of absolute zero. Perform the **Absolute Zero Demonstration**.

DEMONSTRATION

Absolute Zero

This may be done in individual groups — perhaps with each group assigned to measure a single temperature — or you may demonstrate at the front of the room, calling out the measurements as the students plot the information on their own graphs. You may also draw the graph on a blackboard for everyone to see.

Fill a beaker with room-temperature water. Measure its temperature in Celsius exactly and then completely fill a pipette with the water. Count the number of drops the pipette contains by emptying it one drop at a time — the volume should be in the range of 100 drops. "Number of drops" is obviously not a rigorous volume definition, but it serves well enough. This number of drops corresponds to how much of anything — air, liquid, or solid — the pipette holds at room temperature.

Draw a graph of temperature in Celsius on the x-axis versus number of drops on the y-axis, and plot this point. (You will eventually be extrapolating the value of absolute zero, so leave enough room on your x-axis to get down to -273. You need not leave much space for the y-axis to go below zero.)

Fill a second beaker with room-temperature water, and then gently heat it over the hot plate until it is 10 degrees warmer. Take a new, dry pipette and hold it in the heated water bath for a few minutes — don't fill it with water! — thus warming the air inside. As the air warms, it expands, and you may see some bubbles of air escape. Place a finger over the end of the pipette to prevent air from escaping while you transfer it to the original, cooler water bath. Now remove your finger. As the gas in the pipette cools, it loses volume and a small amount of water will be sucked into the pipette. This amount of water will be the same volume as the amount of air that escaped. (Make sure the students understand why this is!) Wait until the pipette has reached room temperature again, remove the pipette, and carefully count the drops of water. Add this amount to the original count, and you will have measured the total volume for the air that was warmed in the water bath. (The original volume of air, plus the volume of air that escaped when warmed, is equivalent to the total volume of the expanded air.)

Plot this new point on your graph.

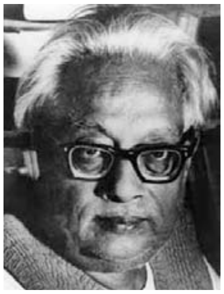
Heat the water bath another 10 degrees, and repeat with a new dry pipette. Do this a few more times — making sure the water doesn't get so hot your students cannot work with it safely.

You may also do this with cold-water baths at various temperatures — in this case, place a pipette filled with room temperature air into the cold water as described above. The volume of air inside will contract, and water will be sucked into the pipette. Count out the number of drops (do not bring the pipette back to room temperature first) and subtract this number from the standard number of drops the pipette contains. The resulting number is the volume of air at that cold temperature. Plot these points on the graph as well.

When you have collected 5-10 points on the graph, draw the best line you can through the points. Where does the line cross the x-axis? Remind the students that the y-axis represents volume — is it reasonable to imagine that the air could ever cross the x-axis and have negative volume? No. The line must stop where it hits the x-axis. Therefore, that point on the axis, that temperature, is the coldest temperature possible — absolute zero.

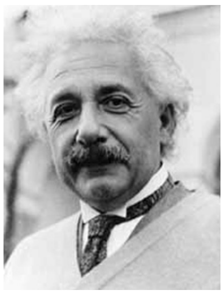
The point: Volume change, too, has a limit — nothing could ever be smaller than zero. You can use this fact to help find the temperature of absolute zero — even without ever having to make air so incredibly cold. (Indeed, if you tried to make it that cold, the air would eventually condense to a liquid and foil your attempts to track down the correct value of absolute zero using this method.)

Bose



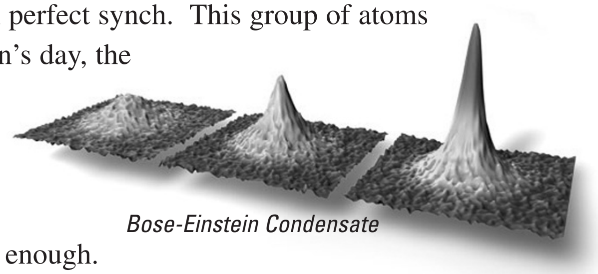
3. The Quest for Absolute Zero

Time for more history! Since atoms never stop moving completely, it's impossible for any object to ever truly be as cold as absolute zero — but that hasn't stopped scientists from trying to get very close. In the early days of studying refrigeration in the 1800s, researchers discovered that by liquefying gases like hydrogen, helium and oxygen, they could achieve extremely cold temperatures. By 1908, they had reached five degrees above absolute zero.



Einstein

In the early 1920s Satyendra Nath Bose was researching a new theory that people were just beginning to study, called quantum mechanics. He used this new type of physics to come up with a set of rules for how photons behaved, but he had trouble getting his ideas published, until he got a little help from a friend — Albert Einstein. With Einstein's help the ideas finally saw print. Later Einstein applied these same rules to atoms. His math showed that if the atoms were cold enough, something very unusual should happen. Normally atoms move independently of each other, like a crowd of people wandering around on the streets, but Einstein realized that if atoms got cold enough, they would lock up like a marching band in a parade, and begin to move in perfect synch. This group of atoms was named a Bose-Einstein condensate (BEC). In Einstein's day, the temperatures needed to see a BEC were far colder than anyone had ever been able to reach, but it gave physicists who studied the cold a new goal — to get atoms cold enough to create a Bose-Einstein condensate.



Bose-Einstein Condensate

It wasn't easy. Simple refrigeration techniques weren't enough. Instead, researchers learned how to slow atoms down using lasers and magnets. Remember an atom is "cold" when it's as still as it can be, so if you can hold an atom still you've made it extremely cold.

In 1995, three scientists, Carl Wieman, Eric Cornell, and Wolfgang Ketterle, all managed to slow down enough atoms and make them cold enough — at 170 billionths of a degree above absolute zero — to create a Bose-Einstein condensate. The condensate behaved as Bose and Einstein predicted: all the atoms joined up into a single superatom which moved as a unit.

With an Internet-connected computer, please explore http://www.colorado.edu/physics/2000/bec/temperature.html to play some games that demonstrate how lasers and magnets can be used to create a Bose-Einstein condensate.

Additional Ideas:

- If it's not practical to play the online Bose-Einstein condensation games, you can devise a similar live demonstration, with some students acting out the role of moving atoms, while others cause them to slow down, either through a simple tag, or some other technique like throwing a crumpled piece of colored paper at them to simulate the photons of laser light.
- The Absolute Zero Demonstration will rarely give the exact temperature for absolute zero. Talk the group through the various uncertainties — the imprecise volume scale, for example — and ask them to brainstorm ways to make the experiment more precise.
- Have students research what's happened in the studies of Bose-Einstein condensates since 1995. Have students research what technologies might some day make use of Bose-Einstein condensates.

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National Science Education Standards for Levels 5-8

Modules in this guide meet the content standards of the National Science Education Standards (prepared by the National Committee on Science Education Standards and Assessment, National Research Council) as follows.

Science as Inquiry Standards:
Abilities Necessary to Do Scientific Inquiry:
Thermometers, States of Matter, Understanding Heat and Energy, Refrigeration, Cold Animals, Cryogenics and Technology, The Quest for Absolute Zero
Understanding about Scientific Inquiry:
Thermometers, States of Matter, Cold Animals, Cryogenics and Technology, Superconductivity, The Quest for Absolute Zero

Physical Science Standards:
Properties and Changes of Properties in Matter:
Thermometers, States of Matter, Understanding Heat and Energy, Refrigeration, Cold Animals, Cryogenics and Technology, Superconductivity, The Quest for Absolute Zero
Motions and Forces:
Understanding Heat and Energy, Cryogenics and Technology, Superconductivity
Transfer of Energy:
Thermometers, Understanding Heat and Energy, Refrigeration, The Quest for Absolute Zero

Life Science Standards:
Structure and Function in Living Systems:
Cold Animals

Science and Technology Standards:
Abilities of Technological Design:
Thermometers, Refrigeration
Understanding about Science and Technology:
Understanding Heat and Energy, Refrigeration, Cryogenics and Technology, Superconductivity

Science in Personal and Social Perspectives:
Science and Technology in Society:
Refrigeration, Cold Animals, Cryogenics and Technology, Superconductivity

History and Nature of Science Standards:
Science as a Human Endeavor:
Thermometers, Understanding Heat and Energy, The Quest for Absolute Zero
History of Science:
Thermometers, Understanding Heat and Energy, Superconductivity, The Quest for Absolute Zero

Additional Resources

Absolute Zero Campaign Web Site http://www.absolutezerocampaign.org

Low Temperature Science posters http://www.ph.rhul.ac.uk/lowtemp/posters/

American Chemical Society, Activities on Matter and Its Changes http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education%5Cwande%5Cresourcechem%5Cmatter%5Cmatter.html

Exploratorium Demonstrations on Heat and Cold http://www.exploratorium.edu/snacks/iconheat.html

Kitchen Chemistry http://www.chatham.edu/pti/Kitchen_Chem/abstract_page.htm

The History of the Refrigerator and Freezers http://inventors.about.com/library/inventors/blrefrigerator.htm

The Origins of Home Refrigerators Lesson Plan http://66.46.139.215/proj_01/vmcp/docs/chill_lesson2.pdf

American Society of Heating, Refrigerating and Air-Conditioning Engineers Cool Science Kit
http://www.ashrae.org/content/ASHRAE/ASHRAE/ArticleAltFormat/200411151367_347.pdf

Newton's Apple TV Show: Cryogenics
http://www.reachoutmichigan.org/funexperiments/agesubject/lessons/newton/Cryogen.html

Pulse of the Planet: Arctic Ground Squirrels http://www.pulseplanet.com/archive/Nov98/1764.html

Science in Antarctica http://www.antarcticconnection.com/antarctic/science/index.shtml

The Bose-Einstein Condensation Homepage http://www.colorado.edu/physics/2000/bec/index.html

Jefferson Lab Teacher Resources http://education.jlab.org/indexpages/teachers.html

Jefferson Lab Physics Fest Teacher Packet http://education.jlab.org/physicsfest/teacher_packet.pdf

National Science Education Standards http://www.nap.edu/readingroom/books/nses/html/6a.html

State Science Standards http://www.caosclub.org/totalcaos/members/statestandards.html

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