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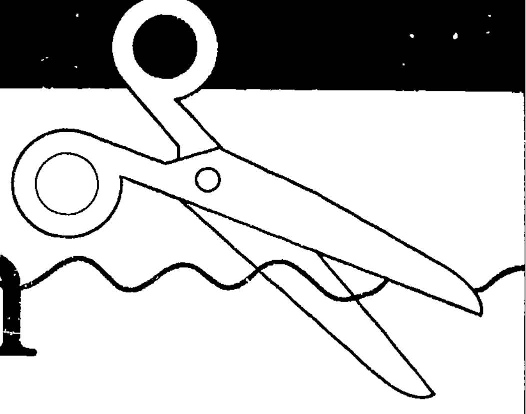
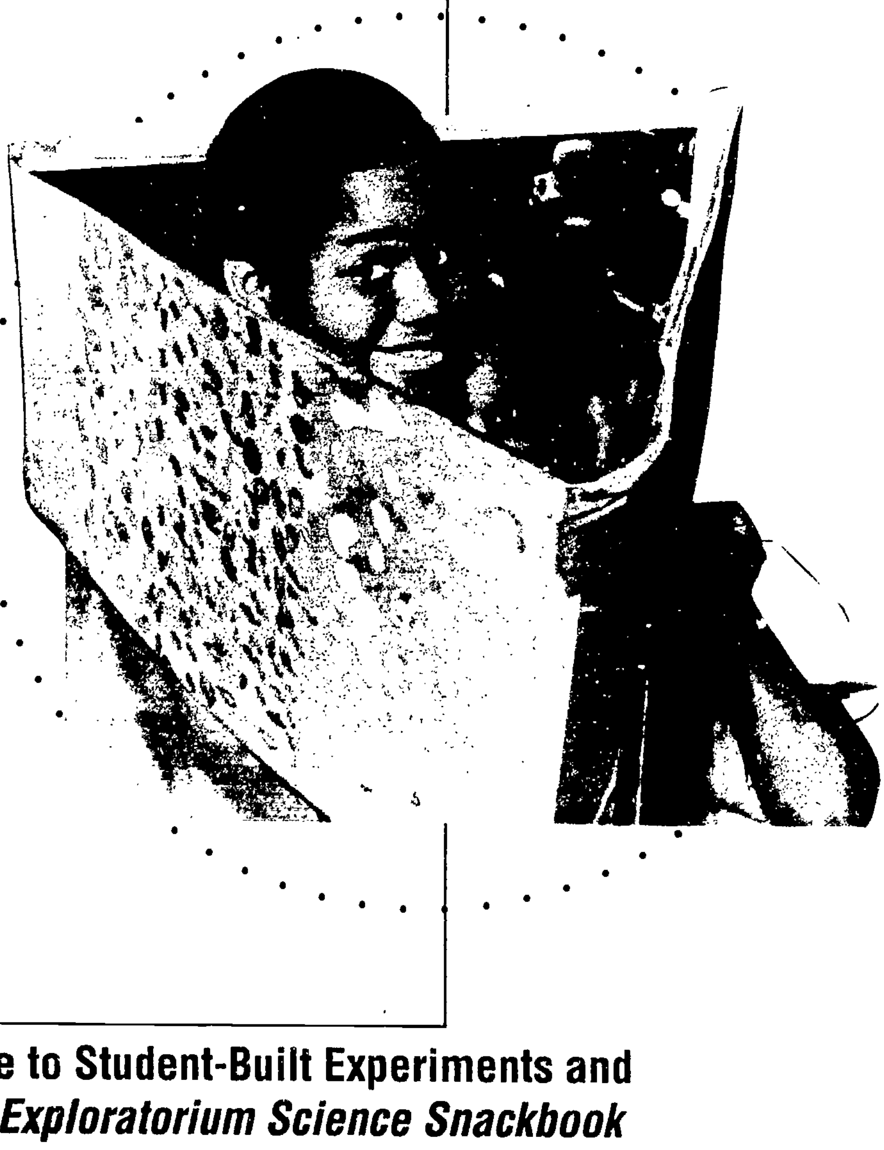
ABSTRACT

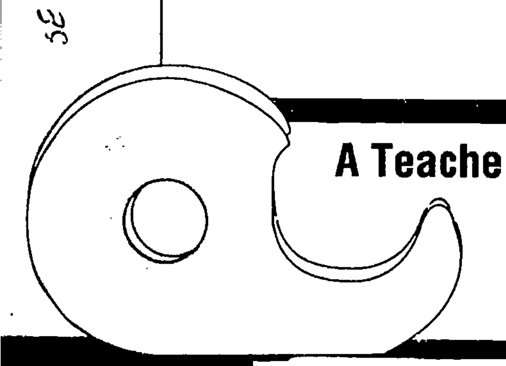
This booklet was written to help teachers climb out of their textbooks and join their students in discovering science for themselves. It features articles by elementary, middle, and high school teachers who have adapted hands-on science for their classrooms, and now teach science using interactive materials from "The Exploratorium Science Snackbook." Articles include: (1) "Getting Hands-On Science Into the Classroom"; (2) Building a Mini-Exploratorium"; (3) "Hands-On Science, In Class and Out"; and (4) "Making Your Own Science Exhibits." Eight science activities are presented. (PR)

The Exploratorium



Hands-On Science





A Teacher's Guide to Student-Built Experiments and *The Exploratorium Science Snackbook*

HANDS-ON SCIENCE
A Teacher's Guide to Student-Built Experiments and *The Exploratorium Science Snackbook*

Surrounded by infinite images of themselves, three students peek out from a triangle of mirrors. "Duck Into Kaleidoscope" is just one of more than 100 do-it-yourself exhibits in The Exploratorium Science Snackbook.

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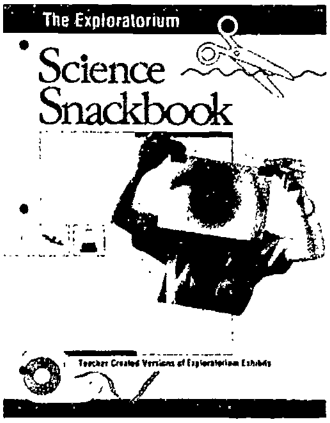
⚠

BE CAREFUL! Follow instructions closely! The experiments in this book and in *The Exploratorium Science Snackbook* were designed with safety and success in mind. But even the simplest activity or the most common materials can be harmful when mishandled or misused. Use common sense whenever you're exploring or experimenting.

Introduction



In 1987, two dozen middle and high school science teachers met at the Exploratorium in San Francisco to begin the three-year process of writing *The Exploratorium Science Snackbook*. The *Snackbook*, written by teachers, for teachers, shows how to build exciting, hands-on science exhibits for the classroom.

While *Snackbook* may seem an odd name for a publication about hands-on science, it's more apt than you might think. For many years, the Exploratorium has published a series of *Cookbooks* that contain exhibit "recipes"—instructions used by other museums to build duplicates of Exploratorium exhibits. The *Snackbook* contains exhibit recipes, too—but not for the complex, full-sized exhibits designed for other museums. *Snackbook* "Snacks" are inexpensive, classroom-sized versions of the same science exhibits we have here at the Exploratorium.

This booklet, "Hands-On Science," was written to help teachers climb out of their textbooks and join their students in discovering science for themselves. It features articles by elementary, middle, and high school teachers who have adapted hands-on science for their classrooms, and now teach science using interactive materials from *The Exploratorium Science Snackbook*. ┘

See back cover for ordering information.

Hands-On Science

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Getting Hands-On Science Into the Classroom

The Exploratorium
Science Snackbook:
*what it is and how
you can use it.*

by Paul Doherty

Paul Doherty, Co-Director of the Snackbook *project, is the Acting Director of the Exploratorium's Center for Teaching and Learning. He has been working with high school and middle school teachers at the Exploratorium for six years. Before coming to the Exploratorium, Paul was a physics professor at Oakland University in Michigan, where he learned the importance of using hands-on science in high school classrooms from the Detroit Metropolitan Area Physics Teachers. He is now gathering teachers to start work on* Son of Snackbook.

Who we are and what we do

THE EXPLORATORIUM is a hands-on museum of science, art, and human perception in San Francisco. It's been called a scientific funhouse, a giant experimental laboratory, even a mad scientist's penny arcade.

Each year, more than half a million visitors come to the Exploratorium; 60,000 of them are students on field trips. Once inside, visitors of every age have the opportunity to use interactive exhibits to discover for themselves the wonder and joy of science. We often see our visitors become science teachers: they discover things for themselves, then show their discoveries to someone else. Kids turn to their parents and say, "Look at this!" More than 600 hands-on exhibits allow visitors to discover that science is fun.

How the *Snackbook* began

Ever since its opening in 1969, teachers from around the San Francisco Bay Area have brought their classes to the Exploratorium to get their kids excited about science. From the very beginning, these teachers asked us to help them learn the science behind the exhibits. In response, the Exploratorium created two teacher-training programs: the School in the Exploratorium, for elementary school teachers, and the Teacher Institute, for middle and high school teachers. These programs teach science to teachers using hands-on discovery—the same method we encourage them to use in teaching science to their students.

The teachers in both programs often asked, "How can I bring these exhibits home to my classroom?" That was a challenge the Exploratorium couldn't ignore. We already had three *Cookbooks*, which were written to help other museums create duplicates of Exploratorium exhibits. But *Cookbook* instructions were complex and demanding, and relied on materials and skills well beyond those available to the average teacher. The Teacher Institute helped a group of teachers to write the book they wanted—a book telling how to build simple, inexpensive, classroom-sized versions of Exploratorium exhibits.

For three years, nearly one hundred teachers and Exploratorium staff members created and tested recipes for classroom science exhibits. With assistance from the Exploratorium's own science, writing, and graphics staff, these recipes were turned into the *Exploratorium Science Snackbook*—or the *Snackbook*, for short. The *Snackbook* contains 107 recipes for "Snack-sized" versions of Exploratorium exhibits.

Each Snack was developed by one or more teachers trying to create a classroom-sized version of a full-sized Exploratorium exhibit. Often, a teacher's first attempt to duplicate an Exploratorium exhibit would fail, but everyone on the *Snackbook* team worked together to solve problems, come up with new ideas, and find creative ways to bring these experiments into the classroom.

Time after time, the teachers experienced the joy of discovering new ways to do science. Sometimes their innovations even improved on the original museum exhibit. The rubber-glove-in-the-bottle version of the "Fog Chamber" Snack, for instance (see page 7), allows students to feel the pressure changes that create the fog in the jar. The full-sized Exploratorium version does not.

The excitement of the *Snackbook* brainstorming sessions was contagious. Teachers told us that they felt a rejuvenated interest in teaching science.

What's in a Snack?

The design of the *Snackbook* reflects the needs and requests of the teachers who created it. The Snacks are divided into easy-to-follow sections that include instructions, advice, and helpful hints. Each Snack begins with drawings and photographs of both the original, full-sized exhibit, and the teacher-created, classroom-sized version. A short paragraph introduces the science behind the exhibit. There's a list of the materials needed, and suggestions on how to find them. Other sections give complete assembly instructions and contain descriptions of how to use the completed experiments.

Since the teachers insisted that correct scientific explanations accompany the hands-on activities, each Snack explains the science behind the phenomenon being demonstrated. A section called "Etc." contains interesting bits of additional historical and scientific information.

Soap Film Painting *is an excellent example of an Exploratorium exhibit. Visitors pull a long rod up out of a tray of soap solution to create a wall of soap film. They can poke the soap film and break it, blow into it to make it bulge, or wiggle it to make standing waves. With patient observation, the visitor can watch the wall of pastel colors change with time as the soap film thins to the thickness of a wavelength of light and less. As children and adults explore the exhibit, they are exposed to a tremendous range of scientific concepts—from the nature of surface tension to the interference of light.*

How to use the *Snackbook*

After its publication in August of 1991, the *Snackbook* rapidly found its way far beyond the San Francisco Bay Area. Within a week, for example, the Exploratorium had received a request from the Outback of Australia asking us to help teachers there find a supplier of plastic mirrors for their *Snackbook* experiments.

We also discovered that a wider range of teachers were using the *Snackbook* than we had originally expected. Though the *Snackbook* was written primarily for high school teachers, we began to hear of successful applications in elementary schools, middle schools, colleges and universities. We also heard from local science teachers who had special education classes or were working with students learning English as a second language. While these students had great trouble learning science from their textbooks, many excelled at building Snacks and investigating science.

We found that the *Snackbook* was particularly useful in school districts where science department funding was tiny. With its emphasis on inexpensive or scrounged parts, the *Snackbook* gave teachers in less-well-funded districts a way to do hands-on science activities on a tight budget. Teachers who had never been to the Exploratorium asked us how to weave the hands-on activities described in the *Snackbook* into their classrooms. The need for a guide like this one became obvious.

There are many ways to incorporate interactive science activities into your classroom. In the articles that follow, we will show you how several of our local teachers use the *Snackbook* to help their students create science exhibits of their own. Eight Snacks are also provided for you. We hope that this booklet will give you a few new ideas. ┘

With middle-school students as exhibit builders, you can create a science museum in your classroom.

by Modesto Tamez as told to Mary K. Miller

Building a Mini-Exploratorium™

ONE OF THE TRUE JOYS OF TEACHING is when you see the "lights go on" in a student's eyes: the lights of curiosity, wonder, and understanding. I get excited when I hook students; when they start asking and then answering their own questions, discovering for themselves that science can be fun *and* understandable. This is what I see when the tools for teaching are hands-on experiments that students choose and build themselves. With a little organization and effort, these individual projects can form the basis of a science museum in a classroom, a resource that can be shared with the entire school. There are probably as many ways to use the *Snackbook* as there are teachers to use it, but this is the method that works best for me.

Creating a mini science museum is easier and cheaper than you may think. I recently organized two science classes to build fifty-five exhibits. The exhibits took us a little over a month to complete and cost about three hundred dollars. The rewards in student pride and knowledge and the attention the mini-Exploratorium™ garnered for the school's science program were well worth the time, effort, and expense. You can do it too, with help from your students and the recipes in *The Exploratorium Science Snackbook*.

I start by selecting and building ten or twelve Snacks to demonstrate to my class. All the Snacks in the *Snackbook* are deliberately low tech, but some are more advanced than others. I choose easy-to-handle projects and practice building and demonstrating them before showing them to my class. When I show them to my students, I stress how easy and quick they were to assemble. To reinforce this, sometimes I actually have my students time me putting a Snack together.

Modesto Tamez, a Teacher in Residence at the Exploratorium, has been teaching science and bilingual classes for eighteen years. His first job was teaching at an inner-city elementary school in Chicago. When dwindling enrollment threatened to close the school, Modesto helped develop a hands-on science curriculum to convert the school into a science magnet and draw in more students. Modesto says the idea for creating a mini-Exploratorium™ came to him in a dream. Now he's working in nine schools in the San Francisco Bay Area, including four inner-city schools, helping teachers develop their own classroom science museums.

On the first one or two Snacks, I go slowly through the demonstration. I spend some time helping the students figure out the science behind what they're seeing. Rather than telling them the answer right away, I try to wiggle it out of them. I'm deliberately stingy with answers: I tell my students they have to work for the answers. They soon find out that it's fun to discover the answers for themselves.

I recently used a modified version of the "Fog Chamber" Snack (see page 7) to introduce a class to the concept of air pressure. I stretched a rubber glove over the opening of a glass jar so that the fingers of the glove dangled inside the jar. I called for a volunteer and chose Steve, one of the larger boys in the class, to help demonstrate. I asked Steve to put his hand inside the glove. Steve tried, but much to the amusement of the rest of the class, he couldn't force his hand in. After they stopped giggling, I asked the students to guess why Steve couldn't get his hand into the glove—what was already in the jar that might keep Steve's hand from going all the way in? They answered: "air."

Then I asked a smaller student, Amy, to put her hand in the glove-in-a-jar. Her hand fit in easily, which got another big laugh from the class. What was the difference between Steve's hand and Amy's hand? "Her hand is smaller and doesn't take up as much room," they answered. From that I could tease out the details: the air inside the sealed jar exerts a force on the student's hand; because Steve's hand was larger and took up more room inside the jar, the force exerted on his hand from air pressure was also larger.

This is a very simple experiment, but with it I introduced a fundamental scientific principle to a class that had no previous instruction in any of the physical sciences. By experimenting, observing, and asking questions, the students experienced and learned for themselves that air has pressure.

Sometimes I take a completely different approach to a Snack, as I did recently when I demonstrated "Doppler Effect" (see page 10) to four separate science classes. The students assembled on a grassy knoll outside the classroom while I ran to get my car. For the next few minutes I zoomed past them—back and forth—blaring my horn as they cheered and waved. The students said they could clearly hear the Doppler effect: the pitch of the horn got higher when the car moved toward them and lower when it moved away. The experiment worked beautifully for the first three classes. On the fourth and final class, as I was cruising down the street with my hand jammed full on the horn, I saw the flashing red lights of a police car in my rear-view mirror. The students, of course were delighted.

Peering into my car, the puzzled officer inquired, "What are you doing?" As if it were an everyday activity (which, for me, it is), I replied, "I'm teaching my class about the Doppler effect." This gave the officer pause (perhaps he was wondering what kind of ticket should be issued for someone conducting noisy, open-air science experiments). A school security guard, familiar with my antics, finally came to my rescue. "It's okay," he explained, "he's just a crazy science teacher."

After one or two demonstrations, I give my students some time to play with the completed Snacks. Don't worry if you can't answer all the questions the students ask or if some of the Snacks don't work the way they should. If something goes wrong, tell the class that trial and error is part of the scientific process. Tinker with the Snack and have the students help you try to figure out what's wrong. Pitching in and working together to solve a problem is a crucial part of constructing hands-on science projects.

These two students have built a working periscope. All it took was some tape, PVC pipe and elbows, two plastic mirrors, and a little ingenuity and imagination.

Once the students have been introduced to Snacks, it's time for each of them to choose one of their own to build. I usually select seventy or eighty Snacks from the *Snackbook* that I think are appropriate for my class level. I pass them out to the class and have each student pick three to five Snacks, ranking them from their favorite to their least favorite. I tell my students I'll try to give them their favorite, but if other students choose the same Snack I may have to give some of them an alternate choice. Sometimes I opt for one of the harder Snacks rather than give a student his or her first choice, because I want to challenge those students that I know are capable of handling more difficult assignments.

After the students know which Snacks they're building, I give them a week to gather the materials. The students are left to their own resources: some materials will be in the classroom; others they'll have to find for themselves. If they can't find something on their list, I encourage them to substitute. I tell them it's okay if their Snack isn't exactly the same as the one in the book.

It usually takes three to four weeks for the students to assemble and put the finishing touches on their Snacks. This gives them plenty of time to tinker and perfect. If they run into problems or want to try a different approach, I talk it over with them. I encourage them to experiment and work together with other students or their parents. I'm always amazed at the creative solutions my students come up with; often, a modified Snack is an improvement over the original.

Even though each Snack has only one builder, the students often work together to find solutions to each others' problems. As ideas are bounced around the class, the students all improve their problem-solving skills. In a recent class, one of my students was working on "Mirrorly a Window" (see page 9). She didn't want to glue wooden dowels to the mirrors because she thought that it would be too messy. Instead, she decided to drill holes through the plastic mirrors. She might have been able to drill the holes herself in a high school shop class, but this school didn't have the facilities. We talked it over and she decided to take the mirrors to a plastics supply store. I asked her how big the hole should be and she found the answer by measuring the dowel. But when she brought the drilled mirrors back to class, she discovered that the hole was too big and the dowel just slipped through without sticking. Another student suggested that she could wrap some duct tape around the dowel to make it fatter. This ended up being a great solution. The tape around the dowel looked exactly right because the edges of the mirror were also wrapped in duct tape.

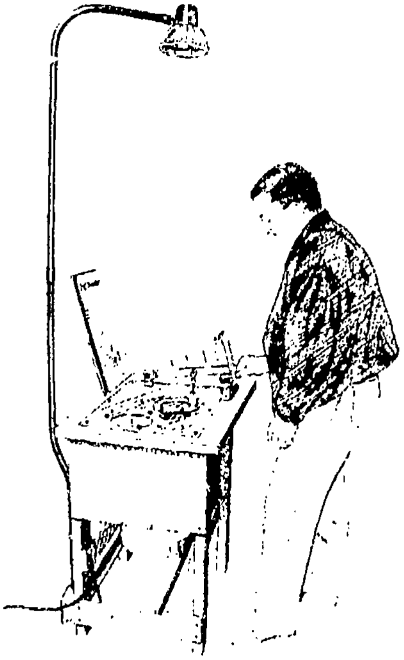
As the students experiment with their Snacks, they are also working out the science behind their projects. The final step of Snack-building is writing and producing "graphics," the instructions and explanations that accompany each project. Rather than copying the text from the *Snackbook*, I ask the students to put the instructions into their own words. If the graphic could benefit from a diagram, which is almost always the case, I have them draw one. It's up to you whether to edit for grammar and spelling, but I always check the explanations to make sure the science is correct. If one of my students has misunderstood a concept, I talk it over and have him or her redo the graphic.

Using cardboard tubes, tape, and a pine board, these kids have built the "Pipes of Pan" Snack from The Exploratorium Science Snackbook. *Because each tube is a different length, each resonates with a different sound.*

If you have computers in your class, you can have the students use them to print out their graphics. If not, a typed or neatly written graphic is fine. It's important only that the sign is easy to read and attractive-looking.

Once all the Snacks are built and the graphics completed, it's time to unveil the mini-Exploratorium™. The Snacks are assembled on long tables in the classroom, four per table. I assign four students at a time to be "Explainers," science guides who answer visitor questions. This means that the students must be familiar with all the Snacks, not just their own. You can invite the whole school to the mini-Exploratorium™. I'd also suggest a special parent's night exhibition. If you invite school administrators to the event they might be so impressed with the students' work that they loosen the purse strings for other innovative science programs. It also doesn't hurt to call up the local press and toot your horn: the positive publicity makes you, the principal, and the school look good.

But the real benefit of a mini-Exploratorium™ is for the exhibit-builders themselves. Putting together hands-on experiments involves much more than learning about science. It also builds skills in reading, planning, writing, artwork, using a computer, problem-solving, presentation, teaching, and interpreting science. Having the students select their own Snacks is important; it empowers and engages the students. Planning, problem-solving, and hands-on activity keeps them interested in concepts they might otherwise find tedious and difficult. Having students share their new-found knowledge with others reinforces and cements the concepts: as any teacher or writer knows, you must first understand a concept before you can explain it to others. The combination of all these activities is a very powerful, engaging, and fun way to build learning skills.



Fog Chamber

Make a portable cloud in a bottle. Now you see it, now you don't!

Materials

- ○ **One-gallon clear glass or plastic jar with a wide mouth** (a pickle jar works well).
- ○ **One rubber glove** (Playtex™ brand works well).
- ○ **Matches.**
- ○ **Water.**

⚠ **Be careful** with glass.

Introduction

Clouds form when invisible water vapor in the air is cooled enough to form tiny droplets of liquid water. In the atmosphere, this usually happens when moist air cools as it rises to higher altitudes. At higher altitudes the pressure is lower, so the gas expands, loses internal energy, and cools. You can accomplish the same cooling by rapidly expanding the air in a jar.

Assembly

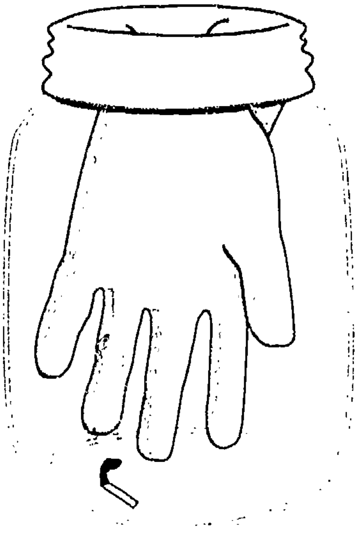
Barely cover the bottom of the jar with water. Hang the rubber glove inside the jar with its fingers pointing down, and stretch the glove's open end over the mouth of the jar to seal it.

To Do and Notice

Insert your hand into the glove and pull it quickly outward without disturbing the jar's seal. Nothing will happen. Next, remove the glove, drop a lit match into the jar, and replace the glove. Pull outward on the glove once more. Fog forms inside the jar when you pull the glove outward, and

Fog Chamber

disappears when the glove snaps back. The fog will form for 5 to 10 minutes before the smoke particles settle and have to be replenished.



What's Going On?

Water molecules are present in the air inside the jar, but they're in the form of an invisible gas, or *vapor*, flying around individually and not sticking to one another. When you pull the glove outward, you allow the air in the jar to expand. But in expanding, the air must do work, which means that it loses some of its thermal energy, which in turn means that its molecules (including those of the water vapor), slow down slightly. This is a roundabout way of saying that the air becomes cooler!

When the water molecules slow down, they can stick to each other more easily, so they begin to bunch up in tiny droplets. The particles of smoke in the jar help this process along: the water molecules bunch together more easily when there's a solid particle to act as a nucleus. When you push the glove back in, you warm the air in the jar slightly, which causes the tiny droplets to evaporate and again become invisible.

In the atmosphere, air expands as it rises to regions of lower pressure, and cools off, forming clouds. This is why clouds often obscure mountain tops. Dust, smoke, and salt particles in the air all provide nuclei that help the droplets condense.

Meteorologists consider a falling barometer reading (low air pressure) to be a sign of an approaching storm, while high pressure is usually a sign of clear weather. The temperature at which water vapor begins to form droplets on a surface is called the *dew point*.

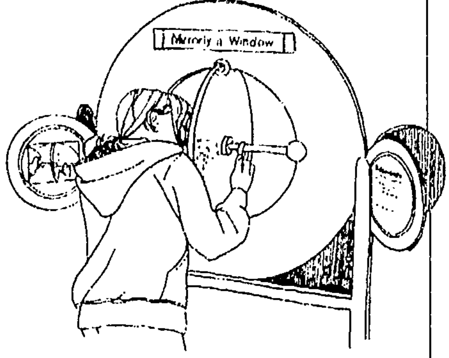
Etc.

For an added treat, shine a slide projector through the cloud you make in the jar. When the smoke is fresh, the droplets will be large compared to all wavelengths of visible light, and the light they scatter will be white. As the smoke dissipates, the water drops will become smaller and the light scattered will create beautiful pastel colors at some viewing angles. Light of different colors diffracts around the small droplets, going off in different directions. If you look at clouds near the sun, you can often see bands of these pastel colors. (Remember you should never look directly at the sun.)

For a longer discussion of this effect, see the book *Clouds in a Glass of Beer*, by C. Bohren.

Mirrorly a Window

What you see is often affected by what you expect to see.



Materials

○ **Two mirrors**, 12" x 12", either glass mirror tiles or plastic mirrors.

○ **Two wooden dowels**, 1" in diameter x 1' long.

○ **Epoxy glue**.

○ **Duct tape**.

⚠ **Be careful** with glass.

Etc.

A simpler version of this experiment uses a single 12"-square mirror with no epoxied handles. Prop the mirror up on a table. Hold one of your arms on each side of the mirror so that you see the reflection of one arm as the continuation of the other arm. Snap the fingers on both hands simultaneously, then stop snapping the fingers on only one hand. Or have someone drop an object (such as a set of keys) into the hand behind the mirror.

Light

Reflection

Introduction

When your brain expects to see one thing, and is presented with something quite different, you can feel some peculiar sensations.

Assembly

Glue the mirrors together, back to back. If you are using glass mirror tiles, tape the sharp edges. Glue a wooden dowel to each mirror. The dowel should be positioned so that it sticks straight out of the middle of the mirror. If you are using plastic mirrors, you can drill a hole through the center of the double-mirror and pass a wooden dowel through the hole.

To Do and Notice

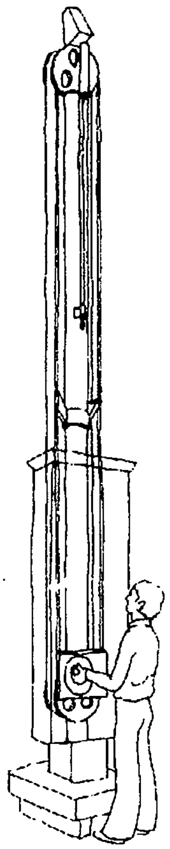
Grab a dowel with each hand. While looking at one side of the mirror, move the hand on the other side of the mirror.

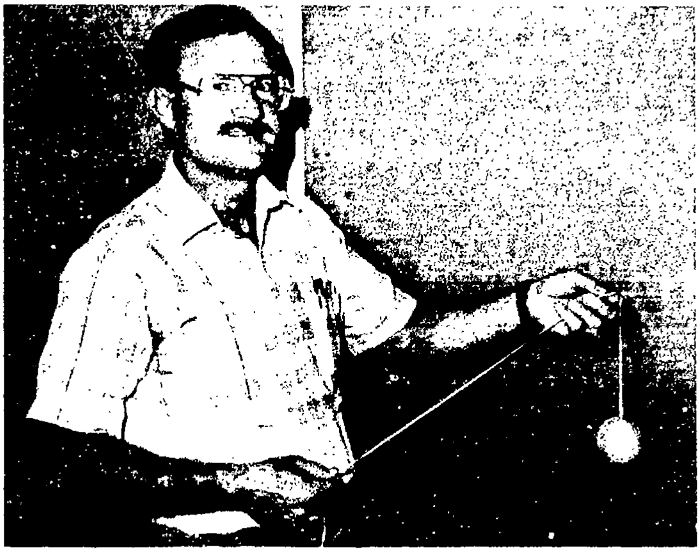
What's Going On?

Your brain is fooled into thinking that the image it sees in the mirror is actually your other hand. When you move that hand, your brain naturally expects to see the hand move. After all, messages from the nerves in that hand tell your brain that the hand is moving. The hand's apparent failure to move is profoundly disturbing to your brain, which doesn't enjoy having its assumptions trifled with!

Doppler Effect

The Doppler effect causes the "neeeeeoouwm" sound of a speeding car passing by.





Materials

○ **Tennis ball** or wiffle ball.
○ **One 9-volt buzzer** (available at Radio Shack; high pitch works best).
○ **One 9-volt battery** and connectors.
○ **Strong string**.
○ **Heavy rubber bands**.
○ **Knife**.
○ **Scrap paper** to pack inside the ball.
○ **Optional:** On off switch (available in Radio Shack or hardware stores).

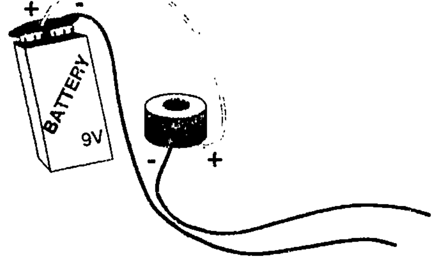
Waves Sound

Introduction

When a sound source moves toward or away from you, its pitch changes. From this effect you can determine whether the source is moving toward or away from you, and you can estimate how fast it's going.

Assembly

Cut a slit halfway around the ball with a sharp knife. Connect a wire between one terminal on the battery and one terminal on the buzzer. If the buzzer has a (+) and (-) terminal, be sure to connect the buzzer terminal to the proper battery terminal. Connect a wire to the remaining terminal on the battery, and another wire to the remaining terminal on the buzzer. Each of these wires will now have one unconnected end. Place both battery and buzzer inside the ball, leaving the two unconnected wire ends protruding from the ball. Pack the ball loosely with paper, leaving the buzzer near the outside. Close the ball with tape or rubber bands, and twist the wires together to turn the buzzer on. You may want to wire a switch into your circuit so you can turn the buzzer on and off more conveniently.



Doppler Effect

To Do and Notice

Attach the ball to a string and twirl it around your head, or have your students toss the ball back and forth. Notice how the pitch of the buzzer changes as the ball approaches you or moves away from you.

What's Going On?

When an oscillator (the buzzer) moves toward you, in effect it is catching up slightly with its own sound waves. With each successive pulse of the buzzer, the sound source is a little closer to you. The result is that the waves are squeezed together, and more of them reach your ear each second than if the buzzer were standing still. Therefore, the pitch of the buzzer sounds higher. As the buzzer moves away from you, fewer waves reach your ear each second, so the resulting pitch sounds lower. The frequency of the buzzer itself does not change in either case.

For your ears to detect this effect, called the *Doppler effect*, the sound source has to be moving toward or away from you at a minimum speed of about 15 to 20 mph. As the source moves faster, the effect becomes more pronounced.

If the buzzer has a frequency of 100 hertz, and it is moving toward you through still air at 35 meters per second, then the pitch you hear will be 110 hertz. This result comes from the equation, pitch = $f(1-v\ v_s)$, where f is the frequency, v is the speed of the source of the sound, and v_s is the speed of sound, 350 meters per second. If the object is moving away from you, simply replace the minus sign with a plus sign.

Etc.

The Doppler effect is also observed with light. In the case of light, it's the color that changes. The color of an object moving away from us becomes slightly redder; if an object is approaching, it appears bluer. This effect allows astronomers to determine whether galaxies are approaching us or moving away, and even how fast they're moving (the bigger the "red shift," the faster they're moving away from us).

Police with radar guns use the Doppler effect to determine whether you're speeding! The bigger the Doppler effect of the radar waves, the faster you're going.

Hands-On Science, In Class and Out

Three high school teachers show how they use Snackbook *experiments as laboratories, demonstrations, and tools for motivation.*

by Paul Doherty

THE HANDS-ON EXPERIMENTS in *The Exploratorium Science Snackbook* are natural teaching tools for the high school classroom. Let me tell you how three California high school teachers use Snacks in quite different ways. Don Rathjen uses them as demonstrations and motivational tools; Vivian Altmann uses them to attract the attention of her at-risk students; and Judith Christensen uses them as the heart of the laboratory activities in her multicultural classroom.

Snacks On the Edge: Placing hands-on science materials around your classroom

Don Rathjen, known to other teachers as Mr. Snack, designs and builds hands-on exhibits, then uses them as demonstrations in his high school physics classroom in Pleasanton, California. Don knows how to grab his students' attention. He breaks a Pyrex® stirring rod in half, drops it into a beaker filled with Karo® syrup, and lets his students watch as the rod disappears in the fluid. Then he puts his hand in and pulls out a whole rod. Of course, the broken rod is still in the beaker—and the unbroken rod was there all the time. They just couldn't be seen.

This simple demonstration, called "Disappearing Glass Rods," is one of Don's favorite Snacks. He leaves the beakers and rods and syrup lying around his classroom for months. The students who play with them get sucked into exploring and discovering science on their own.

Don Rathjen says he has been teaching high school science "since the crust cooled." When you press him, he admits to thirty years of teaching, including experience in both Liberia and Turkey, where he learned the value of hands-on teaching using simple, available materials. Don, who was the Teacher Project Director for the Snackbook, *has been working with other teachers at the Exploratorium since 1984 and was named Outstanding Teacher by the Exploratorium in 1988.*

When you enter Don's classroom, you may come face-to-face with a page-size Fresnel lens hanging from the ceiling (see the "Giant Lens" Snack, page 17). Don tells of students who duck under the lens for months, and then suddenly discover it. Don finds it essential to allow his students the time to discover things on their own.

When Don teaches optics, he uses the "Giant Lens" as a demonstration. By holding the lens at just the right distance in front of his face, his class sees his head replaced by a giant eye. (You can see this amusing effect on page 17.) The students laugh, but they want to try it too. When they come to Don with questions, he guides them in their personal investigations of image-making.

The page-magnifier lenses that Don uses are rugged, plastic Fresnel lenses available for less than two dollars each at discount stores. Two upside-down metal binder clips, resting on their flat bottoms, hold the lenses upright and in place on student's desks.

Don always has his eyes open for interesting science materials. He finds them at plastics stores, toy stores, even flea markets. A Fresnel lens that came from the back window of a delivery van looks just like the one Don has hanging in his class, but produces the opposite visual effect. When Don holds it in front of his face, his head appears to shrink. The students love it.

Even if lenses are not a part of your curriculum, says Don, don't let that stop you from leaving them around for kids to experience. Don's classroom is filled with attention-getting materials: a gyroscope fashioned from a bicycle wheel; a pile of blocks used to demonstrate center of gravity; pendulums that swing in peculiar ways, and many, many more.

pendulums that swing in peculiar ways, and many, many more.

These attention-grabbers—whose construction is detailed in the *Snackbook*—motivate students. Try them yourself. You may be surprised at the discoveries both you and your students make.

Vivian Altmann is a teacher who works with students in non-traditional settings. As head of the Exploratorium Children's Outreach Program, she and her team go out into the neighborhoods to bring the Exploratorium's style of hands-on science to at-risk and underserved kids.

Hands-On Science in Non-Traditional Classrooms

Vivian Altmann and today's Exploratorium Children's Outreach team, Liana Crouch, Marco Jordan, and Lael Kopke, arrive at the Whitney Young Community Center in Hunter's Point, San Francisco, with boxes of hands-on activities. The boxes contain parts for the "Stripped-Down Motor" Snack (see page 20). The teenagers in the room are labeled at-risk and underserved, but once they get going, it's hard to tell them from any other group of energetic kids.

After the usual introductions, Vivian divides the kids into teams. She gives each group a length of insulated wire, a paper cup, twenty cents worth of small magnets, two metal paper clips, a D-cell battery, and a rubber band.

The teams immediately initiate a friendly competition to see who can build the "best" motor. Soon, one team has its motor turning, then another team. The groups compare motors to see whose is fastest. When one group cannot get their motor to run, Viv gets the "experts" from another team to help. The kids decide to swap parts between motors: the problem turns out to be a dead battery! The motor construction is just fine, after all. The kids razz the Exploratorium team for bringing them a dead battery, and then turn back to their motors. The room is buzzing.

Without even noticing it, these kids are learning about electricity, magnetism, and motors. When the kids make guesses about what will make their motors run better, and then test them, they are doing science. Will twice as many magnets make the motor turn twice as fast? Vivian answers by giving the team more magnets. The motor turns faster, but not twice as fast. What about using two batteries? The questions and suggestions came thick and fast, and the kids get the satisfaction of making discoveries on their own. They're learning important techniques for answering questions and solving problems; they're working cooperatively, making new friends, showing off their skills, and succeeding in science.

Judith Christensen, 1989 recipient of the Exploratorium's Outstanding Teacher Award, currently teaches five sophomore physics classes at Galileo High School in San Francisco. She has taught preschool, elementary, middle school, and special-education classes and works with teachers at all levels to promote hands-on science. Her class is noisy, messy, and exciting—a place where kids discover the mysteries of physics for themselves.

Using Snacks as a Science Laboratory

In Judith Christensen's physics class, thirty-six high school sophomores are packed around six laboratory tables. The crowded class contains members from a variety of ethnic backgrounds: Asian, African-American, white, Latino, and more. The class is popular, but the students know they're expected to pitch in and work because, in Ms. Christensen's class, you learn science by doing science.

Judith organizes her class into six multi-ethnic groups. Each group builds its own equipment, does a scientific investigation using that equipment, and then presents oral and written reports based on its explorations. The students also evaluate each other's work. This day, the class is building the "Electroscope" Snack (see page 15). Once the electroscopes have been constructed, the students will use them to investigate electrostatics.

For this laboratory, all of the teams have successfully built electroscopes by draping charged strips of Scotch Brand Magic Tape® over bent soda straws stuck into film cans full of clay. Judith found the tape in administrative supplies; the straws were donated by a local fast-food restaurant; the film cans came from a neighborhood camera store, and the clay came from Judith's own collection of supplies. The resulting electroscopes are not black boxes made by some science supply house; there are no hidden or mysterious parts. The students have built them, and so "own" them. If an electroscope breaks, the students fix it or build a new one.

Each group checks the electroscope it has built. One girl combs her hair and brings the plastic comb toward the strips of tape dangling from the soda straws. One piece of tape is repelled by the comb, but the other is attracted. The electroscope works! The team cheers and brags to the surrounding tables. They call Judith to come see their work. She lets them give her the complete demonstration, then reminds them of the importance of writing down what they see.

To build the exhibits, each team draws on the talents of all its members. Some students are better at figuring out how to build equipment from the illustrations and photos, some are better at reading, others are better at making things work. If you listen carefully, you'll hear discussions in Cantonese, Vietnamese, and Spanish, but English is the *lingua franca* of this classroom. Students who are better at English become language teachers for the others in their laboratory group. Students who are better at science become science teachers, even if they are just learning English. The final result is a team effort.

In addition to science and English, students in this classroom are learning about different cultures. Judith finds that when students from different backgrounds work together, they become more understanding of each other. As a spur to participation, she requires that the groups give each member a group cooperation grade.

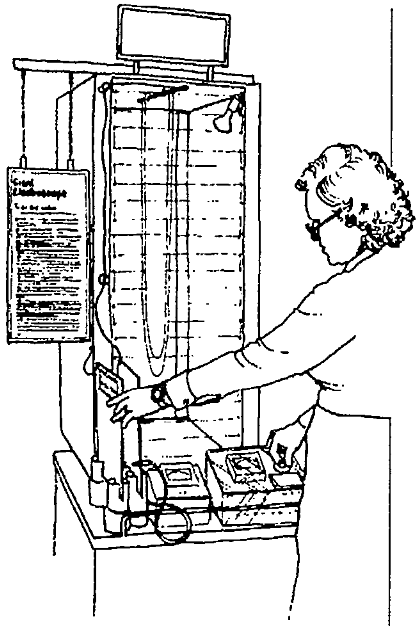
There is a commotion over at one of the tables. Rather than attracting one piece of tape and repelling the other, a comb has attracted both pieces of tape. With Judith's guidance, the students test their comb on another team's electroscope. When it attracts both tapes of that electroscope as well, they guess that the comb is the problem. When they try another comb, they realize that the first comb wasn't charged. Their electroscope works just fine. Not only have they solved the problem themselves, but they've also discovered an important extension to the simple rule that like charges repel and unlike charges attract: charged objects attract uncharged objects. Judith doesn't let the matter stop there. She asks her students to write down what they saw and did. Judith can then guide them as they delve further into the behavior of electrical charges.

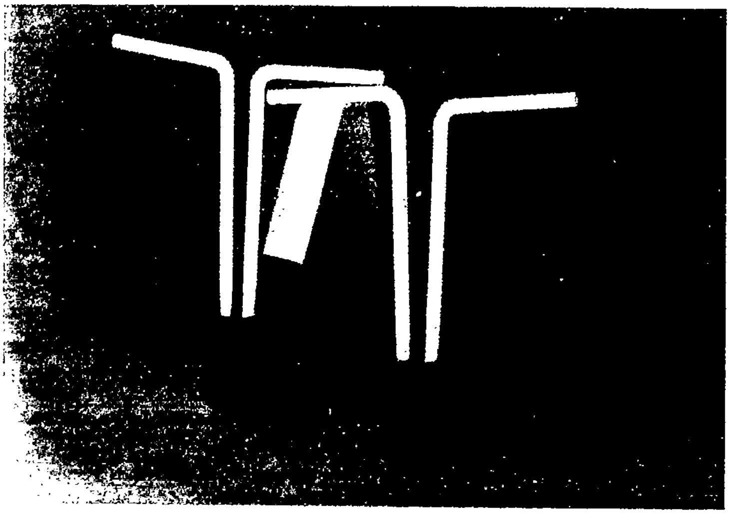
Judith doesn't have all the answers for her student's questions, but she admits when she doesn't know them and encourages her students to help her find the answers. Each year, she and her students learn more about science. And each year, the students guide Judith toward becoming more comfortable and adept at helping them to find their own answers. ❑

Judith Christensen's physics class uses no text books. Her kids learn science by doing science.

Electroscope

What's your (electrical) sign?





Materials

- ○ **Four plastic soda straws** with flexible ends.
- ○ **Two plastic 35mm film cans.**
- ○ **Enough modeling clay** to fill the film cans halfway.
- ○ **One roll of 3-M Scotch Magic™ Tape**, 3/4" width. (Don't substitute other brands of tape the first time you try this Snack. Once you know what to expect, you can experiment with other tapes.)
- ○ **Plastic comb** and hair or a wool sock.

Introduction

A commonly available brand of plastic tape can gain or lose negatively charged electrons when you stick it to a surface and rip it off. By suspending pieces of tape from a straw, you can build an *electroscope*, a device that detects electrical charge. A plastic comb will enable you to identify whether the pieces of tape are positively or negatively charged.

Assembly

Press enough modeling clay into both film cans to fill them halfway to the top. Press the inflexible ends of two soda straws into the clay in each can, and bend the flexible ends to form horizontal arms that extend in opposite directions. The heights of the straws should be the same.

To Do and Notice

Tear off two 4" pieces of tape. Press each piece firmly to a table top or other flat surface, leaving one end of each tape sticking up as a handle. QUICKLY pull the tapes from the table and stick one piece on an arm of a straw in one film can, and the other piece on an arm of a straw in the other film can. Move the cans so that the two tapes are face to face, about 6" apart. Then move the cans closer together. Notice that the two tapes repel each other.

Tear off two more pieces of tape and press the sticky side of one against the smooth side of the other, leaving one end of each tape sticking out as a handle. QUICKLY pull the tapes apart and stick them to the two remaining arms. Bring the arms close together. Notice that these two tapes attract each other.

Run the comb through your hair, or rub the comb with the wool. Then hold the comb near the dangling tapes. Notice that the comb repels the piece of tape whose smooth side was in the middle of the "sandwich" and attracts the tape whose sticky side was in the middle. When you hold the comb near the tapes pulled from the flat surface, the comb will repel both tapes if they were pulled from a Formica™ surface; the comb may attract tapes pulled from other surfaces.

Electricity

Electroscope

Try pulling other kinds of tape from various surfaces, or rubbing various objects together, and then bringing the tape or objects near the tapes on the arms. Bring your hand near the tapes and notice what happens.

What's Going On?

When you rip the two pieces of tape off the table, there is a tug-of-war for electric charges between each tape and the table. The tape either steals negative charges (electrons) from the table or leaves some of its own negative charges behind, depending on what the table is made of (a positive charge doesn't move in this situation). In any case, both pieces of tape end up with the same kind of charge, either positive or negative. Since like charges repel, the pieces of tape repel each other.

When the tape sandwich is pulled apart, one piece rips negative charges from the other. One piece of tape therefore has extra negative charges. The other piece, which has lost some negative charges, now has an overall positive charge. Since opposite charges attract, the two tapes attract each other.

When you run a plastic comb through your hair, the comb becomes negatively charged. Tapes repelled by the comb have a net negative charge, and tapes attracted by the comb either have a net positive charge or are uncharged.

You may have found that your hand attracts both positively and negatively charged tapes. Your body is usually uncharged, unless you have acquired a charge—by walking across a carpet, for example. An uncharged object attracts charged objects. When you hold your hand near a positively charged tape, the tape attracts electrons in your body. The part of your body nearest the tape becomes negatively charged, while positive charge remains behind on the rest of your body. The positive tape is attracted to the nearby negative charges more strongly than it's repelled by the more distant positive charges, and the tape moves toward your hand.

Etc.

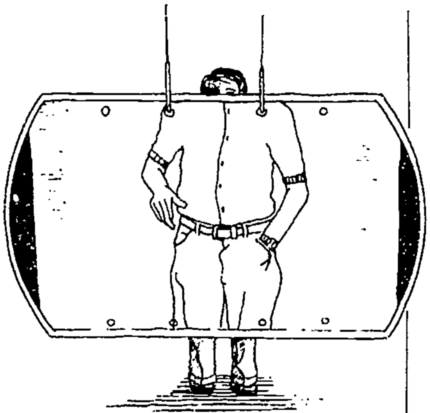
Since some table surfaces will not charge the tape, be sure to test your surfaces before trying this demonstration with a class.

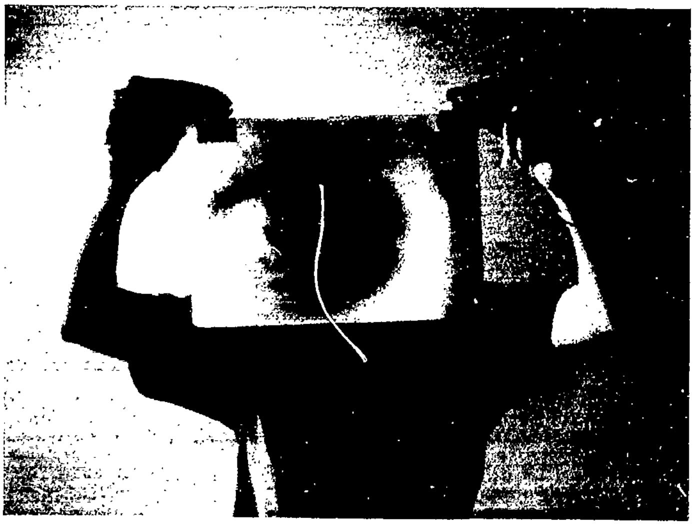
Charge slowly leaks off the tape into the air or along the surface of the tape, so you may have to recharge your tapes after a few minutes of use.

You can use your electroscope to test whether an object is electrically charged. First use the comb to determine the charge on a piece of tape, and then see whether an object whose charge is unknown repels the tape. If the tape is negatively charged and an object repels it, then the object is negatively charged. Don't use attraction to judge whether an object is charged: a charged object may attract an uncharged one. If a tape is attracted to an object, the tape and the object may have opposite charges, or the tape may be charged and the object uncharged, or the object may be charged and the tape uncharged. But if the tape is repelled by the object, the tape and the object must have the same charge. The only way that a tape and an object will neither repel nor attract is if BOTH are uncharged.

Giant Lens

A lens creates an image that hangs in mid-air.





Materials

- ○ **A large plastic page magnifier Fresnel lens** (6"x 9" or larger). Be sure you don't get a wide-angle viewer lens. If you look through the lens at a hand held an inch or so beyond the lens, the hand should appear larger, not smaller.
- ○ **Spring clips** from a stationery store. (See drawing.)
- ○ **String**.
- ○ **Corrugated cardboard** or foamcore sheet, 9" x 9".
- ○ **Two soda straws**.
- ○ **Common pins**.

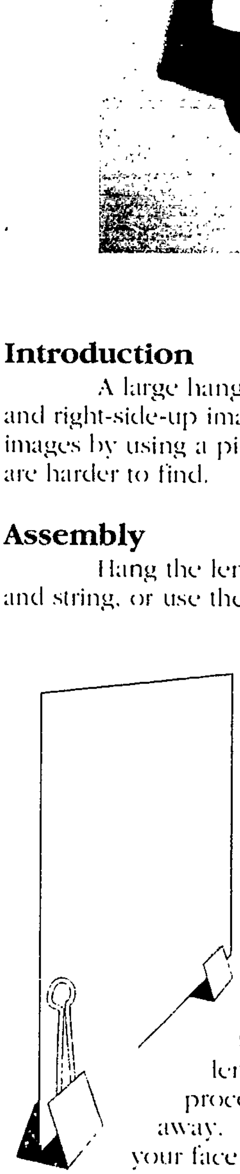
⚠ **Be Careful** with focused sunlight.

Introduction

A large hanging lens creates upside-down images of distant objects and right-side-up images of nearby objects. You can locate the upside-down images by using a piece of white paper as a screen. The right-side-up images are harder to find.

Assembly

Hang the lens from the ceiling at about head height using the clips and string, or use the clips to support the lens on a table top, as shown in the drawing.



To Do and Notice

Stand a few feet back from the lens and look through it at objects on the other side. Distant objects will appear upside-down; nearby objects will appear right-side-up.

Stand close to the lens. Hold your hand close to the lens on the other side and notice that your hand is magnified and right-side-up.

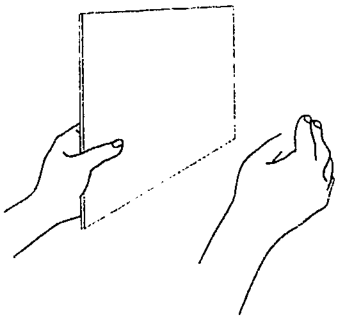
While you stand an arm's length from one side of the lens, have a friend stand an arm's length from the other. Look at your friend's face through the lens. Have your friend bring his or her face closer to the lens as you back away, keeping the same two-arms' length distance between the two of you. Then reverse this procedure: you step closer to the lens while he or she moves away. Notice how his or her face appears; ask your friend how your face appears.

Find an object that's brightly illuminated (such as a light bulb or a computer screen) and dim the lights in the rest of the room. Hold the lens at least several feet from the object. Hold a large piece of white

Refraction Light

Giant Lens

paper against the side of the lens that faces away from the object. Slowly move the paper away from the lens until an image of the object comes into focus on the paper.



What's Going On?

Light from a point on an object spreads out in all directions. When the spreading light hits the page-magnifier lens, it is bent toward the axis of the lens. (This page magnifier is called a positive, or *converging*, lens because it bends light rays together.)

Page magnifiers have a *focal length* of about 10" (25 cm). A focal length is the distance from the lens to an image the lens makes of a distant object. If an object is farther than one focal length (10") from the lens, the lens can bend all the light that arrives from one point on the object until it comes back to a point on the other side of the lens. This point is a point on the image of the object. If you put white paper at the place where the light rays meet at a point, an image will appear on the paper. An image that can be focused on a piece of paper is called a *real image*. (See Figure 1.)

However, you don't need the white paper to see the image. Simply put your eye about 1' farther away from the lens than the location of the image, and look at the lens. You'll see the image hanging in space. Move your head slightly from side to side and watch the image move. (Actually,

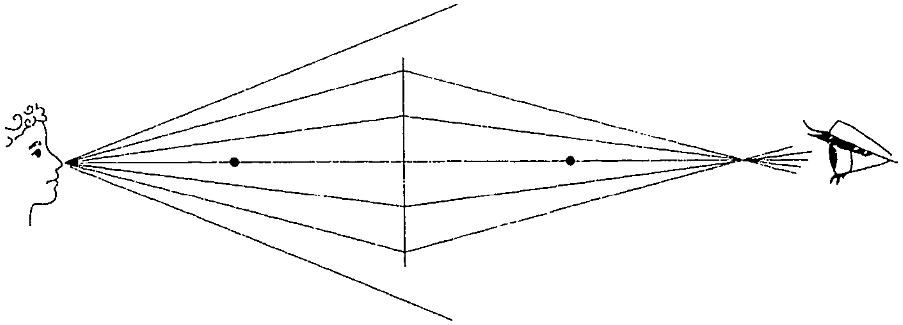


Figure 1 Your eye-brain follows the light back to the point from which it spreads. This type of image is called a *real image*.

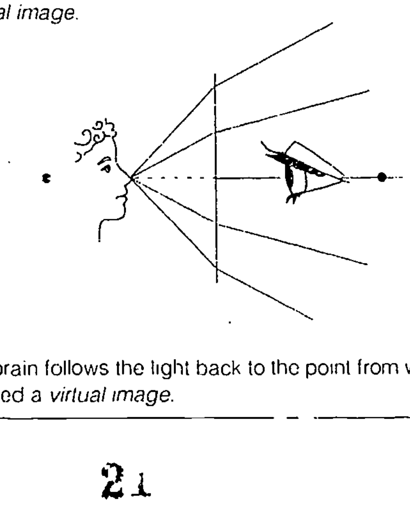
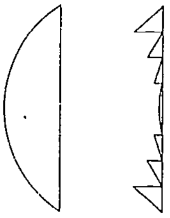


Figure 2 Your eye-brain follows the light back to the point from which it appears to spread This type of image is called a *virtual image*.

Giant Lens
Etc.

You can find the focal length of your particular lens using a bright light source that is more than 30' away. (CAUTION: Don't use the sun! The image you make can be so hot that it can burn the paper, and so bright that it can damage your eyes.) Hold a piece of paper against the lens on the side opposite the light. Move the paper away from the lens until a sharp image of the light appears on the paper. The distance from the lens to the image is the *focal length*.

This type of lens is called a *Fresnel lens*, after August Fresnel, who figured out how to make these lenses for the French lighthouse commission in the late 1800s. Lighthouses needed large lenses to gather the light from a lamp and make it into a beam. If such a lens were ground out of glass, it would be thick, heavy, and expensive. Fresnel realized that the bending of light at the lens occurred at its curved surface, and that the thick glass played little role in image formation. He figured out a way to maintain the curvature of the surface, but get rid of the useless glass. He made his lighthouse lenses out of prisms.



The plastic lenses we have used are made out of wedges of plastic. The wedges must be thicker at the edge in order to bend light more, and thinner in the center. Run your finger over the ridges of the Fresnel lens and notice from the sound that the ridges are higher near the edge and lower and smoother near the center.

your eye-brain system may refuse to interpret the image as hanging in the air. It is so unusual to see something hanging in the air that your brain may insist that the image is on the surface of the lens or even behind the lens—however, the image is actually hanging in space.)

If an object is closer to the lens than the focal point, the lens cannot bend the light spreading from the object enough to return it to a point. To your eye-brain system, it looks like there is an image on the same side of the lens as the object. This type of image is called a *virtual image*. It cannot be focused on a piece of paper. (See Figure 2.)

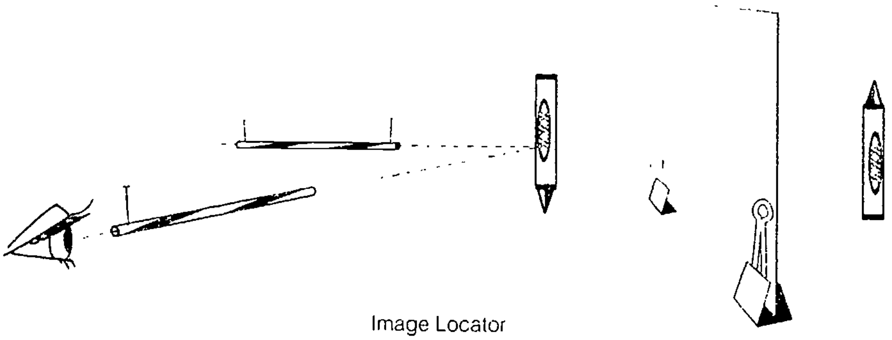


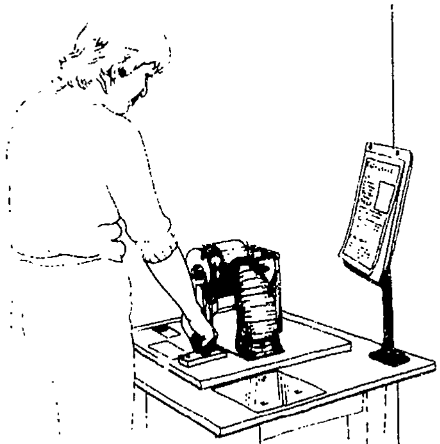
Image Locator

You can find the location of a real or virtual image by building an image locator. Push a pin through one end of each soda straw. Use the pins to attach the soda straws to adjacent corners of the 9" x 9" corrugated cardboard sheet. Push another pin through the other end of one straw to mount it along one edge of the cardboard. The other straw will be free to rotate about its end.

Mount the image locator firmly in place so that you can look through the straw fixed to one edge and see one point on the image (see diagram). Then rotate the other straw until you can look through it and see the same point on the image. (You'll have to move your head to look through the second straw.) The image is located where two imaginary lines, one drawn through each straw, cross. If the image is a real image, you can place a piece of paper there and see it on the paper.

Stripped-Down Motor

As motors go, this is about as simple as it gets.



Materials

○ **Five small disk or rectangular ceramic magnets** (available at Radio Shack).

○ **Two large paper clips**.

○ **Plastic, paper, or styrofoam cup**.

○ **Solid (not stranded) enameled or insulated 20-gauge copper wire**, about 2' long.

○ **Masking tape**.

○ **Battery or power supply**. We have successfully run motors on one 1.5-volt D cell; additional batteries seem to make it easier to get the motor to run. You may want to try 6-volt lantern batteries. We have also had excellent results using a power supply (battery eliminator) set to about 4 volts. The advantage of the power supply is that it will supply a substantial current over a period of time. Unlike batteries, it doesn't have to be replaced. Experiment with what you have, and use whatever works!

○ **Two alligator clip leads** (available at Radio Shack).

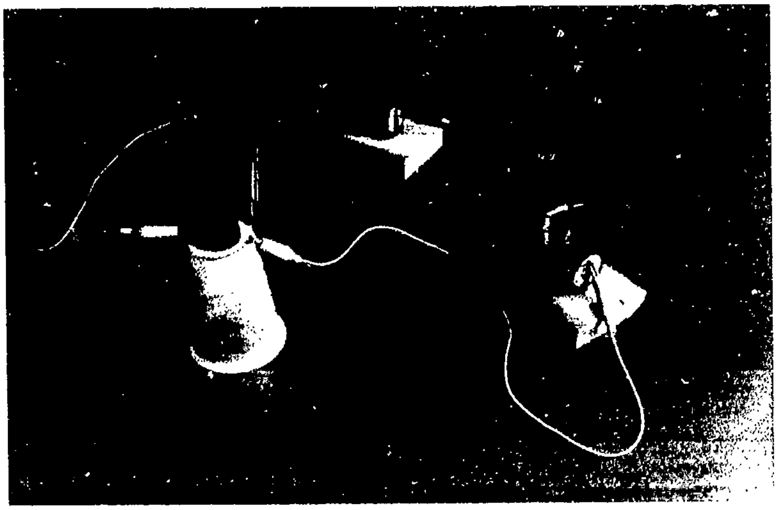
○ **Wire strippers** (if you are using insulated wire).

○ **Sandpaper** (if you are using enameled wire).

○ **Black, waterproof, felt-tipped marker**.

○ **Battery holder**. (See Assembly for instructions.)

Magnetism Electricity



Introduction

A coil of wire becomes an electromagnet when current passes through it. The electromagnet interacts with a permanent magnet, causing the coil to spin. Voila! You have created an electric motor.

Assembly

Wind the copper wire into a coil about 1" in diameter. Make four or five loops. Wrap the ends of the wire around the coil a couple of times on opposite sides to hold the coil together. Leave 2" projecting from each side of the coil, and cut off any extra. (See diagram.)

If you are using insulated wire, strip the insulation off the ends of the wire projecting from the coil. If you are using enameled wire, use the sandpaper to remove the enamel. Color *one* side of *one* of the projecting ends black with the felt-tipped pen. (NOTE: It is very important that the orientation of the painted side corresponds to the orientation shown in the drawing below. If the coil is held in a vertical plane, paint the *top* half of *one* of the wires black.)

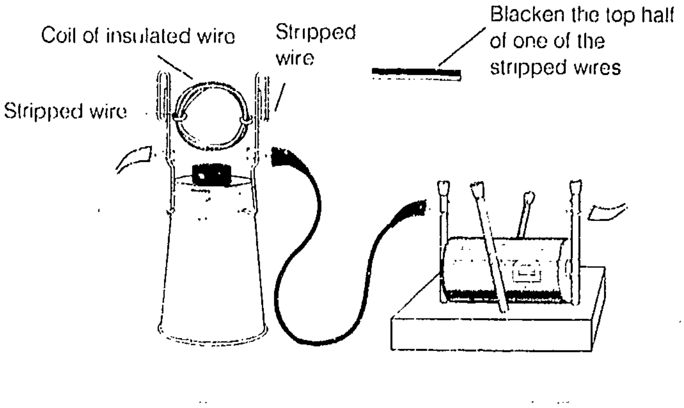
Turn the cup upside-down and place two magnets on top in the center. Attach three more magnets inside the cup, directly beneath the original two magnets. This will create a stronger magnetic field as well as hold the top magnets in place.

Unfold one end of each paper clip and tape them to opposite sides of the cup, with their unfolded ends down. (See diagram.) Rest the ends of the coil in the cradles formed by the paper clips. Adjust the height of the paper clips so that when the coil spins, it clears the magnets by about 1/16". Adjust the coil and the clips until the coil stays balanced and centered while spinning freely on the clips. Good balance is important in getting the motor to operate well.

Once you have determined how long the projecting ends of the coil must be to rest in the paper-clip cradles, you may trim off any excess wire. (The length of the projecting ends depends on the separation of the paper-clip cradles, which in turn depends on the width of the base of the cup you are using. See diagram.)

Stripped Down Motor

If you are using a battery, place it in a battery holder. You can make your own from a block of wood and four nails, as shown in the diagram. Use the alligator clip leads to connect the battery or power supply to the paper clips, connecting one terminal of the battery to one paper clip and the other terminal to the other paper clip.



Give the coil a spin to start it turning. If it doesn't keep spinning on its own, check to make sure that the coil assembly is well balanced when spinning, that the enamel has been thoroughly scraped off if enameled wire has been used, that the projecting end has been painted with the black pen as noted, and that the coil and the magnet are close to each other but do not hit each other. You might also try adjusting the distance separating the cradles: this may affect the quality of the contact between the coil and the cradles.

Keep making adjustments until the motor works. Have patience! The success rate with this design has been exceptionally good.

What's Going On?

Current flows through the wire coil and creates an *electromagnet*. One face of the coil becomes a north pole, the other a south pole. The permanent magnet attracts its opposite pole on the coil and repels its like pole, causing the coil to spin.

Another way to describe the operation of the motor is to say that the permanent magnets exert forces on the electrical currents flowing through the loop of wire. When the loop of wire is in a vertical plane, the forces on the top and bottom wires of the loop will be in opposite directions. These oppositely directed forces produce a twisting force, or *torque*, on the loop of wire that will make it turn. (See *Motor Effect* Snack.)

Why is it so important to paint half of one projecting wire black? Suppose that the permanent magnets are mounted with their north poles facing upward. The north pole of the permanent magnet will repel the north pole of the loop-electromagnet and attract the south pole. But once the south pole of the loop-electromagnet was next to the north pole of the permanent magnet, it would stay there. Any push on the loop would merely set it rocking about this equilibrium position.

By painting half of one end black, you prevent current from flowing for half of each spin. The magnetic field of the loop-electromagnet is turned off for that half-spin. As the south pole of the loop-electromagnet comes closest to the permanent magnet, the paint turns off the electric current. The inertia of the rotating coil carries it through half of a turn, past the insulating paint. When the electric current starts to flow again, the twisting force is in the same direction as it was before. The coil continues to rotate in the same direction.

Etc.

In this motor, the sliding electrical contact between the ends of the coil of wire and the paper clips turns off the current for half of each cycle. Such sliding contacts are known as *commutators*. Most direct-current electric motors use more complicated commutators that reverse the direction of current flow through the loop every half cycle. The more complicated motors are twice as powerful as the motor described here.

This motor can also be used to demonstrate how a generator works. Try hooking up the ends of the paper clips to a sensitive galvanometer instead of the battery. Spin the coil and see if any current registers on the meter.

Elementary school students create their own exhibits.

by Erainya Neirro

Making Your Own Science Exhibits

Erainya Neirro teaches math and science in a combined fifth/sixth-grade class at the Presidio Hill school in San Francisco. Even before The Exploratorium Science Snackbook *was available, Erainya sought new ways to teach science, and found a model here at the Exploratorium that she adapted for her students. Hands-on science facilities are popping up all over the country. If there's one in your area, you can do what Erainya has been doing for six years: encourage learning by building science "mini-exhibits" for the classroom. If there's no hands-on science museum nearby, or if it's not feasible for your students to visit one, the* Snackbook *can provide that missing link. That's what it's for.*

I HAVE ALWAYS USED A HANDS-ON, do-it-yourself approach to science. Over the years, I've noticed that science becomes "real" for those students who can put something together and watch what it does. Six years ago, while looking for ways to expand my own repertoire of science activities for kids, I enrolled in a class offered by the Exploratorium Teacher Institute. The class, called "Exploring the Exploratorium," was directed by Don Rathjen and Thurston Williams, two energetic, personable high school teachers.

I had such a great time! For six weeks, twelve teachers became inquisitive, involved students. We roamed the museum and played with its more than 600 exhibits. Our goal was to choose an exhibit and build a model that would somehow demonstrate the same scientific principle that the sophisticated Exploratorium exhibit illustrated.

During the class, I built four of my own original mini-exhibits and watched my colleagues construct and improve their own. I was more excited about hands-on science than ever. But most importantly, I really enjoyed and relied on the support of the other teachers as we all struggled together to perfect exhibits that sometimes worked, and sometimes didn't. I came away with innumerable projects for my classroom, and the realization that this kind of approach didn't have to be just for the teachers. My kids could do the same thing-- learning about science, working with the support of their peers, doing things on their own, and having fun, too. I wanted my students to have this experience.

Since Presidio Hill School is close to the museum, most of my students were familiar with the Exploratorium. When I suggested the idea of a future "Exploring Science" project based on my own experiences at the Exploratorium, the response was overwhelmingly enthusiastic—especially from the kids.

In the summer of 1988, I wrote to my students and told them about the project. For the first semester of the school year, I said, they would go to the Exploratorium three times, and choose a new exhibit on each visit. Their goal would be to design original models of each of these three exhibits. With twenty students in my classes, I looked forward to having sixty different mini-exhibits at the end of the semester—a hands-on science museum of our own.

When school began, we talked about the project before going to the Exploratorium. I brought in the four exhibit models I had built and let my students play with them. I told them that the Exploratorium exhibits I had replicated looked very different from my models, but both my models and the museum exhibits "said" the same thing about physics. Like me, they wouldn't copy the construction of the exhibit. Each student had to find some way to build a model that would show the same scientific principle that an Exploratorium exhibit demonstrated.

Finally, we were ready for our first visit to the Exploratorium. Once inside the museum, the kids were given an hour to play with exhibits and pick the first one they wanted to replicate. This exploration time was essential. Kids would become captivated by an exhibit, grab a friend to try it out, and spend time talking and planning and experimenting together. Each student in the class was expected to build a different exhibit. As the students made their decisions, they came right back to me: they knew that it was first come, first served.

Over the course of their three visits to the museum, my students chose to build exhibits that demonstrated many different scientific principles, but several favorites came from sections of the Exploratorium that demonstrated perspective, vision, color, and light. Two favorites were "Bird in the Cage" and "Blue Sky."

If you look at the "Bird in the Cage" Snack (see page 27), you can see the exhibit's potential flexibility: a variety of colors and shapes can be used to demonstrate the concept of afterimages. The "Blue Sky" exhibit (see page 25) is appealing because it's easy for the kids to figure out what they will need: essentially, water and some kind of light source. Besides this relatively simple assembly, "Blue Sky" answers a question that fascinates them: "Why is the sky blue?"

Once an individual choice had been made, the student and I went to look at the exhibit and make preliminary plans. I asked them to tell me how they would design this exhibit for the classroom. It was important to assess whether their plans were feasible. Often, the student's plan was very workable; occasionally, I had to make suggestions to help simplify the process. I also had to direct one or two students to different, less complicated exhibits. (In a museum of more than 600 exhibits, this was relatively easy.)

I left the students alone with their exhibits so they could sketch preliminary designs and write notes from the information at each exhibit. I asked them to think about how other people would use their model, and to consider the science that their model would illustrate. Before we left the museum, I checked each student's design and notes at least once. Many had to return to an exhibit to clarify some point in the design or to get more scientific information. My class and I were in the Exploratorium approximately four hours during each of these three field trips.

Two students discover the unexpected sound-focusing properties of a balloon filled with carbon dioxide. The details of this Snack—called "Conversation Piece"—can be found in The Exploratorium Science Snackbook.

Back at school, several class sessions were devoted to building each student's science project. We all brought in a variety of materials. Like most long-term science teachers, I have lots of stuff—often more than I can store. For this project, I found I needed large cardboard boxes, construction paper, posterboard, batteries of various voltages, copper wire of various widths, tape, glue, flashlights, markers, and scissors.

Since storage space is practically nonexistent at Presidio Hill, I asked each child to get a sturdy shopping bag with handles, so they could easily carry their "in process" exhibit from school to home and back. Of course, this presented its own problems. Some of my students ended up misplacing their half-built exhibits; some left their projects on the bus. Other projects and materials just sort of "disappeared." None of the materials were expensive or irreplaceable, but it was no fun for those unfortunate students to start over again.

In the classroom, students selected the materials they needed and helped each other with the construction of their exhibits. During this process, which took several class periods, students made comments to each other to help improve designs or make an exhibit easier to assemble or allow the exhibit to be a better demonstration of a scientific principle. I was amazed at how little they needed my help. I helped with the scientific explanations, and found information for them in the encyclopedia, but when they were building their exhibits, they used each other as resources.

These sessions were chaotic, but wonderful. We had materials all over the room and at least three conversations going at once. We might start with a question like, "What color should I make this part of my spinning disk?" and end up with a complex examination of how cones in the human eye actually work.

Not everything went perfectly, of course. It would be dishonest of me not to mention the time I found one student carving his name in his pencil instead of cutting out the cardboard squares he needed for his model. But all in all, these sessions were very productive. The kids were committed to building with care. If something didn't work the first time, they pitched in to help each other. First they had to find the problem, and then figure out a solution. A student often built his or her project two or three times before the final product was satisfactory. The finishing details were done at home.

Besides the time spent building the models, homework included a rough draft of a paper explaining each exhibit. After I edited this paper and made suggestions on how to improve the scientific explanations, each student revised his or her paper and wrote a final draft.

As for the math part of the class curriculum, it taught itself. The kids were so busy calculating, counting, and measuring, they hardly even noticed how much they were learning. Though I suggested they use inches and feet when they built their projects, for instance, many discovered that it was easier to work with the metric system, and learned how to convert from one to the other.

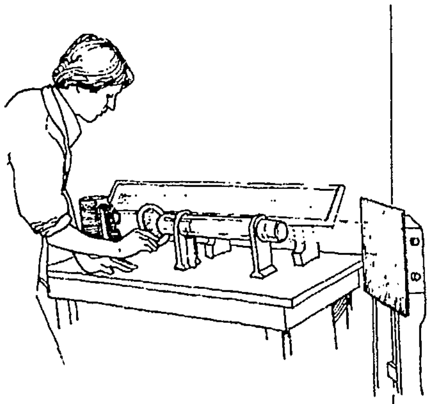
Finally, we had Evaluation Day. The students presented their projects and let their peers play with the finished exhibits. This display generated the kind of peer support I was hoping for. The majority of my kids were so invested in their work that each one came away with something they were proud of and that they thoroughly comprehended.

Their classmates were genuinely impressed. They had all seen the prototypes in their various stages, and now they got to play with a finished model that actually worked and showed them something intriguing. I didn't have to use an inadequate textbook or workbook: I had a kid-directed course that was highly productive, encouraged peer support, and built the self-esteem of every student.

In one semester, my students were required to create three models based on Exploratorium exhibits, give oral presentations to demonstrate their exhibits, and write scientific and exhibit explanations. We explored many different topics, and we all learned new and exciting things. The kids worked together, solving problems on their own and making unexpected discoveries as they went along.

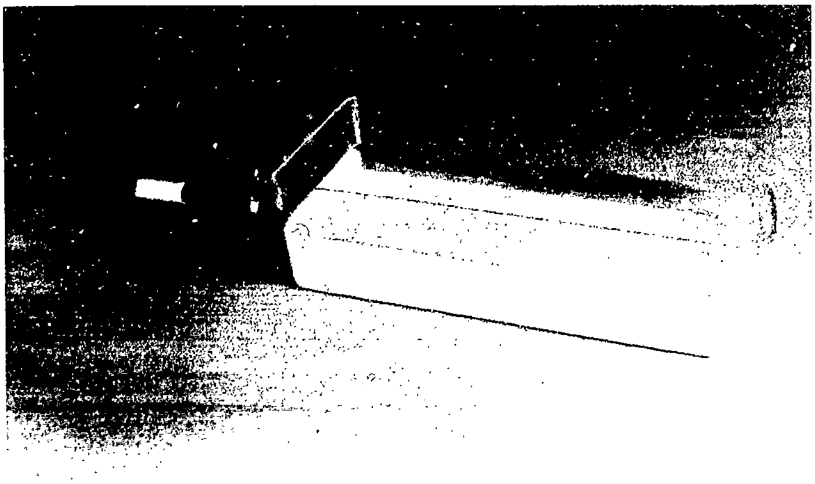
I encourage any teacher to give these hands-on science experiments a try. Once you have a set of these demonstrations in your classroom—whether you do it by working with a local museum, or by building the Snacks in the *Snackbook*—you'll have a student-built science museum of your own.

Any vertical mirror can become an "Anti-Gravity Mirror." You can find information about this Snack in The Exploratorium Science Snackbook.



Blue Sky

Now you can explain why the sky is blue and why the sunset is red.



Materials

- ○ **Transparent plastic box**, or a large beaker, jar, or aquarium.
- ○ **Flashlight or projector** (either a slide or filmstrip projector).
- ○ **Powdered milk**.
- ○ **Polarizing filter** (such as the lens from an old pair of polarized sunglasses).
- ○ **Blank white card** for image screen.
- ○ **Hole punch**.
- ○ **Optional**: Unexposed (black) 35 mm slide or photographic film, or an index card cut to slide size.

⚠ **Be careful** with glass.

Introduction

When sunlight travels through the atmosphere, blue light scatters more than the other colors, leaving a dominant yellow-orange hue to the transmitted light. The scattered light makes the sky blue; the transmitted light makes the sunset reddish-orange.

Assembly

Fill the container with water. Place the light source so that the beam traverses the container. Add powdered milk a pinch at a time and mix it until you can clearly see the beam shining through the liquid.

To Do and Notice

Look at the beam from the side of the tank and then from the end of the tank. You can also let the light project onto a white card, which you hold at the end of the tank. From the side, the beam looks bluish-white; from the end, it looks yellow-orange.

If you have added enough milk to the water, you will be able to see the color of the beam change from blue-white to yellow-orange along the length of the beam.

If you want to look at a narrower beam of light, use a paper punch to punch a hole in the unexposed, black slide or in a piece of 35 mm film, or even in an index card cut to size. Place the slide, film, or index card in the projector. (Do not hold it in front of the lens.) Focus the projector to obtain a sharp beam.

Color Polarization Light

Blue Sky

Etc.

Scattering can polarize light. Place a polarizing filter between the projector and the tank. Turn the filter while one person views the transmitted beam from the top and another views it from the side. Notice that when the top person sees a bright beam, the side person will see a dim beam, and vice-versa.

You can also hold the polarizing filter between your eye and the tank and rotate the filter to make the beam look bright or dim. The filter polarizes the light and so does the scattering. When the two polarizations are aligned, the beam will be bright; when they are at right angles, the beam will be dim.

Scattering polarizes light because light is a transverse wave. The direction of the transverse oscillation of the electric field is called the *direction of polarization of light.*

The beam of light from the slide projector contains photons of light that are polarized in all directions: horizontally, vertically and all angles in between. Consider only the vertically polarized light passing through the tank. This light can scatter to the side and remain vertically polarized, but it cannot scatter upwards! To retain the characteristic of a transverse wave after scattering, only the vertically polarized light can be scattered sideways, and only the horizontally polarized light can be scattered upward. This is shown in the drawing below.

What's Going On?

The sun produces white light, which is made up of light of all colors: red, orange, yellow, green, blue, indigo, violet. Light is a wave, and each of these colors corresponds to a different frequency, and therefore wavelength, of light. The colors in the rainbow spectrum are arranged according to their frequency: violet, indigo, and blue light have a higher frequency than red, orange, and yellow light.

When the white light from the sun shines through the earth's atmosphere, it collides with gas molecules. These molecules scatter the light.

The shorter the wavelength of light, the more it is scattered by the atmosphere. Because it has a shorter wavelength, blue light is scattered ten times more than red light.

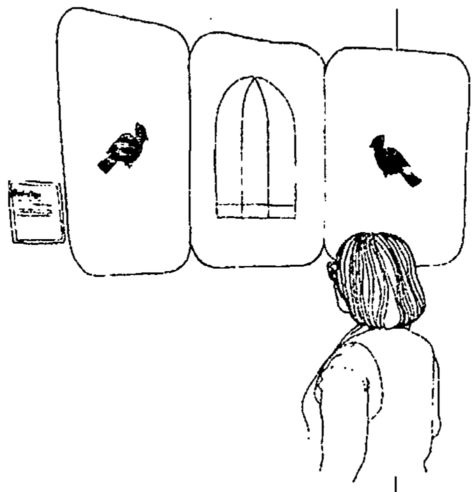
Blue light also has a frequency that is closer to the resonant frequency of atoms than red light. That is, if the electrons bound to air molecules are pushed, they will oscillate with a natural frequency that is even higher than the frequency of blue light. Blue light pushes on the electrons with a frequency which is closer to their natural resonant frequency than red light. This causes the blue light to be re-radiated out in all directions, in a process called *scattering*. The red light that is not scattered continues on in its original direction. But when you look up in the sky, the scattered blue light is the light that you see.

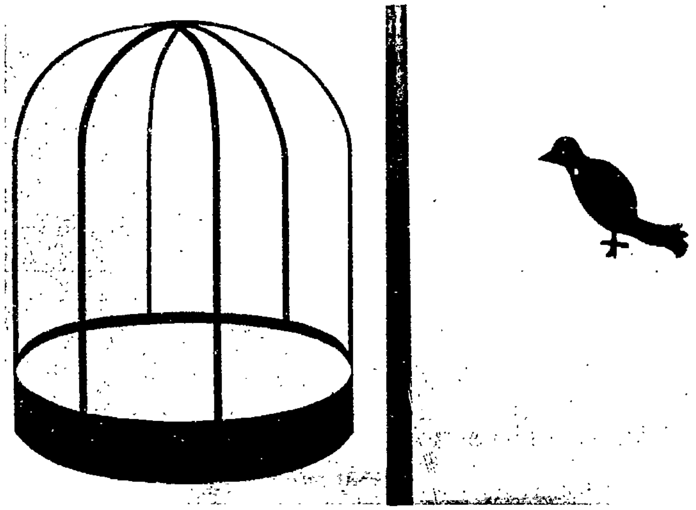
Why does the setting sun look reddish-orange? When the sun is on the horizon, its light takes a longer path through the atmosphere to your eyes than when the sun is directly overhead. By the time the light of the setting sun reaches your eyes, most of the blue light has been scattered out. The light you finally see is reddish-orange, the color of white light minus blue.

Violet light has an even shorter wavelength than blue light: it scatters even more than blue light does. So why isn't the sky violet? Because there's just not enough of it. The sun puts out much more blue light than violet light, so most of the scattered light in the sky is blue.

Bird In the Cage

Stare at a color and see it change.





Materials

- ○ **Four white posterboards** or pieces of paper.
- ○ **Bright red, green, and blue construction or contact paper**.
- ○ **Small piece of black construction or contact paper**, or black marker pen.
- ○ **Scissors**.
- ○ **Glue or glue stick** (if you are using construction paper).

Introduction

You see color when receptor cells (called cones) on your eye's retina are stimulated by light. There are three types of cones, each sensitive to a particular color range. If one or more of the three types of cones becomes fatigued to the point where it responds less strongly than it normally would, the color you perceive from a given object will change.

Assembly

Cut the same simple shape, such as a bird or a fish, from each of the three colored papers. Glue each shape on its own white board. Leave one white board blank. Cut a small black eye for each bird or fish or draw one in with your pen. If you choose a bird as the shape, draw the outline of a birdcage on the blank board; if you choose a fish, draw a fishbowl, etc. (Be creative!)

To Do and Notice

Place the boards in a well-lit area. (Bright lighting is a significant factor in making this effect work well.)

Stare at the eye of the red bird for 15 to 20 seconds and then quickly stare at the birdcage. You should see a bluish-green (cyan) bird in the cage. Now repeat the process, staring at the green bird. You should see a reddish-blue (magenta) bird in the cage. Finally, stare at the blue bird. You should see a yellow bird in the cage. (If you used a fish, try the same procedure with the fish and the bowl.)

Color | Light | Perception

Bird In the Cage

Etc.

You can design other objects with different colored paper and predict the results. Try a blue banana! For smaller versions, you can use brightly colored stickers (from stationery, card or gift stores) on index cards.

One classic variation of this experiment uses an afterimage to make the American flag. Draw a flag, but substitute alternating green and black stripes for the familiar red and white stripes, and black stars on a yellow field for the white stars on a blue field. For simplicity, you can idealize the flag with a few thick stripes and a few large stars. When you stare at the flag and then stare at a blank white background, the flag's afterimage will appear in the correct colors.

You may also want to experiment with changing the distance between your eye and the completely white board while you are observing the afterimage. Notice that the perceived size of the image changes, even though the size of the fatigued region on your retina remains the same. The perceived size of an image depends on both the size of the image on your retina and the perceived distance to the object.

What's Going On?

The ghostly fishes and birds that you see here are called *afterimages*. An afterimage is an image that stays with you even after you have stopped looking at the object.

The back of your eye is lined with light-sensitive cells called *rods* and *cones*. Cones are sensitive to colored light, and each of the three types of cones is sensitive to a particular range of color.

When you stare at the red bird, the image falls on one region of your retina. The red-sensitive cells in that region start to grow tired and stop responding strongly to red light. The white board reflects red, blue and green light to your eyes (since white light is made up of all these colors). When you suddenly shift your gaze to the blank white board, the fatigued red-sensitive cells don't respond to the reflected red light, but the blue-sensitive and green-sensitive cones respond strongly to the reflected blue and green light. As a result, where the red-sensitive cells don't respond you see a bluish-green bird. This bluish-green color is called *cyan*.

When you stare at the green bird, your green-sensitive cones become fatigued. Then, when you look at the white board, your eyes respond only to the reflected red and blue light, and you see a red-blue, or *magenta*, bird. Similarly, when you stare at a blue object, the blue-sensitive cones become fatigued, and the reflected red and green light combine to form yellow.

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