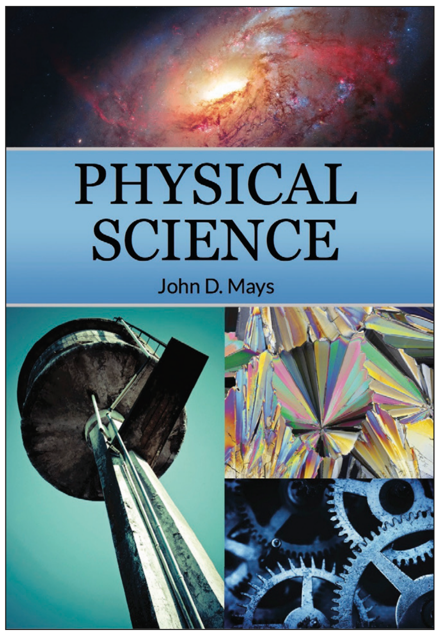
Physical Science

Experiment Resource Manual



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Introduction

The purpose of this manual is to provide the information necessary to conduct each of the experiments included in *Physical Science*, by John D. Mays, published by Centripetal Press. For additional information about this text and the publisher, please visit the website at centripetalpress.com.

Experimental Complexity and Learning Objectives: Please Read

Some of the experiments included in *Physical Science* are relatively simple; others involve a rather complex setup with a lengthy list of materials. Thus, it is not surprising when some of those using the text wonder why some experiments are so complicated. Can't we simplify everything to make the experiments easier to perform and more accessible? We have all heard of simple "kitchen chemistry" science activities. Can't we have a set of simple "garage physics" experiments that don't require so many special parts? At Centripetal Press, we have seen this topic raised in some home school discussion forums where *Physical Science* is discussed. This issue is very important, so we want to take a moment to address it here.

At issue is the distinction between demonstrations and true experiments. Simple demonstrations are easy to come by. But in the physical sciences (physics and chemistry), most experiments need to be quantitative to be effective. This means that students must gather numerical data and analyze it to see what it says. This is because the laws of physics and chemistry, which are our models of nature, are mathematical. At the elementary-school level, students explore physics and chemistry with simple demonstrations. But beginning in middle school, the goal is increasingly to enable students to experience what real experiments are like. And such experiments involve collecting data, analyzing it, and often tabulating and graphing it so that mathematical patterns in the data become apparent. This is the factor behind the complexity of some of the experiments included here. Some experiments, such as experiment 3 on electrostatic forces, are very simple and entail minimal cost. But experiment 3 does not include taking data and is actually more of demonstration than an experiment. The experiments involving data collection are quite a bit more complex.

To illustrate further, we can demonstrate the effect of friction by rubbing two wooden blocks together and feeling the heat as they warm up. But an experiment that sought to quantify the amount of energy involved would be quite complicated. We would have to take into account the amount of force used when the blocks were pressed together, the length and timing of the stokes, and the temperature rise. We would find that measuring any of these variables would be challenging; measuring all of them in a way accessible to middle-school students would be very challenging. (And we do not include such an experiment in P*hysical Science*.)

It is important for teachers and home-school instructors to understand this issue, and to appreciate the fact that proper science instruction needs to incorporate quantitative experimentation as soon as students' mathematical backgrounds are ready for it, which means beginning in middle school. Simple demonstrations are great and should be part of students' daily classroom experience. Such demonstrations are an essential part of instruction that seeks to help students comprehend scientific physical principles. But understanding general principles is far from the quantitative nature of contemporary physics and chemistry, and introducing students to this means taking data. This necessarily involves complexity because experiments must be designed such that measurements of the values of all relevant variables may be accurately made.

We kept two goals in mind while developing the experimental investigations included in *Physical Science*. First, we sought to give students a thoroughly quantitative laboratory experience. But in order to make the overall laboratory workload manageable, we did make use of non-quantitative demonstrations as well as quantitative experiments. Experiments 3, 4, and 9 involve only observation and do not entail taking measurements. Second, we use the experiments as part of an overall strategy of getting students' mathematical brains engaged. The mathematical problems in the text do not begin until the spring semester, in Chapter 8. But the very first experiment—which appears after Chapter 2—involves collecting and graphing data. This is quite intentional—even though we are well aware that students in 7th grade may have had little experience with graphing. To make this pedagogical approach accessible to the students and tractable for the instructors, we included the "Getting Started with Experiments" section in the text. That article includes a fairly detailed tutorial on constructing a scientific graph. Additional information for the instructors who will be helping students construct their graphs is included in this resource manual. The goal for all of us is not simply "covering material." *We seek to draw students upward into the adult world of science.*

In view of the importance of a quantitative laboratory experience, we encourage instructors and home school tutors to include as many of the experiments as possible in the course, preferably all of them. Without question, this takes a lot of planning and preparation. We encourage you to engage in the preparation with patience and joy. Think of the laboratory *practicum* as providing the same sort of hands-on engagement as that students receive on the playing field or in an orchestra. Both involve many hours of preparation, training, and practice. Laboratory work in science is like this. Avoiding it because it takes too much time would be like a baseball team in which players are taught the rules of the game, but have short, superficial practices because more in-depth practices take too much time. But we all know that for a baseball team to accomplish its purpose, the solid practice time is not optional. The same logic applies to science.

Contemporary culture has us all running around like crazy with thousands to things to do every week. But we cannot treat the education of our children like a factory floor where efficiency and productivity are primary values. One of the great things about teaching science is just this: it takes time and effort to do it well. We are compelled to slow down, plan our work thoroughly, prepare the apparatus carefully, take the data carefully, and spent time analyzing it and reporting on it. (This is how science itself works, not just science education.) We may as well relax and enjoy it. If we do this with patience, the experience of our students is engaging and meaningful. Additionally, the experience of working with them to conduct the experiments will be most rewarding, as it always is when an instructor or coach journeys with students down a challenging road.

Assembling the Special Parts

If at all possible, students should assemble the apparatus for the experiments themselves. Part of experimental science is skillful assembly of apparatus. This takes time, patience, tools, and experience working with tools. An adult will need to lead and supervise the work, but students should do as much of the work as possible for themselves. Building things is also a lot of fun, and students will enjoy the work.

Five of the experiments entail the use of special jigs or parts (see the table below). Building these special items is not complex or expensive, but does require some time and the use of several power tools. If possible, let students work with a knowledgeable adult to make these items. The adult supervisor can operate the power tools involved, or teach the student(s) how to use the tools in cases where using the tools is age appropriate. Students who have the opportunity to work with a teacher, classroom volunteer or parent to build the experimental apparatus for themselves will have a much more rewarding experience conducting the experiments.

If your school does not have access to shop tools, see if you can find a parent volunteer who will work with your students to make the special items needing fabrication. For home school families, building the parts can be a great opportunity for parents to be involved with the kids. For families who do not have the needed power tools, try to find a friend or neighbor who does and who is willing to work with you.

The *Physical Science* Special Parts Kit is available for anyone who does not have the tools, time or know-how to assemble these items. The kit includes only the special wooden and metal parts that require cutting and assembly. Ordinary parts and supplies that can be sourced elsewhere not included. The Special Parts Kit items includes:

Experiment Where Used	Item
1: Kinetic Energy	Hot Wheels Track Clamp Support Base
1: Kinetic Energy 12: Magnetic Field Strength	Double Support Stands with Adjustable Crosspiece, quantity (2), each consisting of two support stands and an adjustable crosspiece.
5: Determining Volume 6: Determining Density	Five Metal Samples, made of steel, aluminum and brass
8: Inertia and Force	Four-hole Spring Mounting Block

You may purchase any of these items individually, or all together as a kit, from Centripetal Press. Classroom teachers purchasing any of these items should consider occasions in which students will be divided into small groups for work on experiments and purchase quantities accordingly (see the Individuals versus Groups section in this Introduction). For those who wish to make these items on your own, I am including in Appendix 1 the complete specification we use for making the items in the Special Parts Kit.

Supplies and Standard Lab Apparatus Items

Each experimental description includes a complete parts list. Common household items such as masking tape and index cards are listed but not included in the costs.

There are a number of pieces of standard lab apparatus you will need that are listed in the table below. A functioning science lab at a school will ordinarily have these items on hand, so these are not included in the experiment cost lists. (However, except for the refrigerator/freezer they are all listed in the Master Materials List in Appendix 2.) For home school students, I recommend using the real thing if possible (e.g., using beakers instead of glasses or jars), but costs do add up. So if cost is an issue, there are low-cost alternatives listed for most items. The goal in any educational environment is to give the students the best possible introduction to experiments using real scientific apparatus, including items such as beakers and flasks.

Item	Comments
beakers	Pyrex beakers can be used for mixing as well as heating on a burner or hotplate. Various sizes are needed, including 250 mL and 600 mL. For some experiments you will need two or three beakers of a particular size. You can get a set of five Pyrex beakers of various sizes from The Lab Depot (labdepotinc.com) for $29.96. The low-cost alternative to using beakers is to use glass jars for mixing chemicals, and a sauce pan for heating water. Beakers may be cleaned with soap and water and reused. Glass jars used for chemicals should be discarded after use. Do not use glass jars for heating, because the glass can break.
beaker tongs	For handling hot beakers. Science Company (sciencecompany.com) has them for $5.50.

Item	Comments
Bunsen burner	A flame burner is needed for Reaction 3 in the chemical reactions experiment (#9). (A hot plate will not get hot enough.) If you have a built-in natural gas supply in a lab, use a high-BTU Bunsen burner such as the H-5865 available from Humboldt Manufacturing Co. (humboldtmfg.com) for $16.80. Connecting the burner to a laboratory gas supply valve requires a length of 5/16-inch ID (inside diameter) nitrile rubber hose. This is available as item no. RM1 from hosecraftusa.com for 1.76/ft in 5-ft increments. If you do not have natural gas, use a Lenk Butane Lab Burner with built-in butane tank. These are commonly available. Amazon.com lists two of them from different suppliers for under $50. For home school students and others who have access to a kitchen stove, this is the easiest and least expensive alternative. If you have a kitchen stove, by all means use it. Yet another alternative is to use a camp stove if you have one, such as a Coleman stove.
burner tripod	The Lab Depot (labdepotinc.com) has these in the $5–$8 range. As with the Bunsen burner, this is needed for the chemical reactions experiment if you are using a Bunsen burner. If you are using a kitchen stove or camp stove, the burner tripod is unnecessary.
digital thermometer	For this course, digital thermometers are needed instead of glass ones, because in the heat of fusion experiment (#7) they will be frozen. (Glass thermometers might be damaged.) A good option is part no. ACC370DIG from The Lab Depot (labdepotinc.com). These go for $24.30 each. A lower cost option is a digital kitchen thermometer. These can be obtained for $15–20 each at a department store or discount store. You will need at least four thermometers; five is even better.
flasks	Flasks are suggested for only one experiment (#9). Beakers or glass jars may easily be used as a substitute. Glass jars or drinking glasses used for chemicals should be discarded after use. A source for buying sets of flasks for a school is The Lab Depot (labdepotinc.com), item GIFT1. A good source for buying two 250-mL flasks for experiment #9 is The Science Company (sciencecompany.com), item no. NC-7884.
graduated cylinder, 100 mL	There is no substitute for these. You will need two graduated cylinders for each group of students. Available individually as part no. NC-0306 from Science Company (sciencecompany.com) for $14.95 ea, or a six pack for $30.86, part no. 2355-100-P, from The Lab Depot (labdepotinc.com).
hot plate	A hot plate is necessary for the thermal conductivity experiment (#2). The Cimarec Basic Hotplate may be purchased from The Lab Depot (labdepotinc.com) for $179 (often on sale for $152.15).
mass balance, aka bench scale	You need a scale for determining masses. If you have triple-beam balances, and wish to teach the students how to use them, that's fine. But with middle school students it is less expensive and less complicated to use a digital scale that reads directly in grams. You need a scale with at least 0.1 g resolution. For use in later chemistry courses, 0.01 g resolution is better. A very economical choice is the Digital Pocket Scale available at Home Science Tools (homesciencetools.com) for $29.95. For this course, the 200 g/0.01 g model is ideal.
meter stick	These are not expensive. Amazon.com has them for $5.49. A yardstick may be used as a substitute, but will require units conversions on most of the measurements.
refrigerator/freezer	Just about anything will do, as long as you have both refrigerator and freezer compartments. For schools on a tight budget, put the word out that you need a family to donate one to your science department. There is always someone who is replacing their old refrigerator.

Item	Comments
ring stand	Needed for the refraction experiment. Science Company has them for $13.50. The low-cost alternative is to rig up some other way to support and activate the laser pointer for that experiment.

Individuals versus Groups

Some of these experiments work well with students divided into groups of 3–5 students. For others, it makes more sense to do the activity with the whole class together. Clearly, doing an experiment with the class together as one group saves on materials expense. In these cases, the materials listed for each experiment may be purchased and used for the one big group. Students should take turns performing different roles in the experiment so that everyone gets involved. If controlling costs is an essential consideration, you may wish to conduct all the experiments this way.

The advantage of dividing students up into small groups for experiments is that each student gets more intimately involved and plays a more active role. However, if you divide a class of students into smaller groups, you must multiply the quantities of materials on the lists to accommodate the number of groups you have. In some cases, such as experiments 3 and 4, the bulk packaging of materials such as salt and aluminum foil means that the listed item contains enough for several groups.

Here are my recommendations for group arrangements:

Experiment	Suggested Group Arrangement	Comments
1: Kinetic Energy	Whole class or small groups	The apparatus for this experiment is elaborate, so teachers may choose to keep the class together. However, the experiment itself is simple and safe. So if building or buying multiple sets of the apparatus is feasible, go with the groups.
2: Heat Transfer by Conduction	Whole class	The complex setup and the requirement for an expensive hot plate mean this experiment is best suited for doing it together as a class.
3: Electrostatic Forces	Small groups	Materials are simple, safe and very inexpensive—perfect for small groups.
4: Growing Crystals	Whole class or small groups	To do this in groups, the instructor can make the saturated solutions in larger quantities, and then give each student group a beaker of liquid.
5: Determining Volume	Small groups	If you can afford the time or funds to procure multiple sets of the metal parts and multiple calipers, this is easy and much better for the students to do in small groups.
6: Determining Density	Small groups	If you used groups for experiment 5, then you have the multiple sets of parts. (However, make sure your sets are labeled so students use the same set for this experiment that they used for experiment 5.) All you need is multiple digital mass balances. Alternatively, students can stand in line and share a balance, since making a measurement only takes a few seconds.
7: Heat of Fusion	Whole class	The continuous use of heat and the refrigerator/freezer make this activity best suited for the class to do together.
8: Inertia and Force	Small groups	Materials are simple and inexpensive. With multiple groups working, the bouncing ball issue will make this experiment even more of a hoot.

Experiment	Suggested Group Arrangement	Comments
9: Observing Chemical Reactions	Whole class	Individual students can assist at various points, but there are important safety issues with the materials and procedures in this experiment. Accordingly, the idea for this experiment is for an adult to handle the materials while the students observe and make notes about the reactions.
10: Refraction	Small groups	Doing this experiment in small groups is a must.
11: Series and Parallel Circuits	Small groups	This experiment is simple and best done in small groups. Most of the expense is in the batteries and digital multimeters. If the expense is a problem, look around for a parent in the school (an electronics buff, for instance) who may have several DMMs that he or she will loan to the class.
12: Magnetic Field Strength	Whole class	This experiment involves a fairly complex and sensitive setup, and the experiment will probably need to be performed on a wooden table out in the middle of a field. Thus, this one is not particularly suitable for small groups.

Ordering Materials

To minimize shipping costs, you may wish to order all the materials from a particular online vendor in a single order. To make this easier, all the materials lists for the 12 experiments are combined into a single Master Materials List, sorted by supplier, in Appendix 2. All items from the table above are included in the Master Materials List except the refrigerator/freezer.

Description from Text

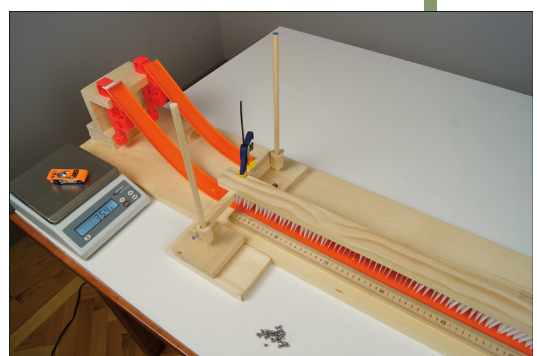
Experimental Investigation 1: Kinetic Energy

Overview

- Using a Hot Wheels car and a ramp of Hot Wheels track, release the car from a standard height repeatedly, adding weights to the car each time to increase its mass. Measure the car's mass before each run.
- *The goal of this experiment is to determine how the kinetic energy of the car varies as its mass changes, assuming the car's speed at the bottom of the ramp stays the same.*
- Use an assembly of friction flaps and a measuring rule to slow the car and measure how far it travels while stopping. Use the stopping distance as a measure of the kinetic energy the car has at the bottom of the ramp.
- Verify that the speed of the car is not affected by mass by releasing two cars with different masses together.
- Collect mass and distance data, and prepare a graph of stopping distance versus mass.

Basic Materials List

- Hot Wheels cars and track
- lead weights (split-shot fishing sinkers)
- mass balance and measuring rule
- friction flap assembly of 3 × 5 index cards, and apparatus for adjusting its height
- apparatus for mounting the track



In the discussion of kinetic energy, you learned that the kinetic energy of a moving object depends on both the object's mass and its speed. In this investigation, we examine how increasing an object's mass increases the energy the object is carrying in its motion. This experiment will be fun because we get to use Hot Wheels cars! Your setup for this investigation is similar to the one shown above.

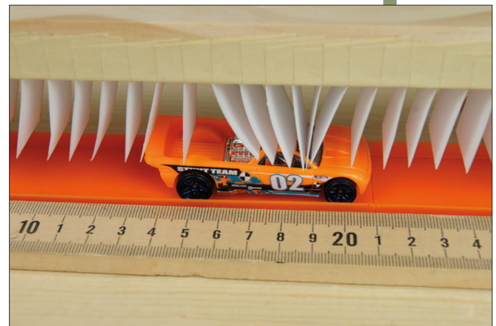
We start the car rolling by allowing it to roll freely down a track formed into a ramp. This is how the car gets its kinetic energy—the gravitational potential energy at the top of the ramp is converted into kinetic energy at the bottom of the ramp. Our setup allows us to increase the mass—and the kinetic energy—of the car without increasing its speed. We do this by releasing the car over and over from the same height, so that its speed at the bottom of the ramp is always the same (more on this in a moment). But each time we release the car, we increase its mass just a bit by adding small lead weights to the car. To enable this, we use a car with a cargo bed to hold the weights.

To get an idea of how much kinetic energy the car has at the bottom of the ramp, we make a device that uses friction to slow the car in a stopping zone. Our friction stopper uses flaps of index card to slow the car, and we gauge the amount of kinetic energy the car has by measuring how far into the stopping zone the car goes before the friction flaps bring it to a stop. The photo to the left shows a car being stopped by the friction flaps. The measuring rule next to the track allows the experimenter to measure how far the car travels into the stopping zone.

Let's go back for a minute to my comment that every time the car is released from the same height it will be going the same speed at the bottom of the ramp. Back in the 17th century, Galileo demonstrated that falling objects all accelerate at the same rate. This means that *any* object released from a given height above a table will be going the same speed when it reaches the table, regardless of its mass. Accordingly, our car will always be going the same speed at the bottom of the ramp, even as we add weight to it.

But rather than take Galileo's word for it, as part of this experiment you need to verify this for yourself. In the photo, you can see two ramps side by side. Before placing the friction flaps over the track, make a few trials with two cars released from the same height. Use two identical cars, and place weights in one of them to make it about 10–15% heavier than the other. As you do this, see if you can verify Galileo's discovery. In order to make this verification, you need to work out a way to release the two cars at exactly the same time.

For collecting experimental data, you use a single car. Adjust the height of the friction flap assembly so it is level, and so it stops the car before the car reaches the end of the track, even when the car is full of lead weights. Release it 3–5 times from the same height, adding another bit of weight to it each time. Vary the weight from a minimum (car empty), up to at least 130% of the car's empty weight. For each run, measure the car's mass and how far it travels into the friction/stopping zone, and record these data in a table in your lab journal.



Analysis

An important part of the analysis is to prepare a graph of stopping distance (vertical axis) versus mass (horizontal axis). Your instructor will help you with setting up your graph and labeling it properly. In your report for this experiment, address the following questions.

1. Were you able to verify that the car's speed at the bottom of the ramp didn't change, even as mass was added to the car? Describe how you did this.
2. How does the stopping distance relate to the car's kinetic energy? Use your graph to help address this question. Explain what caused the stopping distance to increase.
3. Where does the kinetic energy of the car go as the car stops?
4. What does the shape of your graph tell you about the relationship between kinetic energy and mass?

Preparation

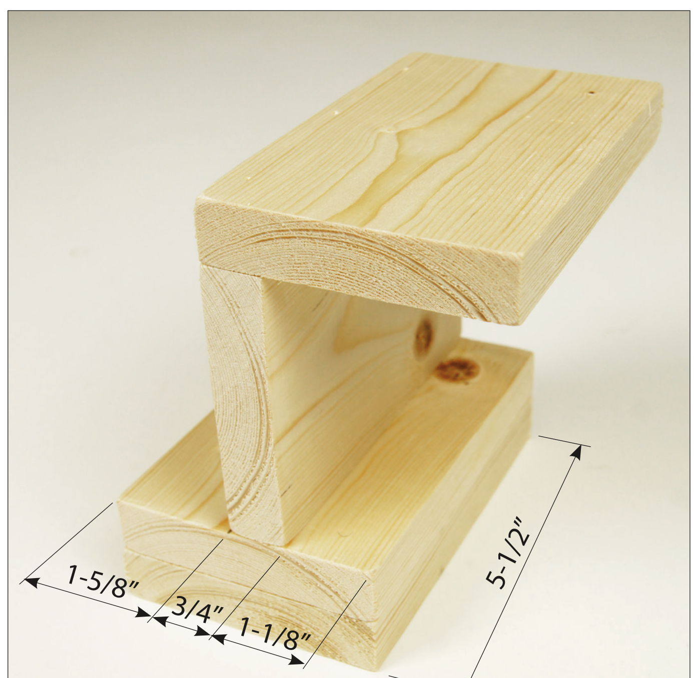
As mentioned in the Introduction, students have the best learning experience with this experiment if they make the required jigs themselves. If this is not feasible, you may order the Hot Wheels Track Clamp Support Base and the two Double Support Stand with Adjustable Crosspiece from Centripetal Press.

The materials list for this experiment is on the next page.

Making the Required Parts

Construction details for the Hot Wheels Track Clamp Support Base and the two Double Support Stand with Adjustable Crosspiece are shown in the next few photos. The photos on this page show the Hot Wheels Track Clamp Support Base. This piece is constructed of 1 × 4 pine. Joints are glued and fastened with finishing nailer with 1-1/2" finishing nails. The base is made of two layers of 1 × 4.

The next two photos show the Double Support Stand with Adjustable Crosspiece. You will need two of these. (They are also used in the magnetic field strength experiment (#12). This item consists of six separate pieces: four support stands and two adjustable cross



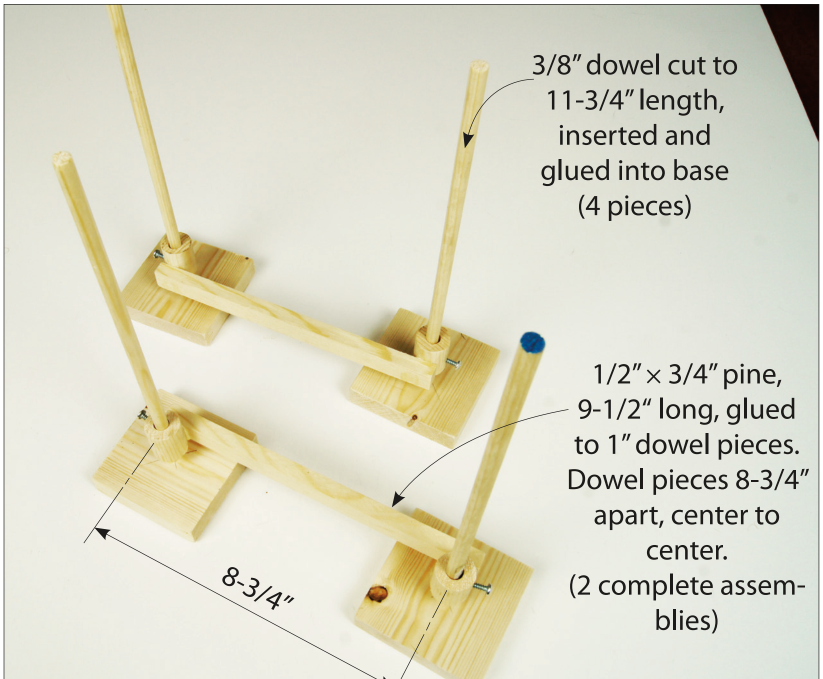
Hot Wheels Track Clamp Support Base

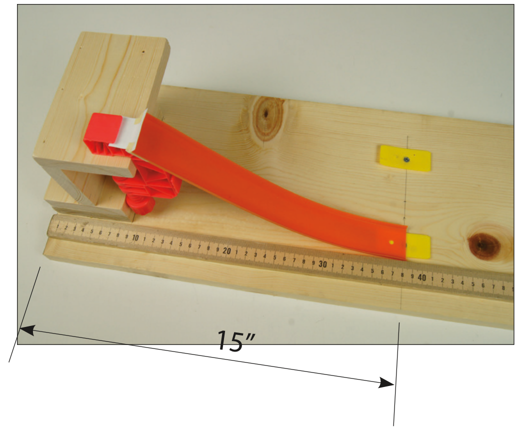
Item	Quantity	Source	Cost	Ext. Cost	Comments
3/8 in wooden dowel	48 in	hardware store	0.98	0.98	These items are used to build the two jigs described for this experiment. They do not need to be purchased if the Physical Science Special Parts Kit is purchased. However, it will be handy to have some scrap pieces of 1 × 4 for supporting the adjustable supports.
1 in wooden dowel	48 in	hardware store	3.96	3.96	
1/2 × 3/4 pine	24 in	hardware store	0.40	0.80	
1 × 4 pine	72 in	hardware store	2.25	2.25	
self-drilling screws, #8 × 3/4 inch	pack of 4	hardware store	1.18	1.18	
1 × 10 pine	72 in	hardware store	8.44	8.44	3/4-in plywood or 2 × 8 may be substituted, if handy.
1 × 2 pine	72 in	hardware store	3.22	3.22	Price for 72-inch piece.
Hot Wheels Mega Jump Kit	2	sporting goods	5.49	10.98	Other Hot Wheels kits may work, too. The essential parts are the track clamp and a few sections of Hot Wheels track with connectors.
Hot Wheels car with cargo space	2	sporting goods	0.97	1.94	Save the packaging for experiment #10.
lead split-shot, size BB	pack of 60	sporting goods	1.09	1.09	These are sold as fishing sinkers with fishing supplies.
Quick Grip clamps, micro size	2	hardware store	5.76	11.52	These great little clamps will be using in several experiments.
#8 × 3/4 flat head wood screws	2	hardware store	1.18	1.18	Price for pack of 12.
masking tape	24 in	common item	n/a		
3″ × 5″ index cards	10	common item	n/a		
wood glue		common item	n/a		
meter stick	1	See Introduction			
mass balance	1	See Introduction			
			Project Total	47.54	

pieces, as shown in the photo at the top of the next page. Support stands are constructed of a 1 × 4 pine base, with a 3/8” wooden dowel glued into a 3/8” hole drilled into the base. Cross pieces are made of 1/2” × 3/4” pine. Cross pieces are glued to sections of 1” wooden dowel, and tacked with a finishing nailer using a 3/4” finishing nail. A 7/16” hole is drilled through the center of each 1” dowel section. One #8 × 3/4” self-drilling screw is screwed into the side of each of the 1” dowel sections.

Use the 1 × 10 pine board as a base for mounting everything. Using either an extra set of clamps or wood glue, attach the Hot Wheels Track Clamp Support Base to the end of the 1 × 10 pine board. Mark a line 15 inches from the end of the 1 × 10. Carefully use a drill or sharp knife to cut a hole in the center of two of the yellow Hot Wheels track connectors. Use the #8 × 3/4-inch flat head wood screws to fasten these two connectors to the 1 × 10. As shown in the photos, the two connectors should be 4 inches apart (center-to-center), and their centers should be 15 inches from the end of the 1 × 10.

Using the clamps that come with the Hot Wheels kits, make ramps for two sections of track by attaching them to the clamps, the clamp support base, and the screwed down track connectors. One of the ramps contains only a single section of track. This one is used only for the initial part of the experiment where the speeds of two cars at the bottom of the ramp are being compared. The other ramp is attached to three or four pieces of track at the bottom. This is the main ramp for taking data during the experiment. As shown in the


3/8″ dowel cut to
11-3/4″ length,
inserted and
glued into base
(4 pieces)
1/2″ × 3/4″ pine,
9-1/2″ long, glued
to 1″ dowel pieces.
Dowel pieces 8-3/4″
apart, center to
center.
(2 complete assem-
blies)
8-3/4″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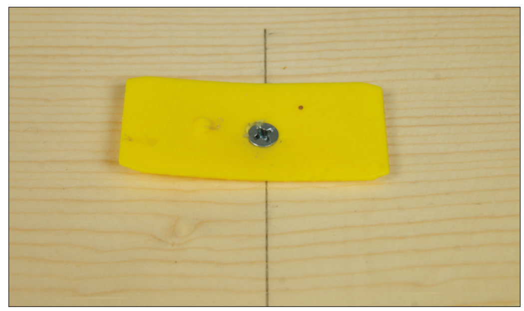
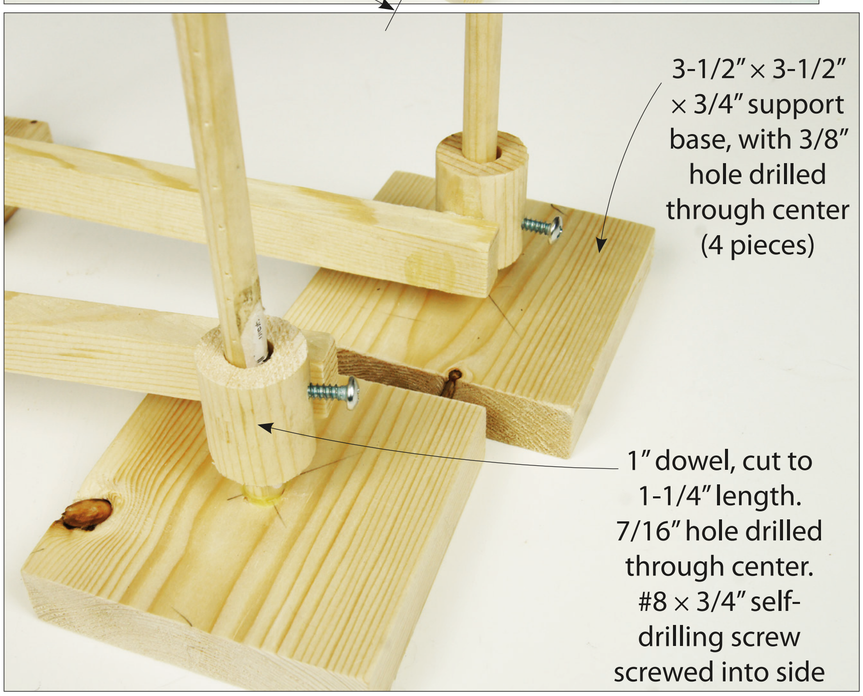
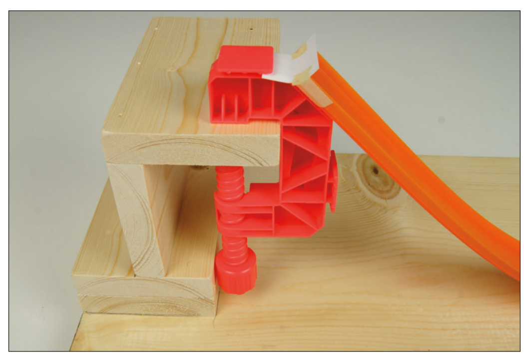
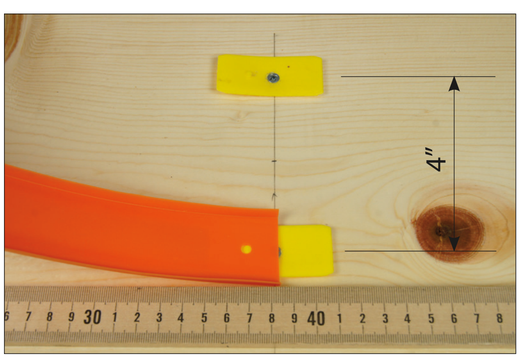



3-1/2″ × 3-1/2″
× 3/4″ support
base, with 3/8″
hole drilled
through center
(4 pieces)
1″ dowel, cut to
1-1/4″ length.
7/16″ hole drilled
through center.
#8 × 3/4″ self-
drilling screw
screwed into side

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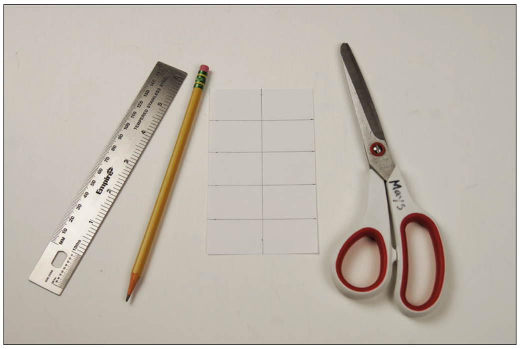
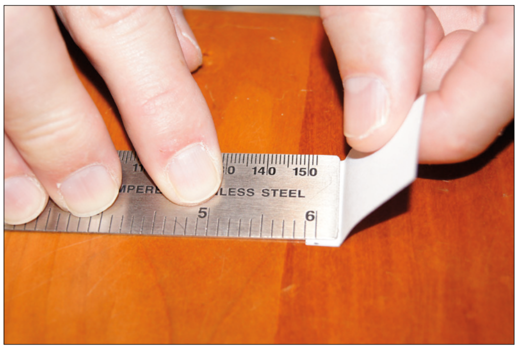
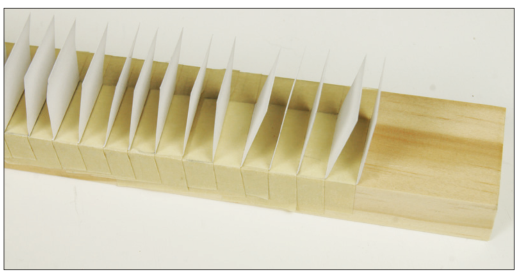
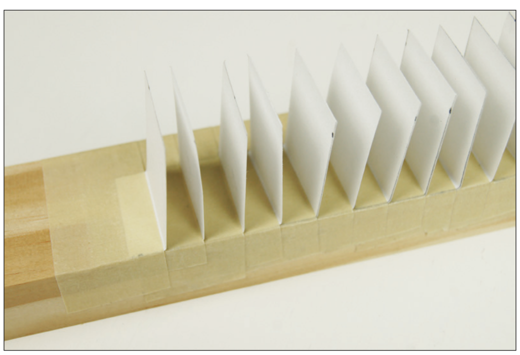
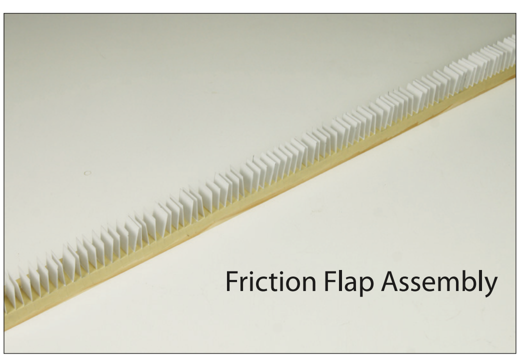










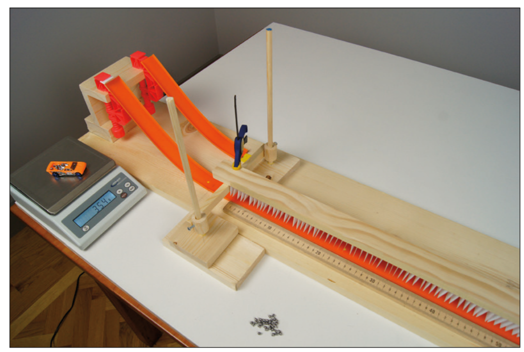
Friction Flap Assembly

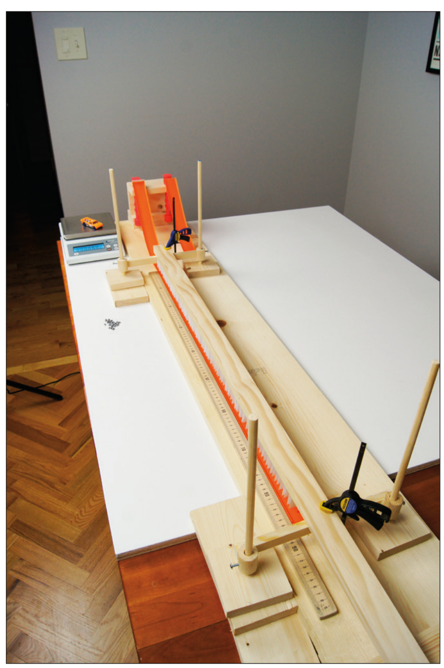
bottom right photo on the previous page, tape a piece of index card across the top of the main ramp so that a car released repeatedly can always be released from the same point.

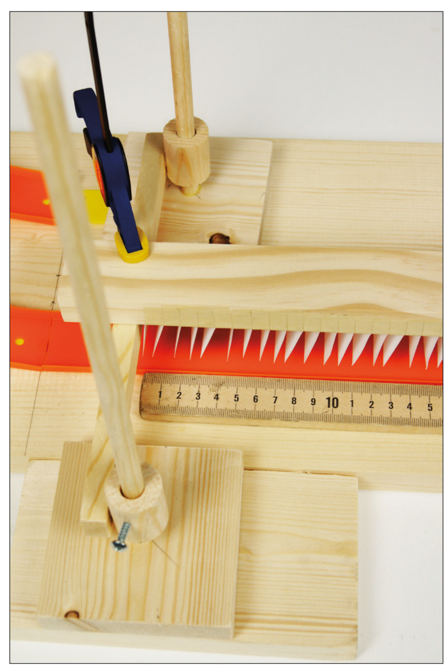
To make the friction flap assembly, mark lines one inch apart on ten 3 × 5 cards, and another line down the middle of each card, as shown to the left. After cutting these you will have 100 pieces of card, each 1" × 1.5". Using the end of a rule and the markings on the rule, bend each flap so that you have a tab on the flap about 3/8" long. Beginning about 2 inches from the end of the 1 × 2 pine, tape each tab to the 1 × 2 with a strip of masking tape. Place each new flap on the 1 × 2 right at the end of the tab of the previous flap. As shown in the photos, when finished you with have 100 flaps evenly spaced down the 1 × 2 for a length of about 40 inches. (Save this 1 × 2 after the experiment is over. It will come in handy for experiment #8.)

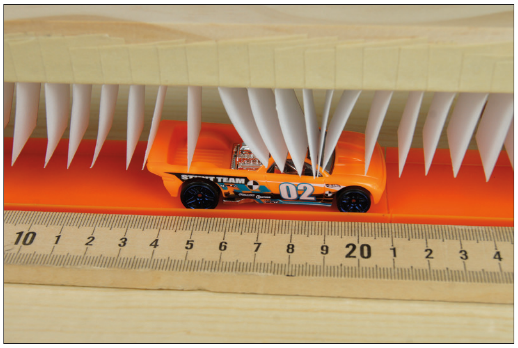
Setting It All Up

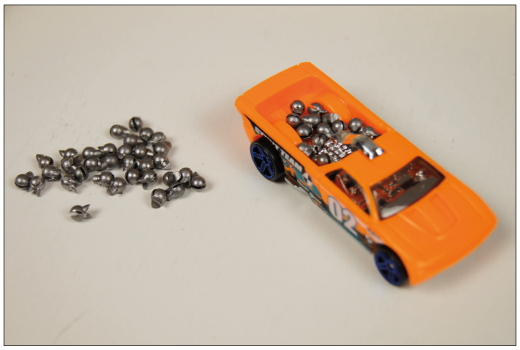
The three photos below illustrate how to set everything up for the experiment. Use the two support stands to hold the friction flap assembly over the main track. Use the small clamps to hold the friction flap assembly in place. Place the adjustable supports on scraps of 1 × 4 where they won't fit on the 1 × 10 with everything else. Position the meter stick along side the track. Align the friction flaps and the meter stick so they begin at the bottom of the ramp, where the track attaches to the connector that is screwed down to the 1 × 10.











At the left is a photo of the car being stopped by the friction flaps.

You want to select a Hot Wheels car that has a lot of cargo space like the one shown. Purchase two of these cars so you can use them for the speed comparison test at the beginning of the experiment.

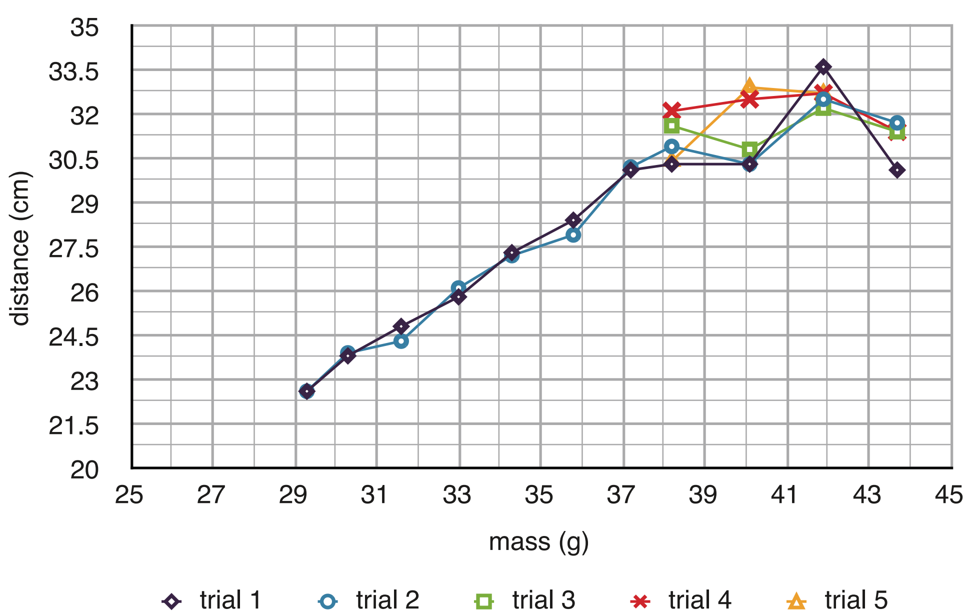
Release the empty car on the main track several times. Adjust the height of the friction flap assembly so the car slows evenly and stops somewhere around 1/3 of the way into the flaps.

For collecting data, release the empty car on the main track several times, recording the stopping place each time. Then add one or two of the small lead fishing sinkers to the car's cargo area and repeat.

The data I collected when doing this are shown in the graph below. Your students will construct a graph similar to this one. As you can clearly see, the stopping distance increases linearly with the mass of the car until the mass gets up to about 37 g. After that, the stopping distances become erratic. I made multiple trials at each mass above 37 g, and the stopping distances varied between 30.5 cm and 33.5 cm. I attribute this sudden onset of erratic stopping distance to the heavy load in the car. The wheels and axles are not designed to carry this much weight, so the wheels are not operating properly. I started with an empty car mass of about 29 g, so this means our test works well until the mass of the car and its cargo gets up to about 130% of the mass of the empty car. For masses above that, my data indicate that stopping distances are no longer useful as a measure of the car's kinetic energy.

Interpretation

The data show that stopping distance is proportional to mass. As the text explains, the kinetic energy is also proportional to mass. We are stopping the car by doing work on it—the friction flaps push against the car for a certain distance. The kinetic energy of the car is being converted into heat by the friction flaps. The more kinetic energy the car has (because of higher mass), the longer the friction has to act on the car to stop it. Technically, we can say the stopping distance is *directly proportional* to the kinetic energy of the car, and thus is a way to gauge the car's kinetic energy. The speed comparison trial at the beginning of the experiment should demonstrate that the car always arrives at the friction flaps at the same speed. Thus, our experiment demonstrates that an object's kinetic energy is directly proportional to the object's mass.



Description from Text

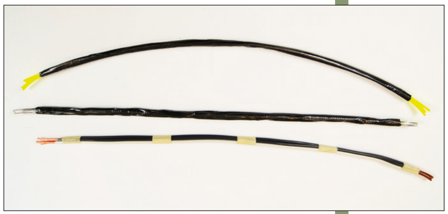
Experimental Investigation 2: Heat Transfer by Conduction

Overview

- Assemble four containers of water. In a beaker, maintain boiling water at 100°C. In three Styrofoam cups place small amounts of room-temperature water. Place thermometers in each container.
- Connect the heat source (hot water) to the room-temperature water with pieces of copper, aluminum, and plastic wire or cord all the same diameter and length. *The goal of this experiment is to compare the ability of these three materials to conduct heat*. The amount of heat a material can transfer by conduction is called its *thermal conductivity*.
- Record the temperatures of the water in all four containers every 20 minutes until *thermal equilibrium* is reached.
- Collect temperature and time data, and prepare graphs of temperature versus time for the water in the four different containers. Plot the three curves for the cups on the same set of axes, and the temperature for the hot water beaker on a separate graph.

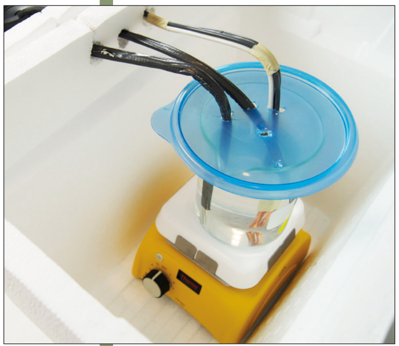
Basic Materials List

- hot plate
- digital thermometers (4)
- Pyrex beaker, 600 mL
- graduated cylinder, 100 mL
- Styrofoam cups and lids
- duct tape
- Styrofoam ice chest (2) and small cardboard box
- samples of copper and aluminum wire, and plastic cord



We expect metals to conduct heat better than plastic. This is why metal tools like tongs and frying pans sometimes have plastic handles. But how much better do metals conduct heat? And is there a difference in the thermal conductivities of different metals? In this experiment, we examine these questions scientifically.

To do this, we need a heat source, which will be a large beaker of water on a hot plate, maintained at a constant, hot temperature. Then we need a place for the heat to go. For this, we use three small Styrofoam cups of water. By monitoring the water temperature in the three cups, we have a way of *quantifying* how much heat is conducted into the water in each of the cups. Third, we need materials to conduct heat from the heat source to the water in the cups. For two of these materials, we use pieces of aluminum and copper wire. This way we can compare the thermal conductivities of these two common metals. For the third cup, we need a plastic material shaped like wire. The nylon monofilament line used in grass trimmers ("string trimmers") works well.



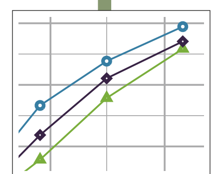
To prepare the heat conductors, cut equal lengths of copper wire, aluminum wire, and nylon line. You need four pieces of each material, and they need to be long enough to reach comfortably from the hot water beaker into the Styrofoam cups. Wrap the four pieces of each material together in duct tape to serve as a thermal insulator, as shown in the first photo. On each end of each pair of conductors, leave one inch of exposed material. Make sure the exposed part is the same length on each material so we have a valid comparison of thermal conductivity.

The setup is illustrated in the next two photos. A beaker containing about 500 mL of water is on a hot plate in a Styrofoam ice chest. This keeps the water in the beaker at a steady temperature of 100°C without warming up the room. Tape the insulating cups to a cardboard box inside a second ice chest. Use the graduated cylinder to measure out 100 mL of tap water into each of the cups, making sure that each cup has the same amount of water in it. Punch two holes in each lid, one for a thermometer and one to allow one of the conducting materials to enter the water. Label the cups so you don't forget which one is which. (The cardboard box is there to elevate the cups to the same height as the hot water beaker, so the thermal conductors can be as short as possible.)

To run the experiment, place the tap water in the cups 2–3 hours in advance so the water is at room temperature when the experiment begins. Insert the three conducting materials into the cups and the beaker through holes in the sides of the ice chests. Record the four starting temperatures in your lab journal. Switch on the hot plate and continue to record all four temperatures every 20 minutes until thermal equilibrium is reached (about four hours). You will know the system is at thermal equilibrium when all temperatures are more or less holding steady.

Analysis

An important part of the analysis is to prepare graphs of the four data sets, using the horizontal axis for the time and the vertical axis for the temperature. Plot the data for the three small cups on the same axes (same graph). The water in the cups begins at around 22°C, so you probably want to scale the vertical axis from 20°C up to a bit above the highest cup-temperature reading you have. Since you are plotting three sets of data on the same graph, you need to use a different symbol or color for each data set, as illustrated in the sample graph to the right.



The hot water temperature is supposed to be steady at 100°C. This is a lot higher than the cup temperatures, so it needs to be on a graph by itself. Your instructor will help you with setting up your graphs and labeling them properly.

In your report for this experiment, address the following questions:

1. From studying the graphs, how do the thermal conductivities of the three materials compare?
2. Why do you think the temperatures from the hot water beaker are recorded and plotted on a graph? What purpose does that serve?
3. Why are the three conductor materials wrapped in duct tape?
4. Why is it important that the three different materials are cut to the same length?
5. Imagine you are designing a part to go inside a machine, which we will call part U. Part U connects to three other parts, called a, b, and c. If you do not want heat to transfer between part U and parts a, b, and c, what kind of material should you consider using for making part U?

Preparation

The heat conductors for this experiment are #10 solid copper wire, solid aluminum wire that is about the same size (diameter), and plastic wire that is the same diameter. I was unable to find a source for #10 solid aluminum wire. But the individual strands inside large aluminum stranded cables are about the same diameter as #10 copper (0.1 inches). To procure the aluminum, go by an electrical supply shop, tell them you are doing a science experiment, and ask for a 24-inch chunk of 500 MCM aluminum cable. A common chain found in just about every town is Dealers Electric. They should be willing to donate two feet of 500 MCM cable to the cause of science, but if not they may charge you a few dollars. While you are there, ask them if they have any waste #10 solid copper wire you can have, and if they do, get about 10 feet of it. This worked for me. If it doesn't work out for you, you can go to a hardware store and get a short roll of 10-2 NM copper wire. But if you can save $18 by getting the copper for free, so much the better.

The third conductor is the plastic wire. What you want is 10 feet of 0.1 inch-diameter monofilament line. This is the line used by professional landscaping crews in their gas-powered trimmers. Those kinds of trimmers are called *string trimmers* these days, although they are often called Weedeaters (a brand name). Note that the smaller string trimmers used by homeowners usually use smaller diameter line. Rather than buy a big roll of 0.1-inch line, I just looked around for a landscaping crew at work and asked them if I could have about 10 feet of their trimmer line for a science project. They were glad to help. The other materials are listed in the table on the next page.

Cut open the 500 MCM aluminum cable and extract four strands of wire. Cut four pieces of copper wire to the same length (24 inches). The copper in the 10-2 NM roll is insulated in white and black jackets.

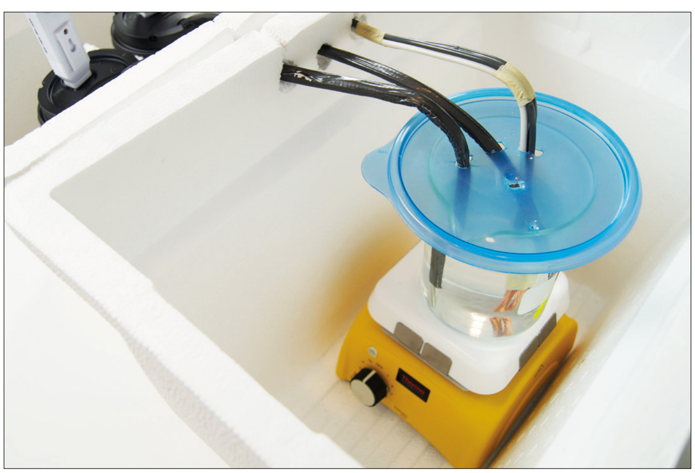
Item	Quantity	Source	Cost	Ext. Cost	Comments
hot plate	1	See Introduction			
beaker, 600 mL	1	See Introduction			
digital thermometer	4	See Introduction			
graduated cylinder, 100 mL	1	See Introduction			
Styrofoam cooler	2	discount store	2.99	5.98	
Styrofoam cups with lids, 12 oz	1 pack	discount store	4.99	4.99	Cost is for pack of 26 cups with lids
copper wire, solid, 10 gauge	8 ft	hardware store	18.37	18.37	10-2 NM with ground, 15 ft
monofilament line, 0.1 in diameter	8 ft	landscape crew	n/a		request free sample
aluminum wire, 500 MCM	2 ft	electrical supply house	n/a		request free sample
plasticware lid	1	common item	n/a		
masking tape	24 in	common item	n/a		
duct tape	36 in	common item	n/a		
small cardboard box	1	common item	n/a		
			Project Total	29.34	

Leave this insulation on. If you obtain free copper wire that is not insulated, that's okay. Take four strands of each conductor—aluminum, copper and plastic—and make them into a bundle. If your copper wires are insulated, remove one inch of insulation from each end of all four wires, and then tape the four wires into a bundle, as illustrated in the upper part of the photo the previous page. The middle item in that photo is the four aluminum pieces. These are not insulated, so you need to wrap them together in duct tape, leaving one inch of aluminum exposed on each end. Do the same with the string trimmer line. And of course, if you happen to have uninsulated #10 copper wire, wrap that in duct tape too, leaving one inch exposed at each end.

The photos on this page show how to set up everything else. The idea is to place the hot plate in one cooler and the three Styrofoam water cups in the other. Tape the cups to a cardboard box to elevate them so they are about the same height as the water beaker on the hot plate. This minimizes the length of conductor you need. Fashion three holes in the upper part of the walls of each cooler to allow the conductors to pass from the hot water beaker into the Styrofoam cups. Make a hole in the bottom of the hot plate cooler for the power cord to come out.

Use an old plasticware lid to cover the hot water beaker. Punch four holes in the top for the conductors and one of the digital thermometers. In the other cooler are the three Styrofoam cups, each containing 100 mL of water measured with the graduated cylinder. Punch two holes in each of their lids for the conductor bundle and thermometer.

The photos at the bottom show the conductors in place between the hot water beaker and the three cups. Getting these in place takes some doing, particularly the copper one, which is quite stiff. If you would like to go to the effort, an even better design than this one would be to place each cup in its own small cooler so



that the heat delivered to each cup warms only the water in that cup and not the water in the other cups. If you try this more elaborate approach, just make sure each conductor bundle is the same length.

If you use a single cooler for the cups as I describe, you will notice that the inside of the cooler warms during the experiment. This warming, which is due to the heat conducted by the metals, has an effect on the temperature of the water connected to the plastic conductors.

The graphs on the opposite page illustrate this. The temperature of the water with the plastic conductors warms about 3.5°C during the experiment. I seriously doubt whether this warming is due to heat conducted by the plastic. More likely, it is due to warming of the cooler from the heat conducted to the other two cups.

But solving this problem by rigging up four coolers for this experiment might make the whole thing just a bit too elaborate. Another approach is to use the design I have shown here, but lead the students in considering the question of the plastic water temperature. Use a fifth thermometer to monitor the temperature inside the cooler with the three cups, which warms noticeably during the experiment. Have the students document this cooler air temperature along with the others in their lab journals. Then compare the cooler air temperature to the plastic cup temperature and see if these data explain the temperature of the water in that cup.

Running the Experiment

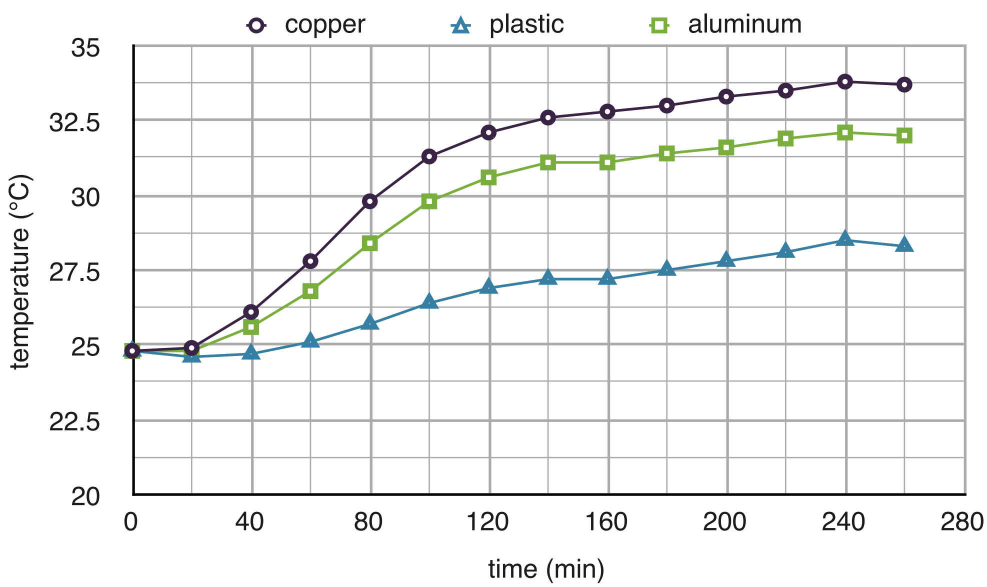
The complete setup while running the experiment is shown below. One of my thermometers is long and I had to make a hole for it in the top of the cooler containing the hot plate. It is important to have the cooler lids on. Otherwise the fluctuations in room temperature will affect the water temperatures in the cups so much you won't be able to see the effects of the heat conduction in the conductors.

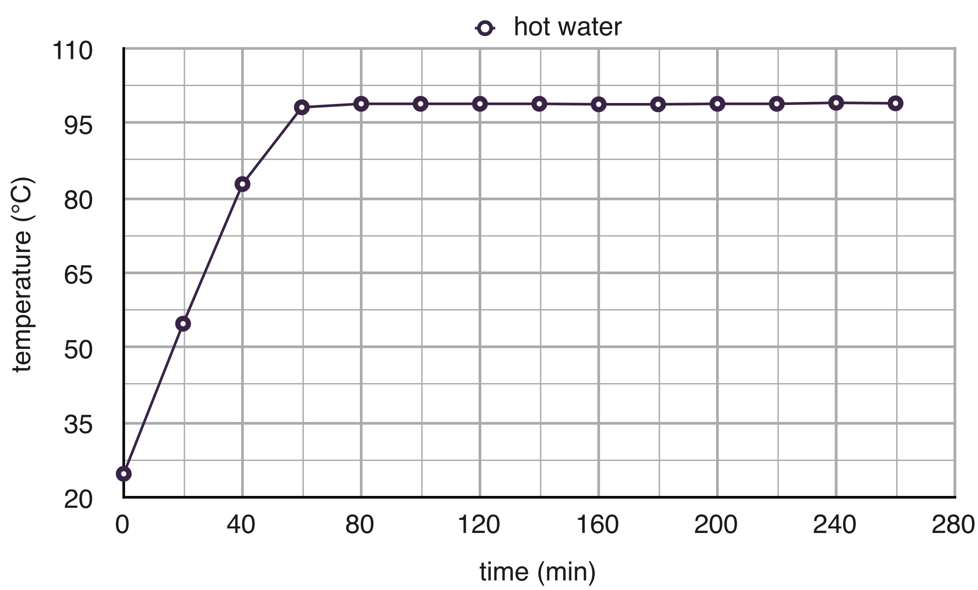
Make sure when you begin that you have at least 500 mL in the hot water beaker, and turn the hot plate control dial up to about 75% so the water will reach the boiling point and stay there. With a cover on the hot water beaker, you should not run out of water during the experiment, but monitor the water level just to make sure. Monitor the hot plate cooler as a whole carefully. I had no trouble with it overheating or posing a fire hazard, but you should monitor it to make sure. Make sure the hot surfaces of your hot plate do not touch the cooler anywhere.

Data Analysis

Your students will construct graphs of their data similar to those shown on the opposite page. You need to let the experiment run long enough for the temperature curves to level off. I terminated the experiment the first time the temperature in the cups went down instead of up, under the assumption that from then on the temperatures would hold fairly steady, moving slightly up and down.

Even with the environmental temperature issue affecting the temperature of the water cup with the plastic conductors (discussed in the preparation section), the superior thermal conductivity of the copper and aluminum is clearly evident. Also evident is the higher thermal conductivity of the copper compared to the aluminum. You may want to point your students to the chart on page 167 in the text, which shows that the thermal conductivity of aluminum is about 55% of the thermal conductivity of copper.


copper
plastic
aluminum
35
32.5
30
27.5
25
22.5
20
temperature (°C)
0
40
80
120
160
200
240
280
time (min)


hot water
110
95
80
65
50
35
20
temperature (°C)
0
40
80
120
160
200
240
280
time (min)

Description from Text

Experimental Investigation 3: Electrostatic Forces

Overview

- *The goal of this investigation is to observe the effects of forces caused by accumulations of electric charge. These accumulations are called "static electricity."*
- Make simple "pith ball" *electroscopes* out of pieces of Styrofoam and fishing line. Apply electric charges by rubbing on hair or fur, and observe how they interact.
- Observe how the Styrofoam "pith balls" behave when close to metal objects.
- Make a simple aluminum-foil electroscope and observe how the leaves interact under the influence of charge accumulations.

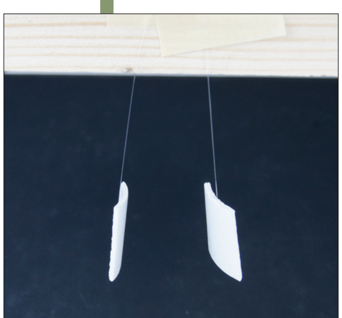
Basic Materials List

- polystyrene foam (Styrofoam) cup
- fishing line (8 inches)
- copper wire (8 inches)
- aluminum foil (1 inch × 2 inch strip)
- quick clamps with plastic clamping surfaces, small (2)

Many of the negatively-charged electrons in metals (*conduction electrons*) are free to move around, while the positively-charged protons are bound in place. Other substances, such as hair and cat fur, will readily donate electrons to objects made of substances such as rubber or polystyrene foam (Styrofoam). In this experiment, we will make use of these two properties to gather up electrons and observe what they do when they accumulate.

Our investigation will take place in three stages. During each stage, carefully document all your observations in your lab journal.

In the first stage, use small pieces of polystyrene foam glued to fishing line. The polystyrene foam easily accumulates electrons from hair or cat fur when you rub the polystyrene on the hair. (Clean dry hair works pretty well. Cat fur works even better.) In experiments like this back in the 17th century, scientists used a spongy material called *pith*, found in the core of some kinds of trees. The scientists would use little balls of pith attached to silk threads. In our day, polystyrene and fishing line are a lot easier to come by than pith and silk. (Feel free to use pith balls and silk threads if you have some.)



Cut two squares of polystyrene foam about 3/4 inch square. Glue a piece of fishing line to the back of each one. Charge up each piece by holding at the edges and rubbing it on your hair or your cat. Then dangle each piece of polystyrene by the fishing line and try to bring their charged surfaces together, as illustrated in the photo above.

Now for stage two. Charge up one of your little "pith balls" again. This time, hold it by the fishing line and watch what happens when you bring the charged surface near any metal object. Try it with as many different types of metal as you can, including painted metal surfaces.

For stage three, make a simple *electroscope* out of an 8-inch piece of solid copper wire and two strips of aluminum foil, as illustrated in the photograph. Cut the foils strips about 1/2 in × 2 in, and cut a small hole near the end of each one. Hang the foil strips from the bent legs of the copper wire. These foil strips are called *leaves*, because back in the 18th century when the electroscope was invented, scientists used light weight "gold leaf" instead of aluminum foil. (Aluminum foil wasn't around back then.)

Use two clamps with insulated (plastic) clamping surfaces to support the copper electroscope vertically. You will need to locate your setup in a calm room, with no fans or open windows to blow the foil leaves around. With the electroscope in place, we will experiment with it in three steps.

For the first step, take a polystyrene cup, or the big chunk of cup left over from the first stage of this investigation, and rub it vigorously on your clean, dry hair or your cat. This accumulates a *lot* of electrons on the cup. Now bring the charged cup very near to the top of the electroscope—without letting them touch—and observe the leaves. You should see them swing apart from each other. Withdraw the cup and observe what the leaves do.

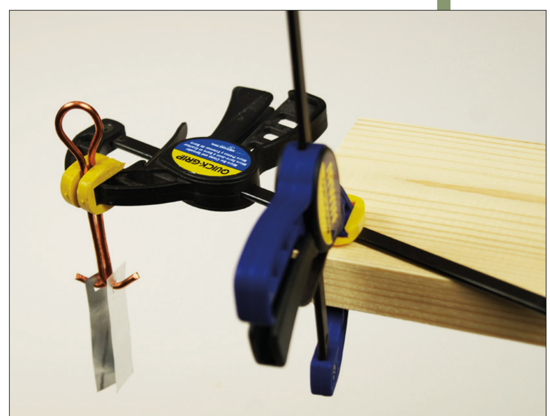
Now for step two. Repeat step one, but this time actually touch the charged cup to the top of the electroscope and rub it around, as if you are scraping electrons from the charged cup onto the electroscope (which, in fact, you *are* doing). If you do this right, the leaves should swing apart and stay apart, even when the cup is withdrawn.

Finally, while the leaves are apart, touch the top of the electroscope with your finger and observe what happens.

Analysis

Make sure all your observations have been carefully documented in your lab journal. In your report, address the following questions.

1. Explain the behavior of the two small polystyrene squares (the "pith balls") when they were charged up and brought near one another. Don't simply describe what happened. Use the principles of electric charge, electric fields and force to explain *why* it happened.
2. Consider how your charged square of polystyrene behaved when brought near a metal. Recalling that the conduction electrons move easily in metals, explain why the charged polystyrene is *attracted* to the metal. Again, be specific, using the principles you have studied.
3. Consider the first step of investigation with the electroscope. Explain why the leaves swing apart when the charged cup is brought near the electroscope (without touching) and relax when the cup is withdrawn. If you are working in a group with other students, discuss your thoughts on this item until you have all agreed on the explanation. Figuring this out may take a bit of discussion and thought.
4. Consider the second step of the electroscope, when the cup is scraped on the copper. Explain why the foil leaves remain apart, even when the charged cup is removed.
5. Finally, explain why the leaves relax when you touch the top of the electroscope.

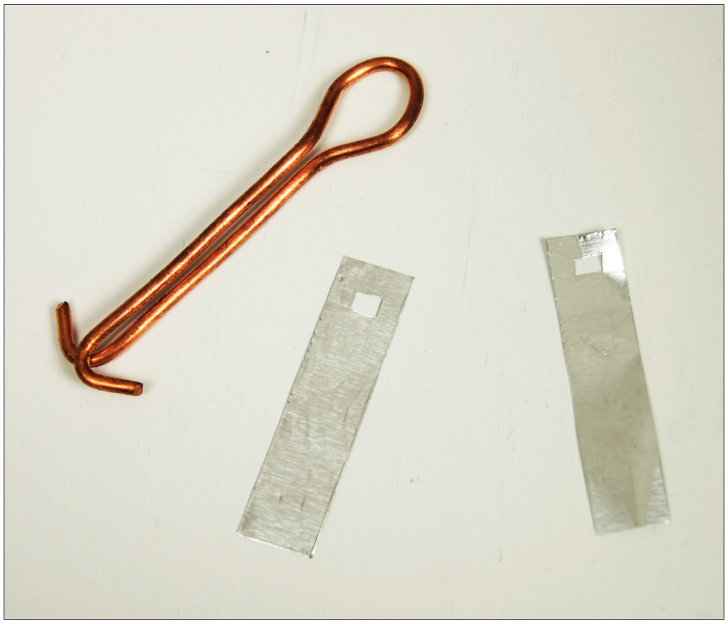


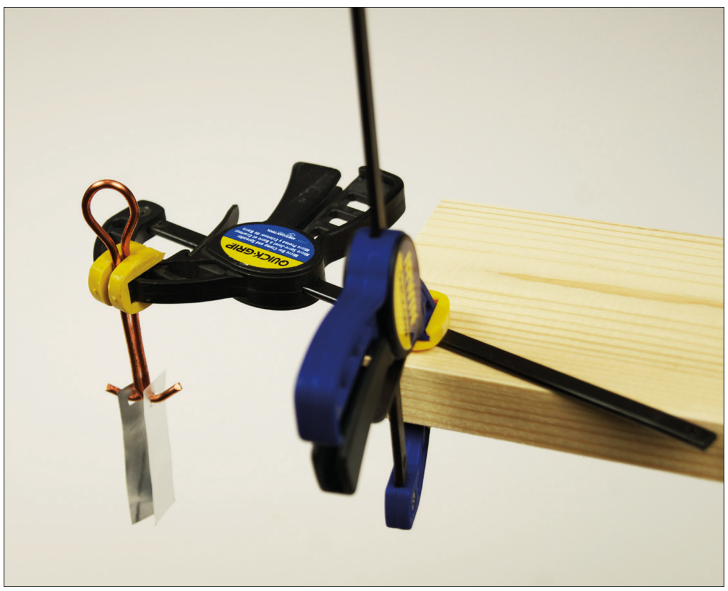
Preparation

The materials list is shown in the table below. The Gorilla glue is for attaching the fishing line to the small squares cut out of the Styrofoam cups. Use a piece of fishing line about 8 inches long for each one (two per group).

The photo at the top of the next page shows how to shape the 10-inch piece of copper wire and the two strips of aluminum foil to make the electroscope. To clamp the copper, use the small Quick Grip clamps from the kinetic energy experiment (#1). It is important to have the plastic (i.e., nonconducting) tips on the

Item	Quantity	Source	Cost	Ext. Cost	Comments
fishing line	1 spool	sporting goods	3.49	3.49	
copper wire	10 inches				Use leftover wire from the heat transfer experiment (#2).
Styrofoam cups	1 per group				Use leftover cups from the heat transfer experiment (#2).
Quick Grip clamps, micro size	2				Use the clamps from the kinetic energy experiment (#1).
aluminum foil	6 inches	common item	n/a		
Gorilla glue, 2 oz	1	hardware store	4.97	4.97	
			Project Total	8.46	





clamping surfaces. Using the two clamps to clamp the copper is shown in the second photo. You can see the yellow plastic tips on the clamps. In the photo I have one clamp holding the copper, and the other clamp holding the first clamp to a horizontal piece of wood. You could clamp to the edge of a table top if that is convenient.

Performing the Tests

The photo at the top of the next page shows the squares of Styrofoam with fishing line attached. The squares have been charged up by rubbing their surfaces on clean dry hair. As I mentioned in the text, cat fur works even better than human hair for producing static electricity (assuming the cat is a normal, healthy cat that keeps himself clean). This would be fun for your students to check out.

The two photos at the bottom of the opposite page illustrate the electroscope tests. In the left photo, the electroscope has been charged by scraping the Styrofoam cup on the top of the copper, and the excess electrons remain on the copper. This causes the leaves to swing out and stay out. When you touch the top of the copper, the excess electrons drain off onto your finger and the leaves relax.

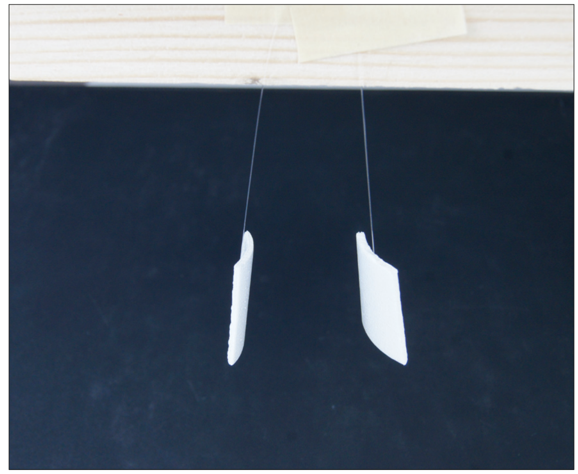
In the photo on the right, the charged Styrofoam cup is brought near to the copper without touching it. This causes the leaves to swing out, and when the cup is withdrawn the leaves relax.

Interpretation and Discussion

I encourage instructors to read Section 13.2 in the text before conducting this experiment. In that section I come back to the topic of static electricity, introducing some more terminology and revisiting some of the results of this experiment.

You will want to have a thorough discussion of student responses to question #2 in the analysis of results. Have students share their explanations first to see if they can arrive at a good answer by discussing things together on their own. The explanation they should arrive at is as follows.

In a metal, the nucleus and some electrons of each atom of metal are fixed in place. But there are a great number of electrons, called *conduction electrons*, that are free to move about. (This is presented to the students in the experiment description, not in Chapter 5. The topic is revisited in Chapters 6 and 13.) When the charged Styrofoam is brought near to any metal, the excess electrons on the Styrofoam push the conduction electrons in the metal away. (The term for this is *induction*, which is covered in Chapter 13.) This leaves the metal atoms' nuclei (and some electrons) at the surface of the metal. The conduction electrons have been forced into the interior of the metal by the electric repulsion of the electrons on the Styrofoam. Without the conduction electrons, these nuclei and other electrons that are fixed in place have a net positive charge. This positive charge attracts the electrons on the surface of the Styrofoam. The result is that whenever the charged Styrofoam is brought near any metallic surface, the Styrofoam is attracted to the metal.

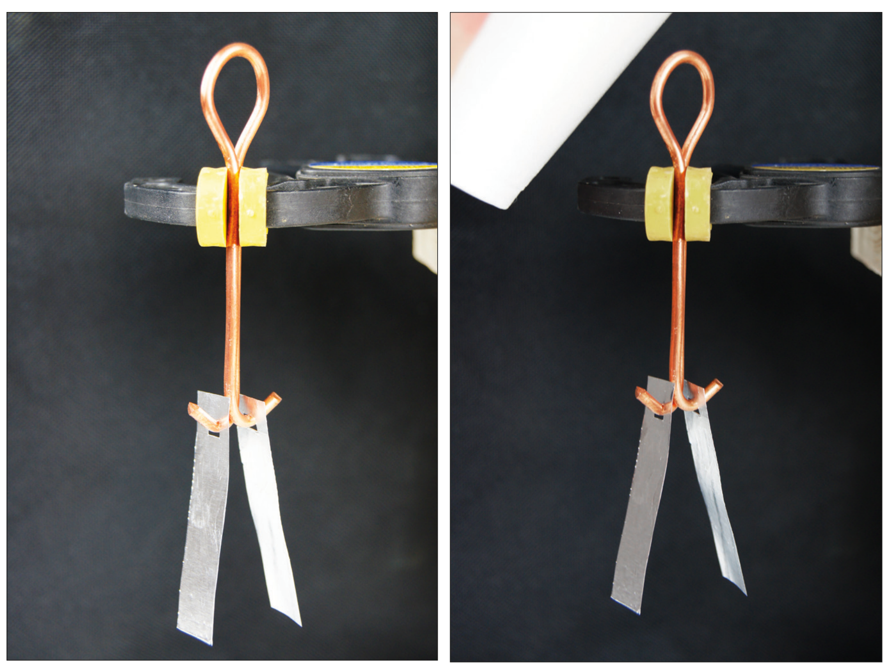


It is interesting to note that the electric fields causing the attractions and repulsions will penetrate through paint, so that the Styrofoam will be attracted to a metal even if it has been painted. Make sure your students experience this. Metal doors, the most common painted metal surface I can think of, are around almost everywhere.

In your discussion of this issue, it is also important for students to see that when the charged Styrofoam is attracted to the metal, we have both electrical repulsion and electrical attraction going on simultaneously. The electrons on the charged Styrofoam are repelling the conduction electrons in the metal. But simultaneously, the electrons on the Styrofoam are attracted to the positively charged metallic nuclei that remain fixed in place at the surface of the metal.

With your students, take this discussion one step further, as follows. In the first chapter we discussed atomic theory. (In Chapter 7 we will go deeply into what theories are and what roles they play in science.) The current theory about matter—accepted by virtually everyone—is that matter is made of atoms. What evidence is there for the atomic nature of matter? Well, there is a lot of evidence from sophisticated experiments in physics labs, but most of us have never examined that evidence. But in this simple experiment, we have very good evidence for the atomic theory of matter. The discussion above for answering question #2 explains the results of this experiment entirely in terms of atoms, the negative charges on the movable electrons from the atoms, and the positive charges on the protons fixed in the nuclei of the metal atoms. One of the hallmarks of a successful theory is its ability to explain the facts we have from observations and experiments.

Finally, in the next chapter (Chapter 6) we see that the atoms in matter are always structured into either molecules or crystals. Metals are crystals, with the atoms all joined together in a regular structure called a crystal lattice. The conduction electrons in a metal are free to move about in this lattice structure, while the metal atoms' nuclei are bound in place in the lattice structure. This is the explanation for the electrical conductivity of metals. So this experiment anticipates the description of crystals in Chapter 6, the discussion of physical properties like electrical conductivity in Chapter 9, and the fuller treatment of static electricity produced by conduction and induction in Chapter 13. Teachers will do well to use this experiment to anticipate the material in those coming chapters, so that students are repeatedly confronted with atomic theory and the charges on electrons and protons. By repeatedly encountering these ideas, students can come to see how central they are to our understanding of just about everything in physics and chemistry.



Description from Text

Experimental Investigation 4: Growing Crystals

Overview

- *The goal for this investigation is to grow crystals, and to observe and describe the crystal formations you see.*
- Grow crystals of alum, sodium chloride, and Epsom salt. If possible, describe the crystal structures you see developing over the course of several hours.
- Harvest the crystals from each solution. Describe their size and shape.

Basic Materials List

- alum, table salt, Epsom salt
- glass jars and bowls
- measuring cups and spoons
- stirring spoon
- magnifying glass
- nylon thread (fishing line), lead weight, and pencil
- beakers, borosilicate, 250 mL and 600 mL
- burner or hot plate
- mass scale
- distilled water

Safety Precautions

Use care when working with a burner or hot plate. Keep clothing and hair away from flames and hot surfaces. Handle hot liquids with caution. Use only borosilicate glassware (e.g., Pyrex) for heating.

Growing crystals is fascinating, but sometimes, when things don't work out the way you hope, it can be frustrating as well. In this investigation you will try to grow crystals from three different salts. If the process does not seem to work well the first time, try it again.

In each case, the process consists of making a *saturated* solution of the salt in water and then letting the solution cool. A saturated solution is formed when the maximum possible amount of solute is dissolved in a solvent. For many salts, more salt dissolves in water when the temperature is high than when the temperature is low. If you heat your solvent (water), dissolve as much salt in the solvent as possible, and then let the water cool, you have a *supersaturated* solution. When the solution cools, it has more solute dissolved into the solvent than the solvent can hold at that temperature. This condition is unstable. Crystals begin to grow as the excess solute "precipitates" out of the solution. In some cases, it helps to give the crystals a "seed" crystal to start growing on. Once crystal growth starts, the crystal keeps on growing until the excess solute finishes precipitating out of the solution.

Begin with alum, which is the easiest crystal to grow. *Alum* is the common name for a compound called hydrated potassium aluminum sulfate. It has all kinds of uses, including water purification in ancient times, underarm deodorant, pickling (to keep vegetables fresh and crisp), and styptic pencils (to stop bleeding when you cut yourself shaving).

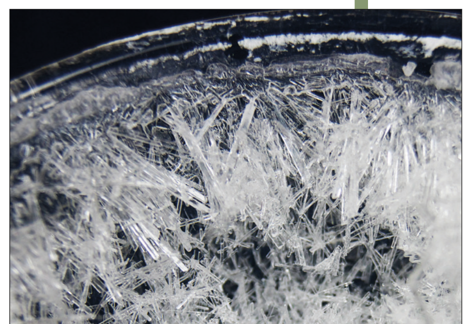
To grow alum crystals, place a small pan or 250-mL beaker with 120 mL of distilled water on a burner or hot plate. Stir in 30 g of alum. Heat the water slowly over medium heat until the alum has all dissolved. Pour the solution into a small, clear glass bowl and let it cool. You should observe some sizeable crystals growing on the bottom of the bowl over the next few hours.

With the next solution you will have crystals of sodium chloride, ordinary table salt. To give the sodium chloride crystals something to grow on, attach a small lead fishing sinker to a 6-inch length of nylon thread (fishing line). Tape the fishing line to a pencil so that when placed across the top of a glass the weight does not touch the bottom.

Place a 600-mL beaker with 475 mL of distilled water on a burner or hot plate. Stir in 165 g of salt. Heat the water slowly over medium heat until the salt has all dissolved, but don't allow the water to boil. Pour the solution into a tall, clear drinking glass. Dip your fishing line and weight down into the hot solution, then remove it and set the pencil across another glass while the solution cools. When the solution has cooled to room temperature, gently lower the nylon thread into the solution so it is held by the pencil. Then cover the glass with a cloth. Some crystal growth will occur within the next couple of hours, but for the growth to run its course you will need to let the solution stand undisturbed overnight. The bottom of the glass will fill with crystals, and you should have tiny crystals formed all along the length of nylon thread.

In the third solution, we will use Epsom salt as the solute. Epsom salt (hydrated magnesium sulfate) gets its name from a saline spring in Epsom, England, where the salt was originally produced. Epsom salt is commonly used as a bath salt to relieve aching muscles or sore feet.

To prepare the Epsom salt solution, place a 250-mL beaker with 120 mL of distilled water on a burner or hot plate. Stir in 170 g of Epsom salt. Heat the water slowly over medium heat until the salt has nearly all dissolved, but don't let the water boil. Pour the solution into a small, clear glass bowl and place it in the refrigerator. Over the next three hours you should see the bottom of the bowl fill with needle-like crystals.



Analysis

Harvest the largest and most perfectly formed crystals from each of your solutions. Handle them as carefully as you can, although the table salt and Epsom salt crystals may break anyway. Place the crystals on a dark cloth under bright light. Measure your crystals and sketch them or photograph them. (If you have access to a DSLR camera with a macro lens, it will really help with the photographs. Inexpensive macro lenses are also available now for use with smart phones.)

In your report, include these comments:

1. Describe your observations as the crystals were growing.
2. Describe the size and shape of the largest or most well-formed crystals from each of the solutions.

Background

You will find a great deal of information about growing crystals at a certain hobbyist's website called waynesthisandthat.com. Under the category of Hobbies there is an entry for growing crystals. Although I neglected to reference it in the text, the basic information for this experiment came from there.

Wayne's main goal is to find ways to grow *perfect* crystals. Doing this requires an elaborate temperature control system that will hold the temperature of your hot saturated solution steady, reducing the temperature by only one or two degrees per day. This would be a lot of fun to do, but requires a lot more sophisticated setup than what we are going to use for this experiment. It also requires a lot of time. But I do encourage instructors to read some of Wayn'es crystal growing descriptions and look at the photos of the crystals he has been able to produce. If your students get really interested in growing crystals, and you have the time and means to put together the temperature-controlled setup he describes, the process of producing near-perfect crystals would be fascinating. Of particular interest is his section called "Growing large, high quality single crystals."

The three types of crystals grown in this experiment are easy to grow, and no special equipment is needed. The materials list is shown on the next page.

Additional Notes

This is not a complicated experiment, so there is not much to add. Make sure to use beaker tongs when pouring hot liquids.

For the sodium chloride crystals, the split-shot lead sinker attaches to the fishing line easily by crushing it on the line with a pair of pliers. The purpose for pre-dipping the fishing line and then removing it is

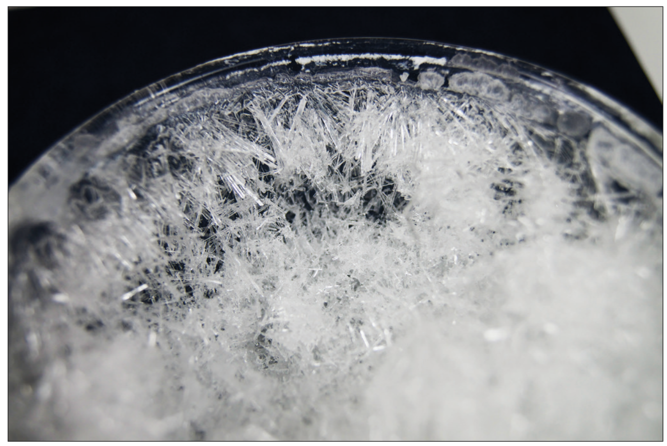
Item	Quantity	Source	Cost	Ext. Cost	Comments
hot plate	1	See Introduction			
beaker, 600 mL	1	See Introduction			
beaker, 250 mL	2	See Introduction			
graduated cylinder, 100 mL	1	See Introduction			
mass balance	1	See Introduction			
refrigerator/freezer	1	See Introduction			
beaker tongs	1	See Introduction			
fishing line	6 inches				Use leftover line from the electrostatic forces experiment (#3).
Epsom Salt, 0.5 gal	1 carton	grocery store	2.99	2.99	
table salt, non-iodized	1 container	grocery store	0.59	0.59	
alum	1 container	grocery store	2.89	2.89	This is found in the spices section of the grocery store.
distilled water	1 gal	grocery store	1.29	1.29	Price for 1 gal. Save extra for the chemical reactions experiment (#9).
lead fishing weight	1				Use one of the split-shot lead sinkers from the kinetic experiment (#1).
clear glass bowl	2	common item	n/a		
tall, clear drinking glass	2	common item	n/a		
pencil	1	common item	n/a		
plastic spoon	1	common item	n/a		
magnifying glass	1	amazon.com	12.95	12.95	Amazon.com has a set of three chrome magnifying glasses for this price.
			Project Total	20.71	

to allow some microscopic seed crystals to form on the line while it dries in the air. Then when the line is replaced in the room-temperature sodium chloride solution you will get crystals to grow on the fishing line. This doesn't always work, and sometimes all you get is a pile of crystals on the bottom of the glass.

Magnifying glasses will make the process of examining the crystals a lot more interesting. It is also fun to photograph the crystals, and to teach the students how to insert the JPG file from a digital camera into a report.

Finally, you can make this class activity even more fun if you have access to a DSLR camera, tripod and macro lens. Or use your phone—macro lens attachments are now also available for smart phones for around \$70. You might also take the opportunity to have someone come in and talk to the students about using a DSLR camera. You will find that close-up macro shots require a lot of light, so you may want to do the close-ups outside.

For taking the pictures below, I placed the crystals on a textbook with a navy blue cloth cover. The dark book cover made a nice background for the white crystals.



Description from Text

Experimental Investigation 5: Determining Volume

Overview

- Use length measurements to calculate the volumes of several different regularly-shaped objects, both cylindrical and rectangular.
- Measure the volumes of each of the same objects using a graduated cylinder and the displacement method.
- *The goal of this investigation is to develop expertise at calculating and measuring the volume of a regular solid object.*

Basic Materials List

- aluminum rod, 3/8 inch diameter × 3 inches long
- aluminum flat bar, 1/8 inch × 3/4 inch × 4 inches long
- aluminum angle, 1/8 in thick, 3/4 × 3/4 × 2.5 inches long
- brass rod, 1/2 inch diameter × 3.5 inches long
- carbon steel flat bar, 1/2 inch × 1/2 inch × 2 inches long
- graduated cylinder, 100 mL
- digital caliper (if possible)
- measuring rule, metric (if a caliper is not available)
- calculator

Safety Precautions

Use care when handling glassware. There are three ways to break glassware—carelessness, silliness, and improper procedures. These are all bad in a lab!

Scientific study often requires the calculation of an object's volume, or the measurement of volume in a lab. In this investigation, you use your calculator to calculate the volumes of five metal samples. Then you measure the volume of each one as a check on your accuracy.

As you learned in the preceding chapter, the volume of a right, regular solid is calculated by determining the area of the base, and then multiplying that by the height. For rectangles, the area of the base is just the product of the lengths of the two sides. For cylinders, the base is a circle with a certain radius (half the diameter) and an area of $A = \pi r^2$. For the sample of aluminum angle (the piece that has an L-shaped base), you can treat the base as two rectangles joined together. Just make sure you include the area of the joining corner in only one of those rectangles.

The best tool to use for making dimensional measurements on small, regular samples like these is a *caliper*. A digital caliper is easy to use, as the photograph shows, and reads out a very accurate and precise measurement directly in centimeters or inches. If you do not have access to a caliper, you can make your measurements with a measuring rule, but they will not be nearly as accurate.

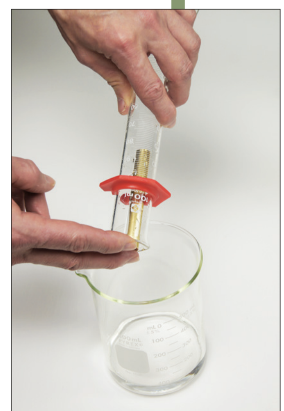
First make all your measurements and record them in your lab journal in a well-organized table. Make all your measurements in centimeters, if possible. If you cannot make measurements in centimeters, then make them in decimal inches and convert each one to centimeters using the appropriate unit conversion factor. Using dimensions in centimeters, calculate the volume of each of the six samples in cubic centimeters.

To check your calculations, we will compare them to measurements made using a graduated cylinder with the *displacement method*. First, fill the graduated cylinder about half full with water. Place the cylinder on a horizontal surface, and read the volume of the water from the scale on the glass. The measurement is in milliliters, which is equivalent to cubic centimeters. (There are some important details to attend to when reading volumes in a graduated cylinder. Please refer to Appendix A for this information.)

After taking the initial water reading, slide your sample gently down into the cylinder and take a second reading. The volume of the sample is the difference between the first and second reading. Measure and record the volume of each of the samples using this method.

When inserting a metal sample into a graduated cylinder, always tilt the cylinder over (without spilling the water), and slide the sample as gently as possible down the side of the cylinder to avoiding breaking the cylinder. When removing the sample, place your fingers loosely over the top of the cylinder to catch the sample, and tip the cylinder over a container or sink to let the water run out. Do not let the sample fall out, because it may damage the sink or become damaged itself.

To compare your calculations to your measurements with the graduated cylinder, we will compute the *percent difference*[1] for each of your six volumes. This calculation expresses the difference between a scientist's prediction and the experimental result as a percentage of the prediction. Neither of your volumes is really a prediction, since they are both based on laboratory measurements, but go ahead and use your graduated cylinder volume measurement as the predicted value and your calculated volume as the experimental value. Then calculate the percent difference as



$$\text{percent difference} = \frac{|\text{predicted value} - \text{experimental value}|}{\text{predicted value}} \times 100\%$$

The absolute value signs mean this percentage always comes out to be positive.

Analysis

Your percent difference values for each of the six samples should not be more than a few percent, maybe as high as 10%. If your difference ratio values are large, then you almost certainly have an error in your calculations or in your measurement procedures. You should find and correct this error and perform the measurements or calculations over again.

In your report, prepare a neat table listing the five samples, all your measurements (with the units of measure), your two volumes, and the percent difference for each.

1 See Appendix B for a note on this terminology.

Preparation

The materials for this activity are listed in the table on the next page. The five metals samples are shown in the photo below. If you wish to procure these metal parts yourself, you have a few options. The aluminum material is commonly stocked at hardware stores in lengths of 36 or 48 inches, and the steel may be as well. To get the brass you may need to locate a metal supply company. I procured my parts from Westbrook Metals in Austin, Texas. They say they are willing to pack and ship to customers outside of Austin, as long as the customer pays the shipping. Another possibility is onlinemetals.com. It is also possible to buy all five of the parts pre-cut to the correct lengths from a metal supply. The downside of ordering from a local metal supply is that they are not generally geared up for making nice looking cuts. So the parts you get may need a lot of work with a grinder and a file to get the ends square and remove the burs and sharp edges. You might be able to address this by talking to the supplier and asking for precise, clean, square cuts.

Cutting metal is very tricky and can be dangerous with power tools. If you do procure bulk metals to cut yourself, make sure the person doing the cutting knows how to operate all the tools safely. All these metals can be

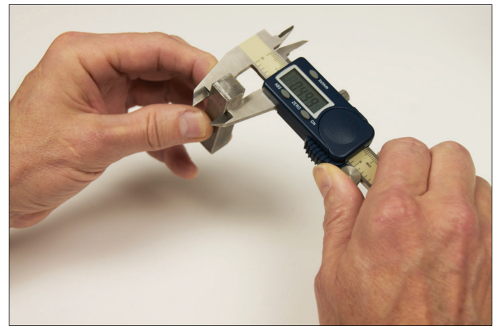
Item	Quantity	Source	Cost	Ext. Cost	Comments
graduated cylinder	1	See Introduction			
beaker, 250 mL	1	See Introduction			
aluminum rod, 3/8 inch diameter × 3 inches long, T-6061 alloy	1	hardware store	I purchased all these parts, pre-cut, from a metal supply shop for $13.10. However, the cuts were not clean at all and a great deal of filing, polishing and work on a bench grinder was required to dress the parts to make them suitable. These parts are available ready-to-use in the Special Parts Kit (see Introduction).		
aluminum flat bar, 1/8 inch × 3/4 inch × 4 inches long, T-6061 alloy	1	hardware store			
aluminum angle, 1/8 in thick, 3/4 × 3/4 × 2.5 inches long, T-6061 alloy	1	hardware store			
brass rod, 1/2 inch diameter × 3.5 inches long, 360 alloy	1	metal supply			
carbon steel flat bar, 1/2 inch × 1/2 inch × 2 inches long, CF-1018 alloy	1	metal supply or hardware store			
digital caliper (if possible)	1	hardware store	24.99	24.99	This price is for the economy option, which has plastic jaws. A higher quality choice is the all-stainless steel Grainger 1AAU4 caliper for $76.05. See grainger.com. (This is the caliper shown in the photos in the text.)
measuring rule, metric (if caliper is not available)	1	hardware store	n/a		
calculator	1	common item	n/a		
			Project Total	38.09	(This is lowest possible price. Using kits and better calipers will cost more.)

cut with a hacksaw. This obviously requires a lot more effort, but it is also a lot safer than power tools. However, it will also be more difficult to get square ends when cutting with a hacksaw. If the ends of the parts are not square, then volume calculations will be inaccurate.

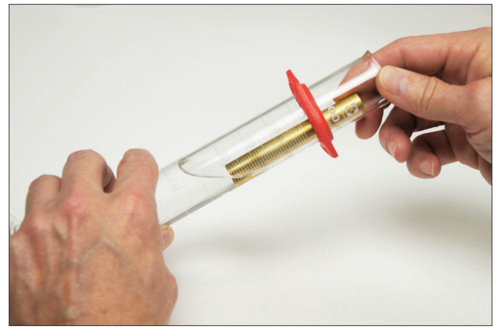
Finally, as previously mentioned, these metal parts are available from Centripetal Press in the *Novare Physical Science* Special Parts Kit or separately.

I strongly recommend procuring digital calipers for the students to use for making their measurements. Not only is this interesting and high-tech, but the measurements are significantly more accurate than measurements made with a rule. In the parts list, the cost for an economy model caliper is shown. These are available at any big hardware store in the tools section. But the economy model has plastic jaws, which will not hold up well over time. Thus, for schools I recommend buying an all-steel model, such as the one suggested in the table from Grainger. If funds are short, buy one or two calipers each year until you have enough for all your lab groups. In the meantime, they can share. The first photo on the opposite page illustrates the use of the caliper to make a measurement.

Procedure



The lab description in the text cautions students on the proper procedures for getting metal samples into and out of a graduated cylinder without breaking the cylinder or the beaker used to pour off the water. To reinforce this message, I recommend that the instructor demonstrate the procedure for the students. Carefully reinforcing proper procedures is a must if one is to avoid broken glassware in a lab. The second and third photos below illustrate insertion and extraction of a metal sample into and from a graduated cylinder.



When making measurements with a graduated cylinder, it is a good idea to repeat the measurement with a different amount of water about three times. Students will be surprised to see how their measurements can vary, and even small variations can produce significant differences between the volume measured in the graduated cylinder and the calculated volume.

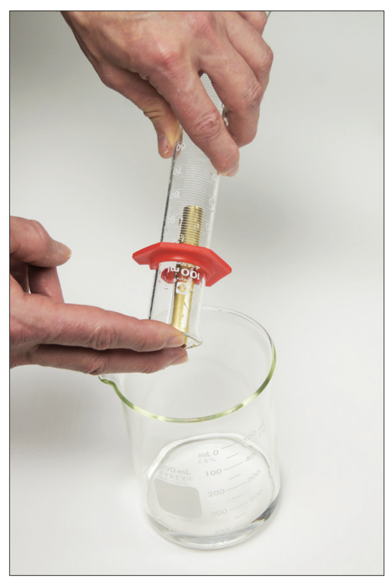
Analysis

In the description in the text, I introduce the students to what I call the *percent difference* for comparing experimental results to a reference or predicted value. Be sure to read the short explanation in Appendix B of the text explaining why I use this terminology. Take the time to help student master this computation. We use it a lot in later experiments, and it is frequently used in other science courses as well.

Sample Results

The table below shows my own measurements when conducting this experiment. With very careful measurements, three of the percent difference values are in the 1–2% range. When looking for an explanation of why the two rectangular aluminum pieces had differences in the 5–6% range, I noted that the corners on these aluminum pieces are noticeably rounded off. This caused my calculated volume to be larger than the measured volume in both cases. This indicates that the volumes determined with the graduated cylinder for those two parts are more accurate than the calculated volume.

Item	Measured Dimensions	Calculated Volume	Volume from Grad. Cyl.	Percent Difference
aluminum cylinder	9.66 mm diam × 79.81 mm L	5.85 cm^3	5.7 cm^3	2.6%
aluminum flat bar	105.10 mm × 3.29 mm × 19.01 mm	6.57 cm^3	6.2 cm^3	6.0%
aluminum angle	65.03 mm × 3.24 mm thick; 19.14 mm side to edge	7.38 cm^3	7.0 cm^3	5.4%
brass cylinder	12.68 mm diam × 87.98 mm L	11.11 cm^3	11.0 cm^3	1.0%
steel flat bar	53.10 mm × 12.66 mm × 12.66 mm	8.51 cm^3	8.4 cm^3	1.3%



Description from Text

Experimental Investigation 6: Determining Density

Overview

- *The goal of this investigation is to determine the densities of several different materials and compare these densities to reference density values.*
- Measure the mass in grams of the five metal samples from the volume investigation (three aluminum, one brass, one carbon steel).
- Using the volume data from the volume investigation (Experimental Investigation 5), calculate the density for each sample.
- Using common reference density values for predicted values and your calculated densities for experimental values, calculate the percent difference for each sample.

Basic Materials List

- aluminum rod, 3/8 inch diameter × 3 inches long
- aluminum flat bar, 1/8 inch × 3/4 inch × 4 inches long
- aluminum angle, 1/8 in thick, 3/4 × 3/4 × 2.5 inches long
- brass rod, 1/2 inch diameter × 3.5 inches long
- carbon steel flat bar, 1/2 inch × 1/2 inch × 2 inches long
- mass balance
- calculator

In addition to giving you an opportunity to work with the density equation, this investigation will also give you some idea of how accurate your volume measurements were from the volume investigation you performed. Our procedure in this investigation is very simple. Begin by measuring the mass, in grams, for each of the five metal samples. Record each of these, along with the units of measure, in a table in your lab journal.

Now calculate the density for each sample, using the density equation,

$$D = \frac{m}{V}$$

In this equation, D stands for the density, m is the mass of the sample, and V is the volume. If your masses are in grams and your volumes are in cubic centimeters, then your calculated densities have units of grams per cubic centimeter, g/cm^3. Your volumes are the values you determined in Experimental Investigation 5, "Determining Volume." In that investigation, you determined each volume two different ways. Use the volume values from your previous work that you think are most accurate.

Use your mass and volume values to calculate the density for each sample. Enter each of these density values, along with the units of measure, in your lab journal. Since three of the pieces are made of aluminum, the density values for these samples should be very close to one another.

Now we want to compare these experimentally determined densities to the standard density values for these materials. We will use the standard values as "predicted values," and your calculated densities as "experimental values." Any time you want to compare an experimental result to a prediction, the standard way to perform the comparison is to calculate the percent difference, according to this equation:

$$\text{percent difference} = \frac{|\text{predicted value} - \text{experimental value}|}{\text{predicted value}} \times 100\%$$

This equation expresses the difference between your experimental value and your prediction as a percentage of the prediction.

You will use the percent difference equation to determine how well your density values compare with published values for the densities of these materials. Use the published values shown in the table as the predicted values to calculate the five percent difference values for your samples.

The most common alloy of aluminum for making structural parts is called T-6061, so I have the density for this alloy in the table. It is likely that your aluminum samples are made of 6061 or a similar alloy. A common brass alloy is called alloy 360. The most common steel alloy for ordinary steel parts is called CF-1018, and it is likely that your steel bar is made of CF-1018.

Material	Standard Density
aluminum, T-6061 alloy	2.72 g/cm^3
brass, alloy 360	8.5 g/cm^3
steel, CF-1018 alloy	7.85 g/cm^3

Analysis

Make a table in your report showing the volume, mass, standard density, experimental density, and percent difference for each of the five samples. Be sure to show the correct units of measure for each entry in your table. Address the following questions in your report.

1. Do your three density values for aluminum agree? That is, are they fairly close together? If they are not, speculate on why they might be so different. What part of the process of determining the densities of the three aluminum samples did you feel was most subject to error?
2. Are your percent difference figures all below 10%? If not, then again speculate why your results might be so different from the reference values. What part of the process of determining the density did you feel was most subject to error? Do you think the problem was with your volume values, or somewhere else? For samples with a high percent difference value, go back and look at your volume data from the volume investigation. There you found volume two different ways. If your two volumes disagreed (that is, were not very close), then try using the other volume for your density calculation to see if it gives a better result. If the percent difference is lower, then your experimental result is a closer match to the prediction. This is what we mean by a "better result."

Preparation

The metal samples used in this activity are the same as for the volume experiment (#5). In addition, you need a mass balance (see Introduction for comments on the balance) and calculator.

Analysis

Since students already have the volume data on the samples, the only thing they need to do is measure the mass, compute the density, and determine the percent differences for each metal.

My own results are shown in the table at the top of the next page. I calculated the density using both of the volumes from the volume experiment (the volume from the graduated cylinder and the volume determined from measurements of the metal part). I also calculated the percent difference for both density values.

As you can see, the percent differences are all quite good; all but one of them are less than 3%, and several of them are 1% or less. These low figures represent excellent agreement between the published reference density values and my own measurements of the material densities.

In the volume experiment (#5), students are instructed to use the graduated cylinder volume as the "predicted value" and the volume based on the part dimensions as the "experimental value." As I mention when discussing that experiment, an accurate measurement from a graduated cylinder is probably more accurate than a volume determined from the part dimensions—at least for the rectangular pieces. This is because the edges of the rectangular pieces are noticeably rounded; the edges are not sharp and square. So calculated volumes are higher than volumes measured with the graduated cylinder. However, it is more difficult to make accurate measurements with the graduated cylinder than with a digital caliper. Students must

Material	Mass (g)	Density from Graduated Cyl. Volume (g/cm³)	Density from Calculated Volume (g/cm³)	Standard Density (g/cm³)	Percent Difference for Graduated Cyl. Volume (%)	Percent Difference for Calculated Volume (%)
aluminum cylinder	15.7	2.75	2.68	2.72	1.1	1.5
aluminum flat bar	17.3	2.79	2.63	2.72	2.6	3.3
aluminum angle	19.6	2.80	2.66	2.72	2.9	2.2
brass cylinder	94.0	8.55	8.46	8.5	0.6	0.5
steel flat bar	66.1	7.87	7.77	7.85	0.3	1.0

attend very carefully to parallax error, reading from the bottom of the meniscus, and estimating the last digit of the measurement from the position of the bottom of the meniscus between the marks on the graduated cylinder. For these reasons, the graduated cylinder measurement may or may not be the most accurate one.

In the description in the text, students are instructed to use the volume values they think are most accurate. However, if you have time, I think the best thing to do is have the students calculate densities from each of their volume measurements, and calculate percent difference values for both densities. They should then make a table similar to the one above displaying all these values. With two percent difference values per part, you can have a much better discussion about the merits of the different measurements.

For example, in the table above you can see that the rectangular aluminum pieces had the highest difference ratios, and this applies regardless of how the volume was determined. Moreover, both of the densities determined from the graduated cylinder volume were higher than the reference value, and both determined from part measurements were lower than the reference values. The low density values for the calculated volumes can be explained by the larger volume values obtained by that volume method. It is unclear why the two graduated cylinder volumes resulted in densities that were higher than the reference values. The only way to track that down would be to perform the same measurements on many more parts and look for patterns (which is probably not worth the effort at this point).

Thinking Scientifically About Experimental Results

As simple as it is, this experiment affords the teacher an opportunity to address a very common weakness of science and math courses at younger grades. This is the tendency for problem-solving activities to lead students to expect a single, exact right answer every time they are dealing with quantitative information. This tendency is nearly universal, and by the time students arrive in 9th grade they are so accustomed to thinking this way that it often takes a year or more to train them to think differently about experimental results.

As an example, assume this experiment were being performed at the very beginning of 9th grade. (Similar experiments do occur in each of my Introductory Physics texts.) If a student determined the density of aluminum to be 2.68 g/cm^3, as I did in one case, the nearly universal response would be for the student to assume her answer was "wrong" because she did not come up with the value 2.72 g/cm^3. This is not an appropriate way to think about experimental results.

Experimental results are always based on measurements and measurements always contain error. Further, measurements involve uncertainty because of the variation in measurements. If you measure the volume of one of these metal parts three times in a graduated cylinder, you are likely to get three slightly different measurements, even when you are being as careful as you can. Further still, experimental results are always limited by the resolution in the measurement tools. This limit to the resolution in a measurement is called the *precision* of the measurement. Our experimental results can only be as precise that the instruments used to make the measurements.

Taken together, all these factors mean that it would basically be a fluke for an experimental value to come out to be identical to the predicted (or reference) value. It is important for students to begin to understand this as early as possible. The goal of this experiment is not for students to determine the density of CF-1018 steel to be 7.85 g/cm^3. The goal is to *determine the density as carefully and accurately as possible*. To assess how successfully we were, we need to compare our result to the value predicted from the theory, or in this case, the reference value. We do this by calculating the percent difference.

What constitutes a reasonable or "good" percent difference? That depends on the quality of the instruments used to make the measurements. If the students measured their volumes using a rule instead of a digital caliper, an agreement of 5% between the reference value and the measured value should be considered "very good." The more precise the measurement tools are, the closer we should expect the agreement to be. Values below 3% with student grade equipment should always be considered very good, and values under 1% should be described with the language I used on the previous page: "*excellent agreement* between the published reference values and the experimental results."

In summary, spend plenty of time discussing this issue with your students. This experiment is not about getting "right" or "wrong" "answers." It is about comparing reference values to our measurements and assessing how well our measurements compare to the published values. Whenever a quantitative experimental result is obtained, the first thing the student should want to determine is the percent difference. This is the value that indicates how closely the predictions and experimental results agree.

Description from Text

Experimental Investigation 7: Heat of Fusion

Overview

- *The goal of this experiment is to observe the effects of the heat of fusion of a substance.*
- Mix equal volumes (100 mL) of water at 20°C (room temperature) and 90°C and measure the equilibrium temperature. Repeat two more times. Repeat with water at 5°C. Then repeat with ice at 0°C.
- Collect initial and final temperature data and prepare charts showing initial temperatures and equilibrium temperature for each of the nine trials.

Basic Materials List

- digital thermometers (at least 3)
- graduated cylinder (2)
- Styrofoam cup, 16 oz (10 or so)
- refrigerator/freezer
- beaker, 600 mL (2), and 1000 mL
- hot plate and tongs
- safety glasses, hot gloves
- water, ice cubes, and ice chest

Safety Precautions

1. When pouring hot water, always use tongs to handle the hot beaker.
2. Wear safety glasses or goggles when pouring hot water, and keep your hands out of the way.
3. Use care when pouring hot water: pour slowly and carefully so hot water does not spill.

As we saw in the previous chapter, heat is needed to raise the temperature of any substance. Heat is also needed to make a substance change phases, even though the substance remains at the same temperature while doing so. The amount of heat required to melt a substance, while keeping its temperature constant, is called the *heat of fusion*.

In this experiment, you will repeatedly mix equal volumes (and thus equal masses) of water at different temperatures (six separate trials) to see how the equilibrium temperature compares to the initial temperatures. Then you will do the same thing with ice at 0°C and boiling water (three more trials). By comparing the mixing of water at different temperatures to what happens when mixing ice with water, the effect of water's heat of fusion becomes apparent.

What do you expect the equilibrium temperature to be when equal quantities of water at different temperatures are mixed? It should seem logical to expect the equilibrium temperature of the mixture to be half way between the two initial temperatures. In other words, the final temperature is the average (mean) of the initial temperatures. Now, what do you expect to happen when one of the water samples is frozen and is at 0°C? Will the final temperature still be the average? We will see. *Before you begin collecting data, write down in your lab journal your hypothesis of how the final temperature will turn out for each of the three sets of trials. Be as specific as possible in your predictions.*

Measure 100 mL of water at room temperature in a graduated cylinder and pour it into a Styrofoam cup. Insert a thermometer in the cup. Prepare two more cool water cups the same way. Fill a 600-mL beaker on a hot plate and bring the water to boil. After the water reaches 100°C, use tongs (very carefully!) to measure out 100 mL of hot water into the graduated cylinder. Have an assistant wearing a hot glove hold the graduated cylinder during pouring to prevent the cylinder from tipping over. The temperature of the hot water will be lower after pouring into the cylinder, so measure the hot water temperature in the graduated cylinder. After recording the hot water temperature, and the temperature of one of the cool water cups, pour the hot water into the cool cup and record the equilibrium temperature. Repeat this two more times. Then repeat this whole procedure using a 600-mL beaker of water that has been chilled to about 5°C.

For the trials involving ice, measure out 100 mL of water into each of three Styrofoam cups, place a digital thermometer into each cup, and place them in the freezer over night. The digital thermometers will allow you to record the temperatures inside the ice without damage to the thermometer. We want the ice to be at 0°C, but after freezing the ice temperature will be much lower than that. To warm the ice without melting it, prepare an ice water bath (1 inch deep) in an ice chest with a lid. Nestle the ice cups in the bath and let them stay there with the lid on until they have warmed to 0°C. Then remove them one by one from the bath and pour in 100 mL of hot water. For hot water in these trials, you must preheat the graduated cylinder by filling it with boiling water, emptying it, and filling again with 100 mL of water. (Without preheating, the water will not be hot enough. Try to achieve hot water temperatures in the graduated cylinder of at least 90°C.) Measure the hot water temperature in the graduated cylinder. Then pour the water into the cup with the ice. Do not record the final temperature for these three mixtures until all the ice has melted.

Cup 1 Initial Temp. (°C)	Cup 2 Initial Temp. (°C)	Equilibrium Temp. (°C)
20°C	90°C	
20°C	90°C	
20°C	90°C	
5°C	90°C	
5°C	90°C	
5°C	90°C	
0°C ice	90°C	
0°C ice	90°C	
0°C ice	90°C	

Enter all the temperature data in your lab journal in a table similar to the one shown above. In the table shown, I have entered the target temperatures. In your table, you should enter your own actual temperature data.

Analysis

Prepare a chart displaying the two initial temperatures and the equilibrium temperature for all nine trials. Your instructor will help you with setting up your graphs and labeling them properly. Use your graphs to help you compare your results to your hypothesis. In your report, address the following questions.

1. Were the results for mixtures involving only water consistent with your hypothesis? Is there a consistent mathematical relationship between the initial and final temperatures for these?
2. Is the relationship between the initial and final temperatures for the trials involving ice the same as it was for trials involving only water? Explain what you found.
3. How do the data indicate the effect of the heat of fusion of water?
4. Try to describe the mathematical relationship between the initial and final temperatures for the ice trials, and see if you can explain how it compares to the water-only trials.
5. Explain what the term *heat of fusion* means, and summarize how the heat of fusion of water affects the results of this experiment.

Preparation

The materials needed for this experiment are listed in the table on the next page. All the items are either standard lab equipment, leftovers from previous experiments, or common household items, so the cost for special items for this experiment is just the cost of a pair of gloves. To perform this experiment in a single class period you need five digital thermometers. If this expense is a problem, then you can make do with fewer thermometers by splitting up the trials on different days. If you perform all the ice trials on the same day you still need four thermometers. As noted in the Introduction, the thermometers are frozen in ice during part of the procedure, so digital thermometers with metal stems should be used instead of glass thermometers.

Running the Experiment

Use separate graduated cylinders for measuring out hot and cold water, and use separate thermometers for measuring their temperatures. This will minimize the effect of the glass and metal from these items on the temperatures of the liquids involved.

Additional Instructions for the Ice Trials

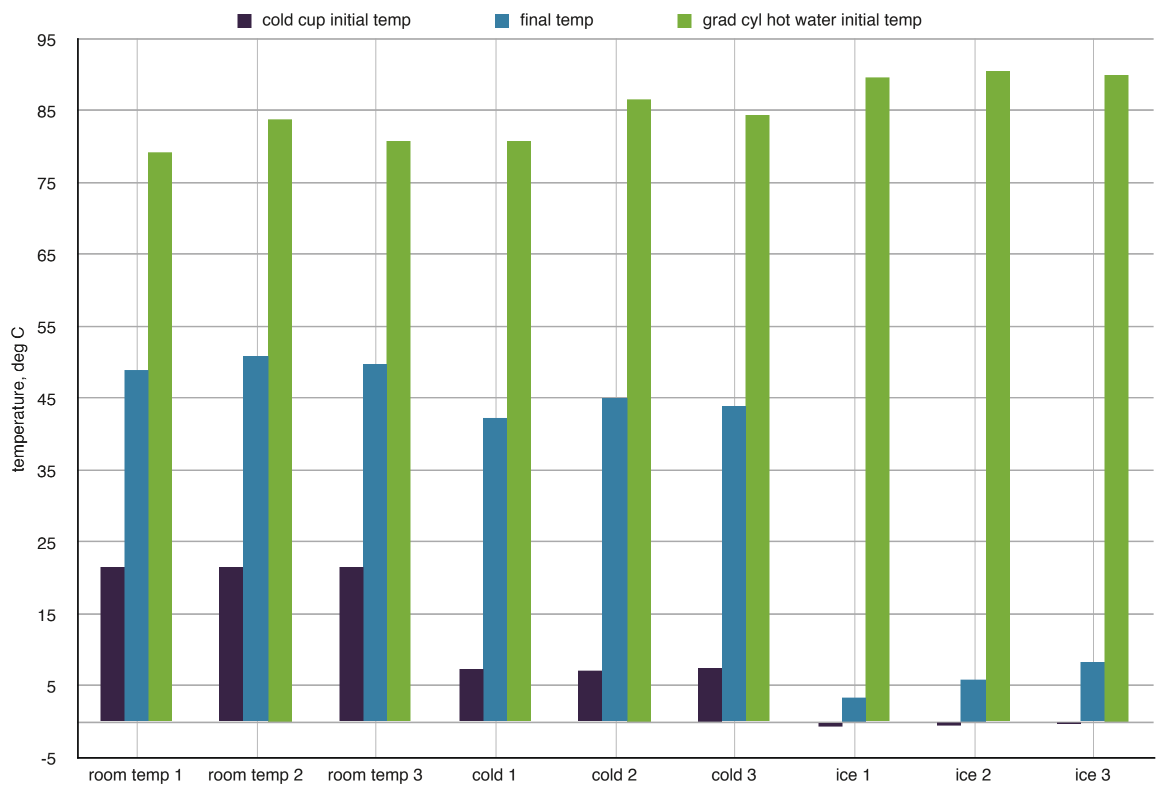
For the ice trials, the digital thermometers survive a night in the freezer without damage. However, when removing the ice cups from the freezer, let them stay in the ice water bath for half an hour or so before

Item	Quantity	Source	Cost	Ext. Cost	Comments
hot plate	1	See Introduction			
beaker, 600 mL	2	See Introduction			
beaker tongs	1	See Introduction			
graduated cylinder, 100 mL	2	See Introduction			
refrigerator/freezer	1	See Introduction			
digital thermometer	5	See Introduction			
heat resistant gloves	1 pair	grainger.com	1.97	1.97	Grainger has many different heat resistant gloves, starting as low as 1.97 per pair. Gloves with cuffs will afford even more protection.
Styrofoam cups, 12 oz	10				Use leftover cups from heat transfer experiment (#2).
Styrofoam cooler	1				Use one leftover from the heat transfer experiment (#2).
			Project Total	1.97	

you switch on the thermometers. The batteries in the thermometers will not be happy after spending the night in the freezer. But once they warm up a bit, they will work normally.

An ice water bath always has a temperature of 0°C. This is because 0°C is the temperature where ice and water can coexist at atmospheric pressure. Allow the ice cups to remain in the ice water bath in the closed ice chest until their temperatures are somewhere between –1°C and 0°C. The accuracy of most thermometers is ±1°C, so even when the ice in the cups has reached the temperature of the ice water bath, your thermometers may read a bit below zero. (All three of mine did.)

Use boiling water for the hot liquid in all nine trials. When poured into a graduated cylinder, the boiling water cools to around 85°C. This is okay for the trials involving room temperature water and chilled water. However, for the three trials with ice, 85°C is not hot enough to melt the ice completely. So for these trials, it is important to pre-heat the graduated cylinder before each trial. To do this, simply fill the graduated cylinder with boiling water from the hot plate, then dump that water into a waste water beaker and immediately fill the graduated cylinder again to the 100 mL mark. Place your thermometer in the graduated cylinder, record the temperature, and then pour the hot water into the cup with the ice. This procedure allows your initial temperature for the hot water to be right at 90°C. Strive to get the hot water temperature to at least 90°C for each of the ice trials.



Graph Preparation

The chart above is called a *side-by-side bar chart*. This is a good way to display the data for this experiment. Each of the nine trials has its own set of three bars. The highest and shortest bars represent the initial temperatures of the hot and cold water (or ice), respectively. The middle bar represents the equilibrium temperature. Setting up this type of chart in software such as Excel or Pages takes some effort. If learning to use computer tools is part of your course objectives, this graphical exercise will be a good experience for your students. But in my opinion, it is fine for middle school students to construct their graphs by hand on graph paper. (Beginning in 9th grade, all graphs should be prepared on a computer.)

In middle school, it is most important that students are learning to set up graphs with care, understanding how to set up the scales, label the axes, show the units of measure, and so on. The importance of learning these skills must not be overlooked. If you have time in your class and wish to go farther by getting into computer applications, then so much the better. Some students will readily take to Excel or Pages and will have their graphs set up in no time at all. Others will find learning about these applications to be a dull and frustrating task. Success with using a computer at this age depends on both the skill of the teacher and the aptitude and interest of the students.

Analysis

The graphs show that for all water-only trials, the equilibrium temperature is approximately equal to the midpoint between the cold and hot water temperatures. For the ice trials, the equilibrium temperature is consistently far below the midpoint, and in fact is just slightly above the ice temperature. This is due to the heat of fusion of the ice—the energy required to melt it. The melting occurs before any subsequent warming. The data show that nearly all the thermal energy in the hot water is used to melt the ice. There is very little thermal energy left over to heat the melted H_2O after it becomes liquid, so the equilibrium temperature is barely higher than the ice temperature.

Description from Text

Experimental Investigation 8: Inertia and Force

Overview

- *The goal of this experiment is to observe how equal forces affect objects with different masses.*
- Assemble a jig that allows a small spring to be compressed by four different fixed amounts. Use the jig to launch balls of different masses straight up from the jig.
- Have an assistant use a pole or board held vertically to mark the maximum height achieved by the different balls.
- Prepare a graph of maximum height vs. mass for each of the four spring compressions.

Basic Materials List

- golf ball, table tennis ball, and 1-inch diameter wooden ball
- launching jig
- spring
- mass balance
- small screwdriver
- measuring pole and measuring tape
- safety goggles

Safety Precautions

The person launching the balls needs to wear eye protection. Protect your eyes by wearing safety goggles.

The force exerted by a compressed spring depends only on how stiff the spring is and how far the spring is compressed. If a given spring is repeatedly compressed by the same amount, then the force exerted by the spring in each case is the same. In this experiment, we use this principle to apply equal forces to balls with different masses. This allows us to observe how the inertia of each ball affects the way the ball responds to a given amount of force.

You have learned that Newton's second law of motion can be expressed in the equation

$$a = \frac{F}{m}$$

According to this equation, if we use the same amount of force to accelerate different masses, then the larger the mass is the lower the acceleration is—an inverse proportion. We are going to use a spring in a launch jig to launch three balls straight up. The three balls are all about the same size, so the air affects them each about the same. But they have different masses, so their accelerations are different. The faster a ball accelerates while the spring is releasing, the faster the ball is moving as it leaves the ground. And the faster it is moving when it leaves the ground, the higher it goes.

In an experiment like this, velocity and acceleration are difficult to measure. So we will use the height each ball achieves to represent the acceleration the ball experienced when it was launched. The height is a bit tricky to measure too, but I think you will have fun doing it.

The launching jig is shown in the photo. There are four spring holes in the jig, with four different depths. To launch one of the balls, press the ball down on the spring with the sides of your thumbs or two fingers, pressing the ball all the way to the wooden block. Then snap your thumbs down suddenly to release the ball. This is tricky to do, and sometimes the ball does not go very straight, or even up, so plan on launching each ball 10 or 15 times from each spring position. When a launch does not work, just retrieve the ball and do it again.

To prevent the spring from flying out of the hole along with the ball, there is a small hole in the side of the jig near the bottom of each spring hole where you can insert a small screwdriver. After the spring is in the hole, insert the screwdriver and the spring is prevented from flying out.

While you or one of your teammates is launching the balls, another team member can mark how high the balls go. Use a long pole or 1×4 held next to the launch jig. For the lighter balls, and the greater spring compressions, the person monitoring the height may need to stand on a step stool or chair. Use your fingers to indicate on the pole the maximum height achieved for a given ball and a given spring compression. After you have seen the ball make it to that same maximum height three times, then measure the height above the launching jig with a measuring tape and record the value (in inches) in your lab journal.

Also measure and record the mass of each ball (in grams), and the height the spring extends above the jig for each hole (in mm). The spring height above the jig is the amount the spring is compressed for launch at each hole.

Analysis

Prepare a graph with four separate curves on it, one for each amount of spring compression. On the graph, the horizontal axis represents the mass of the ball. The vertical axis represents the maximum height achieved. Your instructor will help you in scaling the axes and plotting the points on each of your four curves. In your report for this experiment, address the following questions. Use the mass of the table tennis ball as a reference for these questions.

1. Compared to the table tennis ball, approximately how massive are the other two balls (twice the mass, five times the mass, etc.)?
2. According to the Newton's second law equation, if a mass is twice as much, what should happen to the acceleration? If a mass is five times as much, what should happen to the acceleration? In your case, for the masses you measured for the wooden ball and golf ball, how should their accelerations compare to that of the table tennis ball?
3. Using the maximum height achieved as an estimate for each ball's acceleration, how do the maximum heights compare to that of the table tennis ball (50% as high, 20% as high, etc.)? Do the height comparisons match with what you expected from the mass comparisons? Explain.

Preparation

This experiment requires a four-hole spring mounting block. Instructions for making it are included here and in Appendix 1, but it is included in the Special Parts Kit if you do not intend to make it yourself (see Introduction). If you make it yourself, you can use the leftover 1 × 4 from the kinetic energy experiment (#1) to make the block.

I searched everywhere for a spring that would work well in this experiment. I found only one suitable spring—the springs used in the suspension systems of radio-controlled cars. One manufacturer of these parts is Traxxas. They make many different springs that all look alike but vary in price. The least expensive one is part no. 4457 for $2.49. The next one up is the 4957 for $2.99. One source for these parts is Hobby Town. I could not find these springs on the Hobby Town website, but my local Hobby Town retail store had them. Contact the local Hobby Town retail store nearest you to get the springs, which come in packs of two. There is a store locator on the Hobby Town website.

The hole depths in the spring mounting block were chosen to work with the Traxxas 4457 spring. With this spring and the hole depths shown, you can place the block on the floor and launch the Ping Pong ball from any hole without the ball hitting the ceiling.

Running the Experiment

This experiment is loads of fun with middle-school kids. The balls often fly in strange directions when launched, so expect a lot of jumping around and rushing to retrieve the balls, especially with the Ping Pong ball. Be sure to have the person launching the balls wear eye protection to prevent accidentally getting hit in the eye during a launch.

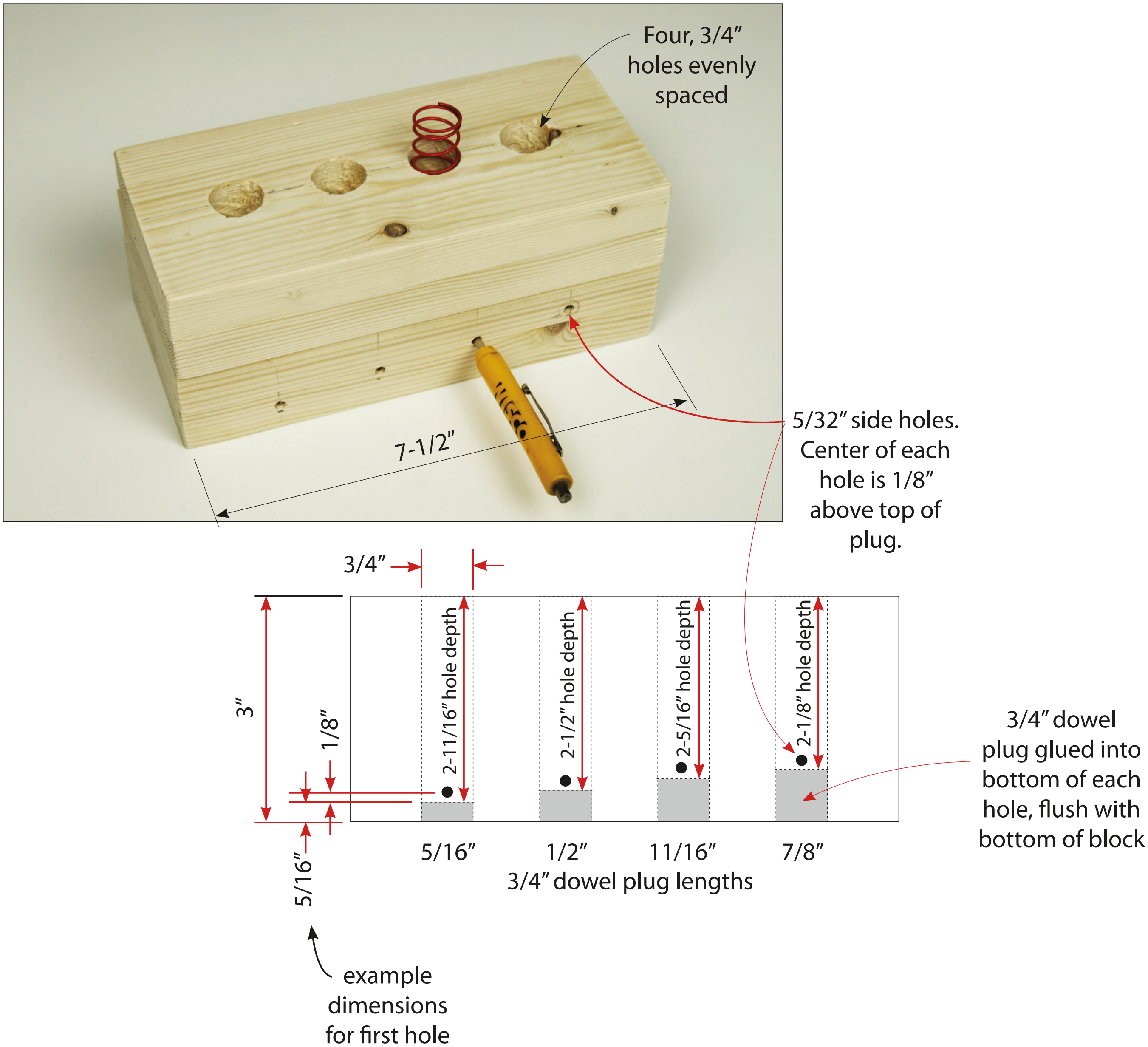
The basic idea for how to launch the balls and measure the height is shown in the photo at the bottom of the next page. One person holds the yard stick with its base on the launching block. Another person presses the ball down on the spring with the sides of two thumbs or two fingers. The fingers are then snapped down

Item	Quantity	Source	Cost	Ext. Cost	Comments
meter stick or yard stick	1	See Introduction			
mass balance	1	See Introduction			
1 × 4 pine	32 in	hardware store	n/a		These items are not needed if kit is purchased. If kit is not purchased, you can use leftover 1 × 4 from kinetic energy experiment (#1). Price shown for the dowel is for 48″.
wooden dowel, 3/4 inch	3 in	hardware store	1.68	1.68	
spring	1	Hobby Town	2.49	2.49	Not needed if the kit is purchased. Get the Traxxas 4457 ($2.49) or 4957 ($2.99) spring kit. Price is for pack of 2.
golf ball	1	sporting goods	6.49	6.49	Price is for box of 12 economy golf balls.
Ping Pong ball	1	sporting goods	2.99	2.99	Price is for pack of 6.
wooden ball, 1″ diam	1	craft store	1.47	1.47	Price is for pack of 6.
safety goggles	1	science supply or hardware store	1.95	1.95	See sciencecompany.com item no. NC-11006.
small screwdriver	1	common item	n/a		
tape measure	1	common item	n/a		
wood glue	1	common item	n/a		
			Project Total	15.40	

quickly to release the ball, and the spring fires it straight up (sometimes). Some people are better at doing the launching than others, so if one person can't seem to do it, let someone else have a shot at it. I never was very good at the launching, but other people had no trouble at all.

The person marking the height should hold his or her fingers on the yardstick at the highest point reached by the ball. Each time the ball is launched and goes up like it is supposed to (instead of off to one side), check the maximum height reached. After a few launches, your fingers on the yard stick should converge to the correct mark for the height of the ball. When the ball goes up to this maximum height three times, without ever going higher, then record this height as the height for that ball and that amount of spring compression.

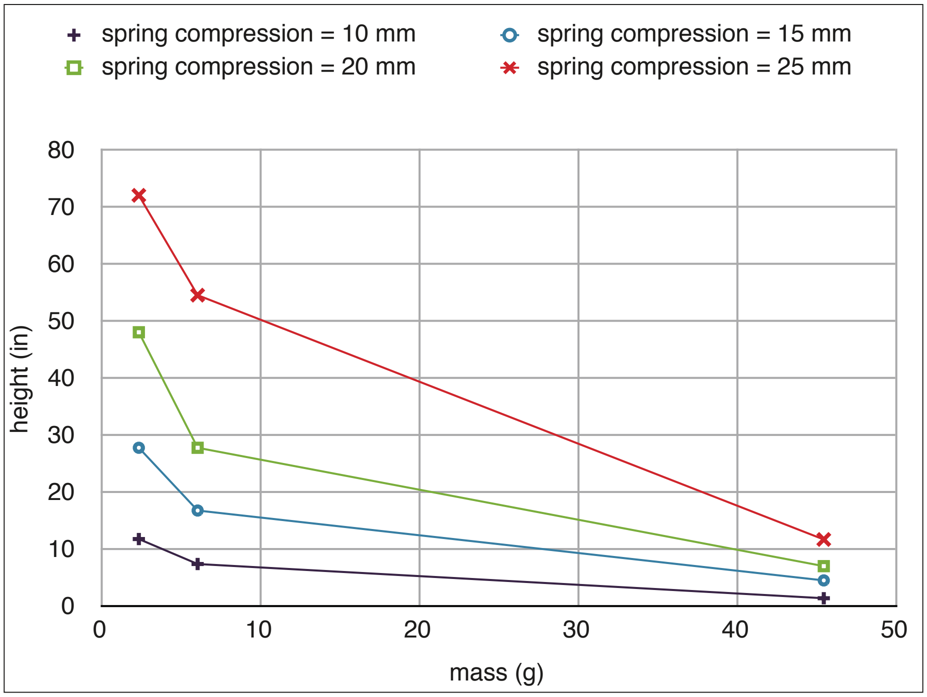
With the dimensions and spring shown here, the spring compressions for the four holes are 10 mm, 15 mm, 20 mm, and 25 mm. Students should measure these, as well as the mass of each ball, and record all the data in their lab journals.



Analysis

A sample of the graph showing the four curves for different spring heights is shown below. By placing the four curves on the same graph, the graph tells an interesting story. We notice first that each curve is an inverse proportion. This is what we expect from Newton's second law, $a = F/m$. In this equation, acceleration is inversely proportional to mass and directly proportional to force. In our experiment, spring compression corresponds to force and height corresponds to acceleration. The curves clearly show that as force (spring compression) increases, acceleration (height) height increases—a direct proportion. Also, as mass increases, acceleration (height) decreases—an inverse proportion.

Also evident in this graph is how the curves maintain their inverse-proportion shape with different amounts of spring compression. Instructors need to show students how to use a legend along with different symbols and/or colors to identify the different sets of data in the graph.



At this level, students are just beginning to understand how to think in mathematical terms about the relationships between scientific variables such as acceleration, force, and mass. Discussing this at length and in depth must be the a central part of this activity, both before you conduct the experiment, and then again after you have data in front of you. So here is a summary about the logic of this experiment, and how it demonstrates the relationship between force and inertia embedded in Newton's second law of motion. You should discuss this with students until it is clear they understand how the experiment demonstrates the mathematical relationship in Newton's second law.

1. When the spring is in a given hole, it exerts the same force on any ball that compresses it. This is because the force exerted by our Traxxas spring depends only on how far it is compressed.
2. Second, we are varying the inertia of the object being accelerated by using balls with different masses. The balls are all more or less smooth, and more or less the same diameter, so we expect external factors such as air friction to be roughly equal. So for the spring in a given hole (a given spring compression), the force is a constant and the mass varies. Since we are varying the mass, we can consider mass to be the independent variable, which gets assigned to the horizontal axis in a graph. Newton's second law says that $a = F/m$. So acceleration is the dependent variable, which gets assigned to the vertical axis in a graph. For any given force, as mass (inertia) increases, acceleration decreases—an inverse proportion.
3. Acceleration is very difficult to measure directly. So we are using the height the ball goes to represent the acceleration it has while in contact with the spring. The higher the ball goes, the greater its acceleration is during the launch.
4. The different holes provide different forces. These correlate to the different curves in the graph above.
5. The graph shows the inverse proportion between acceleration and mass. It also shows that when the force is increased (by increasing the spring compression, a higher curve in the graph), the inverse proportion between acceleration and mass is still there. Newton's second law tells us that *it is always there*. In this experiment, we use three different masses and we find that no matter what the force is, as mass goes up, acceleration goes down, just as Newton's second law says.

One final note. Make sure to reinforce to your students that the scales on graphs must be linear, that is, marked off in equal intervals. It is not uncommon for students to take data, such as the three masses in this experiment, and assign the grid intervals to the data points. In this experiment for example, a student might label the first three grid marks on the horizontal axis as 2.4, 6.1, and 45.5 (the ball masses), instead of 10, 20 and 30 as shown in the graph above. This error indicates that the student does not understand how the geometry of the graph represents the relations between variables. It's okay if it takes some students longer than others to understand relationships between variables. The teacher must help them along that road to understanding by making sure that every student has used a linear scale for both axes of every graph.

Description from Text

Experimental Investigation 9: Observing Chemical Reactions

Overview

- Synthesize (make) three of the compounds contained in the verdigris finish on the Statue of Liberty.
- Watch six chemical reactions (conducted by an adult instructor) and document your observations.
- *The goals of this investigation are to gain experience identifying types of compounds in equations, and to associate chemical formulas and chemical equations with visual observations of what the compounds and reactions look like.*

Basic Materials List

- copper sulfate, sodium hydroxide, sodium bicarbonate, hydrochloric acid
- distilled water
- graduated cylinder, 100 mL
- beaker, 250 mL (2)
- flask, 250 mL (2)
- plastic spoons, large funnel (2), filter paper, paper towel
- plastic gloves, hot gloves, protective eyewear
- frying pan (small), spatula, scraper
- burner and burner tripod.

Safety Precautions

1. Sodium hydroxide is a very corrosive base, and hydrochloric acid is a very corrosive acid. Do not let either substance contact your skin. Wear gloves and protective eyewear when handling NaOH and HCl. Rinse all glassware thoroughly in water.
2. Wear hot gloves and protective eyewear when working with the burner and hot pan.

In this investigation you are going to observe six separate chemical reactions, making careful notes of what you observe in your lab journal. The reactants and products of these reactions are compounds we discussed in Chapter 11. Also, the reactions are all inter-related and fun to watch. It should be interesting to see the chain of events that leads from one set of compounds to the next.

Let's begin with some notes on symbols for chemical equations. To help keep track of the compounds in reactions, it is customary to place parentheses after each compound. Inside the parentheses is a symbol indicating what form the compound is in. Here are the symbols used in this Experimental Investigation:

- (*aq*) means the compound is in an aqueous solution. This could refer to a compound like a salt that is dissolved in water. Also, acids and bases are solutions in water, so they are denoted with this symbol.
- (*s*) means the compound is a solid.
- (*l*) means the compound is a liquid.
- (*g*) means the compound is a gas.

Also, sometimes we need to make it clear in a chemical equation that the reaction doesn't just happen by itself. For example, the reactants may need to be heated to a certain temperature in order for the reaction to take place. This is indicated by placing symbols above and below the reaction arrow like this:

$$\xrightarrow[290^{\circ}\text{C}]{\Delta}$$

The triangle above the reaction arrow means the reactants are being heated, and the temperature underneath indicates the temperature the reactants must reach for the reaction to take place.

As mentioned in the chapter, the verdigris coating on the copper of the Statue of Liberty contains copper hydroxide, copper carbonate, and copper chloride. We *synthesize* (make) each of these in the reactions you observe.

Reaction 1

We begin with this reaction:

$$CuSO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + Cu(OH)_2(s)$$

This equation says that aqueous solutions of copper sulfate and sodium hydroxide react to produce an aqueous solution of sodium sulfate and solid copper hydroxide. Copper sulfate is a salt: the blue crystals pictured on page 226. Sodium hydroxide, also known as lye, is a strong base. The reaction produces another salt, sodium sulfate, as well as *solid* copper hydroxide. Any time mixing solutions together produces a solid, you have a precipitation reaction. The precipitate you get should resemble the compound pictured in Figure 11.19.

Your instructor will conduct the reactions as follows. For each solution, use the graduated cylinder to measure out 75 mL of distilled water. Distilled water is used because tap water contains dissolved salts, which produce all kinds of deposits we do not want. Weigh out 10 g of copper sulfate crystals and add them to the water in a 250-mL beaker. Stir this with a plastic spoon until the crystals are dissolved. (Students can help with this task. It takes about 15 minutes for the crystals to dissolve, so be patient!) Weigh out 10 g of sodium hydroxide pellets, being careful not to let them come in contact with your skin. Add the sodium hydroxide pellets to the water in a 250-mL flask. Swirl the flask until the pellets have completely dissolved. The solid $CuSO_4$ and NaOH are shown in the two pictures below.

The two solutions appear as in the image to the right. Carefully pour the NaOH solution into the $CuSO_4$ solution. Students should observe carefully what happens and document their observations in their lab journals. Note the appearance and color of the reaction products, along with other details. Pour the contents of the beaker into a large funnel lined with filter paper or paper towel. Leave the $Cu(OH)_2$ precipitate to dry for a day or two. As it dries, examine it further.

Reaction 2

The chemical equation for our second reaction is as follows:

$$CuSO_4(aq) + 2NaHCO_3(aq) \rightarrow$$
$$Na_2SO_4(aq) + CuCO_3(s) + CO_2(g) + H_2O(\ell)$$

Again, a $CuSO_4$ solution is one of the reactants. The other reactant is a solution of sodium bicarbonate, also known as baking soda. The reaction again produces the aqueous solution of Na_2SO_4 and a precipitate. The precipitate this time is copper carbonate, pictured in Figure 11.20. The reaction also produces a lot of gas, and it should be obvious to you from what you see that a gas is being produced. The gas is carbon dioxide. The reaction also produces some water.

Make the $CuSO_4$ solution in the 250-mL beaker as before. Weigh out 10 g of sodium bicarbonate. Measure out 75 mL of distilled water in the graduated cylinder, and transfer it to the flask. Add the $NaHCO_3$ and swirl for a moment until the $NaHCO_3$ is more or less dissolved. (Sodium bicarbonate doesn't dissolve very well in water.) Now pour the $NaHCO_3$ solution—a small amount at a time—into the $CuSO_4$ solution. If you pour too much or too fast, this reaction will "boil over" the beaker and make a mess. Pour in small increments until the $NaHCO_3$ solution is gone.

Students document their observations as before. Pour the contents of the beaker into a large funnel with filter paper, and let it drain for a few minutes.

Reaction 3

The chemical equation for our third reaction is as follows:

$$CuCO_3(s) \xrightarrow[290°C]{\Delta} CuO(s) + CO_2(g)$$

This equation says we are going to cook the copper carbonate we made in the previous reaction. When the copper carbonate reaches 290°C, it converts to copper oxide, releasing carbon dioxide gas as well.

To heat the copper carbonate, just heat it in a frying pan over a propane or methane gas flame. (A hot plate does not get hot enough.) After draining off the excess water, pour the blue $CuCO_3$ precipitate from Reaction 2 into the frying pan over a high flame, as shown at the bottom of the previous page.

As this material is heated, first observe how the water separates from the copper carbonate. Then make your observations as the copper carbonate converts to copper oxide. The complete reaction takes 10 or 15 minutes of heating over a high flame. The final product of this reaction, copper oxide, is a dark brown powder, shown to the right.

Reaction 4

The chemical equation for our fourth reaction is as follows:

$$CuO(s) + 2HCl(aq) \rightarrow CuCl_2(aq) + H_2O(\ell)$$

One of the reactants this time is the copper oxide powder produced by the previous reaction. CuO does not dissolve in water, but combined with hydrochloric acid (HCl), an aqueous solution of copper chloride (a salt) is produced, along with some more water.

Place the CuO powder in a 250 mL beaker, as shown to the right. Add small amount of HCl solution, just enough to get all the CuO to react completely. Swirl the beaker. Students write down their observations.

Reaction 5

The previous reaction has left us with an acidic solution in the beaker because we put more HCl in than was necessary to convert the CuO into $CuCl_2$. To neutralize the acid prior to disposal, we add some sodium bicarbonate, a rather mild base. Here is the reaction:

$$HCl(aq) + CuCl_2(aq) + NaHCO_3(s) \rightarrow$$
$$CuCO_3(s) + NaCl(aq) + CO_2(g) + H_2O(\ell)$$

All the reactants and products in this equation are familiar. But look what happens—one of the products is table salt, and another one is copper carbonate again!

Reaction 6

We left the copper hydroxide from Reaction 1 in the funnel to drain and dry out. After a day or so, it should be clear that something has happened to the copper hydroxide. It is no longer a beautiful blue. See if you can speculate what it might be—your instructor will know the answer. Once you have a hypothesis formed, use the reactions you have seen here to suggest a reaction that will enable you to put your hypothesis to the test. You will be surprised and pleased with what you find.

Safety

The chemical reactions described in this experiment are not suitable for young students to do on their own. There are several toxic and corrosive chemicals, and a high-temperature reaction over an open flame. There are some activities where students can be involved, but any time students are involved (other than just watching from a safe distance), they should be wearing nitrile gloves if they are mixing chemicals, or heat resistant gloves if they are working over the burner flame. Anyone engaged in any of these activities must also wear safety goggles to guard against eye injury from chemical splashes, broken glass, or accidents that can occur during the heating (Reaction 3).

The reactions described in this activity are all easy to perform; there is almost nothing tricky or sensitive that can go wrong. Students watching the chemical mixing and reactions from a distance of at least 3–5 feet should be safe from harm. Students who are inspecting at closer range (which I encourage) must wear safety goggles, even if they aren't handling any of the materials. Again, accidents happen. If someone accidently drops a beaker of acid, we want everyone's eyes to be protected from splashing liquid or broken glass. As described in the introduction to the experiments in the text (Getting Started with Experiments, page 36), you should have a fire extinguisher at hand. You should also have at hand means for extended rinsing should someone get a corrosive acid or base on their skin or in their eyes. The best thing to have, usually only possible in a fully equipped chemistry lab, is an eye wash station and a safety shower. Portable eye wash stations are available for science classrooms that do not have running water. Cost for these begins in the $200 range at grainger.com. For a school without permanent laboratory facilities these are a wise investment. For home school students, or schools that cannot acquire a portable eye wash station, the best thing is to have a sink, shower or garden hose nearby.

Spend time before the experiment instructing students on what to do in the event of any type of accident. Specifically, the following standard safety practices should be reviewed with students prior to engaging in this activity:

1. In the event of chemicals in the eye or on the skin, the eye or skin must be flushed for 15 minutes with copious quantities of running water, followed by medical attention.
2. Loose clothing and hair must be fastened back out of the way.
3. Students must never eat, drink, taste or sniff anything in a lab unless instructed by a competent adult to do so (which won't occur in this investigation).
4. Chemical compounds and solutions should not be touched with bare skin.
5. A fire should be addressed with a fire extinguisher, and a person with clothes on fire should "stop, drop and roll." (In fact, it is a good idea to have a wool blanket on hand to use as a fire blanket in the event that someone's clothes should catch fire.)
6. Glassware must be handled with great care.
7. There must never be horseplay.
8. Safety goggles must be worn when handling chemicals or working near an open flame.
9. Protective gloves (usually latex or nitrile) must be worn when handling chemicals.
10. Heat-resistant gloves must be worn when working near hot materials.
11. Always have a mobile phone nearby in the event of an emergency.

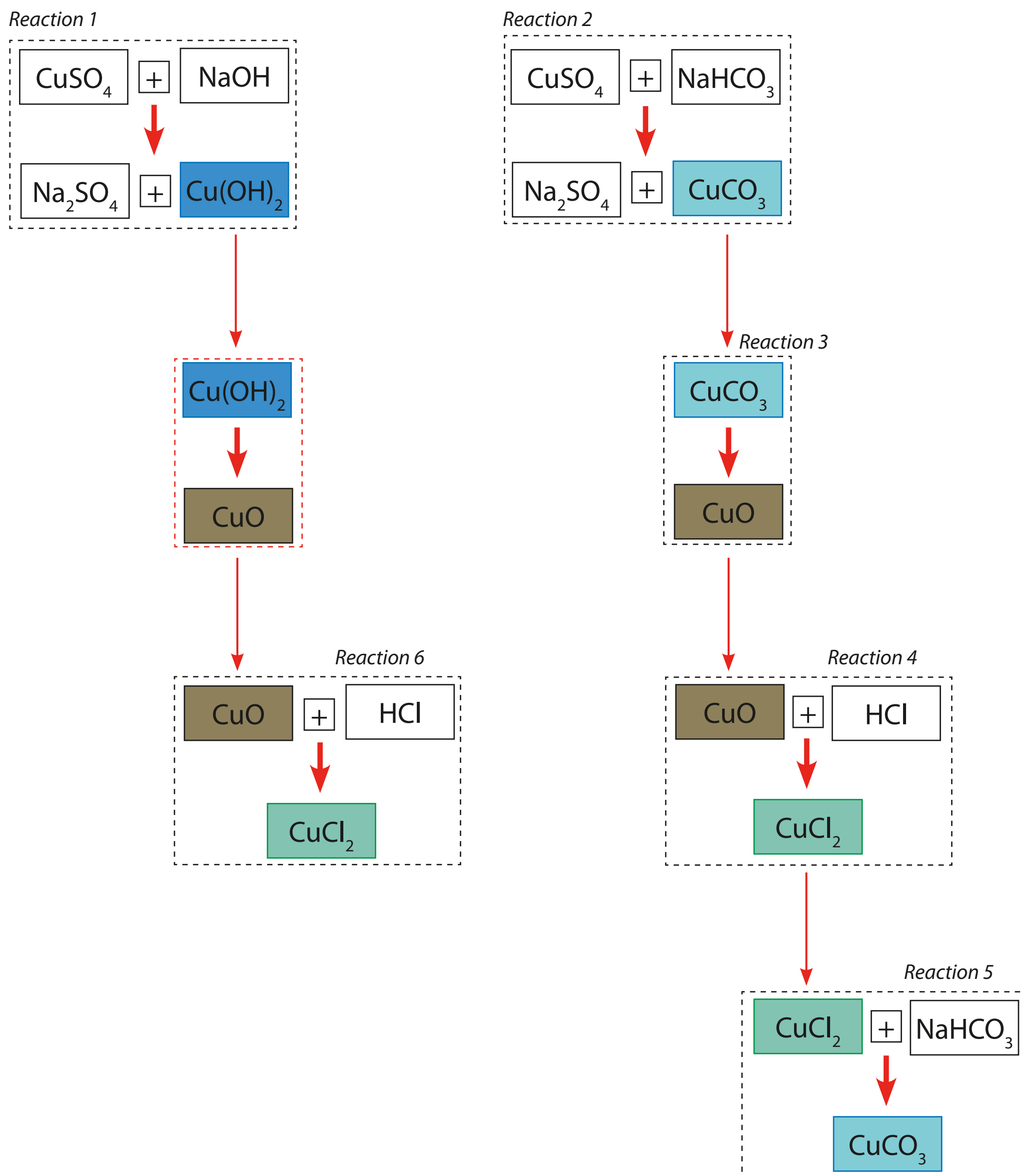
With proper safety procedures and training, it is possible for everyone to engage in these activities safely.

Having said all of the above, I want to encourage instructors not to let these safety issues scare you away from performing these reactions. They are very interesting and very colorful. Without seeing them, all students have is equations on a page. To watch these reactions occur is to see chemistry come alive. But accidents do happen, and we want everyone to be protected from injury.

Preparation

Required materials are listed in the table on the following page. The first two reactions are simple matters of mixing solutions and combining them, followed by pouring the reaction products into a filtering

Item	Quantity	Source	Cost		Comments
mass balance	1	See Introduction			
beaker, 250 mL	3	See Introduction			
flask, 250 mL	2	See Introduction			
Bunsen burner	1	See Introduction			
burner tripod	1	See Introduction			
graduated cylinder, 100 mL	1	See Introduction			
copper sulfate penta-hydrate	20 g	The Science Company, sciencecompany.com	12.25	12.25	Item NC-0304 from sciencecompany.com, referred to as cupric sulfate crystal. Price is for 500-g bottle.
sodium hydroxide	10 g	The Science Company, sciencecompany.com	11.50	11.50	Item NC-0874 from sciencecompany.com, referred to as sodium hydroxide (lye) beads. Price is for 500-g bottle.
hydrochloric acid	50 mL	The Science Company, sciencecompany.com	5.50	5.50	Item NC-1783 from sciencecompany.com, referred to as shydrochloric acid, 10% solution. Price is for 250-mL bottle.
sodium bicarbonate (baking soda)	30 g	grocery store	0.89	0.89	Price is for 454 g box (1lb) of baking soda.
plastic funnel	2	The Science Company, sciencecompany.com	2.95	5.90	Item NC-0448 from sciencecompany.com is a 100 mm plastic funnel.
coffee filter	2	common item	n/a		
safety goggles	1	science supply	1.95	1.95	See sciencecompany.com item no. NC-11006. If you purchased a set for the force and inertia experiment (#8) you can use those.
heat resistant gloves					Use the gloves purchase for the heat of fusion experiment (#7).
nitrile gloves	1 pair	The Science Company, sciencecompany.com	3.25	3.25	Price is for a pack of 10 disposable gloves, Science Company item no. NC-11097. These are also available in boxes of 100 for $12.95. These gloves are good for all common acids and bases except nitric acid and concentrated sulfuric acid. See the Glove Chemical Resistance Guide on The Science Company website.
pH indicator strips	1 pack	The Science Company, sciencecompany.com	14.95	14.95	Item NC-0690. Price is for a pack of 100 test strips, covering a pH range of 0–14.
plastic spoons	4	common item	n/a		
distilled water	300 mL				Use leftovers from crystal experiment (#4).
6-inch frying pan	1	discount store	7.98	7.98	Make sure to get one with a non-stick surface.
stainless steel spatula	1	discount store	4.41	4.41	Price is for the 8” slotted turner at amazon.com.
weigh trays or disposable cups	4	common item	n/a		Lab with weigh trays can use them for measuring out solids. Otherwise, just use some of the leftover Styrofoam cups from earlier experiments.
		Project Total		68.58	



funnel. Reaction 3 requires 15–20 minutes of work over a gas flame. The burner for this reaction can be a laboratory Bunsen burner, a propane stove, or a gas range at home (see Introduction). Any propane or natural gas burner should work, but a hot plate probably won't. It will not get hot enough to make Reaction 3 occur. For reactions 4, 5, and 6 we are back to mixing things in beakers.

As mentioned in the Introduction, you can use mason jars or clear glass drinking glasses instead of beakers and flasks for these reactions. However, any glass container used for these reactions should not be used again for human consumables. Either rinse them out and discard them, or save them for use in a future class.

Combining Theory and Observation

This activity should not be treated as a mere sequence of colorful events in beakers. This essential idea of this investigation is for students to learn to associate the reactants and products described in an abstract chemical equation with the actual materials they see forming in front of them (including the bubbles indicating that a gas is being formed). Therefore, it is essential that at every step of the way, students' attention is repeatedly drawn to the chemical equations involved. The reactions follow a "chemical logic": the product of one reaction becomes a reactant in the next, and end products loop back around to become reactants seen earlier in the sequence. This sequence provides students with more than one opportunity to see the same compounds being formed, and each time they can associate the compound they see with their eyes with the color and texture of the substance they see before them.

The chart above is a graphical representation of the reaction sequence. Reactions 1 and 2 should be thought of as parallel beginnings, rather than as sequential steps. We leave the bright blue copper hydroxide product (a precipitate) of Reaction 1 to itself for a while and carry on with the turquoise copper carbonate product (also a precipitate) of Reaction 2. The heating of Reaction 3 first dries out the copper carbonate, and then converts it to brown/black copper oxide, a granular solid. In Reaction 4 the copper oxide is combined with hydrochloric acid to produce a blue green copper chloride solution with no solid left (except perhaps some impurities). Reaction 5 then uses sodium bicarbonate (baking soda) to form copper carbonate again, which again precipitates out of solution. The reaction sequence that began with Reaction 2 has now come full circle, producing the turquoise copper carbonate we had to start with.

After an hour or two of exposure to the air, the bright blue copper hydroxide is no longer bright blue. In fact, it is brown/black. What happened? This is the question posed to the students in the description in the text. Well, we know the compound had copper in it, so the copper is presumably still there. We haven't done anything to it, except leave it exposed to the air, and this made it turn brown/black. We saw another brown/black copper compound emerge in the other reaction sequence—copper oxide. It's a good bet our copper hydroxide has turned into copper oxide.

If this brown/black substance is copper oxide, then drying it to a powder and combining it with hydrochloric acid should produce the blue green copper chloride solution, just as it did in the other reaction sequence. After having discussed this with the students, we perform this test with Reaction 6, and sure enough—we get the same blue green copper chloride solution as before. (For those who may not yet be convinced, toss in some baking soda and the turquoise copper carbonate precipitate will form again. Now there should be no doubt.)

After demonstrating Reaction 6, go back to the drying copper oxide and discuss what happened to it. Here is what happened:

$$Cu(OH)_2 \rightarrow CuO + H_2O$$

The water has separated from the copper hydroxide and evaporated, leaving only copper oxide. Another way to view what happened is to regard the copper hydroxide as "hydrated copper oxide":

$$Cu(OH)_2 \Leftrightarrow CuO \cdot H_2O$$

The hydrated copper oxide representation models the compound as a copper oxide crystal with water molecules embedded in the crystal lattice. Copper ions are blue when they are hydrated, as with the copper sulfate pentahydrate crystals discussed in the text and used in this experiment. But the copper oxide pentahydrate is not stable; the water molecules evaporate out. Once the water molecules are all gone we are left with the brown/black copper oxide.

Knowing all this suggests a way to speed up the conversion of copper hydroxide to copper oxide for those who do not wish to wait for several days while the substance dries out on its own: heat it. Heating the copper hydroxide quickly drives out the water.

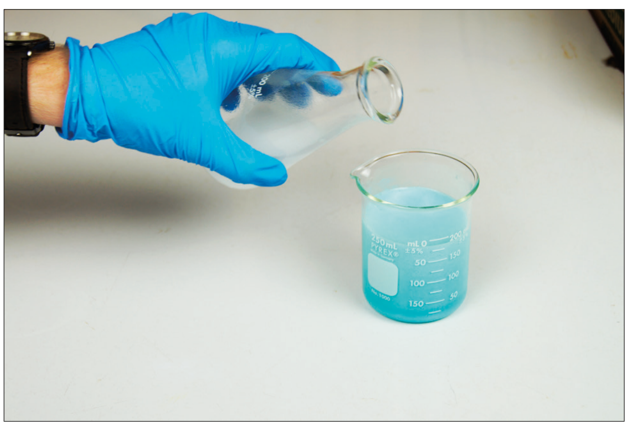
Additional Notes on the Reactions

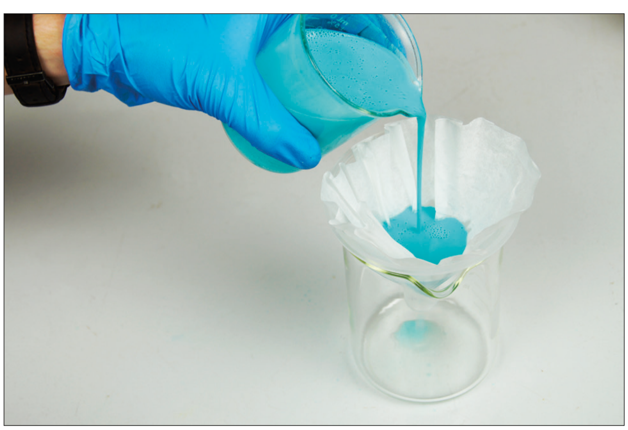
Reaction 1

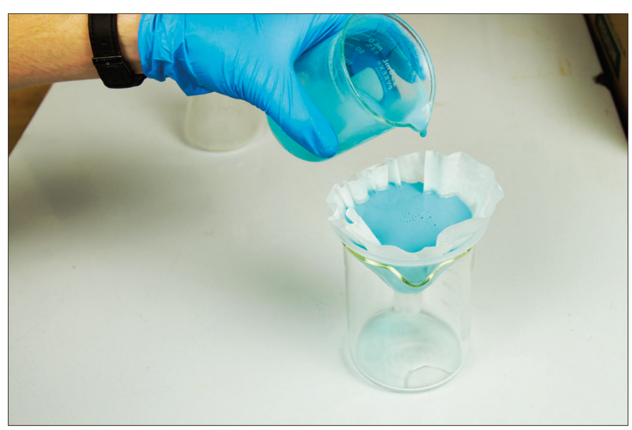
Use two separate plastic spoons to measure out the copper sulfate crystals and sodium hydroxide beads. These spoons can then be used to stir these substances into the water until they dissolve. (If you use a flask for the sodium hydroxide solution, the flask can simply be swirled.) It takes a long time (10–15 minutes of continuous stirring) for them to dissolve, but they do. This tedious stirring is a good way for some students to be involved, but they need to be wearing safety goggles and nitrile gloves. Discard the spoons in the trash when the solutions are ready.

Sodium hydroxide (lye) is a strong base. Be sure to have on all your safety gear when working with it, and do not allow any skin to contact the sodium hydroxide beads.

The photo on the previous page shows pouring the sodium hydroxide solution into the copper sulfate solution to initiate the reaction. You can see the blue precipitate forming in the beaker. The reaction happens instantly. As the rest of the sodium hydroxide



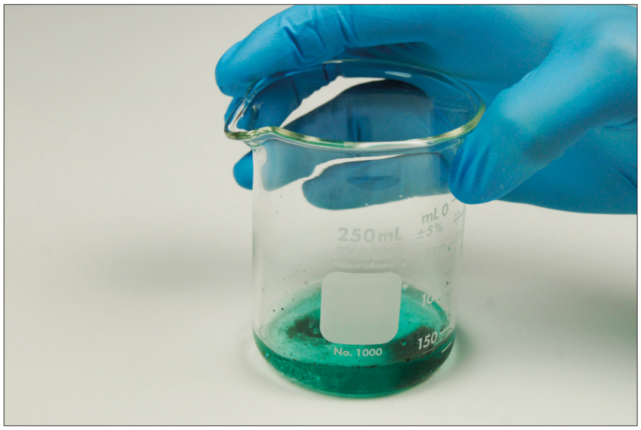




At left, scraping the copper carbonate from the filter paper into the frying pan.

Above right: The 4-inch pan shown here boils over, making quite a mess. Use a 6-inch frying pan as shown below.

A wooden spatula as shown top left and right provides no benefit. The stiff, metal spatula shown here is much better for scraping the dried copper carbonate.



solution is poured in, the beaker of copper sulfate solution will fill with a spongy solid that looks like someone placed a washcloth in a beaker of blue dye. It is very interesting to watch and see.

At the bottom of the previous page, the contents of the beaker are poured into a funnel with a coffee filter. (Official lab filter paper can also be used, but is expensive.) You can now leave this here for a few days to dry out. The warmer the environment, the faster it dries.

Reaction 2

Mix the solutions as before. Sodium bicarbonate does not dissolve well in water, so simply swirl it in the flask until it is more or less dissolved, or at least suspended in the water.

As shown on page 57, gradually pour the sodium bicarbonate solution into the copper sulfate solution. This reaction gives off a lot of carbon dioxide (the fizzing), so take it easy while pouring so that your beaker doesn't overflow. Keep pouring in the sodium bicarbonate solution until it is all in.

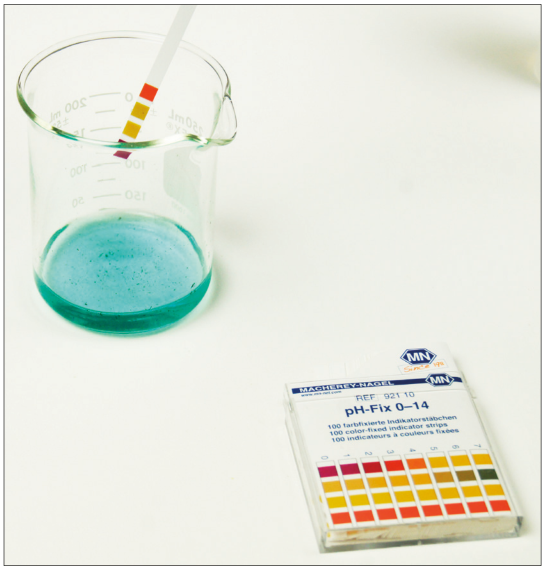
As before, pour the contents of the beaker into a funnel with a filter and let it drain for a few minutes. The turquoise precipitate is copper carbonate. (The students should love this color.)

Reaction 3

For this reaction heat resistant gloves are a must. Even after draining in the filter for a while there is still a lot of liquid in the copper carbonate when you put it in the frying pan, and before the reaction can start you must first boil off all the water. On top of that, the conversion of the remaining copper carbonate powder to copper oxide does not occur until the copper carbonate reaches the uncomfortably hot temperature of 290°C (554°F), which takes several minutes. Thus, you will be working over the very hot frying pan for a good 15–20 minutes before this is all complete. This is why the heat resistant gloves are a must.

Use a 6-inch nonstick frying pan and a stiff metal spatula for this reaction. If working over a laboratory burner you will definitely need to have a burner tripod to support the pan for the extended cooking time.

The photos on page 58 show the stages of the reaction. At the top the water begins to boil away. (The egg pan shown in the top photos had a lot of trouble with boil over. Use a 6-inch pan as shown in the lower photos.) After the water is gone and the copper carbonate has dried onto the bottom of the pan, remove the hot pan from the burner tripod. Place the pan on a solid heat resistance surface and use a stiff metal spatula to scrape the copper carbonate into a pile in the center of the pan. Place the pan back on the burner. Use the spatula to chop and mix the powder, spreading it out and piling it up again until all the copper carbonate has converted into copper oxide. In the close-ups of the frying pan, the blue-green substance is copper carbonate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pH-Fix 0–14
100 farbfixierte Indikatorstäbchen
100 color-fixed indicator strips
100 indicateurs à couleurs fixées


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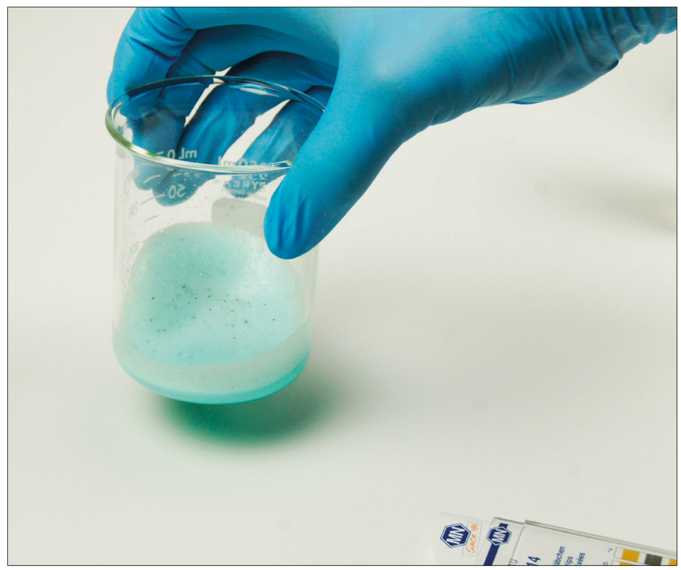


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that has not yet reacted. The dark brown substance is newly formed copper oxide. The reaction is over when you have nothing left in your frying pan but brown/black copper oxide.

Reaction 4

After the copper carbonate has fully converted to copper oxide, remove it from the frying pan and spoon it into a weigh tray or disposable cup. Obtain a clean 250-mL beaker and transfer a small amount (a teaspoon or so) of the CuO to the beaker.

Remove your heat resistant gloves and put on a new pair of nitrile gloves. Add enough hydrochloric acid to the beaker of copper oxide to fully submerge the copper oxide powder (about 40 mL). While the students watch, gently swirl the acid in the beaker. The solid will disappear and a beautiful aquamarine liquid will form. Note that although the copper oxide appears to be dissolving in the liquid, it is not. It is reacting with the HCl to form an aqueous solution of copper chloride and water. If you get a brown liquid, you have not added enough hydrochloric acid. Keep adding hydrochloric acid and swirling until all the copper oxide reacts and you have a nice pretty aquamarine liquid, as shown on page 59. Use plenty of HCl. It's actually desirable to use a bit more than you need, as indicated in the next section.

Reaction 5

When the copper oxide has all reacted with the hydrochloric acid, there will still be a lot of acid in the beaker. We put in more acid than we actually needed. Before we can dispose of this material, we need to neutralize the acid.

This is a great opportunity to demonstrate the use of pH test strips for measuring the pH of acids and bases. Remove one of the strips from the box, and dip it into the copper chloride/acid solution. Compare the colors on the wet strip to those on the box cover until you find the color pallet that matches. The photo at the top of the opposite page shows that the copper chloride/acid solution has a pH of 1, far too acidic to pour down the drain. This is why we need to neutralize this acid.

As described in the chapter, sodium bicarbonate (baking soda) is a mild base, and when a base is combined with an acid, they produce a salt and water. The formation of that salt is our fifth reaction.

Spoon about half a teaspoon of baking soda into your solution and you will see the familiar turquoise copper carbonate precipitate begin to appear. Swirl the beaker while the reaction proceeds. After the reaction is complete (indicated by the cessation of the fizzing), check the pH again. Your goal is to get the pH to the 6–8 range. A pH of 7 is a completely neutral solution, meaning there is nothing in the beaker but salt and water, and you can safely rinse it down the drain. If you inadvertently add too much baking soda and cause the pH to swing all the way over to 12 or 13 (last photo), simply add a drop or two of hydrochloric acid to pull the pH back toward 7.

Reaction 6

The copper hydroxide precipitate from Reaction 1 is still sitting in the funnel where we left it. You can leave it there for several days until it dries out, or you can spoon some of it into your clean frying pan and warm it up for a while. Doing this will dry it out quickly. Either way, as the water molecules escape from the copper hydroxide it changes into copper oxide. You want to lead your students to speculate about this, without telling them what is actually happening. Let them see the dark brown/black substance that has formed from the rich blue copper hydroxide you started with, and let them consider all the compounds they have seen in these reactions and speculate what happened to the copper hydroxide. Once someone guesses that since it is a brown/black solid it might be copper oxide, then ask them how you could find out if that is what it is. The simple answer is that if it is copper oxide, then you can perform Reaction 4 on it (pour in some hydrochloric acid). If the copper oxide goes away and leaves you with the pretty aquamarine solution, you know you have copper chloride, which means you did in fact have copper oxide to start with.

Description from Text

Experimental Investigation 10: Refraction

Overview

- Measure the angles of incident and refracted laser beams as the laser refracts through acrylic glass.
- Use Snell's law to calculate the index of refraction of the acrylic material.
- Repeat these two steps with a transparent tray of water as the refracting medium.
- Compare the experimentally determined indices to standard reference values.
- *The goal of this experiment is to measure the indices of refraction for acrylic glass and water, and to compare the experimental values to published reference values.*

Basic Materials List

- laser pointer
- acrylic glass prism or block
- ring stand and clamp holder
- Hot Wheels car bubble packaging (to use as a water tray)
- graph paper, protractor, ruler
- scientific calculator
- thick, flat books (1 or 2) (to position the prism)

Safety Precaution

Never look into a laser, and never shine the beam or a beam reflection into anyone's eye.

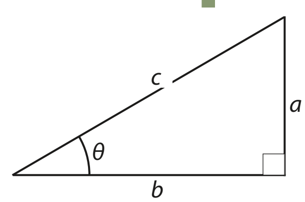
I realize you probably haven't studied trigonometry yet, but in this experiment we will make use of one trigonometric calculation, the sine of an angle. I will first explain what this means. Hopefully you have learned about triangles and measuring angles in degrees. A right triangle is a triangle with one 90° angle in it, like the one shown below. For the angle marked θ in this triangle, the sine of that angle, written as $\sin\theta$, is defined as $\sin\theta = a/c$. In any right triangle, the sine of an angle in the triangle is simply the ratio of the lengths of the side opposite the angle and the longest side in the triangle, called the *hypotenuse*.

One of the important laws in the study of optics and light is *Snell's law*. When a ray of light (like a laser beam) strikes a surface and refracts, Snell's law relates together the angles of the incident and refracted beams (θ_1 and θ_2) and the indices of refraction (n_1 and n_2) for the two media in which the ray is propagating. Snell's law is:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

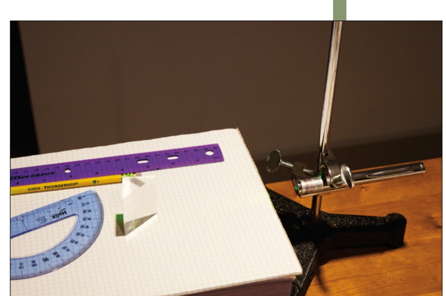
The index of refraction of air is very close to one, so when the incident ray is in air, we can write Snell's law as

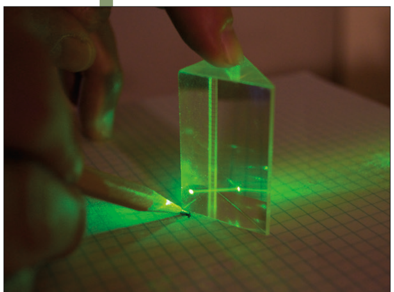
$$n_2 = \frac{\sin\theta_1}{\sin\theta_2}$$



In this equation, n_2 is the index of refraction for the refracting medium, and θ_1 and θ_2 are the angles the incident and refracted rays make with the normal line. With this equation, we can determine the index of refraction of a material. All we have to do is measure the two angles and put them in the equation to calculate n_2.

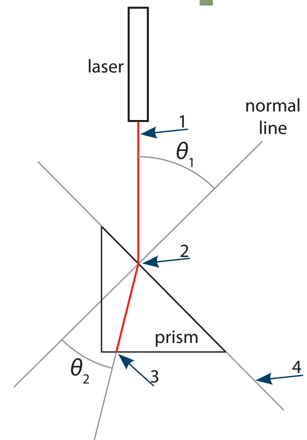
As shown in the photo, set up a laser pointer on a ring stand with a clamp, and adjust the beam so it hits a prism on a sheet of graph paper at an angle. Turn off the lights so you can see the laser beam inside the prism. Now make four marks on the paper. Put a mark directly under the beam near the edge of the paper closest to the laser. Put another mark directly under the spot where the beam strikes the prism. Put a third mark directly under the spot where the beam exits the prism. Finally, holding the prism down with your finger, draw a line on the paper along the front edge of the prism—that is, at the bottom of the side where the laser beam refracts. I have indicated these four marks with blue arrows in the sketch. In the photo be-





low, you can see the laser beam as it passes through the prism while a person uses a pencil to make the third mark.

Once the marks are made, turn on the lights and turn off the laser. Use a straight edge to connect your marks to show the ray paths and the front edge of the prism. Use a protractor to draw in the normal line, right at the place where the incident beam hits the front surface of the prism (mark 2). Now measure and record the two angles, and use them to calculate the index of refraction for the acrylic.



The next part of the experiment is to repeat the whole procedure using water in a transparent tray in place of the prism. The packaging for a Hot Wheels car makes a nice water tray, if a piece of tape is placed across the top to hold the sides vertical. The next photo shows the water tray in place. The bottom edge of the tray curves under a bit, so you can't mark the front edge by drawing a line across the bottom of the tray. Instead, place a ruler along the tray edge, then move the tray and use the ruler to mark the front edge.

The standard reference values for the indices of refraction are 1.49 for acrylic glass and 1.33 for water. Use these reference values as the predictions and your measurements as the experimental values, and calculate the percent difference for both your indices.

Analysis

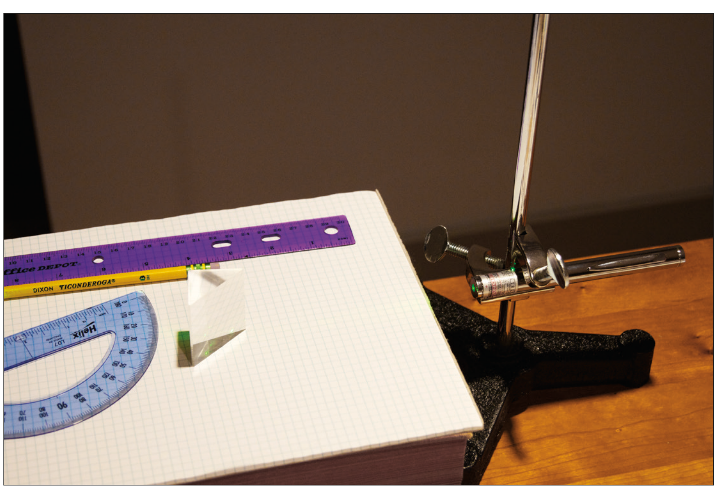
In your report, address the following questions.

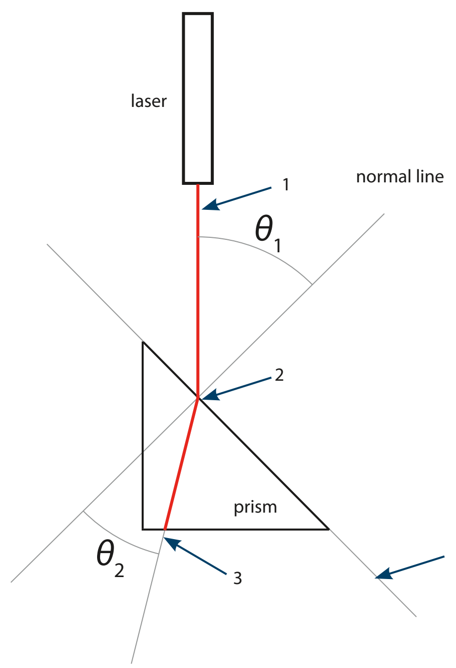
1. For an incident angle of 17°, an error of only 1° in measuring that angle can cause your index of refraction to be off by about 5%. In light of this, do your percent difference figures seem reasonable, given the degree of accuracy with which you were able to measure the angles? Explain.
2. What were the most difficult aspects of the experiment?

Preparation

Materials required are listed in the table on the next page. The purpose of the plastic package from a single Hot Wheels car is to make a tray for holding water that has very thin, vertical, transparent sides. The plastic bubble covering a single Hot Wheels car just happens to work well for this purpose, and for minimal cost.

Use the ring stand and the right angle clamp holder to support the laser pointer horizontally, as shown in the photo to the left. Adjust the laser and the thumb screw on the clamp holder so the screw turns on the laser and holds it on. Use a



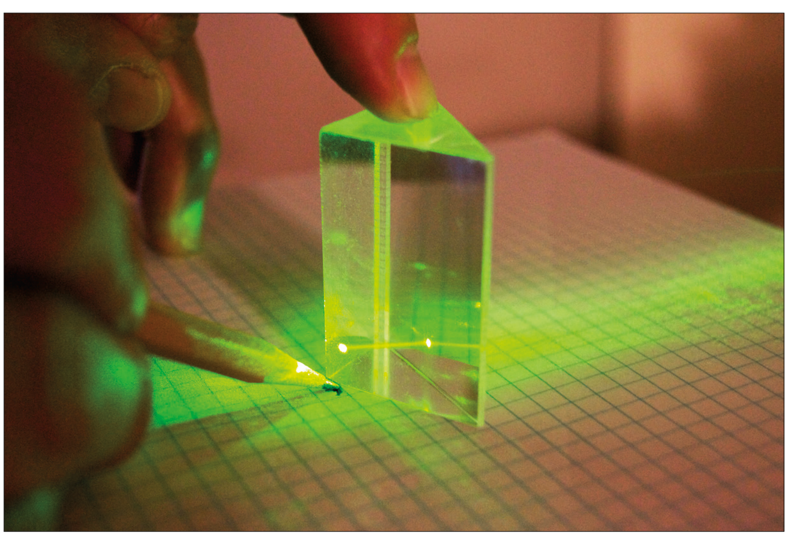


Item	Quantity	Source	Cost	Ext. Cost	Comments
ring stand	1	See Introduction			
rectangular bubble pack	1	discount store	0.97	0.97	Use the plastic packaging for the single Hot Wheels car purchased for the kinetic energy experiment (#1).
clamp holder	1	Lab Depot labdepot.com	3.43	3.43	Item no. P35011 is a right angle holder clamp.
laser pointer, 5 mW or less	1	frys.com	9.99	9.99	Search for the Alpec Black Midget laser pointer. Due to eye hazards, do not buy any laser pointer with a power greater than 5 mW.
acrylic glass prism	1	amazon.com or Hobby Town	5.99	5.99	Amazon has several in the $7 range. Price shown was from Hobby Town. Hobby Town was the source for the spring in the force inertia experiment (#8). Their item number for the prism is TED00013.
protractor	1	common item	n/a		
ruler	1	common item	n/a		
graph paper	6 sheets	common item	n/a		
pencil	1	common item	n/a		
masking tape	6 in	common item	n/a		
			Project Total	20.38	

stack of books to support your graph paper at the right height, so the laser beam passes through the prism or water tray.

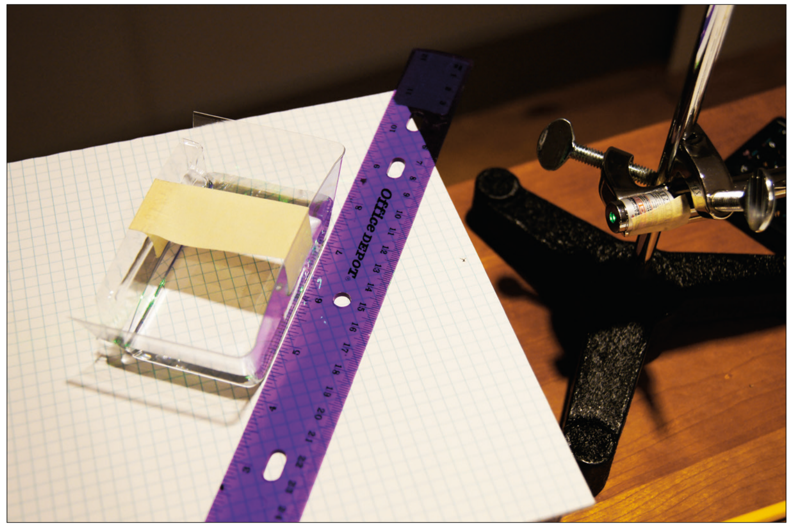
Running the Experiment

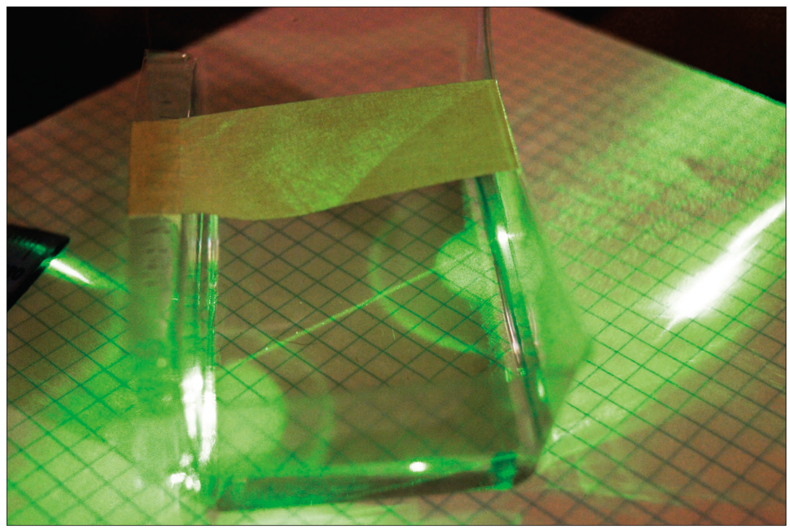
As shown in the sketch on the previous page, orient the horizontal laser beam so it strikes the prism or water tray at an angle. Dim the room lights to make the laser beam easier to see. Draw a line on the paper along the bottom edge of the prism, at the bottom of the surface where the beam strikes the prism. Also mark below where the beam coming from the laser first passes over the paper, where it enters the prism and where it exits the prism. The photo to the left shows the marking of the place where the beam exits the prism. When all the marks are accurately made, remove the prism and use the ruler to draw in the lines, extending them far enough out to measure the angles with the protractor (see pages 66–67 for examples). Use the protractor to draw a line 90° to the line along the bottom front edge of the prism, at the point marked where the beam enters the prism. This is the normal line.



Another and possibly easier way to make the marks would be to mark lines on the paper for the prism edge and the normal line before working with the prism and laser. Then you can simply line up the prism and laser so the prism edge is lined up against the edge line, and the laser strikes the prism directly above where the normal line hits the edge line. Then you would just have to make two more marks to locate the beam paths (marks 1 and 3 in the sketch on page 63).

The photos to the right show the water tray being used for the second part of the experiment. The tape across the top of the tray pulls the sides together to make them vertical.





As mentioned in the text, a slight error in measuring the angle can cause a fair bit of error in the resulting calculated value of the index of refraction. For this reason, students should actually perform each part of this experiment (prism and water tray) three times with different angles, giving six sets of measurements altogether, all made with different angles. Then the index of refraction can be calculated from three sets of measurements for each medium.

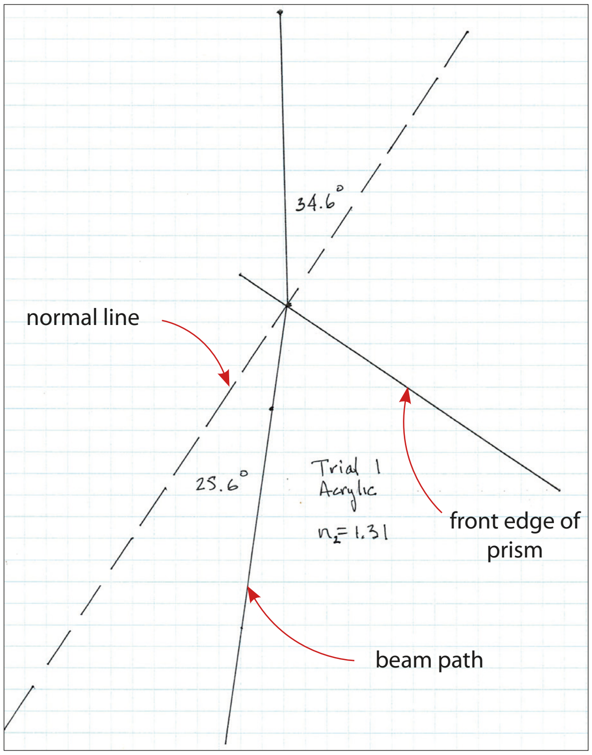
Sample marks on graph paper for a trial run of this experiment are shown on pages 66 and 67.

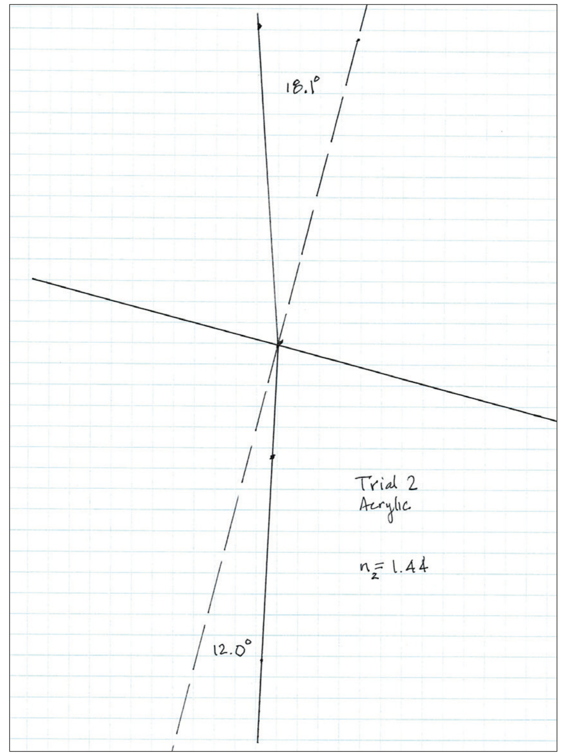
Analysis

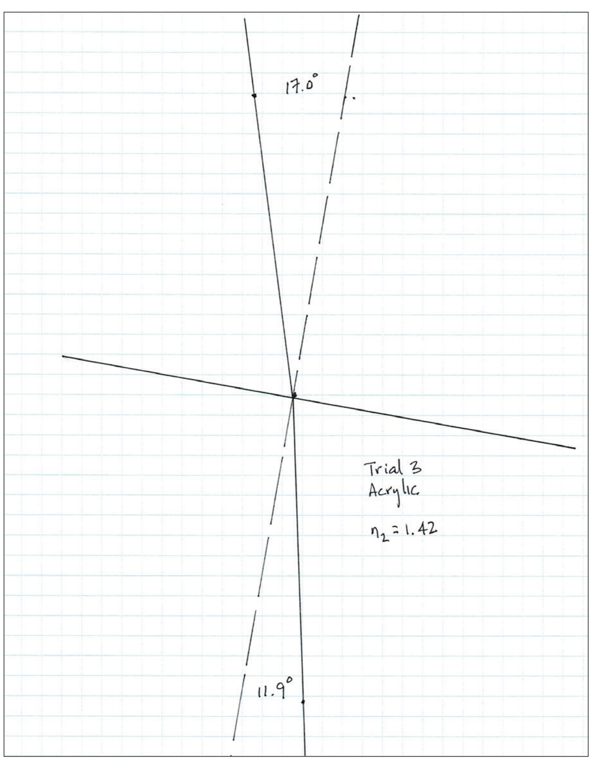
The examples on the following two pages show sheets of graph paper marked for three trials with the prism and three trials with the water tray. The six calculated index of refraction values are shown in the table.

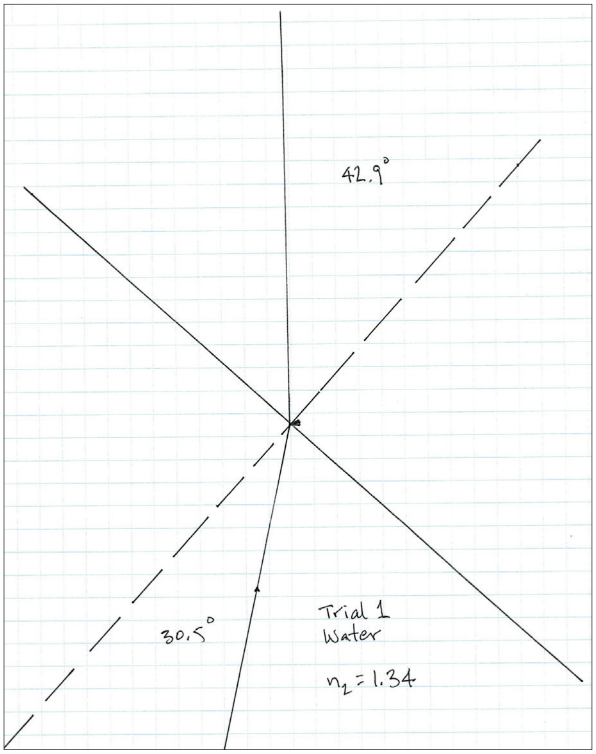
acrylic prism	water
1.31	1.34
1.49	1.33
1.42	1.39
average = 1.46	average = 1.34
percent diff = 2.0%	percent diff = 0.75%

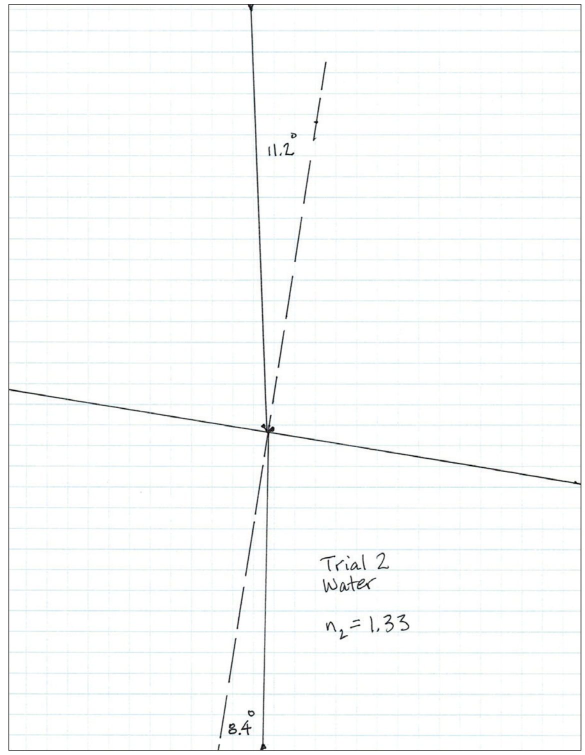
The first value in the acrylic case seems to be significantly different from the other two, so I judged this one as a poor data point and discarded it. Apparently the markings become more accurate with a bit of practice. The second and third values are pretty close together. The measurements for water are much closer together. Computing the two averages gives the experimental index of refraction value for each material. Using the two reference values in the text as predicted values, the percent difference values for acrylic and water come out to be 2.0% and 0.75% These are excellent results, and we would say that the experimental values agree very closely with the published reference values for these two materials.

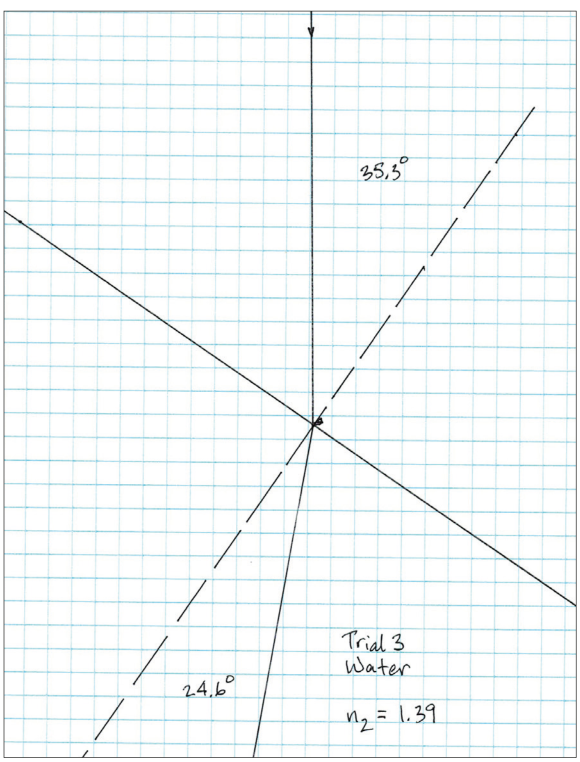

34.6°
normal line
25.6°
Trial 1
Acrylic
n_2 = 1.31
front edge of prism
beam path


18.1°
Trial 2
Acrylic
n_2 = 1.44
12.0°


17.0°
Trial 3
Acrylic
n_2 = 1.42
11.9°


42.9°
30.5°
Trial 1
Water
n_2 = 1.34


11.2°
Trial 2
Water
n_2 = 1.33
8.4°


35.3°
Trial 3
Water
24.6°
n_2 = 1.39

Description from Text

Experimental Investigation 11: Series and Parallel Circuits

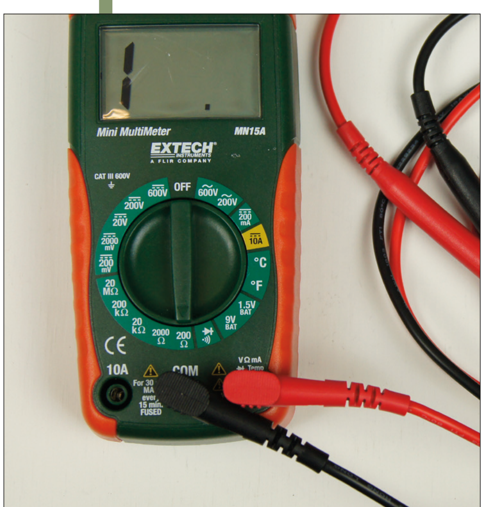
Overview

- *The goal of this experiment is to observe the behavior of resistor networks connected in series and in parallel.*
- Measure the resistance of a small lamp. Then connect two lamps in series and measure the combined resistance. Repeat for three lamps in series.
- Connect two lamps in parallel and measure the combined resistance. Repeat for three lamps in parallel.
- Connect three lamps in series, and then connect the lamp network to a battery pack. Measure the voltage difference across each of the three lamps individually. Remove one lamp from its base and observe the effect on the rest of the lamps in the network. Replace the lamp in its base and make the same test for the other two lamps in the network.
- Connect three lamps in parallel, and then connect the lamp network to a battery pack. Measure the voltage difference across each of the three lamps individually. Remove one lamp from its base and observe the effect on the rest of the lamps in the network. Replace the lamp in its base and make the same test for the other two lamps in the network.

Basic Materials List

- small incandescent lamps with bases (3)
- alligator clip connecting leads (6)
- digital multimeter
- 6-volt lantern batteries (2)

In this experiment, we use small incandescent lamps (common in flashlights before LEDs took over) as resistors. We connect the bulbs first in series and then in parallel to see how these combinations affect the total resistance of the network. Then we try out these two kinds of networks by connecting them to a power supply (the battery pack).

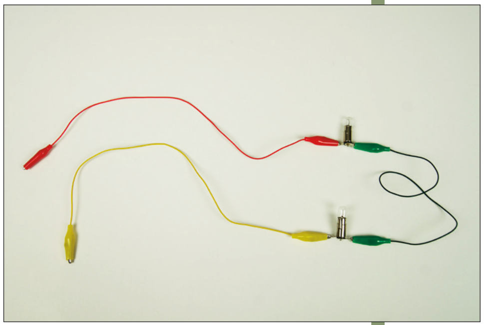


For making measurements with electric circuits, we use a tool called a digital multimeter (DMM). A DMM measures voltages, currents, and resistances. The way the test leads connect to the DMM depends on model of DMM. For this experiment, you use a DMM to measure resistance and voltage, so insert the black test lead into COMMON terminal, and insert the red lead into the VOLT/OHM terminal.

We begin our measurements by measuring the resistance of lamps connected in different ways. First, measure the resistance of a single lamp. To do this, insert the lamp in a base. Set your DMM to measure resistance, using a range selection of 100 Ω to 200 Ω (depending on your DMM), as shown in the first photo. (When the DMM reads "1 ." as in the photo, this means the resistance is too high to measure in the current range setting. You need to set the range to a higher setting. In the photo, the DMM is on but not connected to anything.) Touch the test leads to the terminals on the lamp base, read the resistance, and record the result in your lab journal. (It doesn't matter which test lead is connected to which terminal.) Insert your other two lamps into bases, and perform the same test. If the three resistances are different, compute the average (mean) resistance for the three.

Using wires with alligator clips on each end, connect two lamps together in series, as illustrated in the first photo on this page. Measure the resistance of this series network by touching the DMM test leads to the ends of the network. Then add a third lamp to the chain and measure the resistance of a series network with three lamps. The second photo shows the DMM connected to a series network for the resistance measurement.

Now connect two lamps in parallel as shown in the third photo. Measure the total resistance of this combination. Then connect a third resistor in parallel with the first two and measure the resistance of this three-lamp parallel network.

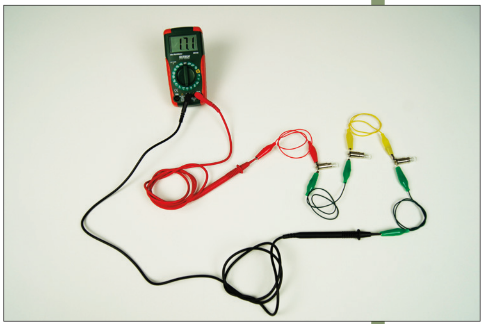


Next, we measure the voltages in circuits formed by connecting the lamps—in series and in parallel—to a battery pack. Our battery pack consists of two, 6-volt lantern batteries connected in series to give us a 12-volt battery, as shown in the fourth photo.

Switch your DMM over to the setting for measuring DC voltages in the range of 10 to 20 V (depending on your DMM).

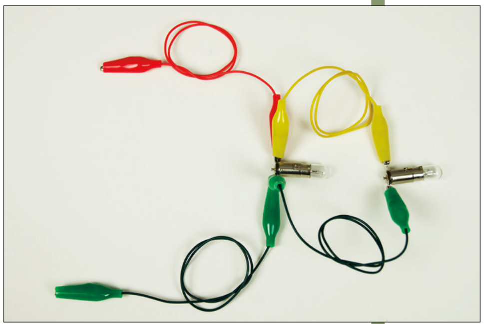
For each circuit arrangement, record the following measurements:

- the voltage across the battery pack
- the voltage across each of the lamps



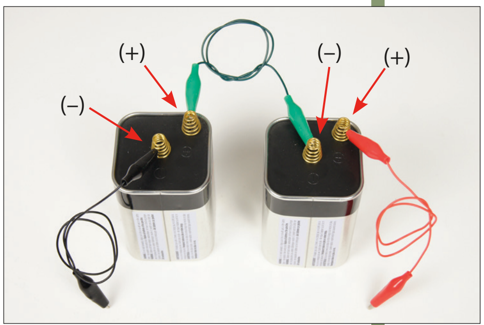
There are five separate circuit arrangements to test: three for series connections and two additional ones for parallel connections. (Note that when a single lamp is in the circuit, the series and parallel connections are the same, since there is only one way to connect a single lamp to the battery pack.) Measure and record all the voltages for these circuit arrangements:

- one lamp connected to the battery pack
- two lamps connected in series to the battery pack
- three lamps connected in series to the battery pack
- two lamps connected in parallel to the battery pack
- three lamps connected in parallel to the battery pack



The first two photos below show the setup connected together for the three-lamp series circuit and the three-lamp parallel circuit. The third photo illustrates a measurement of the voltage across the battery pack.

The measurements with the DMM are now complete. There is one more series of tests to perform, and that is to observe how series and parallel circuits respond when the circuit is interrupted. A light bulb contains a tiny wire, called a *filament*, that gets extremely hot when current flows through it. As you recall from our studies of electromagnetic radiation in Chapter 3, all warm objects emit infrared radiation, but a really hot object emits light at wavelengths across the visible spectrum. When all visible wavelengths are produced simultaneously, the result is white light.



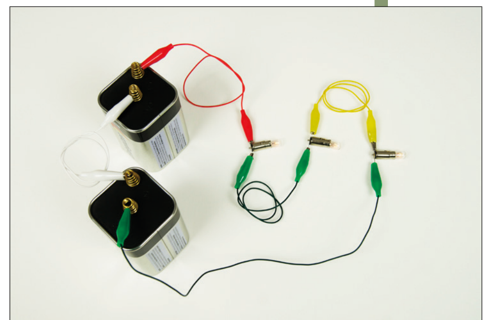
As light bulbs are cycled on and off, the stresses on the filament eventually cause the filament to fail—that is, the filament breaks into pieces and current can no longer flow through it. When this happens, we say the lamp is "burned out." In electrical language, we say there is an "open circuit." In this experiment, we can simulate a lamp burning out by simply removing the lamp from its base. When a lamp is removed from its base, an open circuit is created and current can no longer flow through the lamp filament.

For the last set of tests, we begin with the lamps connected in parallel, since that is how they are connected for the last set of voltage tests. The lamps are probably hot by now from the previous testing, so use a tissue or paper towel to prevent burning your fingers. While the three lamps are connected to the battery and illuminated, remove one of the lamps from its base and observe what the other lamps do. Reinsert this lamp into its base and perform the same test on each of the other two lamps in turn. Record all your observations in your lab journal.

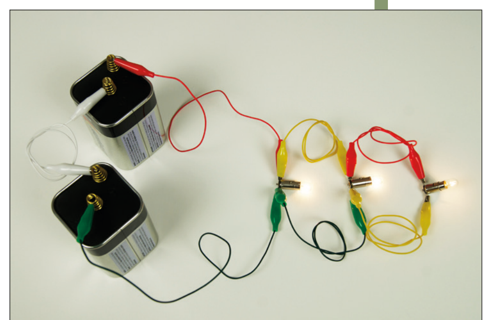
Finally, connect the lamp network back into a series circuit with three lamps (the first photo on the previous page). With the lamps all illuminated, remove each lamp one by one from its base, observe what the other lamps do, and replace the lamp in its base. Record all your observations in your lab journal.

Analysis

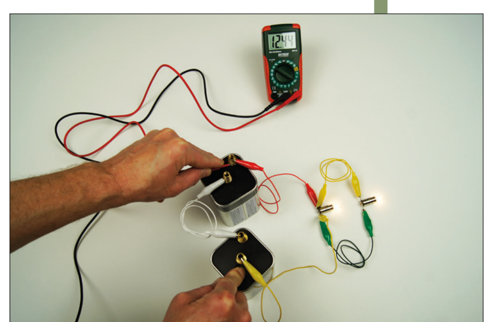
In your report, you need to work out a way to display all your resistance and voltage measurements in a table. It may help to make separate tables for the series connections and the parallel connections. In your report, address the following items.



1. Study your resistance data for a single lamp and for two or three lamps connected in series. From your data, determine the general mathematical rule for the combined resistance of several resistors connected in series. Use your rule to predict the combined resistance for five resistors connected in series, assuming that each of them has a resistance of 1,500 Ω. (Note: The rule you determine works even if the resistor values are not the same.)
2. Study your resistance data for a single lamp and for two or three lamps connected in parallel. Determine the general rule for the combined resistance of several identical resistors connected in parallel. Use your rule to predict the combined resistance of five resistors connected in parallel, assuming that each of them has a resistance of 1,500 Ω. (Note: The rule you determine for parallel resistors may only be valid for the case when the resistor values are identical. There is a more general rule that you may learn in a later course. Or you can look it up if you are curious.)



3. Study your voltage data for a single lamp connected to the battery pack and for two or three lamps in series connected to the battery pack. Determine the general rule for what the voltage across a single resistor is when several identical resistors are connected in series to a battery. Use your rule to predict the voltage across a single resistor if four 250-Ω resistors are connected in series to a 12-V battery.



4. Study your voltage data for a single lamp connected to the battery pack and for two or three lamps in parallel connected to the battery pack. Determine the general rule for what the voltage across a single resistor is when several identical resistors are connected in parallel to a battery. Use your rule to predict the voltage across a single resistor if four 250-Ω resistors are connected in parallel to a 12-V battery.
5. Write a description of how a series circuit of lamps behaves if one of the lamps burns out. Explain why the circuit behaves this way.
6. Write a description of how a parallel circuit of lamps behaves if one of the lamps burns out. Explain why the circuit behaves this way.
7. As you know, Christmas lights for trees or houses have 50 or 100 little lamps wired together in a single string of lights. Back in the early 1970s, the light bulbs for Christmas lights were not as reliable as they are now, and people always kept a few extra lamps on hand to replace those that burned out. Back then, Christmas lights were wired as series circuits. Nowadays, they are always wired as parallel circuits. Based on your experimental results, you should be able to explain why parallel wiring replaced series wiring for Christmas tree lights.

Preparation

There is nothing to prepare for this experiment, except acquiring the parts. These are listed in the table on the next page.

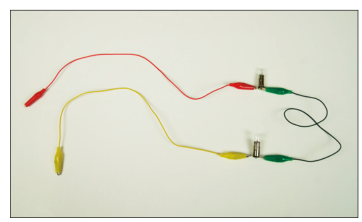
Important Notes About Blowing Fuses

When the selector switch of your digital multimeter (DMM) is in the resistance measurement mode, do not connect the meter to any circuit that has power connected to it. In the resistance mode, connecting a DMM to a powered circuit will probably blow the fuse in the DMM, and the DMM will be out of business until you can

Item	Quantity	Source	Cost	Ext. Cost	Comments
6-volt lantern batteries	2	hardware store	10.48	20.96	
lamp base	pack of 6	Radio Shack radioshack.com	1.99	1.99	Radio Shack item number 272-0355
incandescent bulb, two-pack	2	Radio Shack radioshack.com	2.19	4.38	Radio Shack item number 272-1112
mini-alligator cables, pack of 10	1	Radio Shack radioshack.com	8.99	8.99	Radio Shack item number 278-1156
digital multimeter, Extech MN15A	1	frys.com	26.99	26.99	Fry's item number for this DMM 6893516. Any volt-ohm meter will work. If you don't have one, this one is comes at a great price.
spare fuses	pack of 5	grainger.com	9.61	9.61	These are not strictly necessary, but are recommended. See "Important Notes" on page 70. Grainger item no. 6F090 is the replacement fuse to fit the Extech MN15A DMM listed above.
			Project Total	72.92	

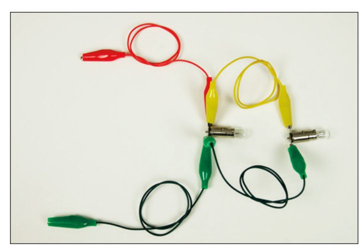
replace the fuse. Instruct and caution your students to perform all of their resistance measurements first. Then they can switch the DMM to the DC voltage setting and begin making voltage measurements.

If a student does blow a fuse in a DMM, it is good to have spare fuses on hand. The replacement fuses for the Extech DMM suggested in the parts list are also listed. To replace the fuse, open the battery compartment on the back of the DMM. Below the battery compartment are two fuses. The one on the left is the fuse that blows when making resistance measurements. Use a small screwdriver to slide this fuse in its holder as far as possible in one direction. Then pry it out with the tip of the screwdriver. Place the replacement fuse on the fuse holder and push it into place with the eraser on the end of a pencil.

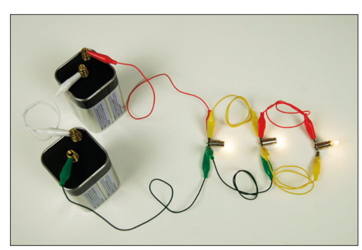


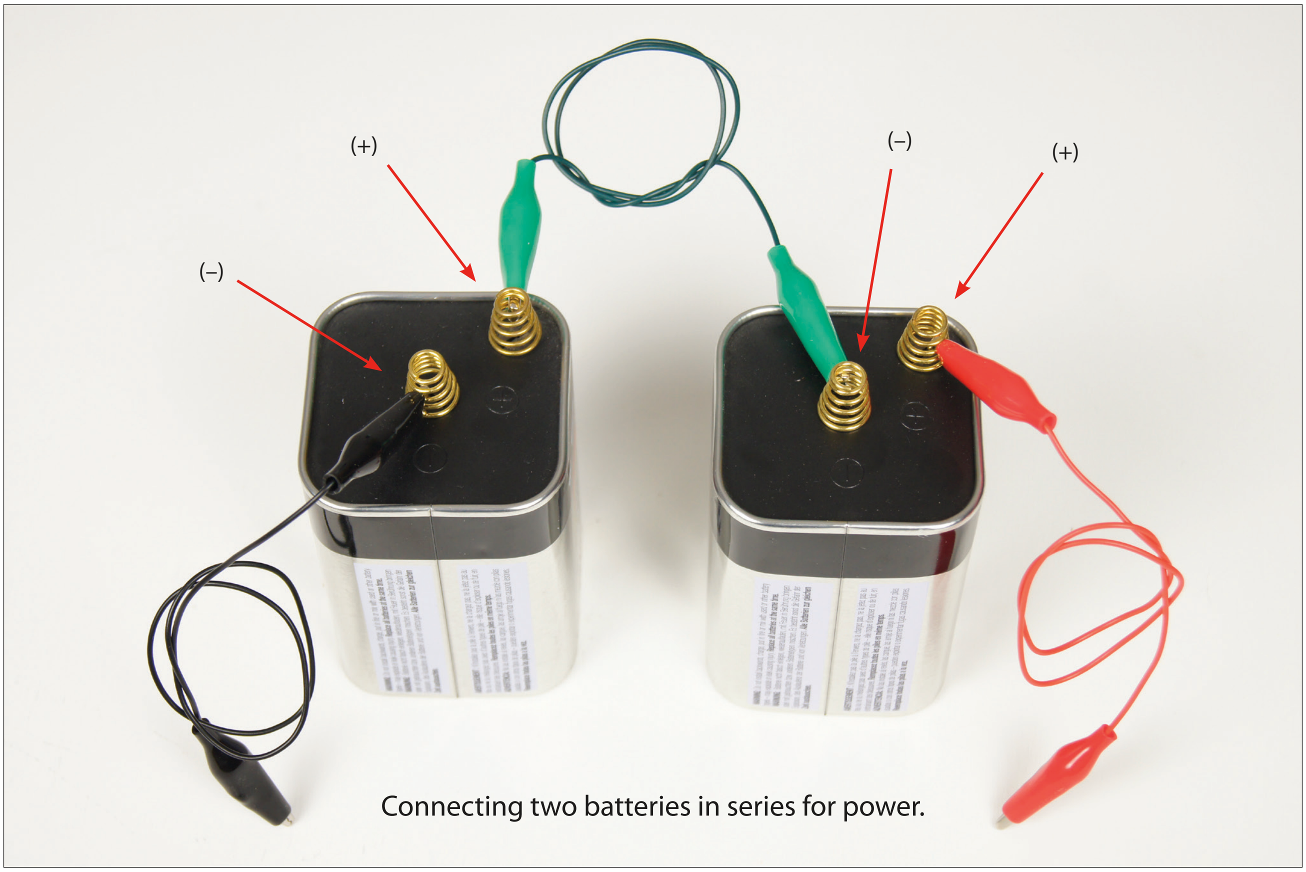
Running the Experiment

Examples of connecting two lamps in series and parallel are shown in the photos to the right. The lower photo shows three lamps in parallel, with the 12-volt battery pack attached.

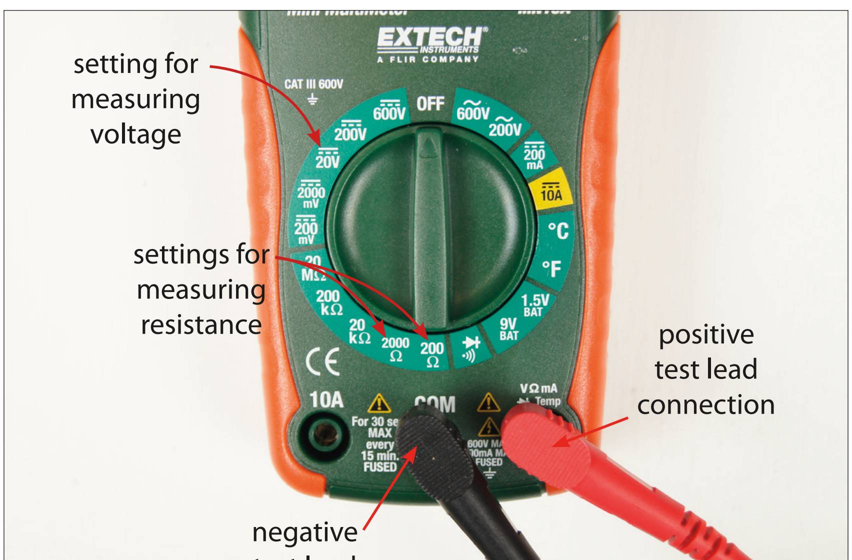


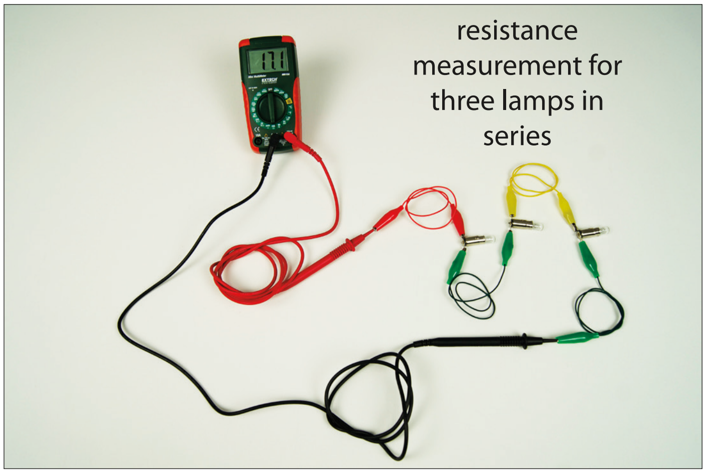
At the top of page 72 are the details of how to connect two 6-volt batteries together in series to make a single 12-volt battery. The photo below that illustrates the way the test leads should be connected to the digital multimeter (DMM). The photos at the top of page 73 show how to connect the DMM to measure the resistance of three lamps in series (left) or in parallel (right). The center photo on that page shows a typical DMM display in the case of (a) the resistance being measured is greater than the range selected, or (b) no resistor is connected, so the meter is reading an essentially infinite resistance. Finally, the last photo shows how to use the DMM to measure the voltage across the battery pack. To measure a voltage across a lamp, simply touch the DMM test leads to the metal terminals on either side of the lamp base. Always touch the red (+) test lead to the terminal closest to the positive (+) terminal of the battery. If you connect it backwards, the DMM will display a negative voltage reading, but causes no harm.

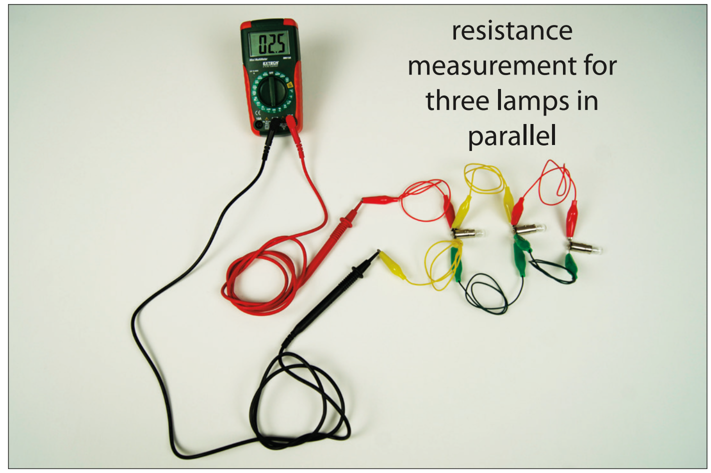


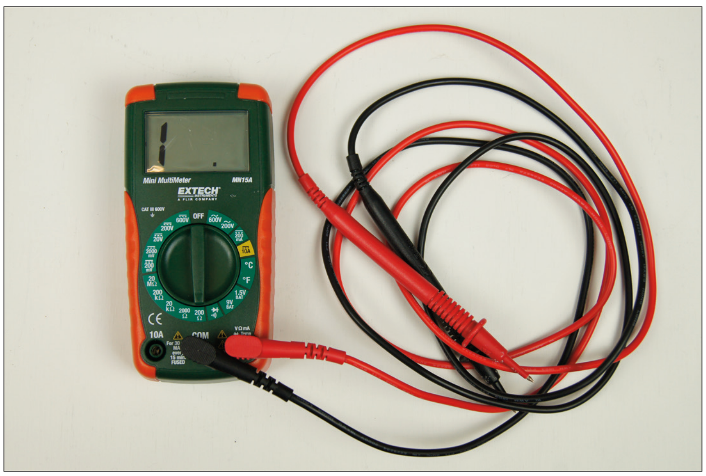


Connecting two batteries in series for power.

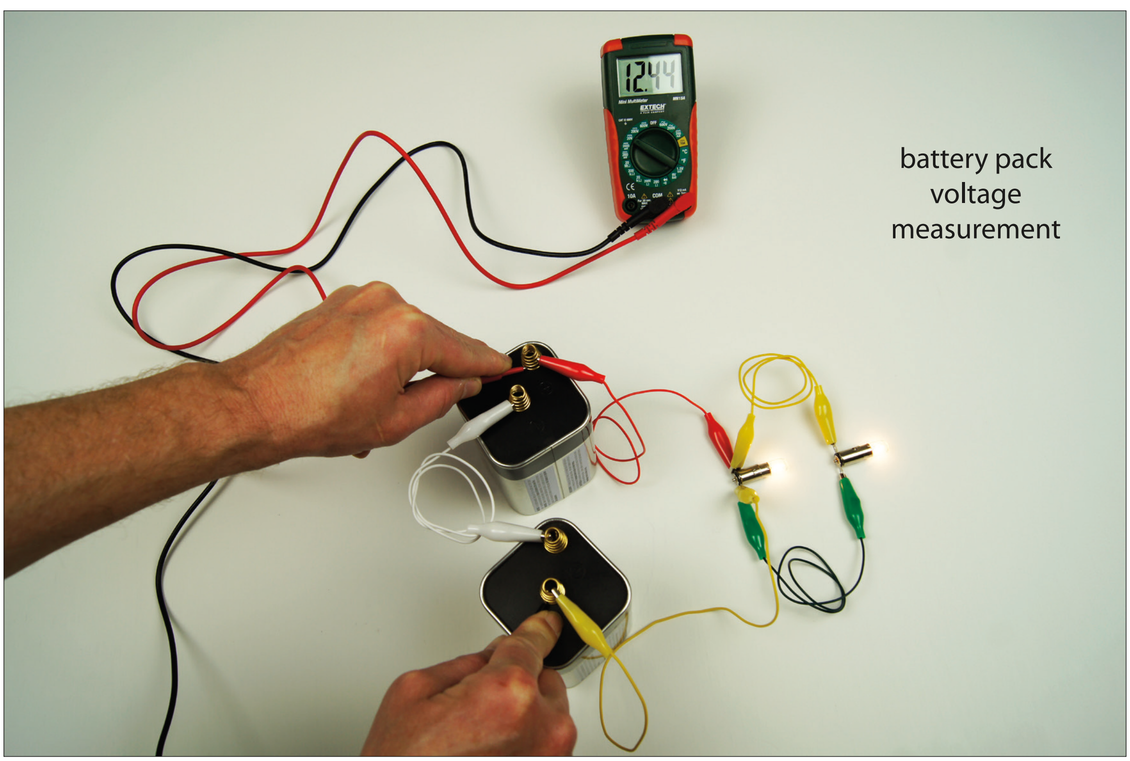








Typical multimeter display in resistance mode when *R* is too high for selected range, or if no resistor is connected.



Description from Text

Experimental Investigation 12: Magnetic Field Strength

Overview

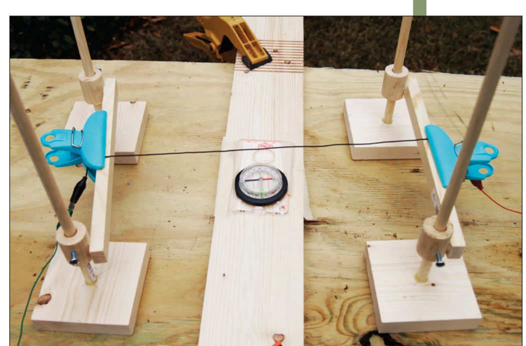
- Set up a simple DC circuit with a 6-V battery connected to a 10-foot loop of wire. With the power to the wire off, place a magnetic compass under the wire so the wire is in line with the compass needle.
- Connect the circuit, and measure the compass needle deflection. Raise the wire a few millimeters, and repeat. Do this at several different heights from 10 mm up to 250 mm.
- *The goal of this experiment is to determine how the strength of the magnetic field around a current-carrying wire varies with the distance from the wire.*

Basic Materials List

- magnetic map compass
- insulated wire with alligator clips (10 ft)
- 6-volt lantern battery
- masking tape
- wooden stands (from the Kinetic Energy experiment)
- plastic work clamps (2)
- plastic clips (2)
- table (non-metallic), carpenter's level
- 1 × 4 pine, 24 to 36 inches in length
- rule, metric, 18 inch

As we have seen in Chapters 5 and 14, Ampère's law states that a current-carrying wire produces a magnetic field circling around it. The strength of this magnetic field is proportional to the current flowing in the wire. In this experiment, we use the deflection of a magnetic compass to determine how the strength of the magnetic field around a wire varies with respect to the distance from the wire.

The experimental setup is shown in the photo below. After you make sure that your table is level, tape a magnetic compass to a 1 × 4, and clamp the 1 × 4 to the work table with plastic work clamps. Adjust the scale on the ring around the compass so the compass needle is in line with the 0° mark. Make a large loop of insulated copper wire, about 10 feet long, with alligator clips on each end. Clip one end of the wire to the battery. The other end will be clipped on and off the battery as needed. Using the two adjustable supports from the Kinetic Energy experiment, arrange the loop of wire so you can adjust it to different heights above the compass and so it passes directly over the compass needle. Run the rest of the wire in a big loop, as far away from the compass as possible.



Here is a very important detail you must attend to: any ferrous metal, such as steel, that is close to the compass will affect the position of the compass needle. This goes for the steel studs often used in building construction, metal furniture, and so on. For this reason, it is best to perform this experiment outdoors, far from any buildings, cars, or metal structures. The larger any nearby metal structure is, the farther you need to be from it. If your school meets in a metal building, you should setup your table for this experiment at least 100 ft from the building. You must also take care that your experimental setup doesn't make use of any steel clamps, tools, or tables.

To begin, adjust the wire supports down as low as they will go. Clip the wire to the support arms with plastic clips, such as are used to close bags of potato chips. Adjust the support stands so the wire is tight, horizontal, and perfectly aligned with the compass needle, as shown in the photo to the right. Use a rule marked in millimeters to measure the height of the wire above the 1 × 4 supporting the compass. By placing the compass on a 1 × 4 instead of directly on the table, the first height measurement may be only 10 mm or so. Record the height measurement in a table in your lab journal. Now clip the other end of the wire to the battery, and read the deflection in degrees on the compass. As soon as you have this reading, disconnect the wire from the battery, and record the compass deflection for that height in your lab journal.

Raise the supports 10 millimeters or so, and adjust them so the wire is horizontal, tight, right over the compass needle, and perfectly aligned with it. Measure and record the wire height. Then briefly connect the power and read the needle deflection. Repeat this procedure until your support stands are as high as they can go. Make sure you have measurements for at least 15 different heights. When you reach the point where your deflection measurements are only changing by a degree or so, then double the distance you raise the wire for the next measurement (e.g., raise it 20 mm instead of 10 mm, etc.).

Analysis

We are using the deflection of the compass needle as an indicator of the magnetic field strength around a current-carrying wire. Prepare a graph of compass deflection in degrees (vertical axis) versus wire height in millimeters (horizontal axis). Your instructor will help you format the axes and scales properly. In your report, address the following questions.

1. Describe the shape of your graph. As the height increases, does the strength of the magnetic field from the wire decrease in a linear fashion, or in some other way?
2. Explain how the results of this experiment would change if we used two 6-V batteries in series to get a 12-V battery, like we did in Experimental Investigation 11.
3. In your own words, explain why turning on the current causes a compass needle to deflect.
4. Imagine that we used 20 feet of wire instead of 10 and made the wire into a double-wrapped loop so that we had two wires passing over the compass instead of one. How would you expect this to change the results of this experiment?

Preparation

The materials required are listed in a table on the next page. Other than procuring materials, there is nothing else that needs to be done ahead of time.

The first order of business is to set up a table made completely of nonmetallic materials. One easy way to accomplish this is with a piece of plywood on top of a couple of plastic sawhorses. These add expense to the experiment, so if that is a problem, any all-wood or all-plastic table will do. Conventional folding tables have steel legs and are not suitable. Use the spirit level to level the table so the compass works properly.

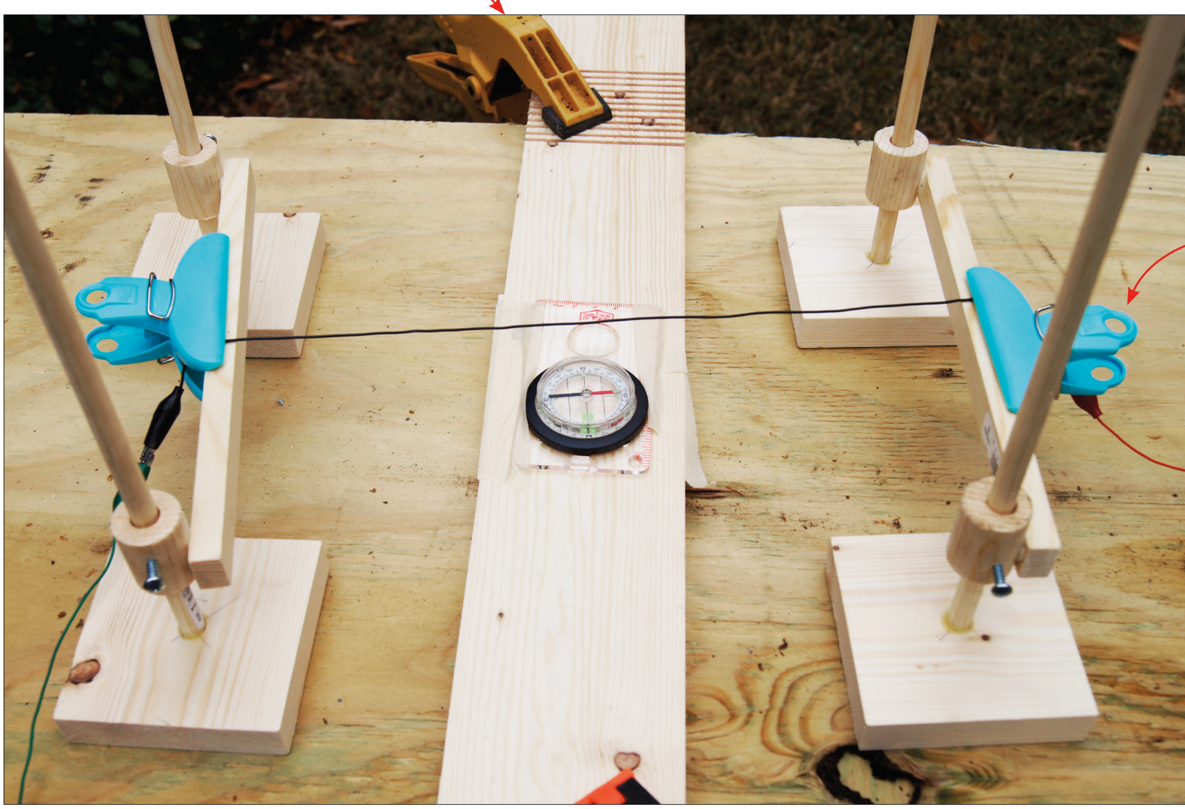
As described in the experiment description in the text, this experiment needs to be performed in a location far away from any metal such as cars, metal buildings, playground equipment or even the metal studs and structural members used in most permanent buildings. A playing field or other large area is ideal. If there are any cars or buildings around, set up your table at least 100 feet away.

The photo at the bottom of the next page shows the layout of the materials on the table top. The wire visible in the picture over the compass is one of the alligator clip wires from the circuits experiment (#11). Connect all ten of the clip wires together into a big loop. Somewhere in the loop, on the ground as far away from the compass as possible, connect in the battery. It does not matter too much which way the battery is connected in, but a positive angular deflection on the compass will make it a bit easier to determine the deflection angle. The basic goal is to have all the wire in the loop, and the battery, as far away from the compass as possible. Only the section of wire passing over the compass should be anywhere near the compass. Extend the wire off the ends of the table in both directions, and orient the loop so the wire makes the widest possible loop around the compass.

All the work clamps and wire clamps in this experiment must be non-metallic (except for the necessary spring).

Item	Quantity	Source	Cost	Ext. Cost	Comments
meter stick	1	See Introduction			
6-volt lantern battery	1				Use the batteries from the circuits experiment (#11).
map compass	1	sporting goods store	3.99	3.99	
mini-alligator cables, pack of 10	10				Use the cables from the circuits experiment (#11).
adjustable support stands	2 sets				Use the adjustable support stands from the kinetic energy experiment (#1).
plastic work clamps	2	hardware store	2.98	5.96	
plastic chip clips	2	grocery store	2.99	2.99	Price is for a 2-pack
spirit level	1	hardware store	4.47	4.47	
table, non-metallic	1	common item	n/a		
1 × 4	24 to 36 in				use leftover 1 × 4 from the kinetic energy experiment (#1).
masking tape		common item	n/a		
			Project Total	17.41	

plastic work clamps



plastic chip clips

The adjustable support stands have bases 3/4 inch thick, preventing the wire over the compass from going all the way down to the table top. By placing the compass on a section of 1 × 4 clamped to the table top, the compass is raised up a bit so the first measurement will be just a few millimeters (10 mm or so) above the compass.

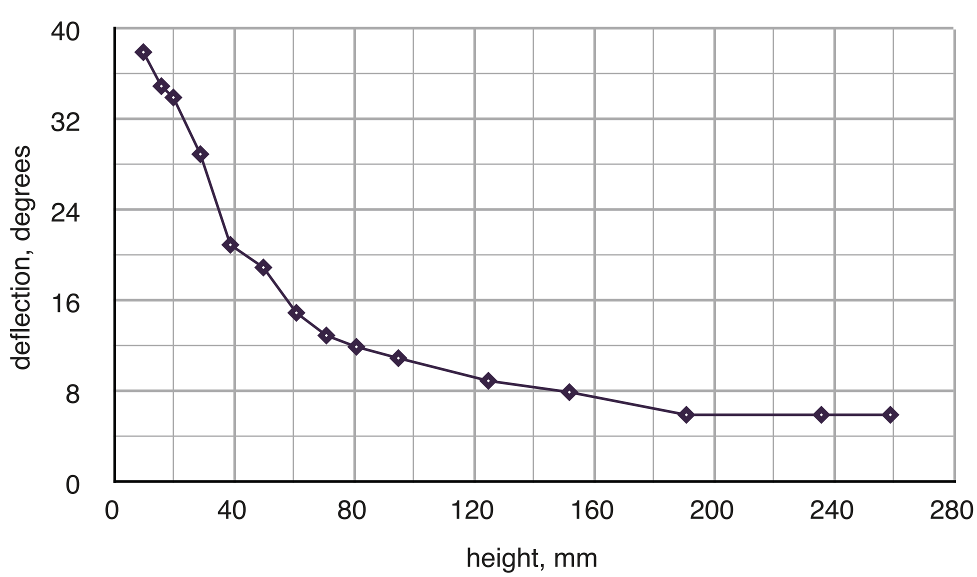
Running the Experiment

With the battery disconnected, align the wire over the compass so it is directly above the compass needle and precisely lined up with the compass needle, as shown in the photo to the right. For each measurement, simply use the meter stick to measure the height of the wire above the compass, connect the battery, and record the deflection angle of the compass needle in degrees. Then disconnect the battery, raise the wire 10 mm or so, measure the height, connect the battery and record the compass deflection. Repeat until the crosspiece supporting the wire is at the very top of the adjustable supports.

Analysis

The strength of the magnetic field around a current-carrying wire decreases in inverse proportion to the square of the distance from the wire. Since the deflection of the compass needle from north depends on the strength of the field, we are using the deflection as a measure of the magnetic field strength. The field strength, and thus the compass deflection, should decrease according to an inverse square law. (Inverse square laws are discussed on page 79 in the text.)

The graph below shows the data from running this experiment. The shape of that curve clearly demonstrates the inverse square relationship between the field strength as indicated by the compass deflection, and the distance of the wire above the compass.



Appendix 1

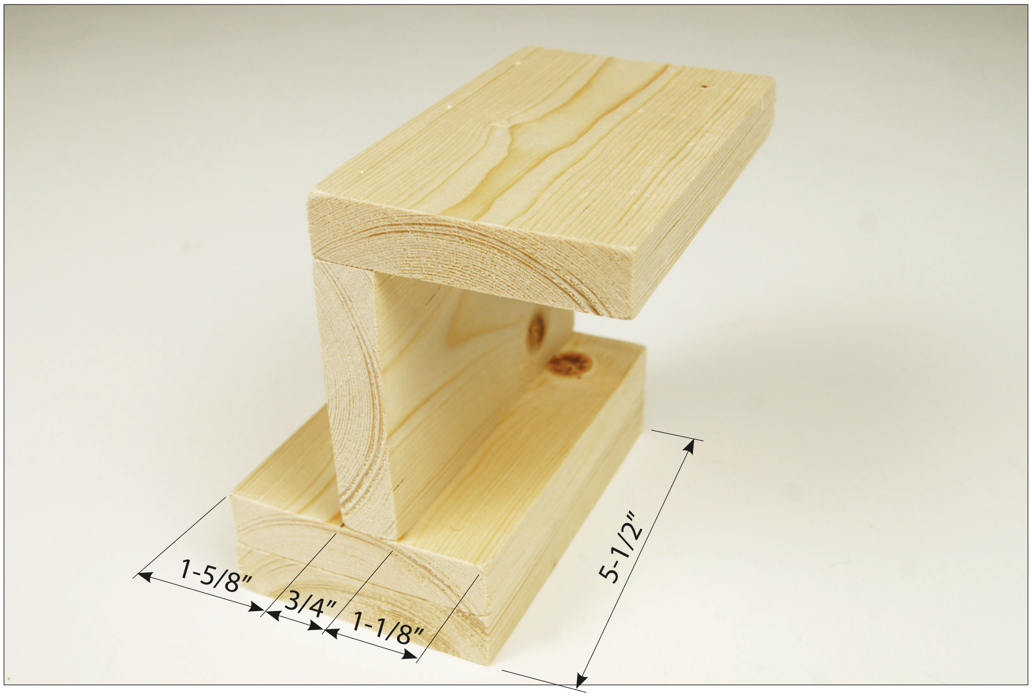
Physical Science Special Parts Kit
Item Specifications

General

1. All holes must be drilled with a drill press (no hand-held drilling).
2. All cuts in metal parts to be straight, clean and perpendicular to the part.
3. All edges, corners and surfaces of wooden items sanded smooth, to be free of burrs and splinters.
4. All edges and corners of metal items smoothed just enough to remove sharpness and burrs to prevent cuts, but still retaining squareness of corner. Surfaces to be free of major gouges or imperfections (even though there are some gouges visible in the sample photos). The single steel part is to be free of rust, wiped with light oil and bagged separately.
5. All wood items must be cleaned with compressed air to be free of wood dust.
6. All metal parts wiped thoroughly with solvent and cleaning rag to be free of metal particles.
7. Each set of metal parts to be supplied in two sealable sandwich bags, one for the steel part and one for the other four parts.
8. All parts to be clean and free of pen and pencil marks, metal marker marks, etc.
9. No finishes are to be applied to any items.

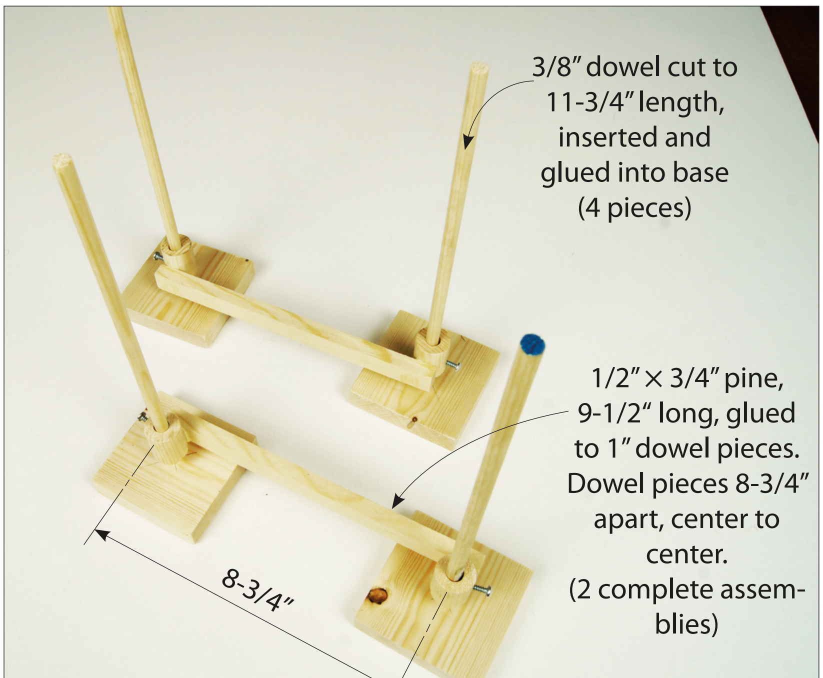
Item 1: Hot Wheels Track Clamp Support Base

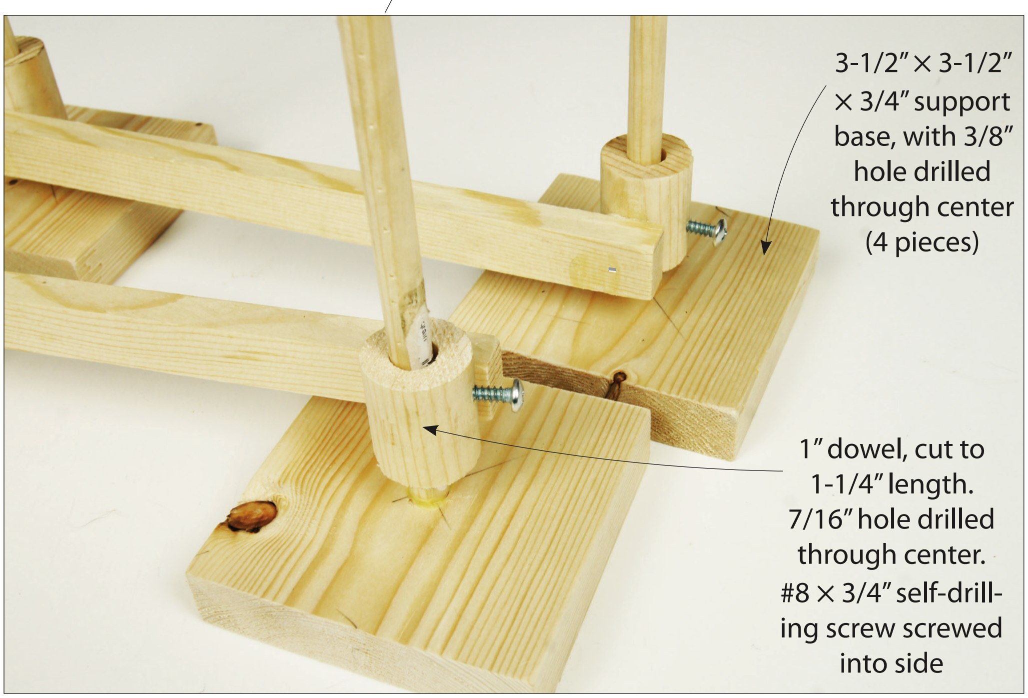
Constructed of 1 × 4 pine. Joints are glued and fastened with finishing nailer with 1-1/2″ finishing nails. All edges, corners and surfaces smoothed. Base is two layers of 1 × 4.



Item 2: Double Support Stand with Adjustable Crosspiece

This item consists of six separate pieces: four support stands and two adjustable cross pieces, as shown in the first photo. Support stands are constructed of a 1 × 4 pine base, with a 3/8″ wooden dowel glued into a 3/8″ hole drilled into the base. Cross pieces are made of 1/2″ × 3/4″ pine. Cross pieces are glued to sections of 1″ wooden dowel, and tacked with a finishing nailer using a 3/4″ finishing nail. A 7/16″ hole is drilled through the center of each 1″ dowel section. One #8 × 3/4″ self-tapping screw is screwed into the side of each of the 1″ dowel sections. All edges, corners and surfaces smoothed.

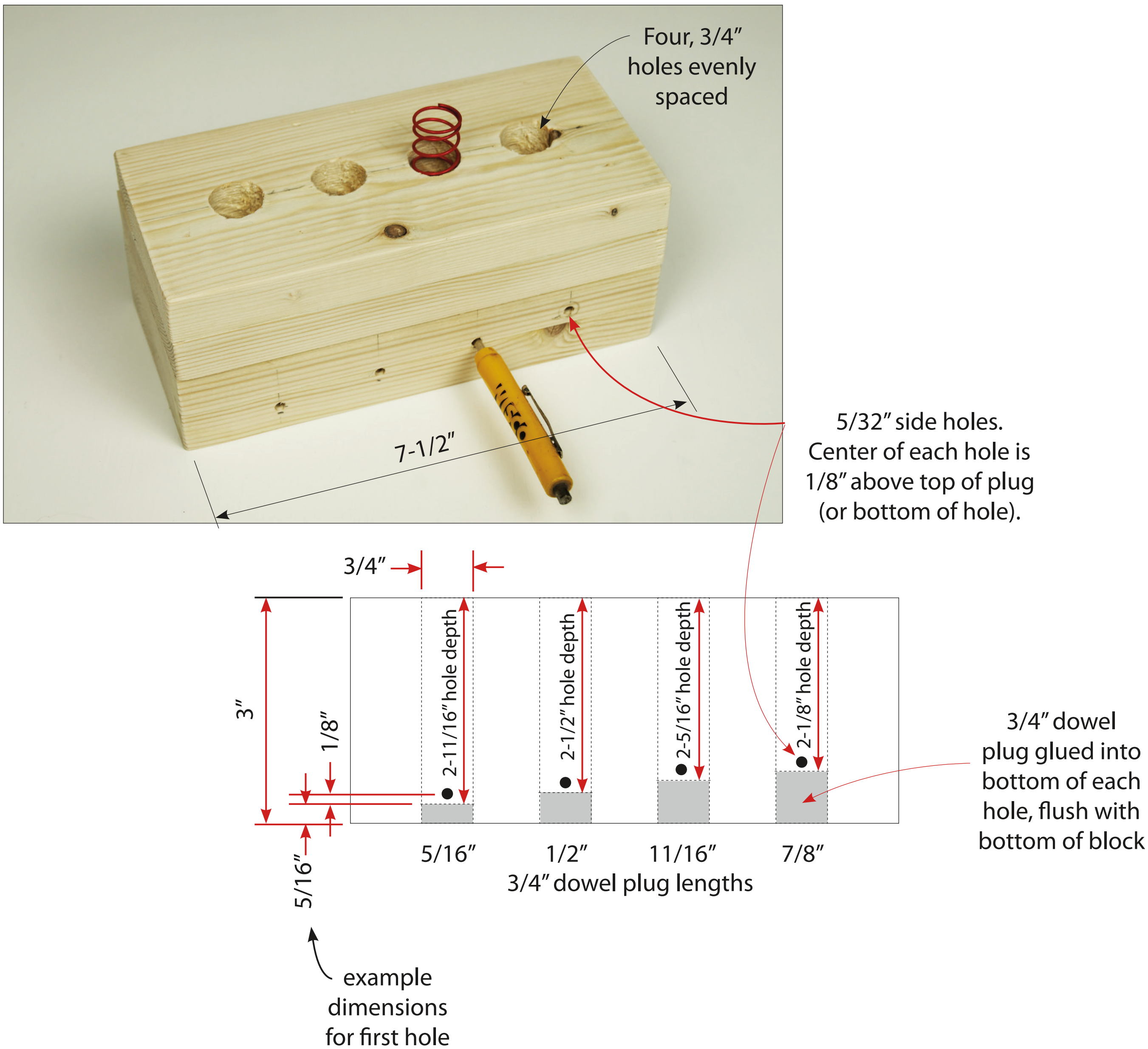




Item 3: Four-Hole Spring Mounting Block

Constructed of 1 × 4 pine and 3/4″ wooden dowel. Block is four layers of 1 × 4 pine glued together. Four 3/4″ holes are drilled through the block, evenly spaced and centered between sides. Sections of 3/4″ dowel are cut to dimensions shown in the sketch below. One section of dowel is glued into the bottom of each hole, in order of increasing length, flush with the bottom of the block. A 5/32″ side hole is drilled into each main 3/4″ hole. Centers of side holes are 1/8″ above the top of the dowel plug. Side holes are on one side of the block only. All edges, corners and surfaces smoothed.

An alternative method for drilling the four main holes is to use a 3/4-inch Forstner bit, which cuts a flat-bottomed hole. Holes are then drilled to the depths shown below and dowel plugs are not needed.



Item 4: Five Metal Samples

Piece 1: Aluminum angle, common T-6061 alloy, 1/8″ thick, 3/4″ × 3/4″ × 2-1/2″ long

Piece 2: Aluminum rod, common T-6061 alloy, 3/8″ diameter × 3″ long

Piece 3: Brass rod, common alloy 360, 1/2″ diameter × 3-1/2″ long

Piece 4: Aluminum flat bar, common T-6061 alloy, 1/8″ × 3/4″ × 4″ long

Piece 5: Steel flat bar, common CF-1018 alloy, 1/2″ × 1/2″ × 2″ long

Appendix 2

Master Materials List

To determine order quantities, you will need to consider your work group arrangements. Quantities listed are for a single group. See the Introduction for suggestions on which experiments work best for dividing a class into small groups. Dividing into small groups requires multiplying most order quantities. Also see the Introduction for notes on alternatives for some of the more expensive items of laboratory apparatus.

Item	Quantity	Source	Experiment	Item No. or Notes
acrylic glass prism	1	amazon.com	10	
Bunsen burner with built-in butane tank	1	amazon.com	9	See Introduction for very important details about this item.
magnifying glass	1	amazon.com	4	
meter stick	1	amazon.com	1, 8, 12	See Introduction for details about this item.
3″ × 5″ index cards	10	common item	1	
aluminum foil	6 inches	common item	3	
calculator	1	common item	5, 6, 10	
clear glass bowl	2	common item	4	
coffee filter	2	common item	9	
duct tape	36 in	common item	2, 7	
graph paper	6 sheets	common item	10	
masking tape	25 ft	common item	1, 2, 10	
pencil	1	common item	4, 10, 11	
plastic spoon	6	common item	4, 9	
plasticware lid	1	common item	2	
protractor	1	common item	10	
refrigerator/freezer	1	common item	4, 7	
ruler	1	common item	10	
small cardboard box	1	common item	2	
small screwdriver	1	common item	8, 11	
table, non-metallic	1	common item	12	
tall, clear drinking glass	2	common item	4	
tape measure	1	common item	8	
wood glue	small bottle	common item	1	
wooden ball, 1″ diam	1	craft store	8	

Item	Quantity	Source	Experiment	Item No. or Notes
Hot Wheels car with cargo space	1	discount store	1	Save the plastic packaging for experiment 10.
Hot Wheels Mega Jump Kit	2	discount store	1	
non-stick frying pan, 6-inch	1	discount store	9	
spatula, stainless steel	1	discount store	9	
Styrofoam cooler	2	discount store	2	
Styrofoam cups with lids, 12 oz	1 pack	discount store	2, 7, 9	
aluminum wire, 500 MCM	2 ft	electrical supply house	2	Ask for free piece
digital multimeter, Extech MN15A	1	Fry's Electronics, frys.com	11	DMM 6893516
laser pointer, 5 mW or less	1	Fry's Electronics, frys.com	10	Alpec Black Midget
digital caliper	1	Grainger, grainger.com	5	1AAU4
heat resistant gloves	1 pair	Grainger, grainger.com	9	
spare fuses	pack of 5	Grainger, grainger.com	11	6F090
alum	1 container	grocery store	4	
distilled water	1 gal	grocery store	4, 9	
Epsom Salt, 0.5 gal	1 carton	grocery store	4	
plastic chip clips	2	grocery store	12	
sodium bicarbonate (baking soda)	30 g	grocery store	9	
table salt, non-iodized	1 container	grocery store	4	
#8 x 3/4 flat head wood screws	2	hardware store	1	
1 in wooden dowel	48 in	hardware store	1	Not needed if parts kit purchased from Novare
1 × 4	24 to 36 in	hardware store	12	
1/2 × 3/4 pine	24 in	hardware store	1	Not needed if parts kit purchased from Novare
1 × 10 pine	72 in	hardware store	1	
1 × 2 pine	72 in	hardware store	1, 8	
1 × 4 pine	72 in	hardware store	1	Not needed if parts kit purchased from Novare
3/8 in wooden dowel	48 in	hardware store	1	Not needed if parts kit purchased from Novare
6-volt lantern batteries	2	hardware store	11, 12	

Item	Quantity	Source	Experiment	Item No. or Notes
aluminum angle, 1/8 in thick, 3/4 × 3/4 × 2.5 inches long, T-6061 alloy	1	hardware store	5, 6	Not needed if parts kit purchased from Novare
aluminum flat bar, 1/8 inch × 3/4 inch × 4 inches long, T-6061 alloy	1	hardware store	5, 6	Not needed if parts kit purchased from Novare
aluminum rod, 3/8 inch diameter × 3 inches long, T-6061 alloy	1	hardware store	5, 6	Not needed if parts kit purchased from Novare
copper wire, solid, 10 gauge	10 ft	hardware store	2, 3	Purchase 15-ft roll of 10-2 NM
Gorilla glue, 2 oz	1	hardware store	3	
plastic work clamps	2	hardware store	12	
Quick Grip clamps, micro size	2	hardware store	1, 3	
self-drilling screws, #8 × 3/4	pack of 4	hardware store	1	Not needed if parts kit purchased from Novare
spirit level	1	hardware store	12	
wooden dowel, 3/4 inch	12 in	hardware store		Not needed if parts kit purchased from Novare
spring	1 pack	Hobby Town	8	Traxxas 4457
burner hose	5 ft	hosecraftusa.com	9	See Introduction for very important details about this item.
Bunsen burner	1	Humboldt Mfg, humboldtmfg.com	9	See Introduction for very important details about this item.
monofilament line, 0.1 in diameter	10 ft	landscape crew	2	Ask for free piece
brass rod, 1/2 inch diameter × 3.5 inches long, 360 alloy	1	metal supply	5, 6	Not needed if parts kit purchased from Novare
carbon steel flat bar, 1/2 inch × 1/2 inch × 2 inches long, CF-1018 alloy	1	metal supply	5, 6	Not needed if parts kit purchased from Novare
incandescent bulb, pack of 2	2	Radio Shack radioshack.com	11	272-1112
lamp base, pack of 6	1	Radio Shack radioshack.com	11	272-0355
mini-alligator cables, pack of 10	1	Radio Shack radioshack.com	11, 12	278-1156
fishing line	1 spool	sporting goods store	3, 4	
golf ball	1	sporting goods store	8	

Item	Quantity	Source	Experiment	Item No. or Notes
lead split-shot, size BB	pack of 60	sporting goods store	1, 4	
map compass	1	sporting goods store	12	
Ping Pong ball	1	sporting goods store	8	
beaker, 250 mL	3	The Lab Depot, labdepotinc.com	4, 5	See Introduction for details about this item.
beaker, 600 mL	2	The Lab Depot, labdepotinc.com	2, 4, 7	See Introduction for details about this item.
burner tripod	1	The Lab Depot, labdepotinc.com	9	See Introduction for details about this item.
clamp holder	1	The Lab Depot, labdepotinc.com	10	P35011
digital thermometer	5	The Lab Depot, labdepotinc.com	2, 7	ACC370DIG See Introduction for details about this item.
graduated cylinder, 100 mL, 6 pack	2	The Lab Depot, labdepotinc.com	2, 5, 7, 9	2355-100-P See Introduction for details about this item.
hot plate	1	The Lab Depot, labdepotinc.com	2, 3, 4	Cimarec Basic Hotplate
mass balance	1	Home Science Tools, homesciencetools.com	1, 4, 6, 8, 9	Digital Pocket Scale. See Introduction for details about this item.
beaker tongs	1	The Science Company, sciencecompany.com	4, 7	See Introduction for details about this item.
copper sulfate pentahydrate	20 g	The Science Company, sciencecompany.com	9	NC-0304
flask, 250 mL	2	The Science Company, sciencecompany.com	9	NC-7884 See Introduction for details about this item.
hydrochloric acid	50 mL	The Science Company, sciencecompany.com	9	NC-1783

Item	Quantity	Source	Experiment	Item No. or Notes
nitrile gloves	1 pair	The Science Company, sciencecompany.com	9	NC-11097
pH indicator strips	1 pack	The Science Company, sciencecompany.com	9	NC-0690
plastic funnel	2	The Science Company, sciencecompany.com	9	NC-0448
ring stand	1	The Science Company, sciencecompany.com	10	See Introduction for details about this item.
safety goggles	1	The Science Company, sciencecompany.com	8, 9	NC-11006
sodium hydroxide	10 g	The Science Company, sciencecompany.com	9	NC-0874