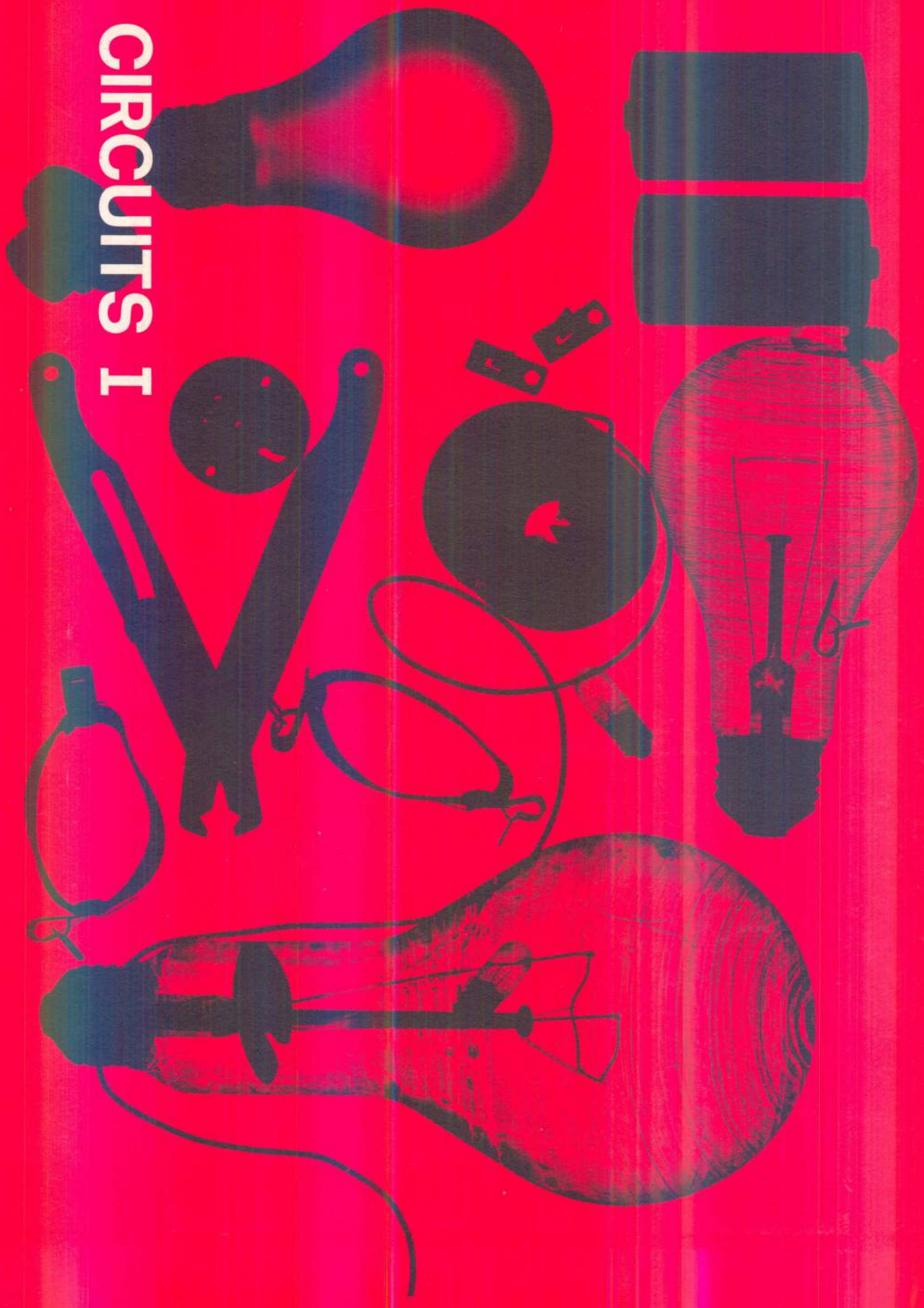


# BATTERIES AND BULBS

Book 1

2.00, 1.00 1.00 83.00 for 50



## CIRCUITS I

# BATTERIES AND BULBS

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**An Early Exploration of Electrical Circuits and Magnets**

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**Teacher's Guide**

**Trial Teaching Edition**

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Watertown, Massachusetts 02172

# BATTERIES AND BULBS

An Early Exploration of Electricity, Circuits and Magnets

Teacher's Guide

First Learning Edition

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## BATTERIES AND BULBS

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# INTRODUCTION

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## What Is Batteries and Bulbs About?

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*Batteries and Bulbs* is an introduction to the study of electricity and magnetism in the course of which each child makes experiments with his own simple equipment (flashlight batteries, small bulbs, various kinds of wire, compasses, magnets) and draws conclusions based on the results of his observation of these experiments. Children investigate such things as ways to light several bulbs with one battery, what happens when more than one battery is used, whether varying lengths and types of wire influence the brightness of bulbs. Indeed, this guide consists largely of questions and problems which have already been pursued by children working with batteries, bulbs and wires.

In the course of these investigations, the child gains the personal experience which makes the electrical behavior of matter an acceptable and familiar phenomenon. From the very beginning, using a battery and a piece of wire to light a bulb, experiments suggest questions which in turn suggest new experiments. Results are predicted. Students check experiments, compare and discuss results and propose explanations.

After experimenting with the materials, children propose rules such as: *If a bulb has its own separate path to the battery, it will be of standard brightness.* These rules are discussed, evaluated and modified by the other children on the basis of their own experiments. The conclusions and generalizations that emerge from the experiments done by one child can be tested by other children to see if they can be reproduced.

These generalizations are important scientific conclusions in their own right. *A coil of wire in a complete electrical circuit acts like a magnet.* This generalization is as true in an electrical dynamo, a telephone or the synchrotron in a nuclear physics laboratory as it is on a child's desk.

### For Whom Is This Material Intended?

*Batteries and Bulbs* has been used in some manner with students in grades 2 to 10. In grades 2 and 3, only a limited amount of this material is appropriate (see *Scheduling* below). By the 7th

and 8th grades students may move rapidly into the study of some of the more complex ideas.

### Scheduling

*Batteries and Bulbs* can take anywhere from 5 to 40 weeks, depending on the students' maturity, the number of sections covered and how many times a week you use the materials. In a 5th or 6th grade class, 45 to 50 minutes three times a week for 5 to 8 weeks is generally enough time to explore *Circuits I*. A comparable amount of time is needed for *Circuits and Magnets* and *Circuits II*. A break of a few weeks can be taken between these study areas, or they may be taught in different years. With grades 2, 3 and 4 you will probably want to explore only *Circuits I*. After *Circuits I*, the order in which the other study areas are presented does not matter. Some classes working with *Circuits I* may become interested in ideas elaborated upon in *Circuits II*. They should by all means be encouraged to move ahead into these more complex areas.

## Who Can Teach Batteries and Bulbs?

You don't have to know very much about electricity to teach *Batteries and Bulbs*. The one prerequisite is that you be willing to let your children investigate at their own rate in directions dictated by the materials and by the limits of their imagination. In fact, you are encouraged to share with your classes in exploring the possibilities of batteries, bulbs and wires. Reference to the *Before Starting To Teach* sections will alert you to materials needed and offer suggestions for experiments you can do by yourself to aid you in later guiding your class. This guide marks a starting point from which you and your students can set off on your own particular exploration.

## Organization of the Guide

*Batteries and Bulbs* is divided into three study areas — *Circuits I*, *Circuits and Magnets*, *Circuits II*—and each study area into several sections (see *Table of Contents*).

Each section of the guides to *Circuits I* and *Circuits and Magnets* is organized into the following subsections:

*Before Starting to Teach*. Under this heading you will find background information on the subject, and projects which will help to familiarize you with the experiments before a set of lessons begins—in other words, a teacher's personal workshop. These before-class workshops are designed to introduce teachers to some of the problems each section poses. The materials needed for each workshop are identified, and typical experiments are suggested.

It is as true for adults as it is for children that there is no substitute for direct personal experience. Therefore we strongly urge that you keep a supply of batteries, bulbs and wires at hand while reading this guide and try some of the ac-

tivities suggested. The many suggestions for specific experiments you might try should be regarded as starting points rather than limitations. Advance exploration on your part will make you familiar with materials and methods and, thus, better able to guide your students in their experiments.

By the time you are ready to use materials in *Circuits II* you should be conversant with the language and approach in this guide and will be able to prepare for each class according to your own needs. Therefore, workshops are phased out gradually as *Batteries and Bulbs* progresses.

*Introducing (the subject) in the Classroom*. Here are presented guidelines as to why, when and how a section might be introduced to a class. Some actual classroom experiences are described to give you a glimpse of how *Batteries and Bulbs* has worked with other students. Your children will not necessarily follow these patterns. These examples are presented only to show some of the possibilities of the materials.

Both the preceding parts are denoted by a light gray edge indexing panel marked *Background*.

*Materials, Some Activities Children May Try, Possible Discussion Questions* and, when appropriate, *Prediction Sheets* and *Special Comments* are the other headings under the various sections.

These pages are provided for quick reference when teaching the class itself. Do not feel compelled to do all the activities or to do them in the order written. Most of the activities will probably be initiated spontaneously by the children.

These sections are denoted by a dark gray edge indexing panel marked *Classroom*.

## Some Classroom Patterns

There is no "correct" method for teaching *Batteries and Bulbs*. However, there are a few guidelines for teacher participation and student

activity which have shown themselves in a number of trial classes to help achieve a balance between free experimentation and the ordering of ideas.

A certain amount of apparent disorder is a necessary ingredient in a session of free experimentation. You should probably allow two or three periods of free activity with the materials before discussing with your students the experiments they have tried. By this time there should have been a good deal of communication among children and between you and individuals or groups of children.

You serve as a guide through the intricate world of batteries, bulbs and wires, as a provider of equipment, as a giver of simple mechanical instructions (such as how to use a wire stripper), as a poser of questions, as a discussion leader and, hopefully, as an enthusiastic participant.

We have found it most effective to divide the class into groups of four or five children. You can then move from group to group, encouraging children to answer their own questions from experimental experience and adding new equipment or suggestions as the need arises.

Timing is perhaps the most important element in the whole sequence of investigation. You can best gauge when your class is ready to talk about their work and when they need to go back to the materials for reassurance. Timing is important in giving out additional materials or worksheets to individuals who are ready for them. By observation of the class you will know when the students are ready for a technical word and when they need more time first to explore the concept for which the word is only a label. Some of the fun of doing real science lies in discovering that a big word is merely the name of something you already understand.

After materials are in the children's hands, exploration sometimes takes as many directions as there are children in the class. There are many paths to each generalization and the fact that chil-



dren may follow different paths to the same conclusion does not make it less appropriate than if they all took the same way to it. There are controls built into the materials and into the structure of the guide which can be applied by judging carefully when to provide materials, prediction sheets, project sheets and discussion sessions.

The sections within each study area in *Batteries and Bulbs* are intended as foundations, not fences. All kinds of diverting side paths lie waiting for the class which has the interest and time to explore them. When you reach questions about liquids under *Testing Pathways* you may want to spend as much as a week exploring the properties of water, salt water, salad oil, various fruit juices and soda pop as pathways between batteries and bulbs. Your schedule limitations and curiosity should be the only restrictions to this kind of creative investigation.

If your pupils sense an enthusiasm for investigation in you, they too will be encouraged to try out new ideas. One group of 6th graders during a free activity period with many-battery and many-bulb circuits suddenly disappeared into the coatroom. When the teacher followed them, she was delighted to discover that they were staring at their circuits in the dark because they had found that they could compare the brightness of different bulbs more accurately that way. Thereafter, the students were permitted to darken the classroom whenever they were experimenting with brightness.

## Prediction

The word *predict* is the key to the progression of ideas which unfolds through experimentation and discussion. Every subject is organized around certain plateaus, or natural resting points, in the process of learning. In *Batteries and Bulbs*, where each new fact adds to the one before it and the generalizations build on these facts, there are several points at which the child can use what

he has already learned to make predictions about unfamiliar situations. "What will happen if you put three bulbs and two batteries in this arrangement?" "How bright will the different bulbs be?" The prediction sheets which accompany these questions are designed so that the child can make his own prediction about what will happen in a specific circuit, then test it and find out if he was correct. These prediction sheets are *not* tests. They are a means for the child to evaluate himself, to find out how to use what he already knows in new ways. The sheets should bring up new ideas and questions to pursue. You may want to use them as a game or use individual examples to illustrate a discussion.

Different children will use different criteria in making their predictions. There is no one right way. One child may have experimented so exhaustively on his own that he has tried every possible combination of batteries and bulbs and can base his predictions on these results. Another child may formulate a rule in his mind and apply it when confronted by an unfamiliar diagram. You will often hear the same rules formulated anew in every class, although the words are sometimes different. A rule may be modified by the experiences of other children and perhaps discarded or replaced.

*Any generalization that the children do not make themselves is not worth introducing to them.* The main point about the rules and generalizations is that they must come out of the children's actual experience with real materials. All the evidence shows that a rule presented by a teacher will have little significance for the child unless he has himself worked out the explanation in the course of his experimentation. When a child is ready to abstract from his experience, he will do so, and in his own words.

## Terminology

Since the scientific definitions of the word *elec-*

*tricity* are so complex and difficult to explain, we have used this term only to denote the title of the subject to be investigated in this guide. Any reference to some characteristic of "electricity" is made in terms of some reaction, such as the brightness of a bulb in a particular circuit.

When a #20 (thick) copper wire is connected directly across a battery it will create a *short-circuit*, even though the wire so used may be much longer than that of the original circuit. A class of 6th graders was delighted to discover that when they put a three-foot piece of wire across a much tinier circuit they were making the path "shorter." Demonstration of this paradoxical phenomenon helped them to understand the rule *electricity always takes the easiest path*.

Note that the terms *thick* and *thin* apply only to the wires as they relate to each other in a given experiment. A wire that is called "thick" in one experiment may be called "thin" in another.

Some prefer to reserve the word *battery* for a combination of "cells." However, since battery is in common usage synonymous with cell, we use it in that way, even in reference to the "D" size flashlight cell. When different batteries are introduced, we refer to them by their names, *i.e.* transistor radio battery or No. 6 battery.

Children usually refer to the #48 bulb as the "pink bulb," since it has a pink bead inside the glass. We have shortened this to *PB* for convenience and use it in this form throughout the guide. When the #41 "white bulb" is introduced we refer to it as *WB*.

Children will use names such as top, bottom, side, tip, glass and thick wire to describe the parts of batteries and bulbs. Encourage the use of this type of terminology in preference to technical terms whose meaning may not be fully understood. For example, "path to bulb" means the same as "current flow" and is easier to understand.

# MATERIALS

Materials for *Batteries and Bulbs* are in cartons designed for long-term storage in a minimum of space.

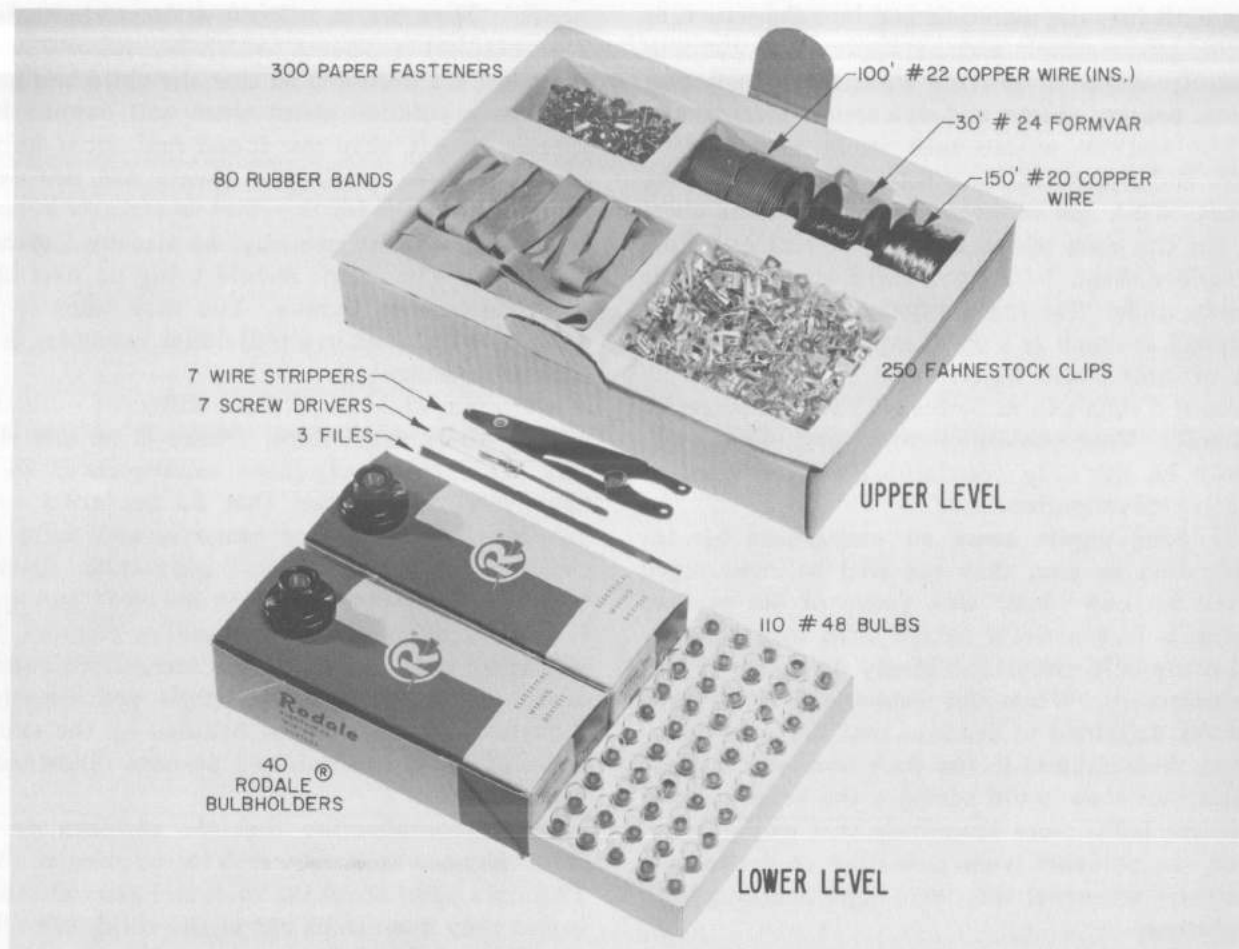
Each box contains materials to be used consecutively as your class explores each study area.

Most of the materials for *Circuits I* are to be found in Box 1. All three boxes contain materials to be used in *Circuits and Magnets* and *Circuits II*. Save the outside packing carton for a "junk box."

The only items necessary to the first few activities which are not included in the kit are batteries. Batteries lose some of their effectiveness over a long period of storage; in fact, a battery that has never been connected to a light bulb may go "dead" just from sitting unused on a shelf. Since you will need at least two "D" (standard-size flashlight type) batteries for each child, it is worthwhile to investigate the possibility of buying them in quantity.

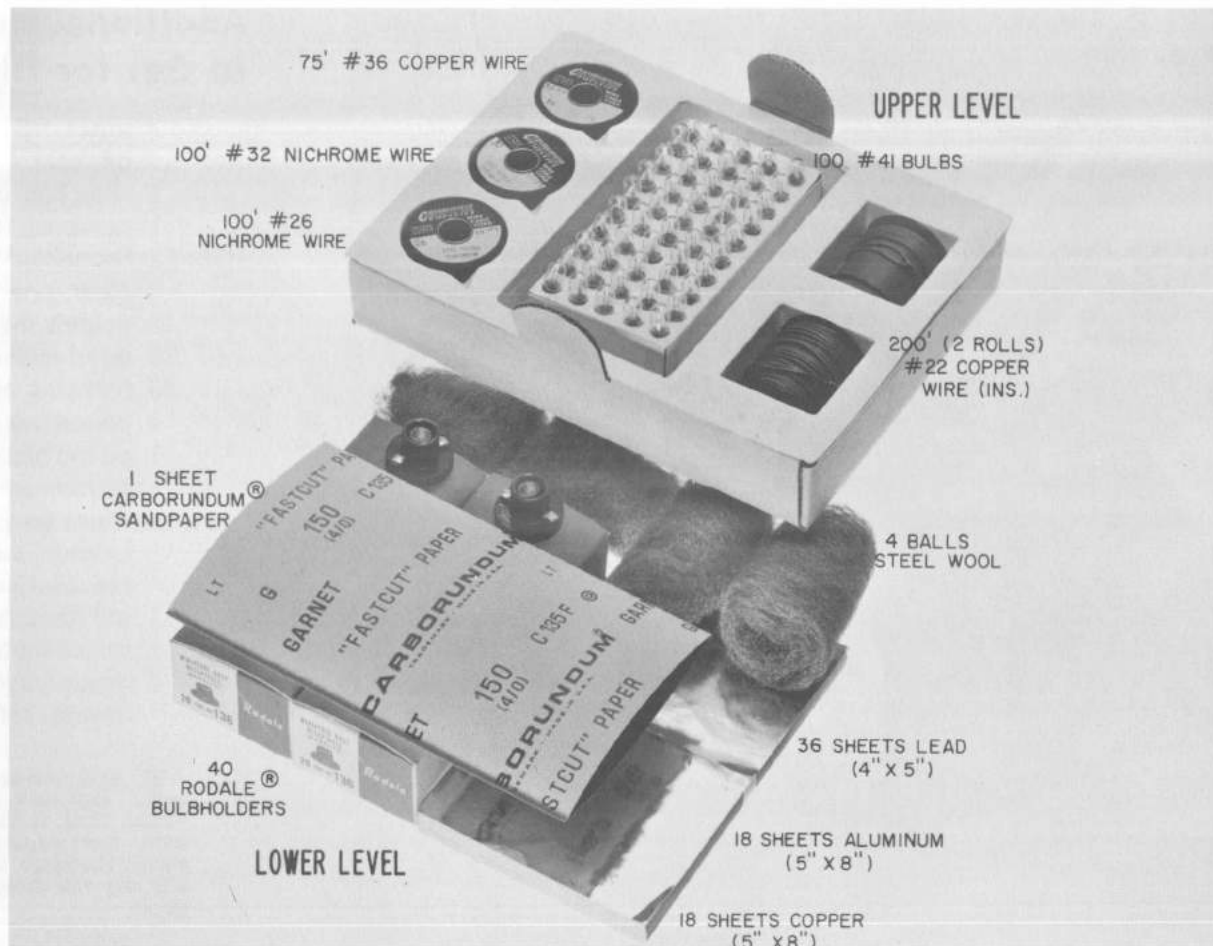
Note: By investing about five dollars in a commercially available device known as a "battery charger" it is possible to save about one third on the total number of batteries eventually needed for a class. This machine will not restore "dead" batteries, but it will help to increase slightly the efficiency of partly used batteries.

## Materials in Batteries and Bulbs Kit



### BOX 1

- |  |  |
|--|--|
| 80 #82 rubber bands ( $\frac{1}{2}$ " x $2\frac{1}{2}$ " | both ends exposed)   |
| 7 screwdrivers (2" blade with plastic handle)            | 40 bulb holders — Rodale #136 (Bakelite)   |
| 7 wirestrippers (to serve also as wire cutters)          | 300 #2 paper fasteners — brass ( $\frac{1}{2}$ " round head)                                       |
| 3 triangular files                                       | 30' #24 Formvar (enameled copper wire)   |
| 110 #48 bulbs (PBs)                                      | 250 Fahnestock clips — brass ( $\frac{3}{16}$ " x $\frac{3}{4}$ " with $\frac{5}{32}$ " dia. hole) |
| 150' #20 copper wire (bare)                              |  |
| 100' #22 copper wire (plastic-insulated, with            |  |

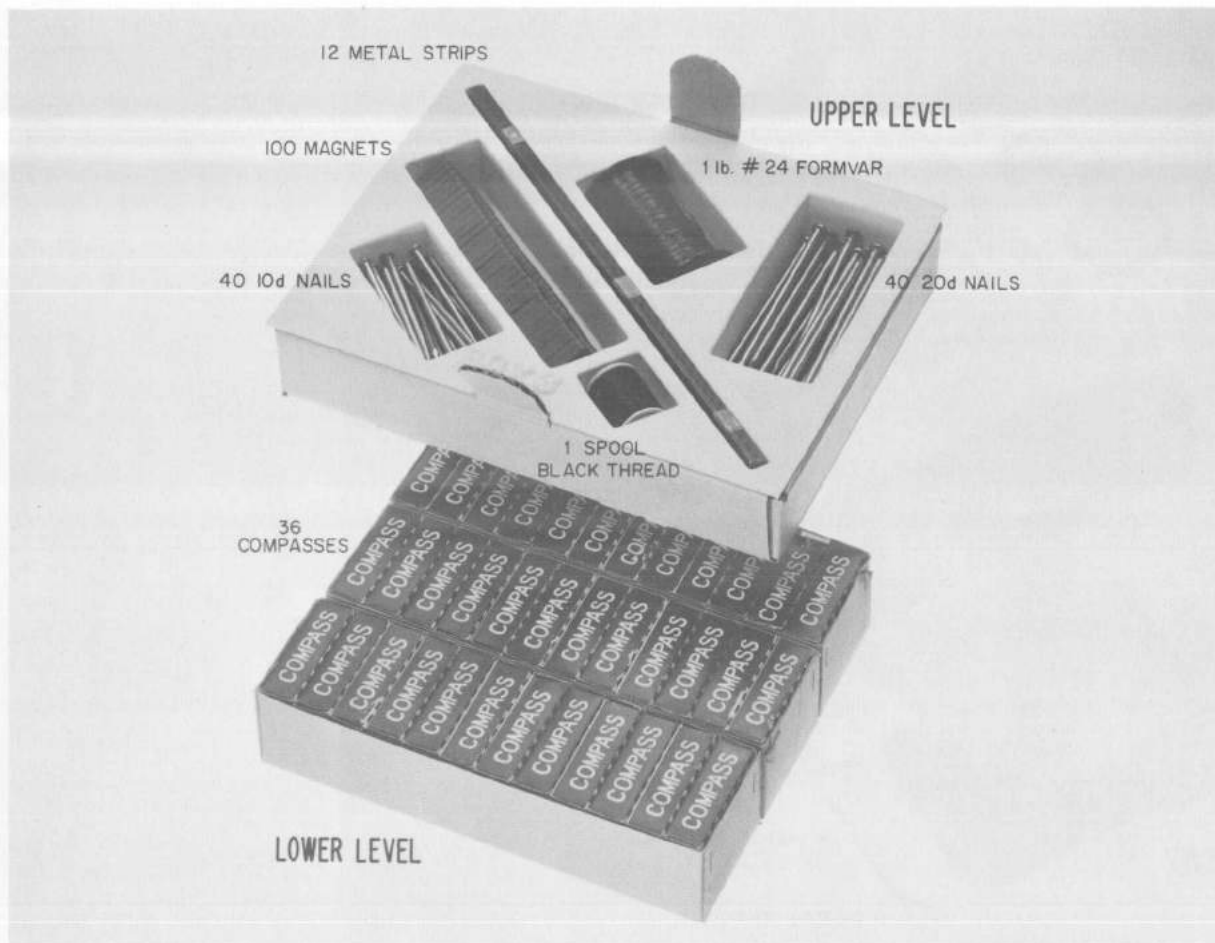


## BOX 2

100 #41 bulbs (WBs)  
 100' #32 Nichrome wire (bare)  
 100' #26 Nichrome wire (bare)  
 75' #36 copper wire (bare)  
 200' #22 copper wire in two 100-foot rolls  
 (plastic-insulated, with both ends exposed)

40 bulb holders — Rodale #136 (Bakelite)  
 4 balls steel wool  
 1 sheet 150-grit sandpaper  
 36 sheets lead (.005" x 5" x 8")  
 18 sheets aluminum (.005" x 5" x 8")  
 18 sheets copper (.005" x 5" x 8")





### BOX 3

- |  |   |
|--|---|
| 12 metal strips (.025" x 1/2" x 12" with 3/16" dia. hole in one end)   | 36 compasses with faces reading in degrees 0-90, 0-90 |
| 40 20d. common nails   | 1 pound #24 Formvar (enameled copper wire)            |
| 40 10d. common nails   | 1 spool black thread                                  |
| 100 magnets — ceramic (1/8" x 3/4" x 1" with 1/8" dia. hole in center) |   |

## Additional Material You Will Need to Get for Circuits I

- 3 boxes "D" size flashlight batteries\* (24 per box)
- 1 shoe box, or paper bag, for each child
- 1 notebook for each child
- 10 to 12 household bulbs: 7 1/2 to 100 watts — one clear, one frosted of each size
- 2 pounds modeling clay
- 50 quart milk cartons — bottom half
- 50 half-pint milk cartons — tops cut off
- 1 pound box of salt
- 1 pound box of baking soda
- 1 pound can of Comet household cleanser
- "Junk box" (see page 41)
- Liquids, such as: milk, instant coffee and tea solutions, muddy water, etc.
- 1 roll household aluminum foil
- 1 roll cellophane tape or masking tape
- 1 magnifying glass
- Several extra shoe boxes

\*"D" batteries sell for prices ranging from 7¢ to 20¢ each. Japanese batteries are available, if you can locate them, at the lowest of these prices if bought in bulk. Most supermarkets sell batteries for 12¢ to 20¢ each. Hardware stores and radio supply houses usually can sell them for 10¢ to 12¢ each in large quantities.

## Additional Material You Will Need to Get for Circuits and Magnets

- 1 roll 3/4" masking tape
- 200 #1 paper clips
- 2 pounds modeling clay
- 60 plain white cards (3" x 5")
- 1 box "D" flashlight batteries (24 per box)
- 1 package of drinking straws
- 10 iron or steel washers (1" dia.)
- 10 wooden blocks, cardboard squares or pieces of plastic (1" x 1" x 1/4")

## Additional Material You Will Need to Get for Circuits II

- 1 newspaper for each child
- 1 box "D" flashlight batteries (24 per box)
- 1 roll white absorbent paper towels (large)
- 20 to 30 assorted additional batteries, such as "AA", 912, 914, "A", "B", "C", No. 6, transistor radio (9-volt), lantern (6-volt)

## Precautions

Experimenting with batteries and bulbs in the way recommended is perfectly safe. *Using household electricity is not!* We suggest you caution your class against playing with household electri-

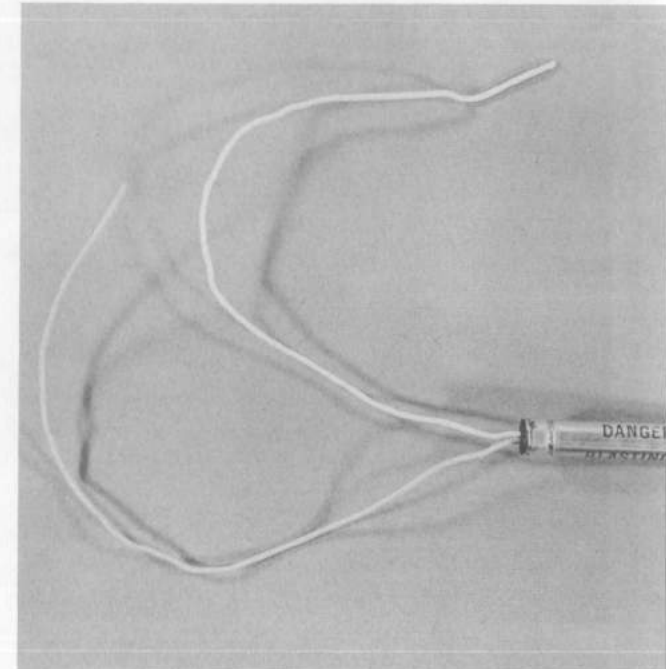
cal outlets and appliances because of the serious danger of shocks or burns, or of starting a fire.

The sizes and types of batteries we recommend using in *Batteries and Bulbs* are shown in the picture below. Batteries are rated in terms of volts. The children may bring other batteries into the classroom; check the strength of these batteries in terms of voltage before allowing them to be used.

The voltage is clearly marked somewhere on the battery case. This rating is not an intrinsic part of *Batteries and Bulbs* but is mentioned here as a way of defining which batteries are safe for classroom use and which are not.

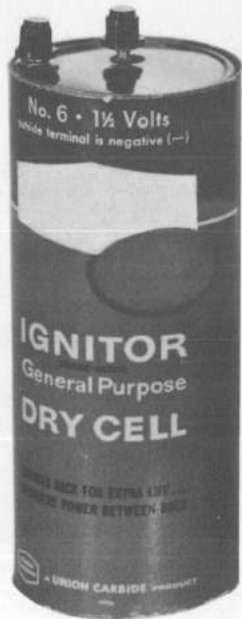
The "D", "AA", "C", 914 and No. 6 batteries are rated at  $1\frac{1}{2}$  volts each. The large lantern battery is 6 volts, and the transistor battery 9 volts. We suggest limiting the number of batteries that can be used end-to-end (additively) in any circuit to the equivalent of twelve "D" batteries, in

other words, to 18 volts. That would limit lantern batteries to three and transistor batteries to two. Since there have been instances of people getting slight "tingles" from handling (with wet hands) circuits powered by  $22\frac{1}{2}$  volt batteries, we have set these limits in order to take no chances. All the experiments in *Batteries and Bulbs* can be done with twelve "D" batteries or less.



The blasting cap in the picture above is a very dangerous explosive. Children have been disabled in the explosion caused by connecting the two wires to a "D" battery. Caution your class strongly against any kind of play or experimentation with blasting caps.

Flash bulbs can also be detonated by a "D" battery, resulting in severe burns. Suggest that the children use flashbulbs only in the flash attachment to a camera.



No. 6  $1\frac{1}{2}$  Volts



Lantern Battery 6 Volts



"C" Battery  $1\frac{1}{2}$  Volts



"AA" Battery  $1\frac{1}{2}$  Volts



"D" Battery  $1\frac{1}{2}$  Volts



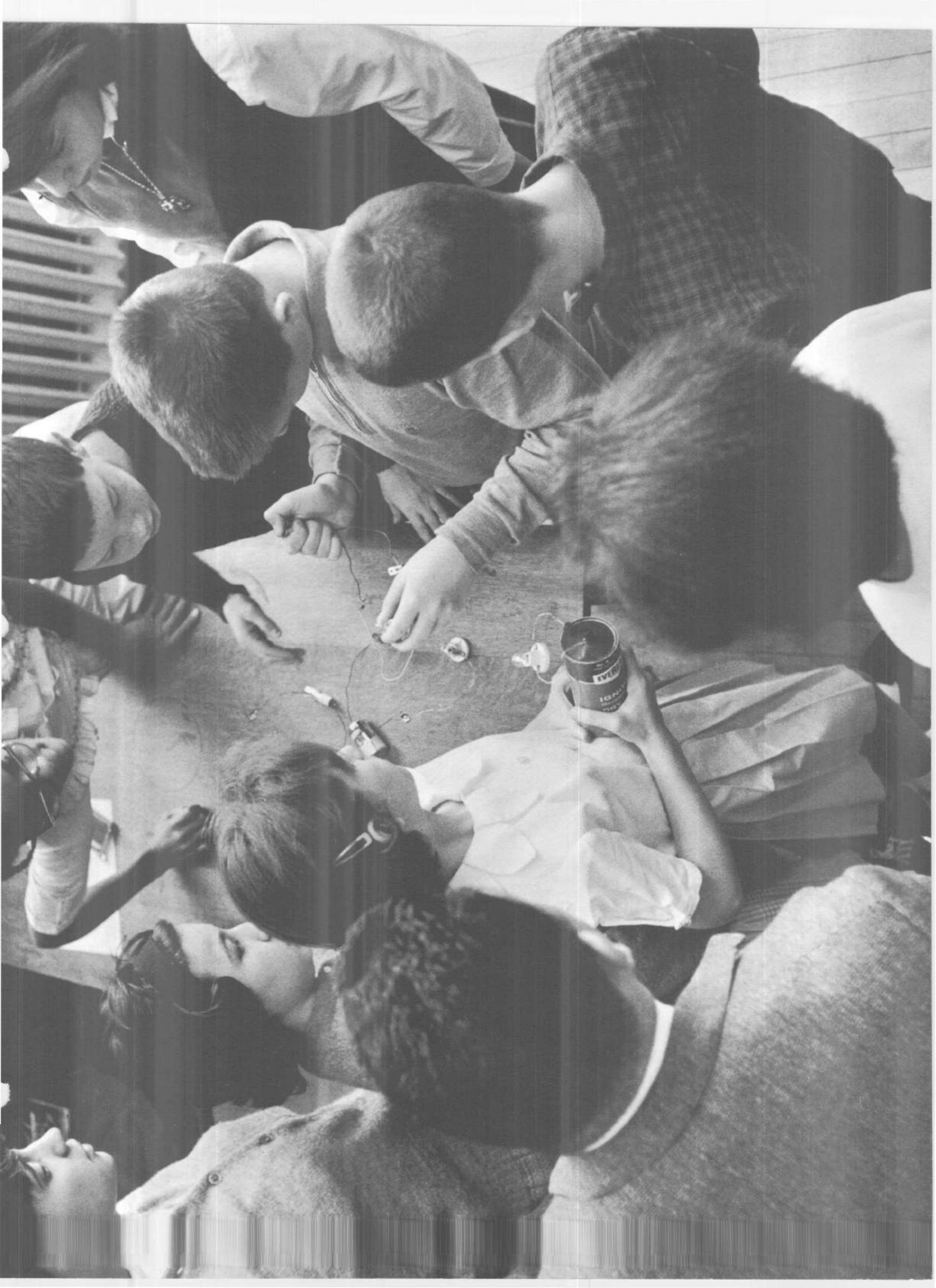
Transistor Radio Battery 9 Volts



912  $1\frac{1}{2}$  Volts



914  $1\frac{1}{2}$  Volts





# BATTERIES AND BULBS

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### Book 1

# CIRCUITS I

Teacher's Guide

Trial Teaching Edition

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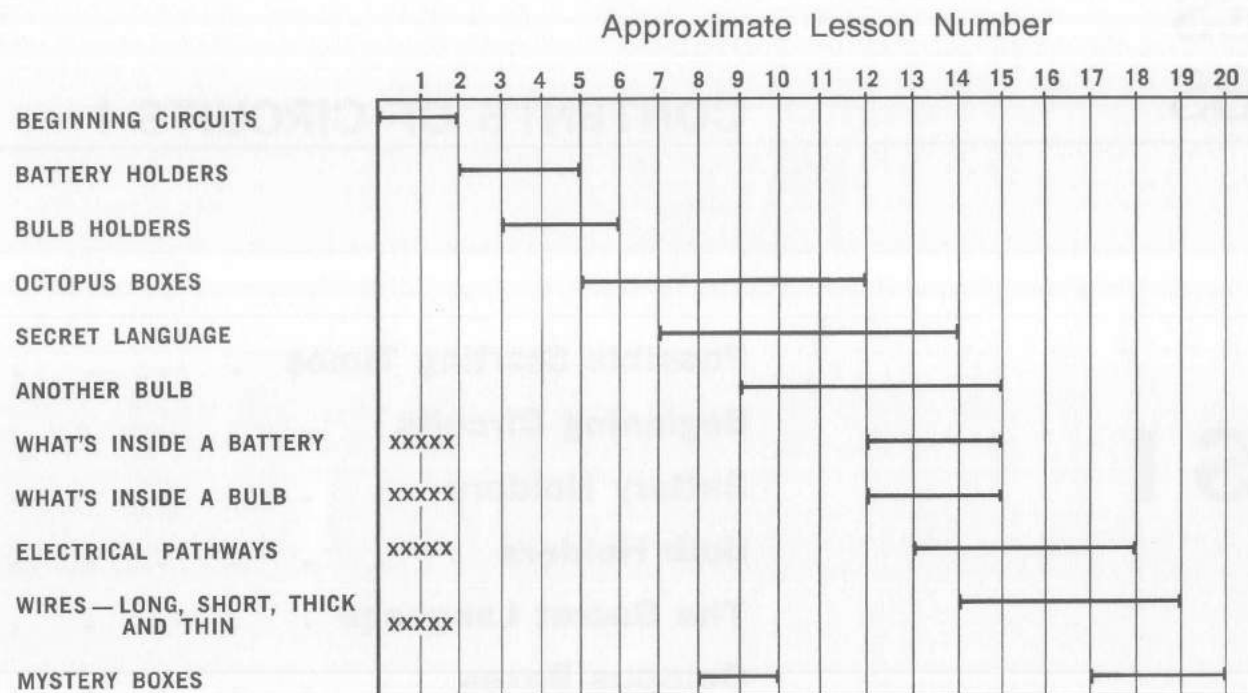
## Possible Starting Times for Each New Section of Circuits I

The purpose of this chart is to indicate how much flexibility can be used in choosing which

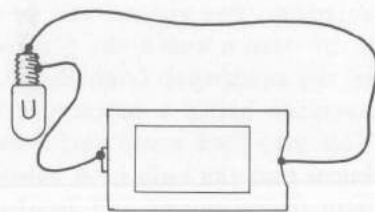
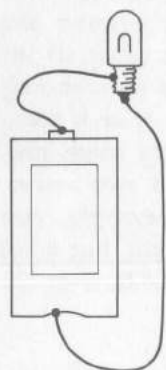
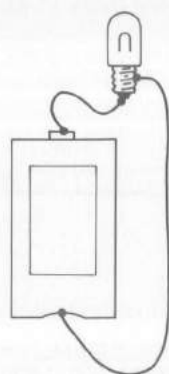
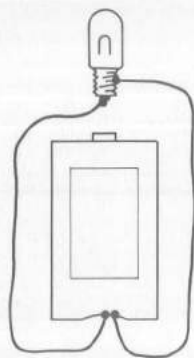
sections in *Circuits I* can be studied after *Beginning Circuits*. The other two study areas can be approached with similar flexibility. The two sections *Bulb Holders* and *Battery Holders* may be started much earlier than indicated in the layout of the guide. But some sections, such as *Mystery*

*Boxes*, can only be attempted after experience with a variety of circuits.

Each line indicates the possible times to introduce each new topic. (XXXXX indicates early informal exploration.)



A few of the many patterns you can try are shown in diagrams *D*, *E*, *F* and *G* below. After a while you should be able to predict in advance whether or not the bulb will light.



You have noticed the strange behavior of *C* on the preceding page. If you remove the right-hand wire in *C*, the pattern becomes identical to that in *A*, and the bulb lights.

Since the right-hand wire in *C* was connected from the top directly to the bottom of the battery, it had been creating a *short-circuit*. In order for a bulb to light it must have a direct path to the

battery. A short circuit interrupts this path and is so called even if the wire creating the "short" is much longer than that leading from the battery to the bulb.

Hold, or tightly tape, the ends of a wire to the top and bottom of a battery. After five minutes you will probably be able to feel the battery getting warm. If you remove the wire after ten minutes and try to light a bulb with the battery, will the bulb light as brightly as before? If you tape the wire to the battery for *several hours*, will the battery be able to light a bulb?

Look carefully at a bulb. Use a magnifying glass if you have one. You have already found out that in order to make a bulb light it is necessary to touch the wire to the metal side and the tip. Now observe the two heavy wires going through the pink bead in the bulb. The thin wire (called the "filament") connected to the tops of the heavy wires is harder to see, but is very evident when the bulb is lighted.

## Introducing Beginning Circuits in the Classroom

Each child is given a battery, a PB and a piece of #20 bare copper wire. The question posed by these materials is, "**Can you make the bulb light?**" Some children will take twenty minutes to get the bulb to light, some will take five. Once one child in a class manages to make the bulb light, his idea spreads fast. Probably only five or six will light the bulb on their own. The rest will follow their neighbor's lead.

As the bulbs are lighted, assure the children that there are different ways to do it, and have them look for more. Invite them to the blackboard to draw the various ways they have tried. Ways in which the bulb does *not* light are just as important and should be included. An under-





# BEGINNING CIRCUITS

## Before Starting to Teach

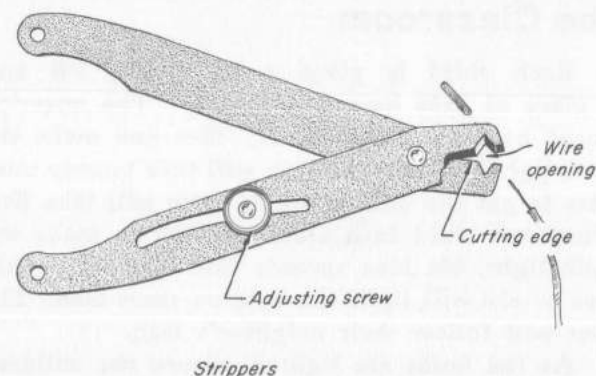
### Materials you will need

- 3 "D" batteries
- 2 eight-inch pieces #20 copper wire (bare)
- 2 eight-inch pieces #22 copper wire (plastic-insulated)
- 1 eight-inch piece #24 Formvar (enameled copper wire)
- 3 #48 bulbs (PBs)
- 1 wire stripper

Before bringing these materials into your classroom, you will probably want to learn about them first from personal experience. With the exception of the batteries the materials are in Box 1. The following suggestions will guide your initial exploration. If you take enough time to try your own ideas as well, you will be ready for the variety of ideas your students are sure to propose.

Using the cutting edge of the wire stripper, cut an eight-inch length from each of the three kinds of wire in the top tray of Box 1. Try to light one of the bulbs, using a piece of bare wire and a battery. Some people have taken twenty minutes to light their bulb so do not

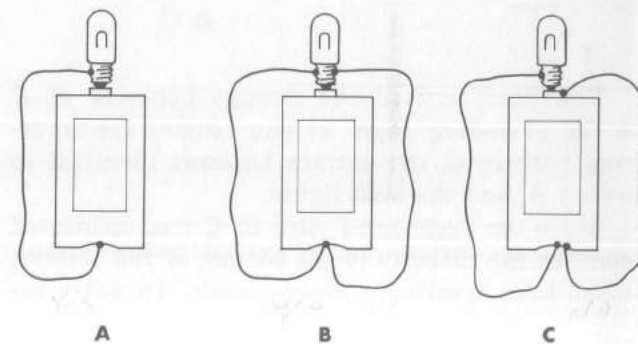
worry if yours does not light the first time. See how many different ways you can devise to make the bulb light. Make sketches of your various attempts, including those that do not work. You have now made at least one *circuit*, a term used to describe any pattern of connections of batteries, wires and bulbs. Light a bulb using insulated wire.



Strippers

You have probably already found that the plastic-covered and the enamel-covered copper wires cannot be used to light the bulb without removing their insulation. The wire stripper is

designed for removing the plastic cover without cutting the wire. You can adjust the knob so that the wire opening will cut only the plastic. Place the plastic-insulated wire in the opening, close the handles, then pull the stripper toward the end of the wire so that it strips off a piece of insulation. The enamel can be removed by scraping it off with a knife, the file from Box 1, or a piece of the sandpaper from Box 2. Now try some connections using a battery, a bulb and two wires. You may find some surprises. For example, you know that the bulb in *A* below will light, but what happens when you add another wire, as in *B* or *C*?



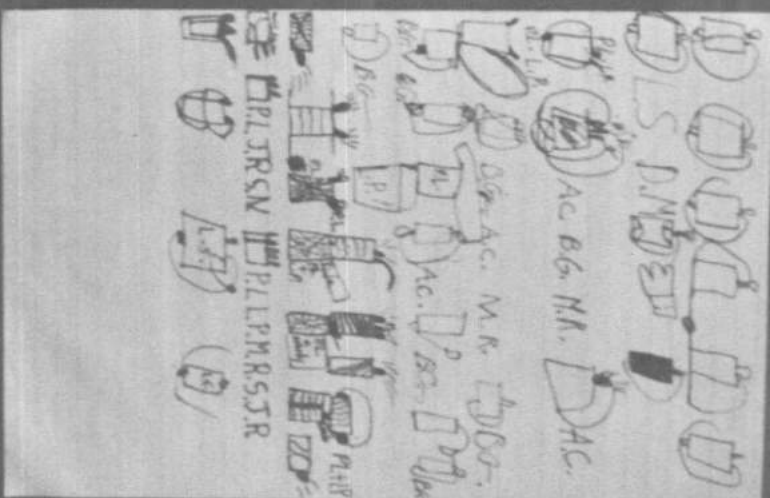
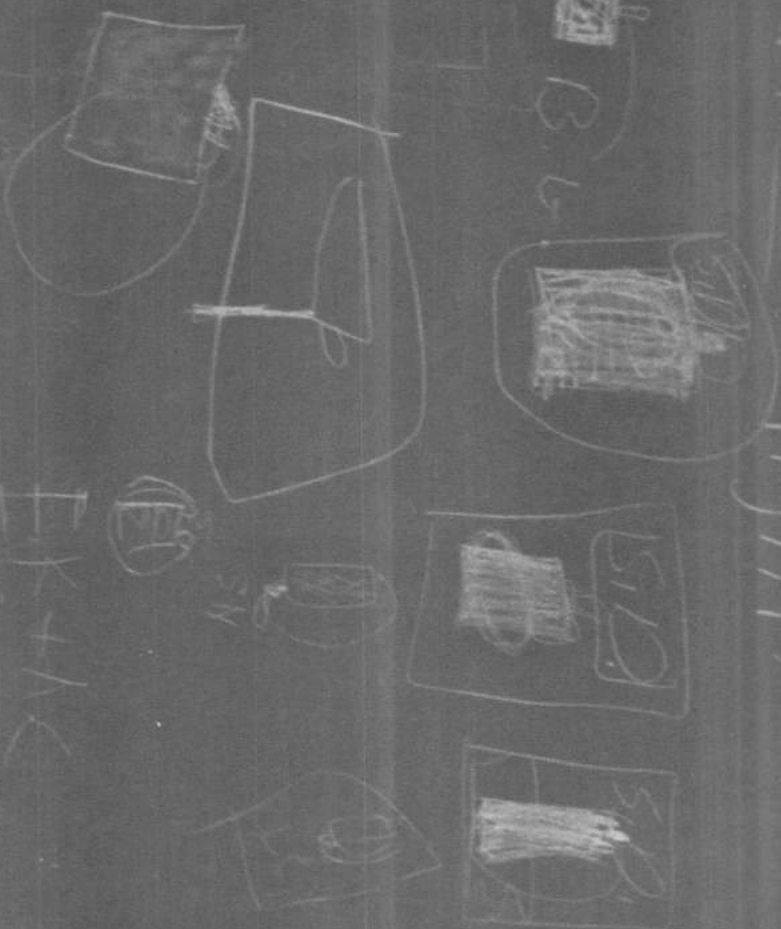
Yy Zz

12345  
67890

short above

spacing spacing

Vlll not light



a drinking glass =  
a measuring cup =  
a half-pint carton

2 measuring cups =  
1 pint

2 pints = 1 quart

4 quarts = 1 gallon

Abbreviations

cup c.

pint pt

quart qt.

gallon gal

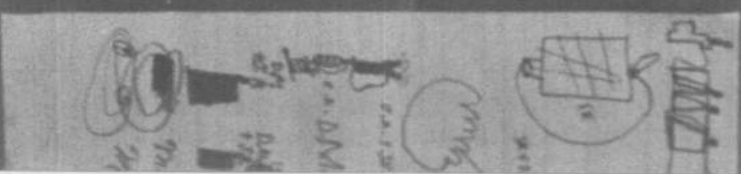
16 times =

1 pound

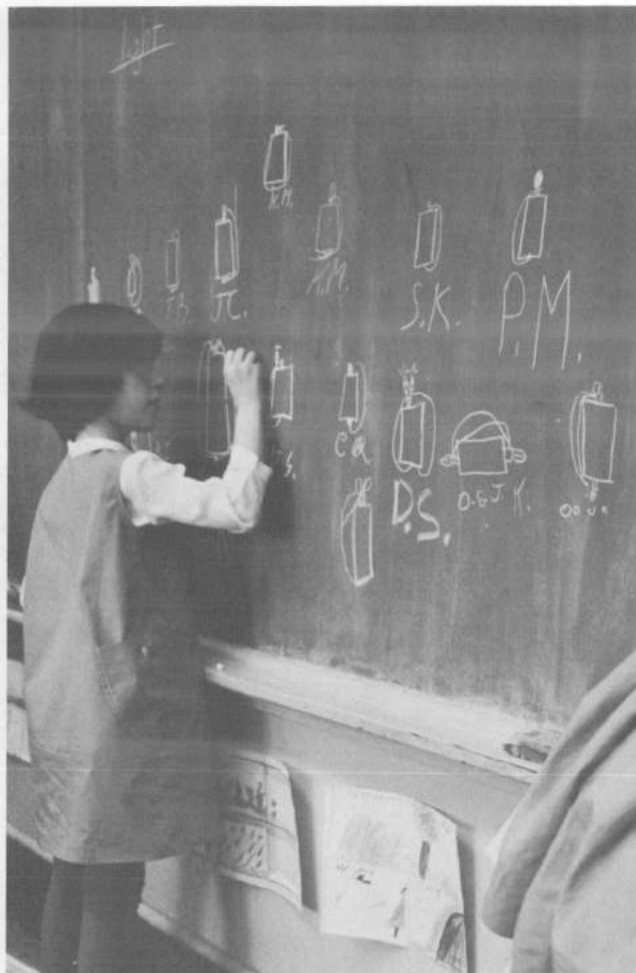
Abbreviations

ounce oz.

pound lb



standing of those conditions which will not allow the bulb to light, as well as those which do, furnishes the focus needed for understanding simple circuits.



Once the children have lighted their bulbs, there are many possible experiments open to them. These experiments may keep the children going on their own for several classes. In fact, it is wise to postpone class discussion at this point to let them go off in various directions in free experimentation.

Grouping the children makes it easier for them to share ideas and for you to present material and assess progress. This guide is written with a class divided into groups of four in mind, which does not mean that children cannot change groups or form groups of different numbers, or even work alone.

Groups of students will pool their equipment—they will try to light one bulb with two or more batteries, or light two bulbs with two batteries. Some children may want to investigate how many bulbs they can light with one battery. Others may want to know how brightly a bulb will shine when three, four, or eight batteries are used; or how many batteries it takes to burn out a bulb. (A section on many-battery, many-bulb circuits is included in *Circuits II*.) Suggestions for other activities are listed on page 16.

It is perhaps best to postpone a detailed, systematic study of the experiments the children are doing and the questions they are raising. It is extremely important to give them a good deal of time for free experimentation, for “messing around” with the equipment, to pursue questions important to them at the time. They will be exploring the limits and possibilities of the materials. Their questions at this early stage will provide significant leads for introducing later work as well as for deciding what to take up next. Very likely the children will profitably pursue their questions for several class periods before the introduction of new materials and techniques. A few children may need additional materials—more bulbs, batteries or an eight-inch piece of one of the insulated wires to experiment with.

Some children might want to know whether they can light a household bulb by using “D” batteries. One class connected seven batteries to a 60-watt bulb and still saw no light. Then a girl felt that the bulb was warm; they added another battery or two and were rewarded by a slight glow. One battery was removed and the bulb dimmed.

They then went on to compare the number of batteries required to light bulbs of a variety of sizes.

Most children are able to learn to use all of the tools in this kit quite well by themselves. However, a few might need some help with the wire strippers. The wire strippers and other tools that must be shared should be freely available for use whenever needed. If the class is divided into groups, there might be one tool box per group. However, groups do vary their membership, so in some cases the tools can be used by all and stored in the teacher's box.

There should always be available additional quantities of any of the materials the children are using. This freedom to use extra batteries or light bulbs will encourage the development of new ideas.

Each child should have a box or paper bag in which to store his materials at the end of each lesson. We suggest that children keep the materials passed out to them for the entire time the unit is being studied. They will continually use these materials as well as others to be distributed later. Whether children take equipment home to work with is up to you.







## MATERIALS FOR BEGINNING CIRCUITS

for each child —

- 1 shoe box or paper bag
- 1 "D" flashlight battery
- 1 #48 bulb (PB)
- 1 eight-inch piece #22 copper wire
- 1 eight-inch piece #20 copper wire

for each group —

- 1 wire stripper

have available —

Extra supplies of above materials  
Several eight-inch pieces of #24  
Formvar wire

## Activities Children May Try

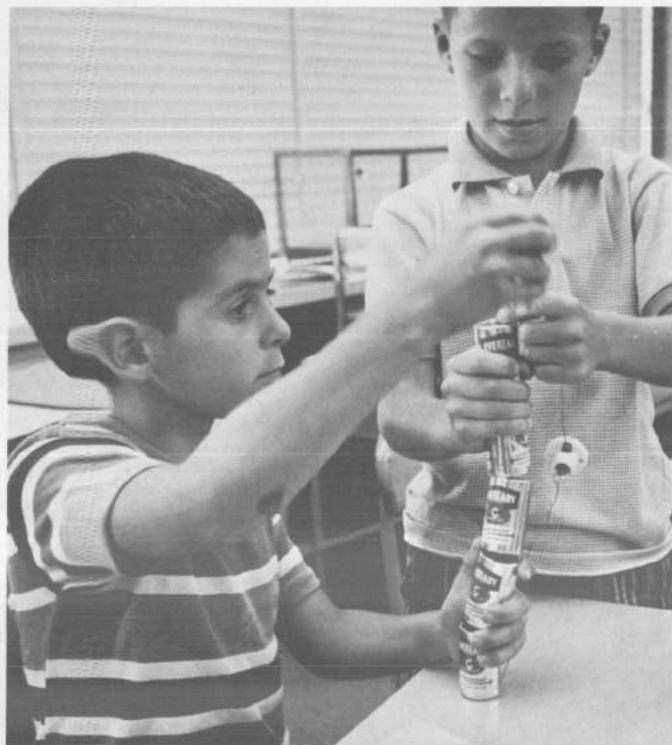
Light the PB using two pieces of bare wire.

Light the PB using the "covered" wire.

Use different objects from their desks or pockets to put in the path to the bulb. (They might use some of the "junk box" items in this exploration.)

Use more wire to see if a PB will still light.

See how many PBs will light with one battery.



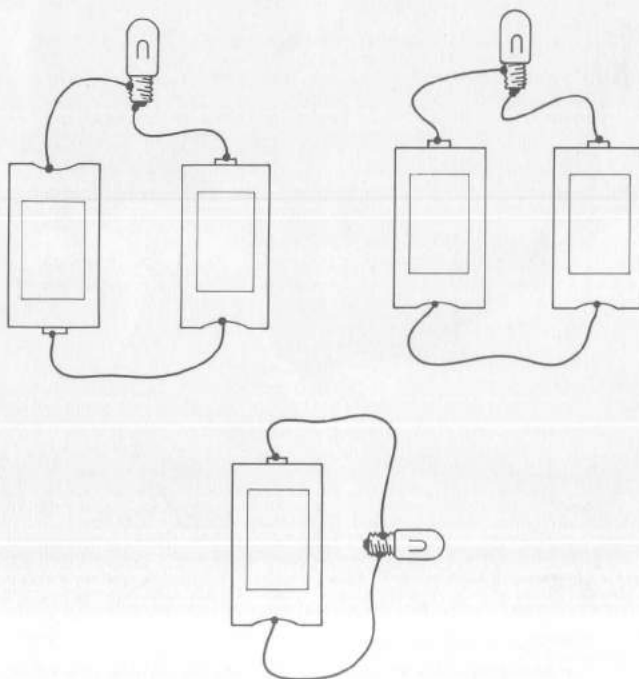
See how many batteries it takes to burn out one PB. Find out which will wear out first if contact between a battery and a PB is maintained for a long time. Find out how long it takes for the battery or the PB to wear out.

Touch a wire from one end of the battery to the other. See how the battery feels after five minutes in this condition, after an hour. See if the battery will now light a bulb.

See how many batteries it takes to light a 60-watt household bulb dimly.

## Possible Discussion Questions

After three or four class sessions with these materials, let the children share their experiences. One way to begin such a session is to draw some circuits on the board to see if the class can predict whether the bulbs in those arrangements will light. Examples of some circuits you may want to use are these:



"Will these bulbs light? Why?"

Let them discuss all of their ideas. Try out each example for verification. Perhaps some students will want to make generalizations about the features of those circuits in which the bulb lights, and those in which the bulb does not.

What did you find out in the last few lessons?

You will find that many children will have forgotten some of their work because they did not keep a record of it. They will now see the need for accurate, neat, but simple notes and diagrams.

Be prepared for variety. Each child should be heard if he or she has something to say.

How many ways can you find to make the bulb light? Does the bulb have to be touching the battery? Does the wire have to be wrapped around the bulb? To light the bulb, what special places must be touched on the bulb?

To light the bulb, what special places must be touched on the battery?

Is there anything similar about the way the bulb will light?

How many bulbs can you light using one battery?

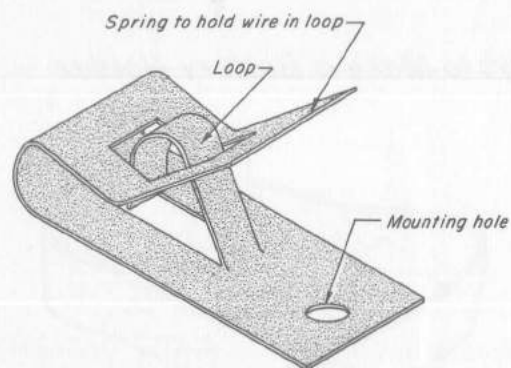
# BATTERY HOLDERS

## Before Starting to Teach

Materials you will need

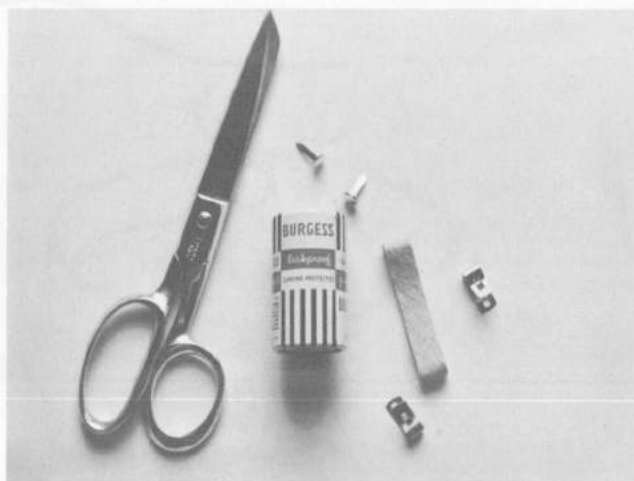
- 2 Fahnestock clips
- 2 paper fasteners
- 1 rubber band

Examine a Fahnestock (fān-stōk) clip. If you squeeze the open ends you can slide the end of a wire under the small loop that is exposed. Join

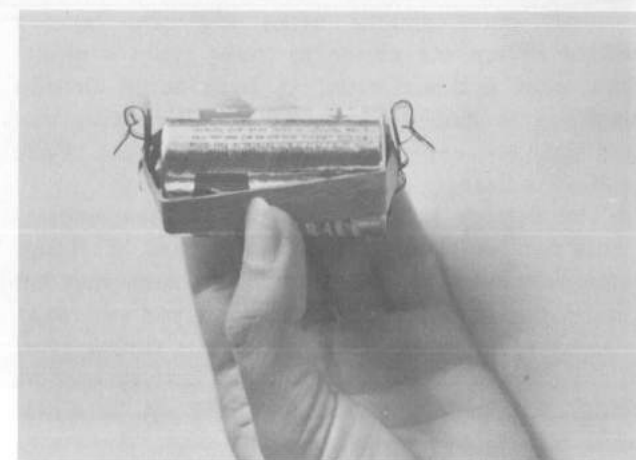
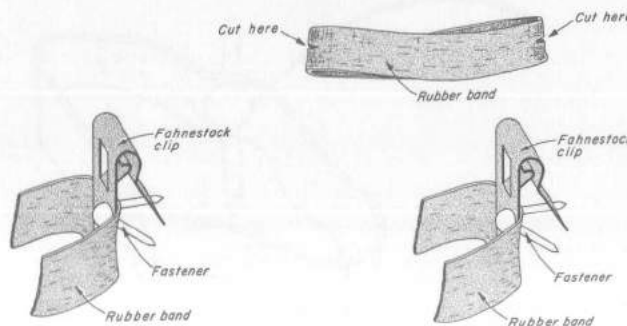


*Fahnestock Clip*

two pieces of wire together using a Fahnestock clip. Use a clip as part of the path connecting a battery to a bulb. Does the bulb light?



Make two battery holders as shown in the pictures and diagrams on this page. You will need one rubber band, two Fahnestock clips and two paper fasteners for each battery holder. These materials are in Box 1. Place the holder on a battery so that some metal part, either the head of the paper fastener or the Fahnestock clip, touches each end of the battery in the special places. Put a #20 (bare) copper wire into each Fahnestock clip. Light a bulb. Remember that these wires must touch special places on the bulb.





The holders do not, of course, play a fundamental role in the study of electric circuits, as do the batteries and bulbs. But there comes a time when two (or even three) pairs of hands can't hold the batteries and bulbs and wires together for the experiments the children are doing. Though the function of the battery holders is a simple one, a good deal of time is needed to investigate how they work.

## Introducing Battery Holders in the Classroom

Some children may feel the need for a holder strongly enough to invent something themselves. In some cases they have attached the components of their circuits with masking tape. You may want to encourage this type of invention, but this would also be a good time to begin to introduce the rubber-band battery holders that make it possible to assemble circuits most easily.

The Fahnestock clip is worth consideration by children as an example of a simple but ingenious device. Children may want to examine them and see how they function as wire holders. After the use of the clip is discussed, the rubber bands and paper fasteners can be handed out.

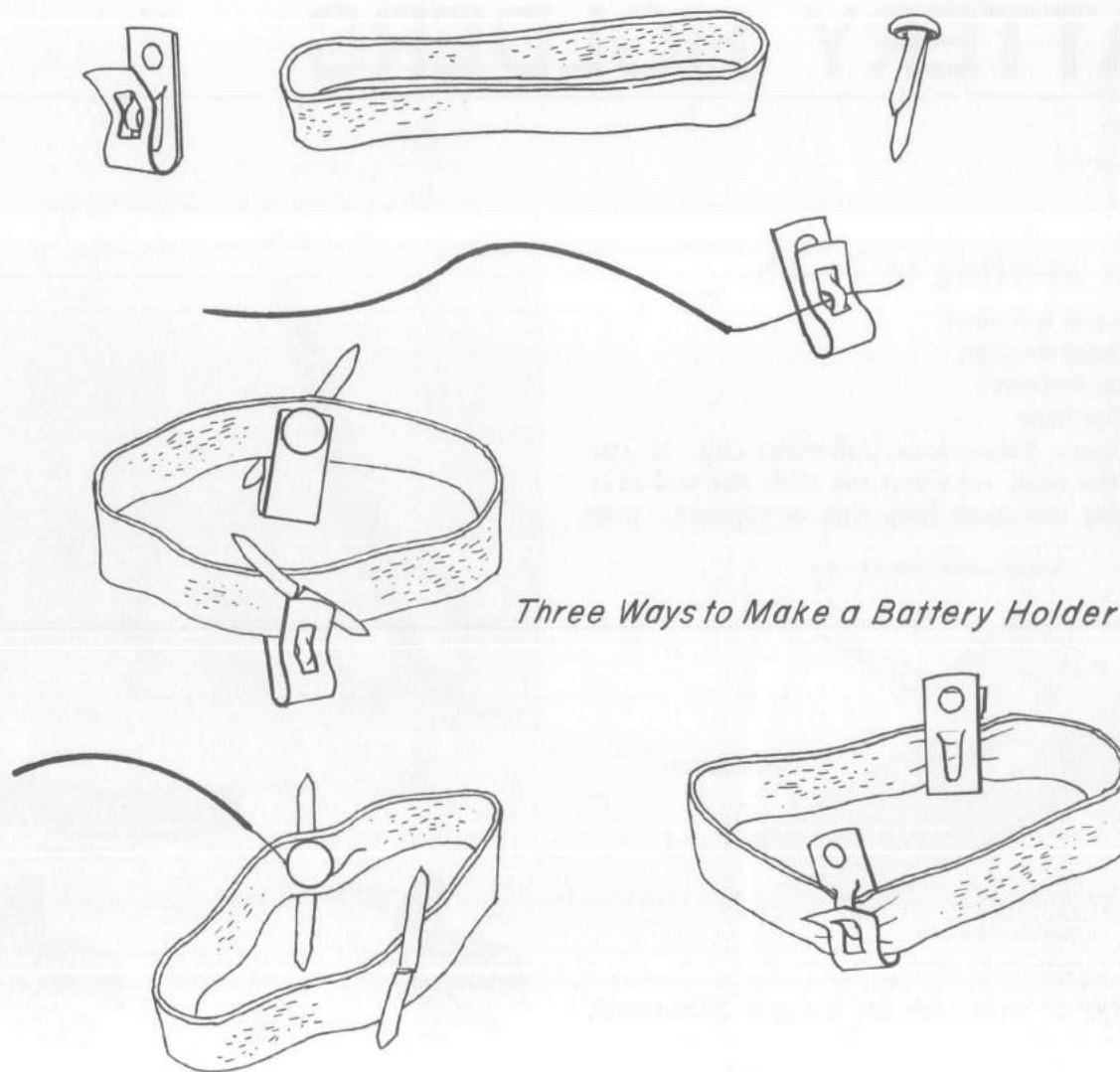
Each child should make his own battery holder. They are easier to make from a model than from a description, so have some already made up to pass around. As an alternative you may pass out copies of the diagram *Three Ways to Make a Battery Holder*.

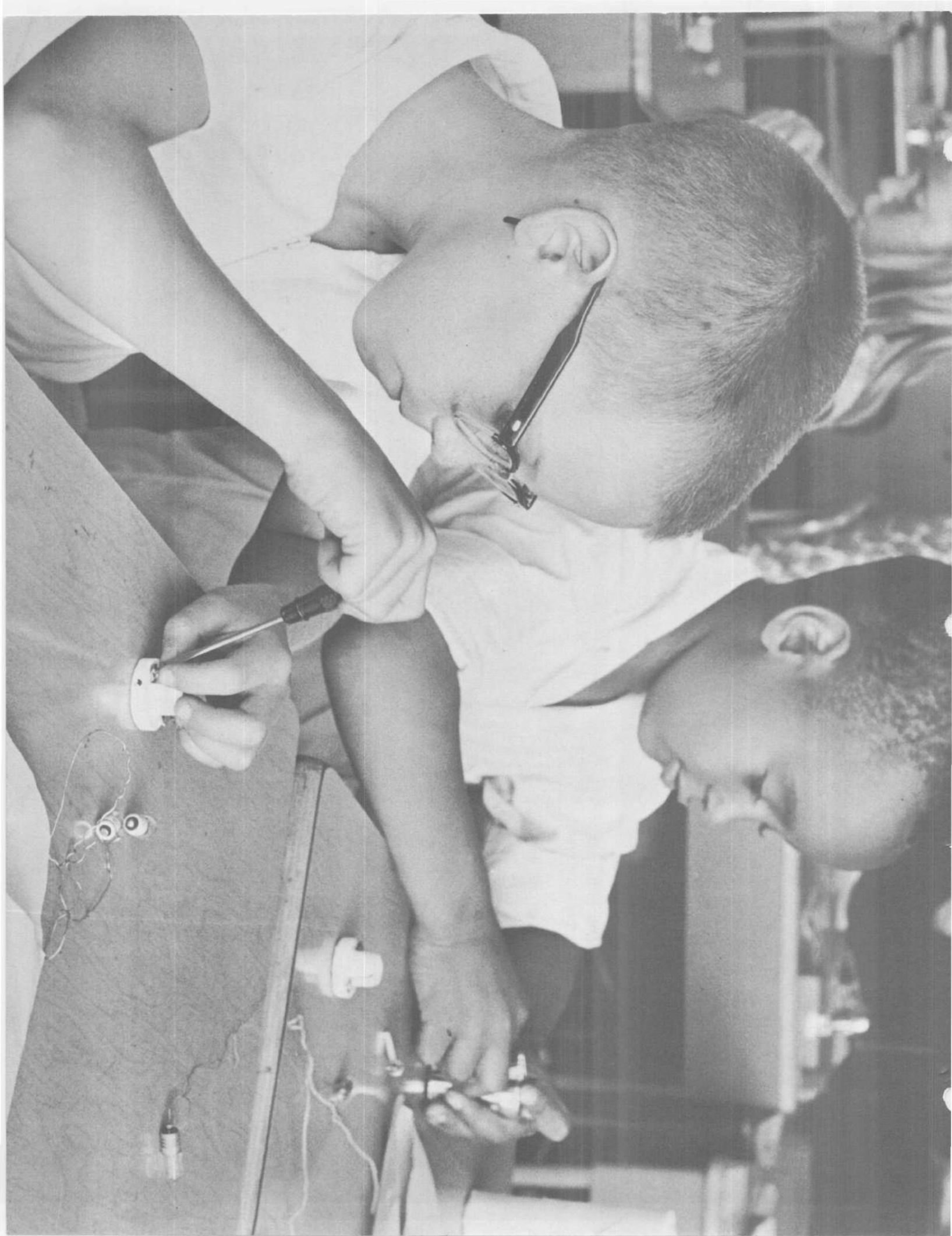
The battery holders may suggest new experiments and invite repetitions of old ones. Children sometimes seem to feel that there is some magical quality to the rubber band. Perhaps you will want to encourage the children to test the rubber band in the path to a bulb; and to make battery holders using other materials, such as cloth, plastic, aluminum foil strips and string.

If some children have not yet used two wires to light a single bulb, this is a good time to introduce them to this problem (see *Beginning Circuits*). Some children may already have connected a wire directly from one end of the battery to the other and found that after a while the

battery became warm. If no one has yet done this, it is worth sacrificing a battery or two for a class experiment to see what happens to short-circuited batteries.

Children in grades 2 and 3 may make only limited use of the battery holders.





## **NEW MATERIALS FOR BATTERY HOLDERS**

for each child —

- 4 Fahnestock clips
- 2 rubber bands
- 4 paper fasteners

### **Activities Children May Try**

Invent various battery holders.

Grip a wire using a Fahnestock clip.

Connect two wires together using a Fahnestock clip.

Connect more than two wires.

Put a Fahnestock clip in the path to a bulb to see if the bulb will light.

Put a rubber band in the path to a bulb to see if the bulb will light.

Fasten the Fahnestock clips to the ends of the battery using a rubber band and perhaps a paper fastener.

Light a bulb using a battery, bulb and one wire, then two wires.

Connect two or more batteries together and use them in a circuit.

Short-circuit a battery by a wire connected from one Fahnestock clip to the other.

### **Possible Discussion Questions**

Does the battery holder still touch the special places on the battery?

Does the rubber band have any effect on lighting the bulb?

Could you use a metal band instead?

What happens if a single wire is connected between the Fahnestock clips while the holder is on a battery.

What have you found that prevents a bulb from lighting?

### **Special Comments**

The possibility for short circuits will increase after the battery holders are on the batteries. When

the batteries are put away make sure that the wires are disconnected from the holders to prevent the

wires from touching and "wearing out" the batteries.





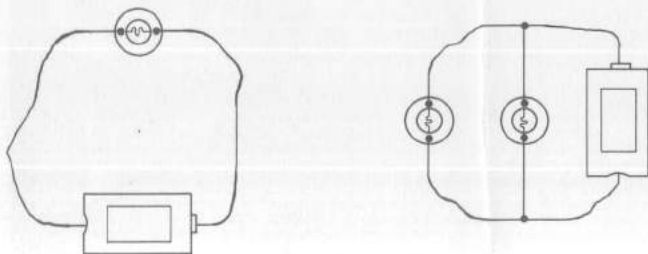
# BULB HOLDERS


## Before Starting to Teach

Materials you will need —

- 2 bulb holders
- 4 six-inch pieces #22 copper wire
- 4 Fahnestock clips
- 1 small screwdriver

Take a bulb holder from Box 1. Inspect it. Put it in a path to a bulb. Screw a bulb into the socket. Light the bulb using a battery and one wire, then two wires. Use a screwdriver to attach a wire under each of the loosened screws on the bulb holder. Reverse the position of the battery end to end. Does the bulb still light? Leave the two wires attached to the holder. Attach two wires to another holder. Connect both holders to a battery as shown in the diagram below.



( is the symbol used in the diagram for a bulb holder with a bulb in place.)

What difference do you see in the brightness of the bulbs in the circuits illustrated in this diagram? Try *Prediction Sheet Two* (page 25).

## Introducing Bulb Holders in the Classroom

Pass out a bulb holder to each child. The bulb holder has a socket, into which the bulb is screwed, and two screws, to which wires can be attached. To minimize future use of screwdrivers about eight inches of wire can be permanently attached to each screw of the holder. Connection to other wires and battery holders can then be made by means of Fahnestock clips. One 4th grader conceived an alternative — he put a Fahnestock clip under each screw, then fastened wires to the bulb holder in the same way as to the battery holder.

The simplest problem facing the experimenter is, of course, to get the bulb to light with this new item. The holders will stand close examination by the class in order to understand how they function.

The introduction of these holders will probably lead to the making of circuits with two or more bulbs, because of the increased convenience. In these more complicated arrangements, the children may see that the brightness of the bulbs is different in different circuits. This is an important observation. The class's attention should be called to it after several children have noticed it. The ability to predict how bright bulbs will be in various circuits is an important element in understanding electric circuits, and some systematic study is devoted to this later. (See *Circuits II*, pages 4-15.) However, the more informal experience the children get, the better. Any attempts they make at predicting brightness will be good background for future experiments.

To describe the brightness of a bulb, it is necessary to have some standard for comparison. A good standard to choose is a PB in the path to one "D battery. This could be called "standard brightness (or any other name the children suggest), and the bulbs in other circuits would then be said to have standard brightness, or more or less than standard brightness. These judgments of brightness cannot be made with great accuracy, but only rough, approximate comparisons are called for here.

## NEW MATERIALS FOR BULB HOLDERS

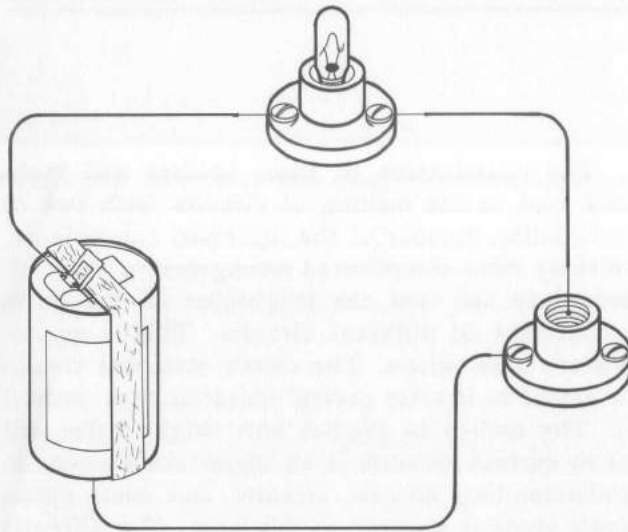
for each child —

- 1 bulb holder
- 2 six-inch pieces #22 copper wire
- 4 Fahnestock clips

for each group —

- 1 small screwdriver

## Activities Children May Try



Find out which part of the socket is connected to which screw by testing.

Light several bulbs using bulb holders. See what happens if a short piece of wire is touched directly from one screw of the holder to the other while a bulb is lighted in the holder.

Make brightness comparisons between circuits in previous diagrams using a PB connected to a "D" battery as "standard" brightness.

Put Fahnestock clips under each screw, or leave a wire attached to each screw, for easier connections.

Make more complex circuits by sharing equipment with others in their groups.

## Possible Discussion Questions

How does the bulb holder work?

Are the special places on the bulb still connected to the special places on the battery?

Which parts of the socket touch which parts of the bulb?

## Prediction Sheet Two


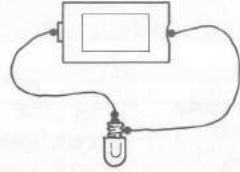
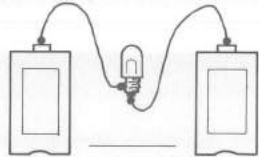
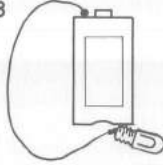
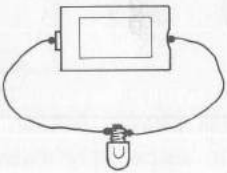
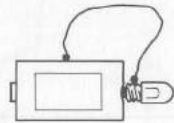
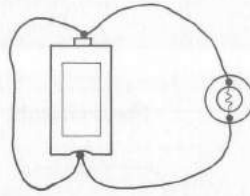
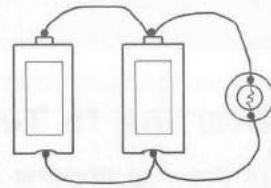

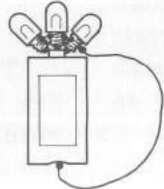
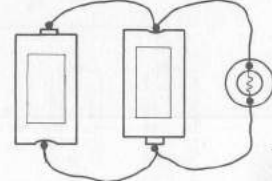
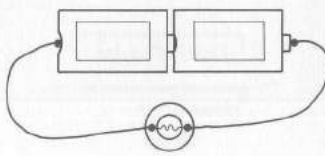
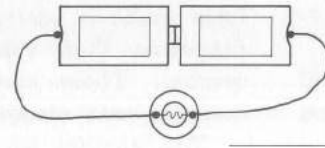
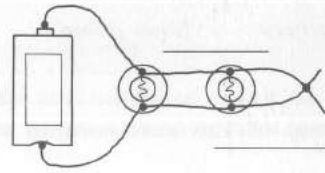
Follow the same procedure for using this sheet as you did for **Prediction Sheet One**. Not all children will be ready to use this prediction sheet at the same time.



# CIRCUITS I

## Prediction Sheet Two

In which examples will the bulbs light?  
Mark a ✓ for those which will and an X for those which will not light.

<p>1</p>  <p style="text-align: right;">_____</p>	<p>2</p>  <p style="text-align: right;">_____</p>	<p>7</p>  <p style="text-align: right;">_____</p>	<p>8</p>  <p style="text-align: right;">_____</p>
<p>3</p>  <p style="text-align: right;">_____</p>	<p>4</p>  <p style="text-align: right;">_____</p>	<p>9</p>  <p style="text-align: right;">_____</p>	<p>10</p>  <p style="text-align: right;">_____</p>
<p>5</p>  <p style="text-align: right;">_____</p>	<p>6</p>  <p style="text-align: right;">_____</p>	<p>11</p>  <p style="text-align: right;">_____</p>	<p>12</p>  <p style="text-align: right;">_____</p>
<p>13</p>  <p style="text-align: right;">_____</p>	<p>14</p>  <p style="text-align: right;">_____</p>		

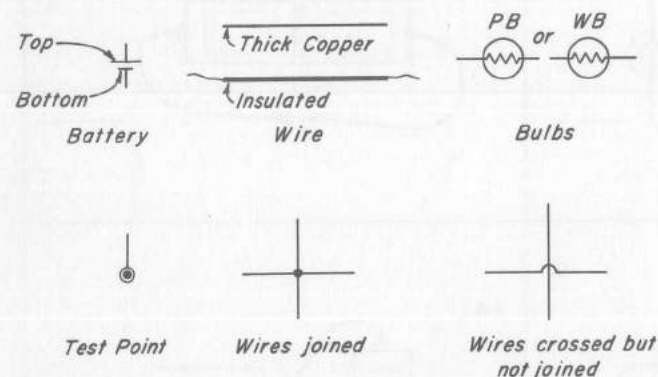


# THE SECRET LANGUAGE

## Before Starting to Teach

Instead of drawing pictures of the actual batteries, wires and bulbs which make up the circuits, most people who work with electricity use symbols for these items.

These are the symbols that are widely known and used:

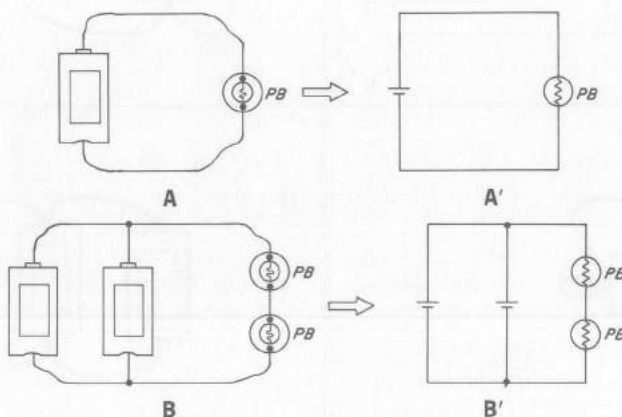


See if you can make the circuits illustrated at the top of the next column with batteries and bulbs.

Make a new circuit using batteries and bulbs.  
Describe the circuit in the *Secret Language*.

These circuits:

can be represented by these corresponding diagrams:

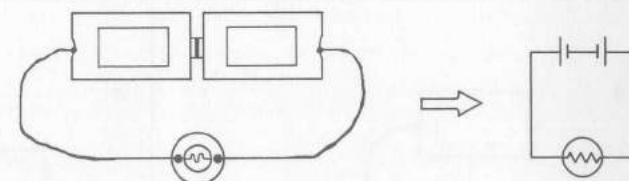


See if you can predict what will happen in a circuit from just a drawing of it. Test your results with batteries and bulbs.

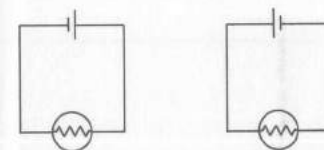
This set of symbols and ones to be introduced later make it easier and quicker to draw circuit diagrams. Only the essentials are implied in each symbol. These symbols are used universally to communicate circuit ideas in a simple form.

The symbol for the battery implies that one battery affects a circuit in two different ways, according to which end is connected to which part

of the circuit. But you already know that the two ends of a battery are not the same. The bulb will not light in the following circuit even though it contains two batteries.

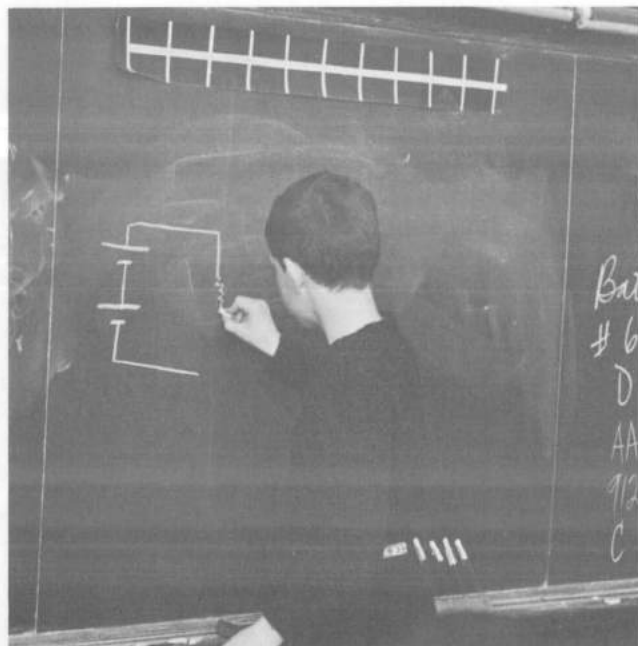


Make up the two circuits shown below. See if the lighted bulbs are the same brightness in each.



The symbol for a bulb implies that the bulb can always be reversed in its position with no change in the circuit. Try reversing the connections on several bulbs to verify this implication.

Square corners in the diagrams do not necessarily mean that in the actual circuit there are



Courtesy, Cornell Alumni News

square corners. Representing wires as being straight and corners as right angles only helps to make drawings neat.

## Introducing The Secret Language in the Classroom

When children first draw their circuits they take elaborate measures to see that the picture conforms exactly to the real circuits. These pictures fulfill their need both to communicate and to save their ideas for future reference. Pictures of this type, however, soon become unmanageably complicated.

Children usually have one or more of these problems:

1. When more complex circuits are made the time taken to draw elaborate pictures discourages record keeping.
2. Their drawings sometimes cannot be un-

derstood because of mistakes or because of different degrees of skill in drawing.

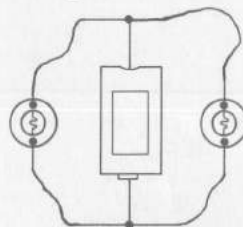
3. Many of the essentials are disguised by "artistic form."

The need arises, then, for a simple, clear *standard* way of drawing circuit diagrams.

The Secret Language is both secret, in that those who do not know the symbols cannot understand what is meant by them, and a language, because it is a tool used in the communication of complex ideas.

The symbols in this part of the Secret Language can be introduced very early in some 6th, 7th and 8th grade classes since the children will be making complex circuits and will have a need to simplify their diagrams. After a week or two of experimentation with and discussion of the material in *Circuits I*, you may wish to make some of these symbols known to the class as a whole. You might present the Secret Language as a game. Because it is an abstract way to represent circuits in diagrams, care must be taken in its presentation and practice.

Draw some simple circuits on the board in pictorial form, for example:



Ask the class to construct the circuit from batteries, bulbs and wire.

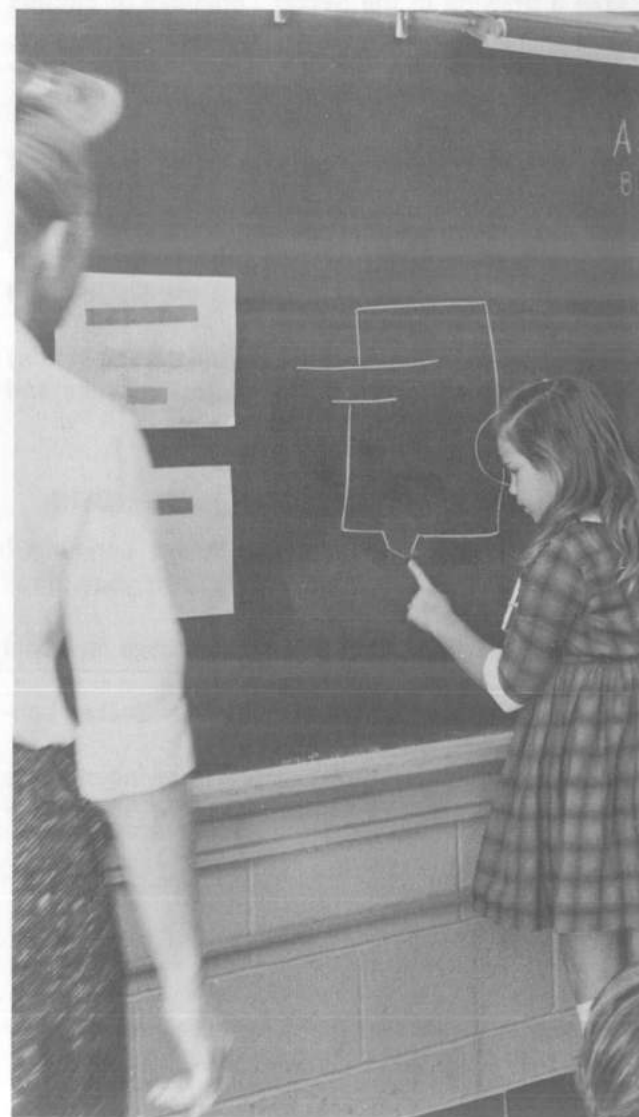
Next, draw a simple circuit in the Secret Language. See if they can construct the circuit with their equipment.

Try several more circuits. Make them more complex as you proceed.

Ask if they can predict what would happen in a circuit from just the symbolic diagram of

that circuit. They can construct the circuit to verify their predictions.

Children may want to challenge the limits of the Secret Language by trying to construct a circuit that cannot be translated into symbols, or by making a drawing in symbols to see if a friend can construct it.



## NEW MATERIALS FOR THE SECRET LANGUAGE

Coordinate with a section which uses batteries, bulbs and wires to make circuits.

### Activities Children May Try

Make a drawing in the Secret Language of circuits they have made.

Predict what will happen in a Secret Language circuit diagram. Check predictions by constructing the circuit.

Practice drawing many circuits using the Secret Language.

Test circuits to see if reversing a battery or bulb affects the circuit.

Try to make a circuit that cannot be diagrammed in the Secret Language.

Draw circuits in the Secret Language. See if they can be constructed out of batteries, bulbs and wire.

### Possible Discussion Questions

Why do you think we use the Secret Language? Does the Secret Language help you in your drawings of circuits?

Why do you think the Secret Language symbols are drawn the way they are?

Can you make a diagram using the Secret Language? (Suggest a circuit.)

What would happen in this circuit (drawing of some circuit in Secret Language) if it were constructed?





# OCTOPUS BOXES

## Before Starting to Teach

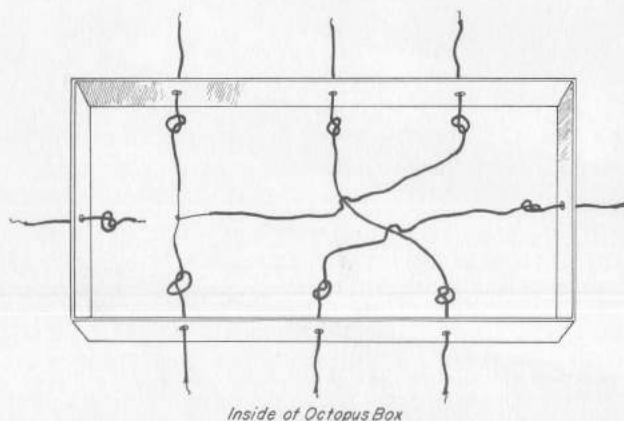
Materials you will need  
for Octopus Boxes —

- 6 shoe boxes
- 48 one-foot pieces #22 copper wire
- 1 roll cellophane tape
- for tester —
- 1 "D" battery
- 1 rubber band
- 4 Fahnestock clips
- 1 bulb holder
- 1 #48 bulb (PB)
- 2 eight-inch pieces #22 copper wire

Using a nail, punch eight holes in the sides of a shoe box, or any box that can be sealed — three on each long side, one on each end. Number the holes 1 to 8.

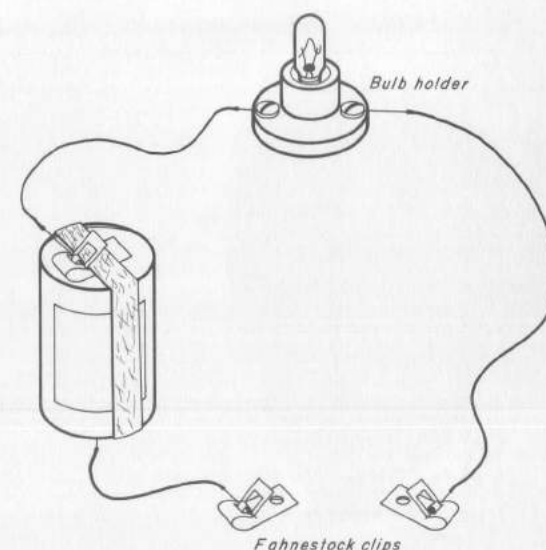
Strip one inch of insulation from each end of the pieces of wire. Push a wire into each hole so that about four inches show on the outside of the box. Tie a knot in each wire on the inside of the box so that the wire won't pull through the holes. Connect the inside ends of 7 of the wires in a pattern similar to that shown in the diagram

below. Leave one wire unconnected. Close the lid and seal the box with cellophane tape.



Make up a tester composed of a bulb connected to a battery, as in the diagram to the right. Using the tester find out which wires are connected together. You might want to make up other varieties of testing devices.

If one of the loose ends of this tester is connected to one leg of the octopus and the other loose wire to another leg of the octopus and the bulb lights, then you know *at least* those two legs are connected. It might be interesting to try



your Octopus Box on another adult.

Make up five more Octopus Boxes, each in a different wiring pattern, for use by your class.

## Introducing Octopus Boxes in the Classroom

This experiment should help children see the

importance of an uninterrupted path to a bulb.

Children will be eager to know what these weird-looking boxes are for. Pass them out to a few individuals or groups who are ready for a new activity. Have each child try several different boxes.

"Which legs are connected?"

Have the children keep a record of which wires they think are attached. See if they can discover for themselves how to find out which legs are connected before suggesting the use of a battery and bulb tester. You should rule out opening the boxes or pulling on the legs.



**NEW MATERIALS FOR OCTOPUS BOXES**  
for each group —  
1 Octopus Box

**Activities Children May Try**

See which legs are connected to which other legs.  
See which legs are not connected to any other legs.  
Make their own Octopus Boxes with different numbers of legs.

See how the bulb holder can be thought of as a  
“four-legged” Octopus Box.

Make up different kinds of testing devices.

**Possible Discussion Questions**

Which legs are attached in each box? How do you know?

What method did you use to find out?

Why does the bulb light in the tester when some legs are tried and not when others are tried?

(Keep a record of the answers. Test each box in class to find out which legs are connected. Open the box as a verification.)



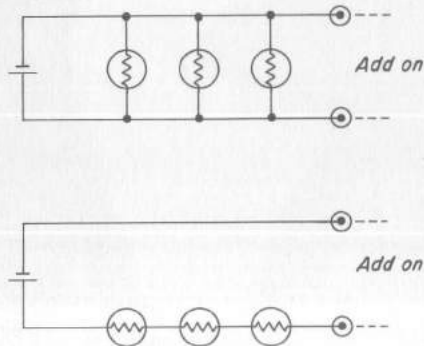


# ANOTHER BULB

## Before Starting to Teach

Materials you will need  
several #41 bulbs (WBs)

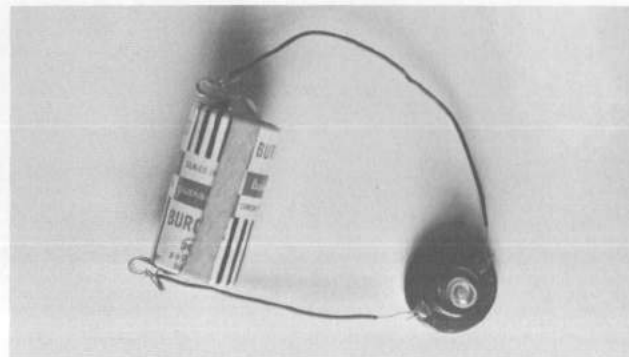
Take one of the WBs from Box 2. Inspect it with a magnifying glass. Notice that it has the numeral "41" on its base, and that it has a white bead and a thicker wire for the filament than does the PB. Try it in a bulb holder. Light it. Compare the brightness of a WB in the path to one "D" battery to that of a PB in the path to one "D" battery. Does the WB seem as bright as the PB? See how many WBs will light in the two circuits pictured below.



## Introducing Another Bulb in the Classroom

This other light bulb can be studied after the children have had a few lessons with the PB. The children usually call this bulb "white bulb" or WB.

When the children get the WB they will want to see how it acts in some of the circuits they have already made. Let them explore the differences between this bulb and the PB as they see them side by side in identical circuits.



## **NEW MATERIALS FOR ANOTHER BULB**

for each child —

1 #41 bulb (WB)

### **Activities Children May Try**

See how a WB and PB differ physically.

Try a WB in several circuits to see if it acts like a PB.

Compare the brightness of a WB to a PB in identical circuits.

See how long a battery will last when attached to a WB.

See how many batteries it takes to burn out a WB.

Find out how many WBs will light in the two diagrams on page 32.

### **Possible Discussion Questions**

How does the WB differ from the PB?

Will the WB work as well in a bulb holder?

Is the WB as bright as a PB on the same number of batteries?

Will the same number of WBs as PBs light on one battery?

Are the special places the same on this bulb as on the PB?



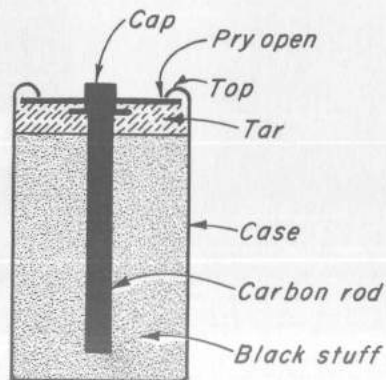
# WHAT'S INSIDE A BATTERY?

## Before Starting to Teach

Materials you will need

- 1 "D" battery
- 1 wire stripper
- 1 piece of newspaper

Place a piece of newspaper on a table. Open a "D" battery by carefully removing the top with a wire stripper. After taking out the metal cap remove the separator, which is made of a tarlike substance. If you are careful, you can twist the carbon rod (black rod), which is now exposed, and slowly pull it out. Try to light a PB with





the black material that is left inside. Try to light the PB when the carbon rod just touches the material from which it was withdrawn. Push the rod in slightly to see where both a WB and a PB will light. Put the carbon rod in the path a PB has to a battery. Will a WB light with the same brightness as a PB if the same length of carbon rod is put into its path to a battery?

The materials inside a battery are not harmful to the skin but may stain clothing, so some care must be taken when batteries are opened.

## **Introducing What's Inside a Battery in the Classroom**

As the children use the batteries and bulbs, there will come a time when some cease to take them for granted. They will want to know something about what is inside a battery. Not all children will want to take a battery apart, nor should you sacrifice that many batteries. One battery for each group will allow each child to see

the process. Taking a battery apart should be done with some care.

Children start by taking off the top, using a wire stripper as the tool. They may dig the "black stuff" out with a screwdriver. Some may find it fun to test the battery as it is being taken apart to see at what stage it stops lighting a bulb. One 5th grader was careful to remove just the carbon rod. As she pushed the rod back into the battery, a WB bulb attached to the battery became brighter and brighter.



## **NEW MATERIALS FOR WHAT'S INSIDE**

### **A BATTERY**

for each group —

1 sheet of newspaper

At least one new and one worn out "D" battery

1 wire stripper

### **Activities Children May Try**

Discover at which points a WB and a PB begin to light as the carbon rod is pushed back into a battery.

See what is inside any bigger, smaller, or stronger batteries that the children may have brought into class.

List the materials that make up a battery which can be put in a path to a PB and still have the bulb light.

### **Possible Discussion Questions**

Is there any difference between the insides of a "dead" battery and one which lights a bulb?

Does a WB or a PB light first as the carbon rod is gradually pushed back into the battery?

Which bulb will light with the least amount of black material left in the battery?

Does the carbon rod touch the bottom of the battery case? Will a bulb light if it does?



# WHAT'S INSIDE A BULB?

---

## Before Starting to Teach

### Materials you will need

Several household bulbs (clear and frosted)

- 1 #41 bulb (WB)
- 1 wire stripper
- 1 triangular file

You have inspected both types of the miniature bulbs provided in the kit. Compare what is inside a household bulb with these bulbs. Clear glass bulbs are most appropriate for this. If you cannot buy clear bulbs, break the glass of the opaque type and carefully remove any jagged pieces with a wire stripper and file. Keep the remains of the bulbs for demonstration purposes in the classroom.

Put one household bulb under water in a sink or dishpan. File along the line which divides the glass from the base until water enters the glass. The pressure outside the bulb is greater than inside, therefore the water is pushed into the glass. Are there any bubbles? Is it air, or another gas, escaping from the bulb?

File the glass of a WB in the same way. Does the glass fill with water? Do you see any bubbles?

Carefully remove the glass. Light the bulb.

It burns out rapidly now. On the basis of this test would you say that there had been air or another gas inside the intact bulb?

You can remove the base from a bulb by screwing it part way into a bulb holder. Then press your thumb against the glass with a firm upward pressure at various points around its circumference. This will loosen the bulb from the metal screw base so that it can be lifted away intact. Gently pull the bulb away from the base, being careful not to break the wires that go from the base into the glass. You can now see where these wires are attached to the base and why these are special places for the battery to touch. Try to light the bulb now by connecting a battery to the two small wires.

## Introducing What's Inside a Bulb in the Classroom

Very early in the study of *Circuits I* children have looked at what is inside an intact PB. They may even have broken a burned-out bulb to see how one is constructed.

After this initial exploration a good way to begin looking at bulbs more closely is to study

some clear glass household bulbs. In these larger bulbs the parts are more readily visible, and there are interesting comparisons and contrasts to be made with the small bulbs.

As a next step let the children look at some household bulbs from which the glass has been removed by you before class. Now they can have a look inside the base of the bulbs, then the silver tip and metal screw base can be pried off, exposing the wires attached inside.

The children are very likely to ask what the glass on a bulb is for. Trying to light a bulb (using batteries) with a small hole in the glass, or without glass, is of course the best way to answer this question.

The class may then want to know whether there is some different kind of gas in the bulb, or whether there is no gas at all. Have them file the glass of a bulb near its metal base while holding it submerged in water. You might remind them to watch for bubbles, and ask them what the bubbles indicate to them about the presence of a gas in the bulb.

With this amount of class activity as a starter, some children may go on to further investigation of the inside of bulbs, and can file open some of their own small bulbs, both new and burned-out.



## NEW MATERIALS FOR WHAT'S INSIDE A BULB for the class —

Several intact clear and frosted household  
bulbs (7½ to 100 watts)

Several household bulbs with glass removed

Wire strippers

3 triangular files

1 ball of steel wool

## Activities Children May Try

Describe and compare the insides of large and small  
bulbs.

Determine the uses of all the parts of a bulb.

Trace the wires from the base to the filament.

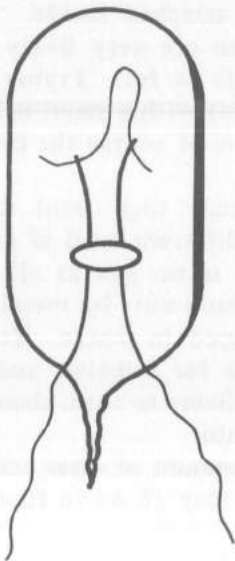
Find out what makes a bulb light or not light.

Make a bulb by putting steel wool in place of the  
filament in both large and small bulbs.

Try to light bulbs whose glass has been removed.

File the glass of a bulb when it is under water.

Light a bulb whose base has been removed but  
whose glass has not been broken.



## Possible Discussion Questions

What are some of the differences between a bulb  
which lights and one which does not light?

What is the bead inside a WB for? Is there any-  
thing like it in a household bulb?

Why are the sides and tip special places for light-  
ing a bulb?

How does the inside of a small bulb compare with  
the inside of a large bulb?

Can you tell if there is a gas inside a bulb or if  
there is nothing by what happens when water  
enters the glass?

Which part of the bulb lights up?

What is the "silver" blob on the outside of the screw  
threads of the metal base of a bulb?

Is there a difference between the way in which a  
bulb with a hole in its glass and a bulb with no  
hole light? With no glass at all?

Will a bulb light if any of the wires inside are  
broken?

## Special Comments

This is the time to emphasize again that the  
children should **not** use the electricity provided by  
wall outlets, at home or at school, for their experi-  
ments.



# TESTING PATHWAYS

## Before Starting to Teach

### Materials you will need

- 2 "D" batteries in holders (see Battery Holders)
- 1 #48 bulb (PB)
- 1 #41 bulb (WB)
- 1 bulb holder
- 2 eight-inch pieces #22 copper wire
- "Junk box" items (see page 41)
- Bottom half of a quart milk carton
- Salt
- 1 can of Comet cleanser
- Various liquids (water, cooking oil, vinegar, etc.)

You may already have made a pathway tester while working with Octopus Boxes. If not, refer the diagram of a tester on page 29 to construct a device which will enable you to discover which materials, when put in the pathway, will allow the bulb to light, and which will not. (Materials for the tester are in Box 1.)

Test any material that is handy, such as paper clips, pencil lead, pencils, scissors, desk tops, coins, paper, glass. Test the materials in your "junk box." Make a list of things that will allow

the bulb to light. Make a list of things that will not allow the bulb to light. In general, what types of materials fall into each list? Do you get the same results with the WB?

Put two batteries in your circuit. Test some liquids, such as a strong solution of salt or Comet cleanser and water, with each bulb. Be sure the Fahnestock clips do not touch each other when they are dipped into the liquids. If they touch you are not testing the liquid but the Fahnestock clips as part of the path. Add the results to your lists. In which list would you put pure water, cooking oil and vinegar?

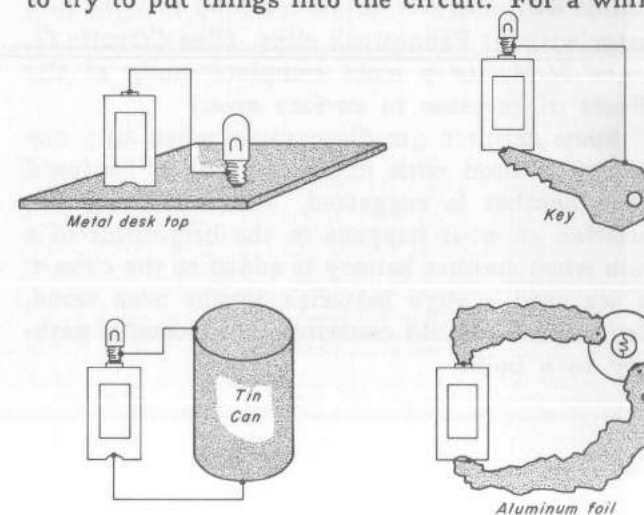
## Introducing Testing Pathways in the Classroom

In joining a battery to a bulb, children may have already substituted several things for wire: paper clips, pins, keys, desks, drawer handles, door hinges, pocket books, faucets, globes, aquariums, pencil sharpeners, walls, hair, thread, scissors, screwdrivers.

Once several children are interested in exploring the electrical properties of materials you

can suggest testing some other things of special interest which they might not think of: aluminum foil, pipe cleaners, pencil lead, Nichrome wire (Box 2), other insulated wire, large light bulbs, empty sockets, air, tin cans, painted metal, and various liquids, such as salt and water solution, milk, vinegar, a solution of Comet cleanser and water, or baking soda and water.

Children may have a number of different ways to try to put things into the circuit. For a while



each of these arrangements will seem entirely new to them. The general notion that they are finding things to "complete the circuit" is not obvious to them at first.

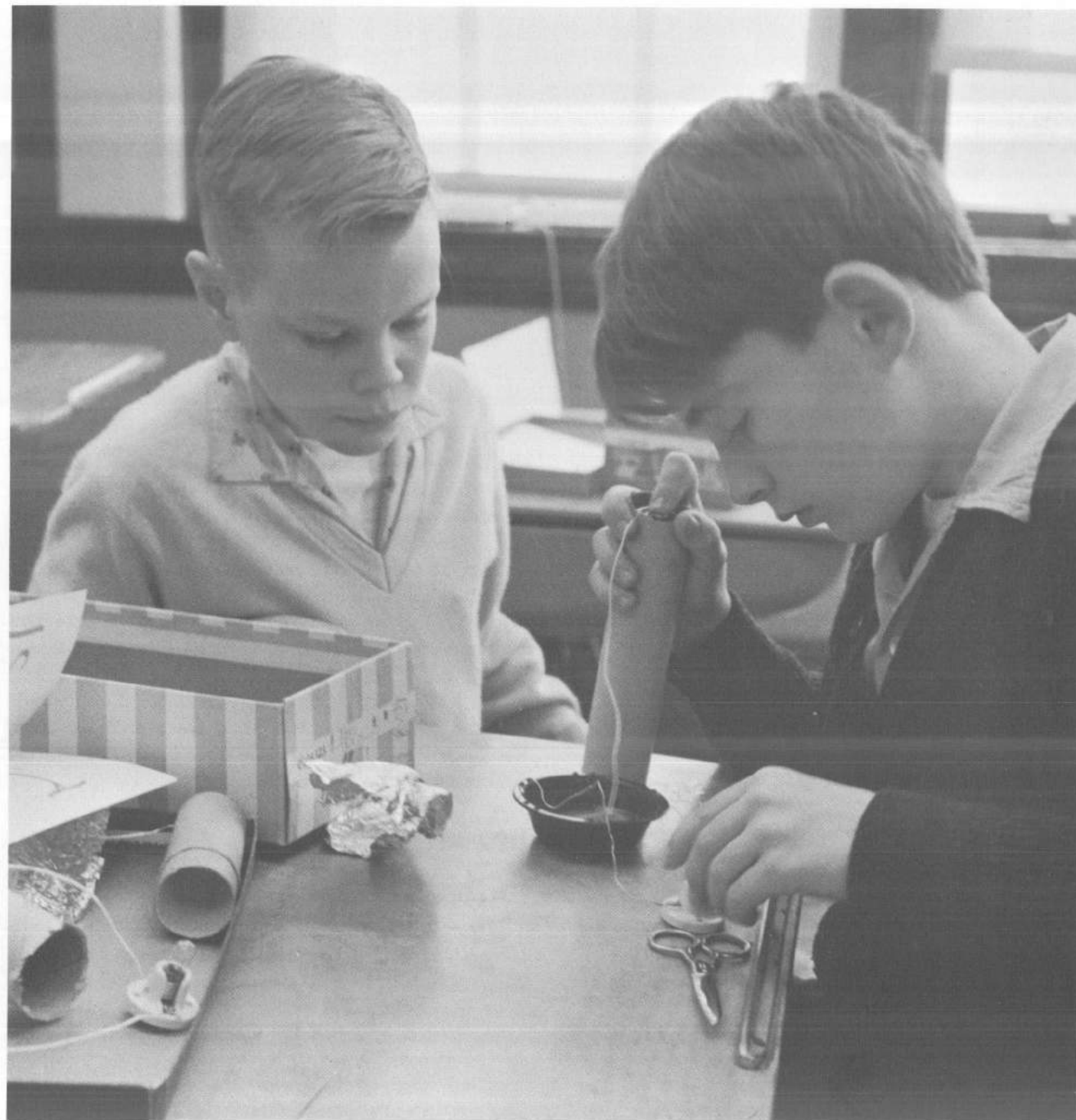
You yourself can bring some order into the activity by raising the following question:

What things can be inserted between the two Fahnestock clips shown in the diagram on page 29 so the bulb will light?

The children can make lists headed *Lights* and *Doesn't Light*, which may be compiled and compared on the blackboard.

Testing liquids will need some guidance from you. It can be very tricky. With a single battery, no liquid seems at first to complete the path. When you add more batteries, a faint glow is seen in the PB. (With four batteries a strong salt solution will allow a PB to light immediately in the test circuit.) If you wait a while the bulb gets brighter without adding more batteries. At this point, if some of the batteries are removed, perhaps even all but one, the bulb will still be seen to glow. The Fahnestock clips are not essential on the ends of the wires inserted in the liquid to be tested, but are advisable since they increase the surface area in contact with the liquid. Some liquids will, however, allow the bulb to light in a tester without Fahnestock clips. (See *Circuits II*, pages 24-28, for a more complete study of the effects of increase in surface area.)

Some children get discouraged when only one battery is used with liquids, and then confused when another is suggested. Refer often to the question of what happens to the brightness of a bulb when another battery is added to the circuit. If we used enough batteries, maybe even wood, air, or plastic could constitute a successful pathway to a bulb!





## NEW MATERIALS FOR TESTING PATHWAYS

for each child—

Bottom half quart milk carton  
Half-pint milk carton, top cut off

for the class —

“Junk box” items (keys, pieces of plastic, small bottles, paper clips, scissors, new or dead batteries, thread, string, metal washers, toothpicks, spoons, sponges, nails, aluminum foil, rubber bands, chalk)

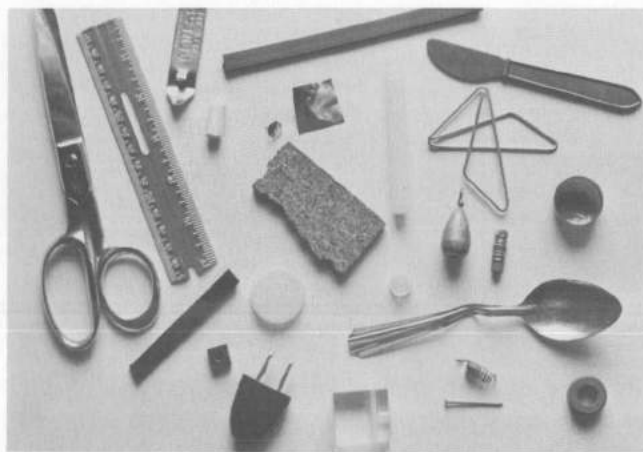
10 to 15 household bulbs (7½ to 100 watts)

Aluminum foil

1 can of Comet cleanser

1 can of baking soda

Various liquids, such as: milk, salt in water, flour in water, dirt in water, instant tea or coffee in water, vinegar, cooking oil



## Activities Children May Try

Put any one object in the path of a lighted bulb.

Put several objects together in that path.

Use both good and “dead” batteries in the path.

Make two or more lists of materials: One containing those materials which **complete** the path

to a bulb, one containing those materials which **do not complete** the path to a bulb and perhaps one which contains those materials which **only under special conditions** complete the path to a bulb.

Study various liquids to see if they can be put in the path to a bulb so that the bulb still lights.

Make parts of a household bulb part of the path.

See which household bulb (7½ to 100 watt) will make a WB brightest if the WB and household bulb are in the **same** path to a battery.

Vary the amount of salt (or other compounds) in solution, the distance between the Fahnestock clips, or the type of bulb used to see if these changes make any difference the way the bulb lights.

## Possible Discussion Questions

The lists of materials that **will** and **will not** complete a pathway so the bulb will light form the basis of discussion for this section on **Testing Pathways**.

How can some materials appear on both lists?

Will another battery complete the path? Does it have to be able to light a bulb to complete the path?

How does the PB differ from the WB when testing the same materials?

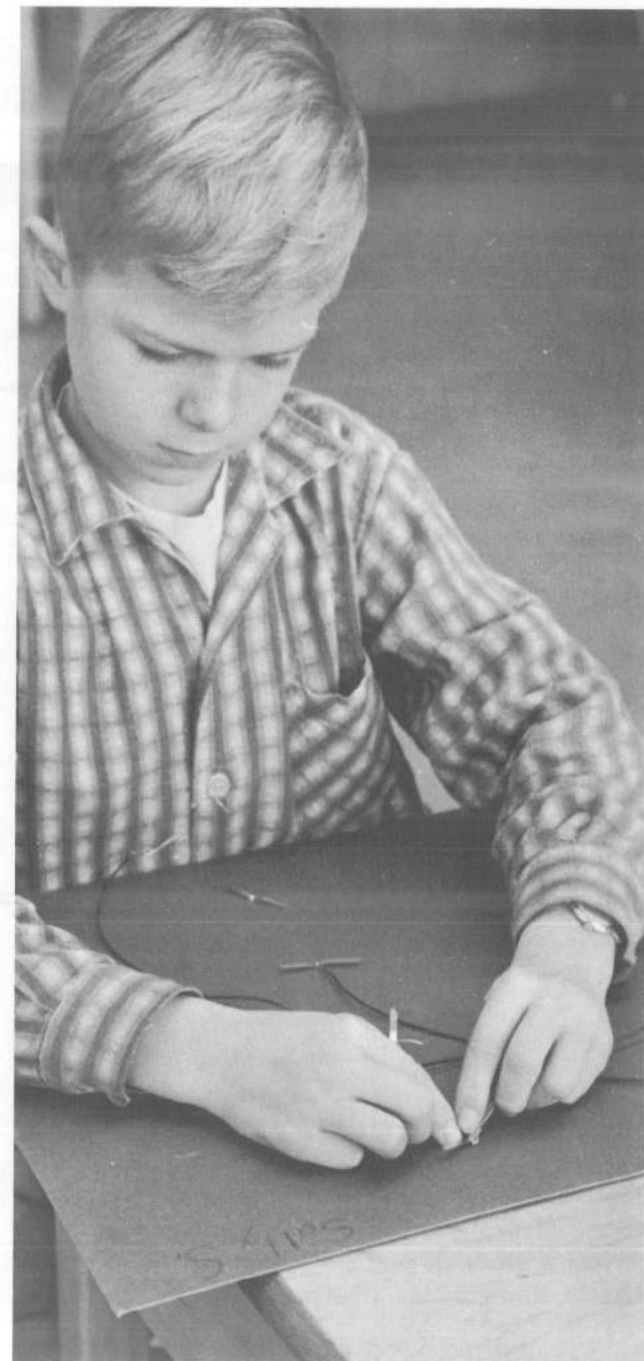
Does the bulb burn with the same brightness for each material that does complete the path?

What result do you get when you test pencil lead, some of the silver colored (Nichrome) wire, or the carbon rod from a battery? Does it matter how long the piece of wire or lead is?

Are there any changes in the Fahnestock clips when you are testing a liquid?

## Special Comments

We will use □ as the symbol for a Fahnestock clip in the Secret Language.



# WIRES—Long and Short, Thick and Thin

## Before Starting to Teach

### Materials you will need

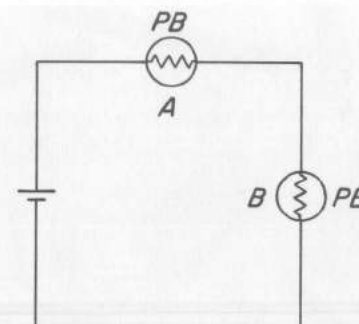
- 1 two-foot piece #32 (thin) Nichrome wire
- 1 four-foot piece #26 (thick) Nichrome wire
- 2 rolls #22 (thick) copper wire
- 1 roll #36 (thin) copper wire
- 1 #41 bulb (WB) and holder
- 1 #48 bulb (PB) and holder
- 1 "D" battery and holder (see Battery Holders)

Put a twelve-inch piece of #32 (thin) Nichrome wire between the Fahnestock clips in the device you used in *Testing Pathways*. The bulb dims. Experiment to find a piece of wire that will cause a PB to go out. Do the same with a WB. Try a piece of #26 (thick) Nichrome wire. How long a piece of this thick Nichrome wire will dim the bulbs the same amount as does 12 inches of thin Nichrome wire? What is the difference between the #26 and #32 Nichrome wires? Repeat with #36 (thin) copper wire.

Use a six-inch piece of #32 (thin) Nichrome wire to short-circuit a battery. The wire will get very hot. Does the wire or battery get hot if a piece of #26 (thick) Nichrome wire is used?

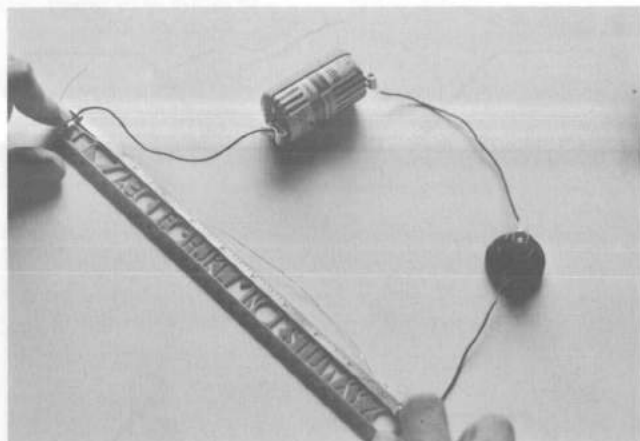
Remake circuit C on page 11 of the section on *Beginning Circuits* by replacing the copper short-circuit wire with a two-foot piece of #32 (thick) Nichrome wire. If the length is shortened the bulb goes out and the wire gets hot. Repeat this activity using #26 (thick) Nichrome wire and #36 (thin) copper wire, but choose different lengths. Repeat using a WB. Fill in the table below, listing the types of wire in progressively greater lengths. Where would you put the length of two rolls of #22 (thick) insulated copper wire in your table? (You can get to the ends of these rolls of wire easily as they have been made available by specially winding the rolls.)

Make this circuit:

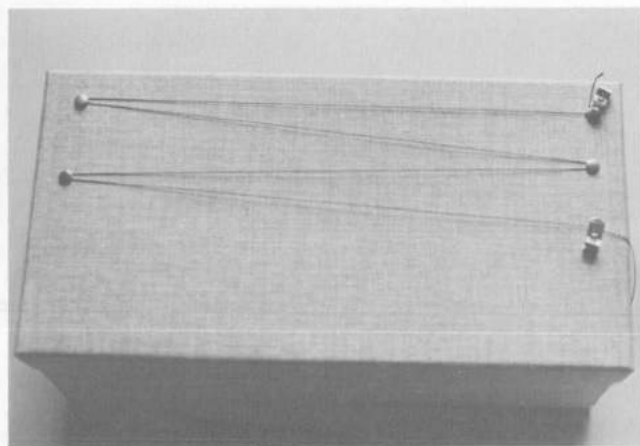


Replace bulb A with a length of #32 (thin) Nichrome wire that will make bulb B light with the same brightness as it did with bulb A in place. Does this give you a clue to how a bulb functions?

Type of Wire	Length of wire that makes the PB go out in circuit C	Length of wire that makes the WB go out in circuit C



When the wire being tested is connected between two Fahnestock clips, the length of the wire in the circuit can easily be varied by sliding

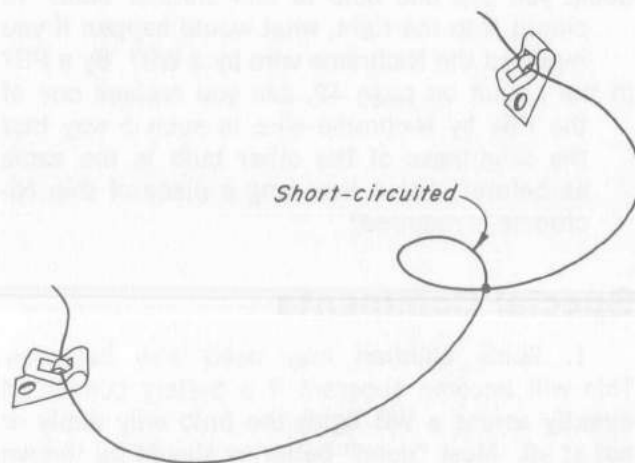


the clips along the wire and then measuring the length of the wire between the clips. It may be more convenient to mount the wire on the top of a shoe box by winding it back and forth under the heads of paper fasteners. A number of different wires may be mounted on the same box. Be sure that two places along a wire are testing do not cross as the loop formed will be shorted out of the circuit and your results will be inaccurate.

## Introducing Wires in the Classroom

Pass out a two-foot piece of #32 (thin) Nichrome wire to each child, and 2 four-foot pieces of #26 (thick) Nichrome wire to each group. Have available the roll of #36 (thin) copper wire.

Once again the children will start with seemingly unsystematic work. Not all children will start this activity at the same time, or move in the same direction. Some will not be interested in pursuing it in depth. Many children will use the wires in circuits without bulbs, and note the differences in how hot each wire gets. (See *Making a Bulb*, page 47.) Some may notice that old batteries act differently from new ones. Many will



repeat circuits they have already made, using these wires in the place of the original copper wire, with little concern for the length of wire involved. Many will combine several kinds of wire in a circuit. Some may want to string a roll of copper wire down the corridor. Some may want to see if a still *thicker* wire will make the bulb still *brighter*.

Only after they have had enough of this type of activity will they focus on the controlled, quantitative questions. And only at these times will record keeping be important to them. Keeping a class chart of some sort is of special interest here, because there are sure to be differences in results. The children themselves will be able to think of reasons for these differences. There may be different opinions as to when a bulb is noticeably dim or "out." Maybe a bulb looks out in a room, but will still glow inside a dark closet. Some children may have had older batteries than did others. Some may have been counting the part of the wire wound around the screw, or attached in the Fahnestock clip.

Agreement should be reached by the class on these matters. They should concur on a certain range of results for each of the measurements taken. They may also come to agree on an experimental technique, such as keeping one circuit as a standard of reference while they vary the wires in another.

In one class a chart comparing wire lengths needed to extinguish bulbs looked like this:

Wire	In a tester: Length to put out a WB	In a tester: Length to put out a PB	Approximate lengths equivalent to one foot of thin Nichrome wire
#22 copper, insulated	300 feet	?	900 feet
#36 copper, bare	8 feet	33 feet	24 feet
#32 Nichrome, bare	4 inches	2½ feet	— — — —
#26 Nichrome, bare	1 foot	8 feet	3 feet



## NEW MATERIALS FOR WIRES — Long and Short, Thick and Thin

for each child —

1 two-foot piece #32 (thin) Nichrome wire

for each group —

2 four-foot pieces #26 (thick) Nichrome wire

for the class —

1 roll #36 (thin) copper wire

2 rolls #22 (thick) copper wire

## Activities Children May Try

Use all the different types of wire, in various lengths, in simple and complex circuits.

Dim and put out either bulb with each type of wire, making a record or chart of the results.

Compare the lengths on the chart and make generalizations as to the effectiveness and appropriateness of a certain wire in a certain circuit. Predict what another wire (such as thick bare copper) would do in a circuit. Predict what would happen if they changed lengths of the same wire or substituted equal lengths of a different wire in a circuit.

Replace a carton of salt water in the path to a bulb and two batteries by a length of #26 (thick) Nichrome wire sufficient to dim the bulb the same amount as did the salt water.

Replace bulbs in circuits by #32 (thin) Nichrome wires of lengths which will maintain the brightness of the remaining bulbs.

## Possible Discussion Questions

Use any chart the class makes as a basis for discussing the characteristics of the different wires in this section.

In a circuit having a battery, a bulb and a piece of wire in the same path, how long a piece of each type of wire will dim each bulb noticeably? Put out each bulb?

If (thick) #26 Nichrome wire in a circuit were replaced by the same length of (thin) #32 Nichrome wire, would the bulb get brighter or dimmer?

If some (thin) #36 copper wire in a circuit were replaced by the same length of (thick) #22 copper wire, would the bulb get brighter or dimmer?

If some thin copper wire in a circuit were replaced by the same length of thin Nichrome wire, would the bulb get brighter or dimmer?

What length of thin Nichrome wire will dim a WB the same amount as 100 feet of insulated thick copper wire?



In which of the two circuits sketched to the right would the bulb be brighter? Would it make any difference if the four thin Nichrome wires were twisted together?

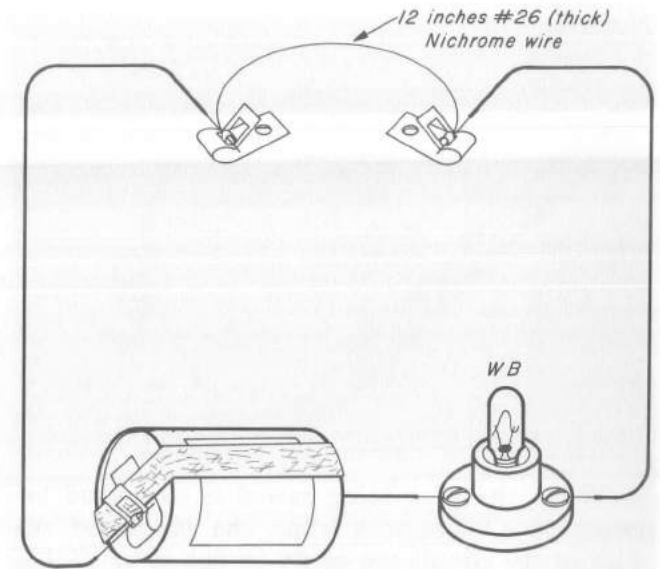
Could you use one bulb to dim another bulb? In circuit A to the right, what would happen if you replaced the Nichrome wire by a WB? By a PB?

In the circuit on page 42, can you replace one of the PBs by Nichrome wire in such a way that the brightness of the other bulb is the same as before? About how long a piece of thin Nichrome is required?

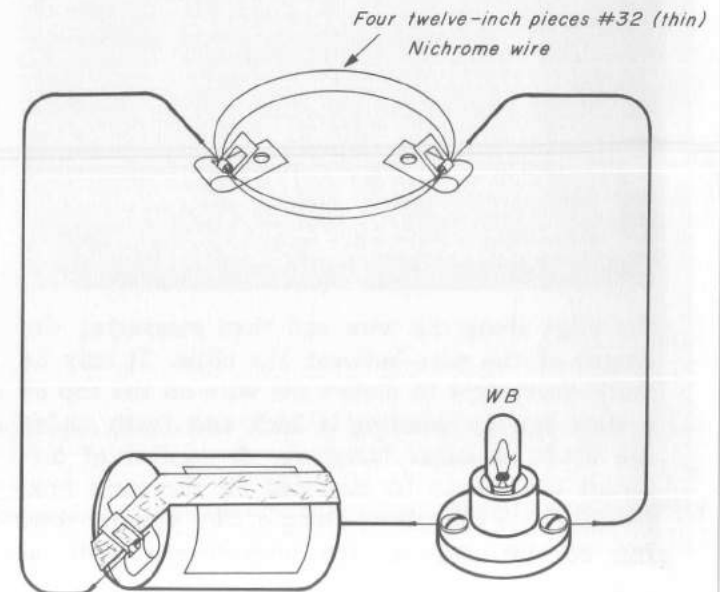
## Special Comments

1. Some children may need new batteries. This will become apparent if a battery connected directly across a WB lights the bulb only dimly or not at all. Most "dead" batteries should be thrown away, but a few might be saved for the "junk box."

2. A new symbol in the Secret Language is  which means a piece of #32 (thin) Nichrome wire or a long piece of any wire. Children will see that there is no difference between 300 feet of thick copper wire and four inches of thin Nichrome wire in the path to a bulb. In this case, since the thick copper wire has an effect on the circuit, it would be represented by  in the Secret Language.



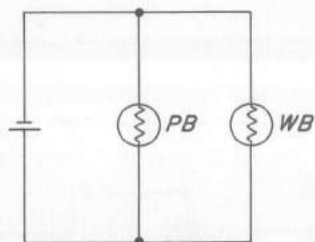
Circuit A



Circuit B

## Prediction Sheet Three

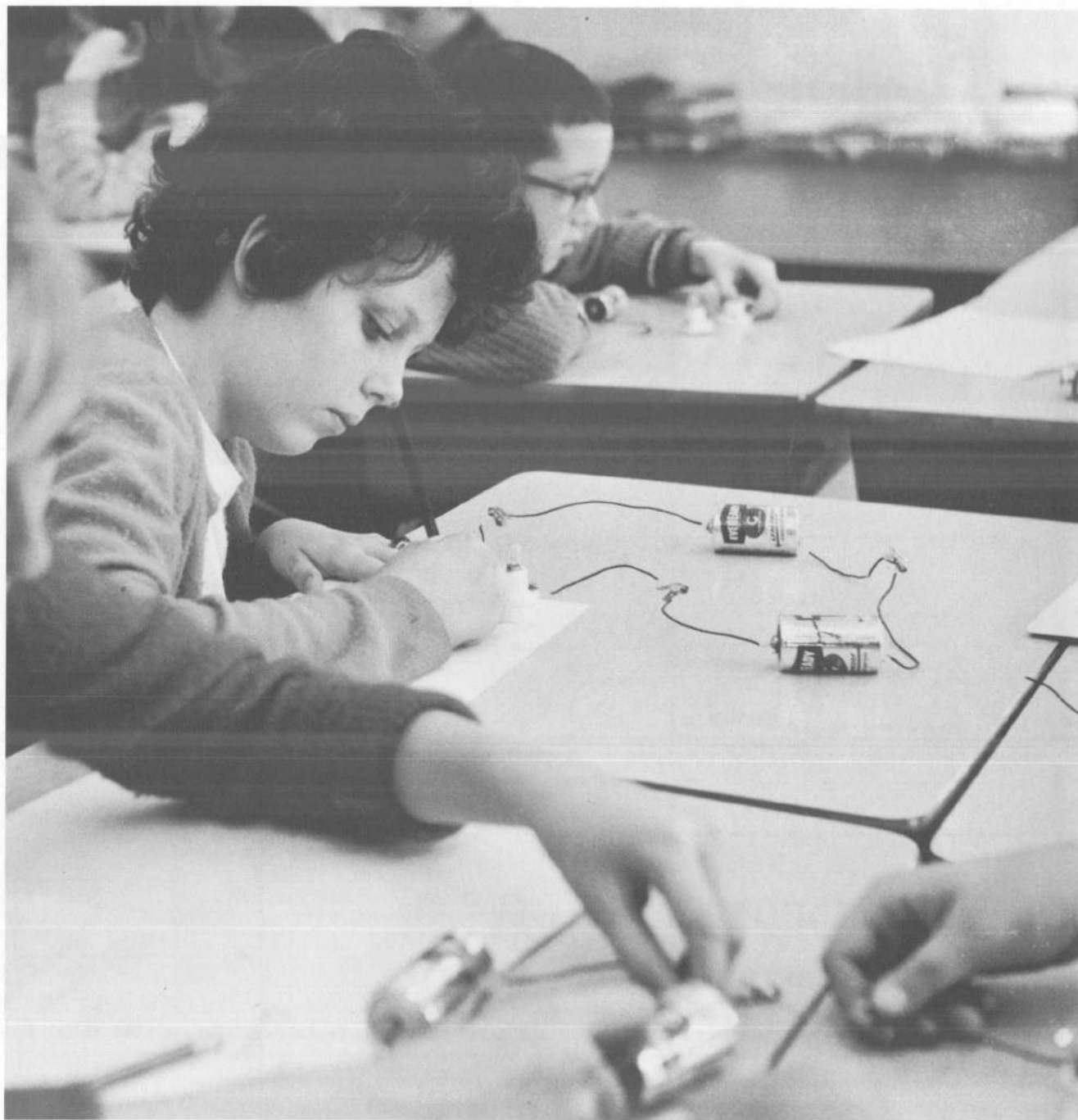
This prediction sheet should be used in the same way as prediction sheets one and two. The eleventh circuit should be particularly noted. The WB will not light, and if you unscrew it, the PB goes out. Two WBs or two PBs will light. If you have two WBs and one PB or two PBs and one WB, only the PBs will light. If more batteries are used, the PBs will burn out before any WBs light. PBs and WBs will all light in this circuit when used separately.



What is the difference between the circuit shown above and circuit 11 on the prediction sheet? (See pages 12 and 13 in **Circuits II** for a discussion of circuit 11.)

Circuit 10 may also be seen in a different perspective after doing the exercises, noted above, in **Circuits II**. Nonetheless, they are of enough interest at this stage to be considered here as well.

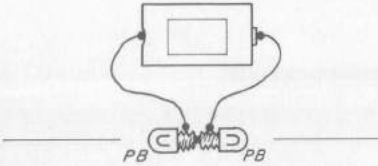
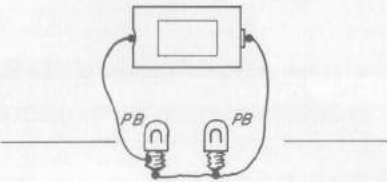
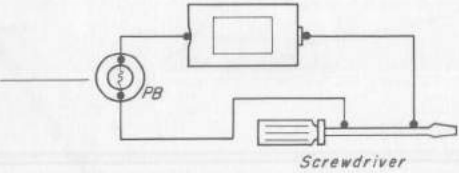
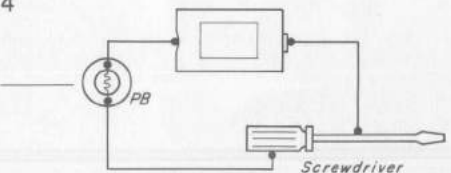
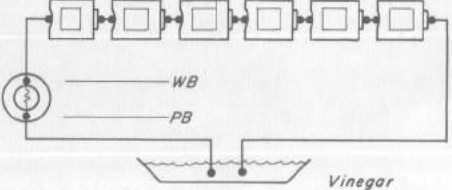
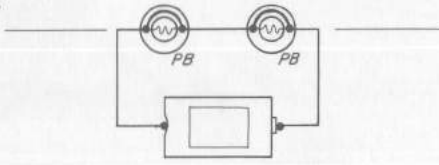
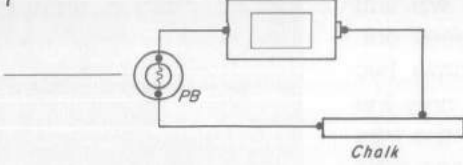
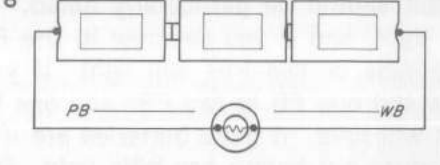
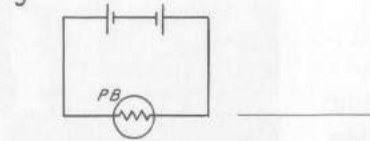
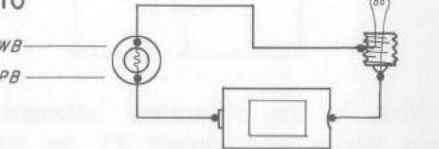
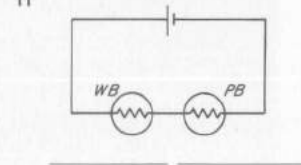
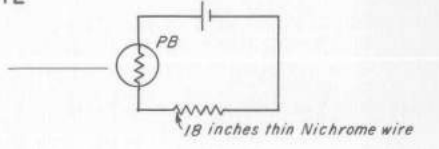
Feel free to use any other circuits for this prediction sheet.



# CIRCUITS I

## Prediction Sheet Three

In which circuits will the bulbs light?  
Mark a  $\checkmark$  for those which will light and mark an X for those which will not light.

<p>1</p> 	<p>2</p> 
<p>3</p> 	<p>4</p> 
<p>5</p> 	<p>6</p> 
<p>7</p> 	<p>8</p> 
<p>9</p> 	<p>10</p> 
<p>11</p> 	<p>12</p> 



# MAKING A BULB

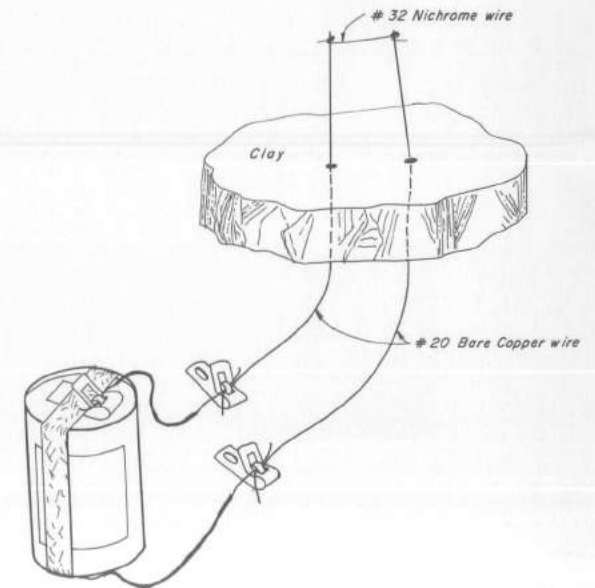
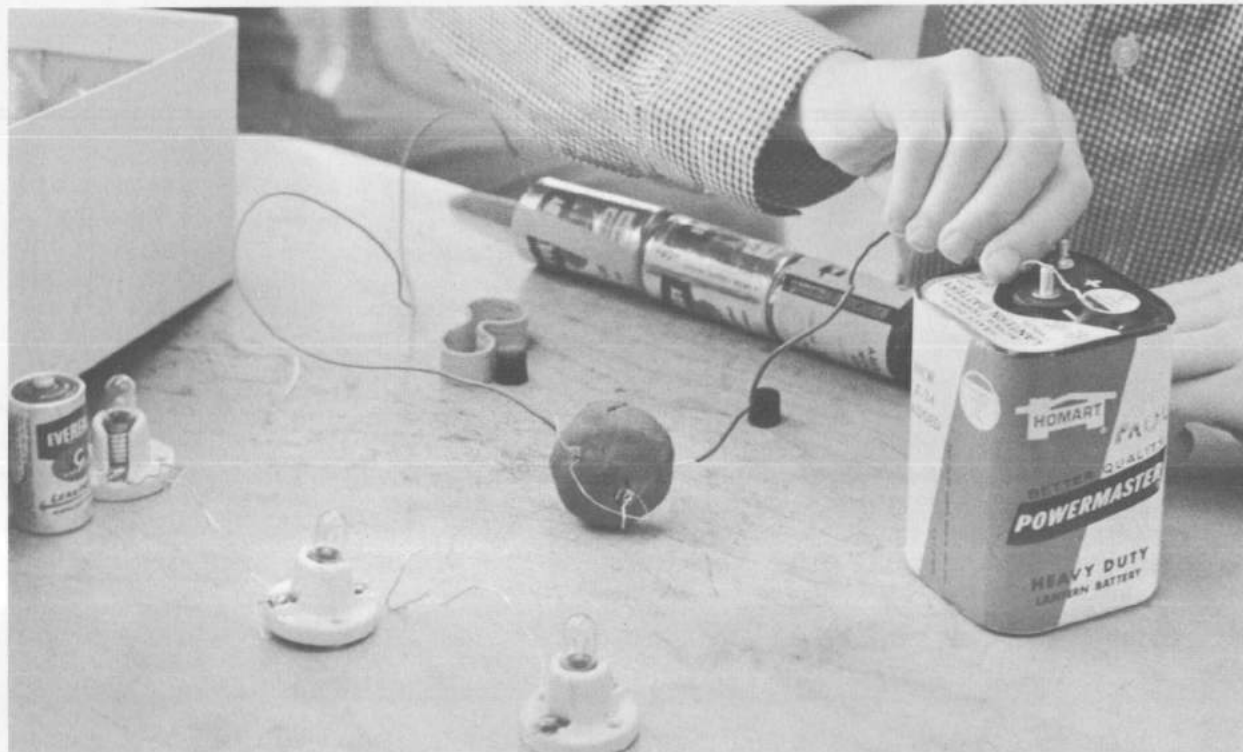
## Introducing Making a Bulb in the Classroom

Many members of your class may already have tried to make a light bulb. If they have ever put steel wool on the upright wires of a broken bulb

in a circuit and produced sparks or a glow, they have discovered some of the things involved in making a bulb. By this time the children should understand fairly well the functions of each part of a bulb.

Two eight-inch pieces of bare #20 (thick) copper wire kept in place by a piece of modeling

clay so that their ends are  $\frac{1}{4}$ " apart, can be used as supports. The children have found in the last study that Nichrome wire gets hot when used to short circuit a battery. Now have them attach one short piece of #32 (thin) Nichrome wire to the supports, as shown below.



## **NEW MATERIALS FOR MAKING A BULB**

for each group —

- 1 two-inch ball modeling clay
- 2 eight-inch pieces #20 copper wire
- 1 three-inch piece #32 Nichrome wire
- Various lengths of other wire

### **Possible Discussion Questions**

Will the Nichrome wire glow with one battery attached?

What happens when more than one battery is used?

Will the thick copper wire glow?

What happens if a longer piece of wire is put in the gap?

Will the bulb light if the support wires cross?

Will any other type of wire glow? How much wire do you use?

How many batteries does it take to light this other wire?



# MYSTERY BOXES — HIDDEN CIRCUITS

## Before Starting to Teach

### Materials you will need

- Enough boxes to make one Mystery Box for each group
- Several bulbs in holders
- Several "D" batteries in holders
- Several pieces of each type of wire
- 2 Fahnestock clips for each box
- 2 paper fasteners for each box
- 1 roll cellophane tape

Make up one Mystery Box for each group in your class according to the directions that follow.

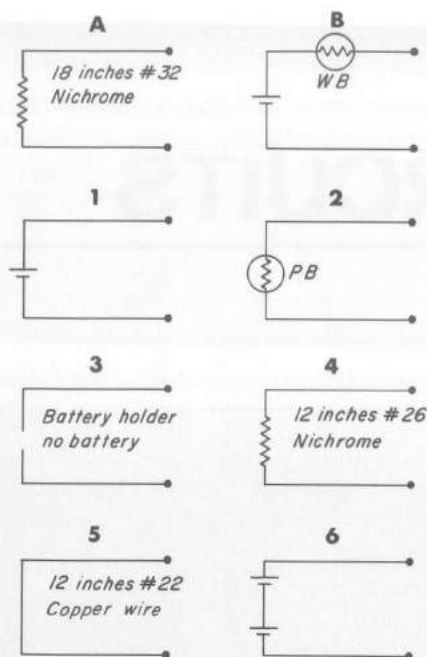
Inside each Mystery Box various circuits are connected under the prongs of two paper fasteners by means of a Fahnestock clip under each fastener. The heads of the two paper fasteners are all that can be seen on the outside of the box.

The materials on the inside of the box can be taped to the lid and connected to the Fahnestock clips. They should be taped securely to prevent rattling and to insure that the wires will not pull loose from the Fahnestock clips. Tape a "D" battery inside each box so that children cannot guess by weight alone.





Examples of materials that may be connected inside the boxes are shown below. A different circuit is needed for each Mystery Box. Other circuits may be added later.



## Introducing Mystery Boxes in the Classroom

This activity draws upon almost everything the children are likely to have done so far. Inside each mystery box is part of a circuit. The problem is to complete the circuit on the outside in such a way as to be able to tell what is inside.

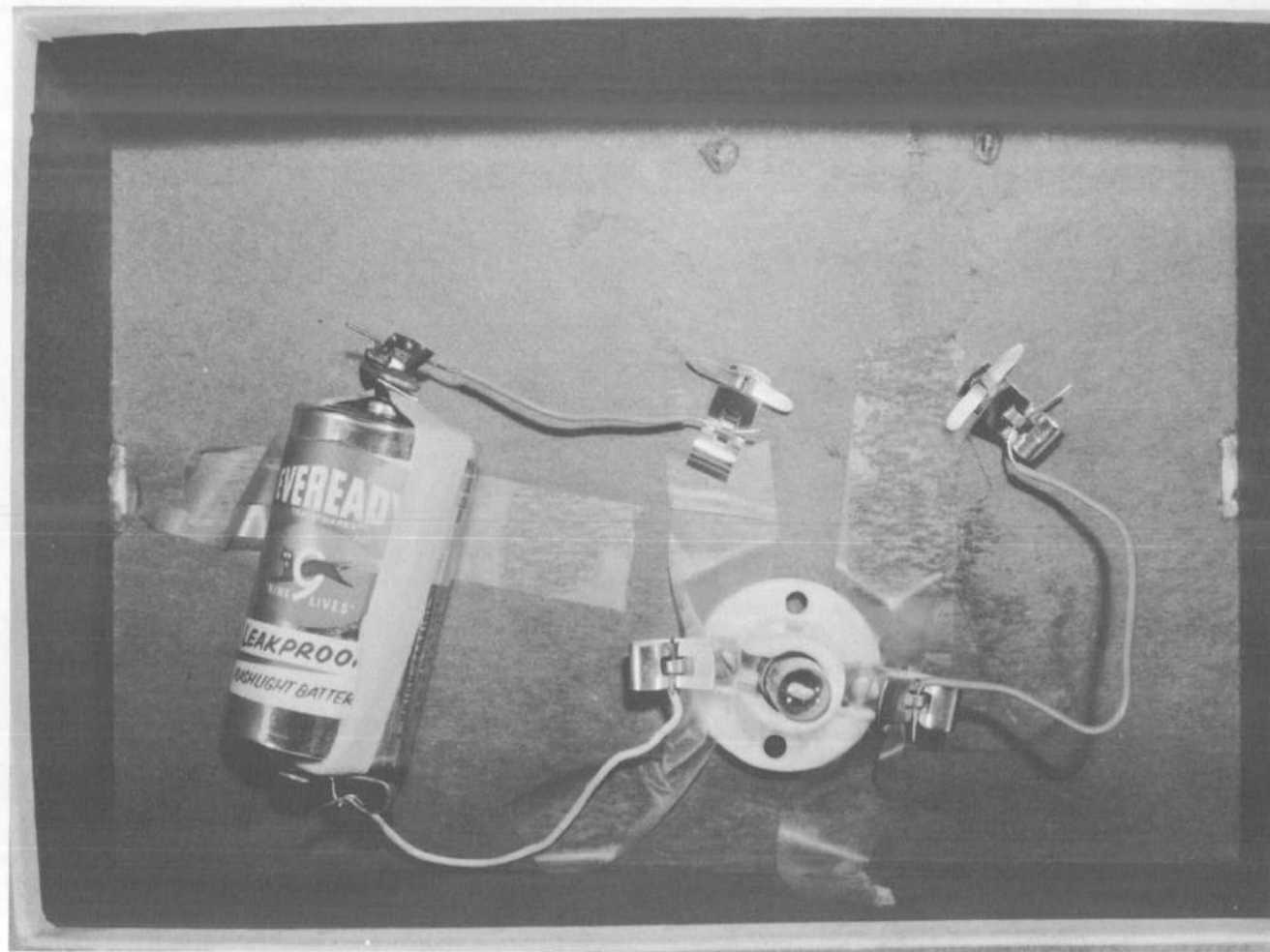
The children will probably need some help in thinking of the sorts of things they can do, and especially in realizing that they may need to do several different operations with one box before they can come to a definite conclusion. Perhaps you will want to do Boxes A and B with the whole class as an introduction. Encourage and follow the suggestions of the children in decid-

ing what tests to make. When they start making guesses about what is inside, they may propose several which are different, but potentially valid. Someone may suggest that Box A contains a PB, or a long piece of thick Nichrome wire, or a very long piece of thin copper wire. Any of these guesses might well be true, even though none of them actually is. The realization that many different things may have equivalent results is one of the chief benefits of the study. The children should have some idea of how to proceed since

they have made similar predictions using testers with *Octopus Boxes*, and in *Testing Pathways*. (See *Special Comments*, page 51, for ways to test the Mystery Boxes.)

Each group can experiment together on all the different boxes. Collect the guesses on a chart on the blackboard, and discuss them before and after the boxes are opened.

This game may be continued, if interest is high, by having children construct Mystery Boxes to challenge each other.



## NEW MATERIALS FOR MYSTERY BOXES

7 to 10 shoe boxes, or other small cardboard boxes that can be sealed

1 roll cellophane tape

2 paper fasteners and 2 Fahnestock clips for each box

Batteries, bulbs and wires used in Circuit I

## Activities Children May Try

Connect circuits they make to the paper fastener heads on the top of each box to figure out what is inside.

Draw a circuit diagram for the circuit (tester) outside the box.

Draw a circuit diagram for the circuit they think is inside the box.

## Possible Discussion Questions

You may want to wait until each member of the class has written down his or her prediction as to the circuit in each mystery box to have a discussion of these predictions. You can take each box in turn and ask the children for their circuit guesses and

their reasons for each choice. Let each circuit be discussed and thought about. Open the boxes for verification.

## Special Comments

1. Some of the tests that prove useful in making predictions are (1) observing the brightness of a PB connected to the two fasteners, (2) observing the brightness of a WB connected to the two fasteners, (3) observing the brightness of a PB when the bulb and a battery are connected to the two fasteners and (4) observing the brightness of a WB when the bulb and a battery are connected to the two fasteners. In addition, other tests may be made if desired. For example, the battery in tests 3 and 4 above may be reversed to see what happens, or two batteries may be used.

2. Do not be surprised if two potentially valid circuits are predicted for one box. Even though one is not the circuit to be found inside the box the data collected by the student will show that it would have produced the same result, at least up to a certain point. For example, a PB inside the box might be misinterpreted as a two-foot piece of #26 Nichrome wire. Eight batteries would have to be

attached to the paper fasteners of the box to show that there must have been a PB in the box, since this test produces no reaction from the tester, indicating that the eight batteries have blown out the PB.

3. Comparison circuits can be made in advance to be checked with the one inside the box when it is opened. This procedure has the advantage of proving on an analogous circuit that the child's prediction works before the box is opened.

**NOTE:** By now, some classes, especially in grades 6 and 7, will have explored some of the material in *Circuits II*, as it is closely related to the ideas in *Circuits I*. Read *Circuits II* briefly to see how that material might apply to your classroom.

You may use *Circuits II* now, and leave *Circuits and Magnets* until last, or you may next enjoy the new materials and explorations of *Circuits and Magnets*. If you go on to *Circuits II* you will have to omit those areas dealing with the use of galvanometers, which depend on having done *Circuits and Magnets* first. *Circuits and Magnets* depends only on *Circuits I* as a prerequisite.

