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Overcoming student preconceptions about simple series circuits: promoting conceptual change with text manipulations and a microcomputer simulation

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Overcoming student preconceptions about simple series circuits: Promoting conceptual change with text manipulations and a microcomputer simulation

by

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GENERAL INTRODUCTION

Most students encountering a science topic in an educational setting already have informal ideas that have been developed through everyday experience with the subject (Champagne, Gunstone & Klopfer, 1985). These informal ideas in science learning have been called such things as "misconceptions" (Fredette & Clement, 1981), "naive conceptions" (Champagne, Gunstone & Klopfer, 1983), "children's science" (Osborne, 1981), "alternative frameworks" (Driver & Easley, 1978), "alternative conceptions" (Zeitsman & Hewson, 1986), and "preconceptions" (Ausubel, Novak & Hanesian, 1978). Although the term "misconception" is the most prevalent in the literature, the word seems to carry an error connotation. Not all informal ideas that students have are erroneous, and those that are sometimes provide "creative constructions which are useful first-order theories in the student's daily life" (Fredette & Clement, 1981, p. 280). Therefore, the word "preconceptions" has been chosen to represent those informal ideas. These preconceptions are quite widespread among students in many areas of science, and they also are very resistant to change. Preconceptions affect the students' subsequent learning (Nussbaum & Novick, 1982a; Driver & Easley, 1978); Ausubel, Novak and Hanesian (1978) point out that "unlearning of preconceptions might prove to be the most determinative single factor in the acquisition and retention of subject-matter knowledge" (p. 372).

In general, preconceptions refer to the previously developed ideas and beliefs that learners bring to their formal study of science. Over the past ten years, researchers have documented students' previously existing conceptions in many diverse areas including light and vision (Anderson & Smith, 1986), the human circulatory system (Arnaudin & Mintzes, 1986), photosynthesis (Roth, 1985), air and gasses (Nussbaum & Novick, 1982b; Sere, 1986), mechanics (Clement, 1987), and electric circuits (Fredette & Lochhead, 1980; Shipstone, 1988). Students observe and learn about each of these areas of study long before they receive formal training on the subject. For this reason, students develop ideas and beliefs over years of casual observation of the scientific phenomenon involved, and such ideas often are not in agreement with the scientific theory (Cohen, Eylon, & Ganiel, 1983; Driver & Easley, 1978). Although the students' beliefs may be in direct conflict with accepted scientific theory, Driver and Easley (1978) state that many students hold on to their incorrect preconceptions tenaciously. The authors suggest that "in learning about the physical world, alternative interpretations seem to be the product of pupils' imaginative efforts to explain events and abstract communalities they see between them" (p. 62). Nussbaum and Novick (1982a) observe that preconceptions are "not a matter of 'not understanding' but of 'understanding differently'..." (p. 184).

In discussing physics preconceptions specifically, Fredette and Clement (1981) characterize them as "concepts or ideas which, from the point of view of the average professional physicist, lead to unacceptable solutions or answers to questions or problems in the context of a course" (p. 280). As stated previously, these preconceptions are not always useless or undesirable, yet, because they might be incorrect, they also can conflict with the more formal theory that is being taught.

Schema Theory and Science Learning

To understand how preconceptions affect the student, one must first understand something about schema theory. Norman (1982) describes schemas as "organized packets of knowledge gathered together to represent single units of self-contained knowledge" (p. 54). Norman (1982) states that schemas may contain both knowledge and rules for using knowledge. The rules state relationships among otherwise isolated facts, creating a structure that is useful in explaining a person's view of the world. A person's schema for an electric circuit might contain information describing the flow of electricity, the physical characteristics of a battery, the brightness of light bulbs, and series or parallel connections of the electrical components. This information is tied together by relationships among each of the facts. For example, the flow of electricity and the brightness of bulbs might be related by a rule that states that the bulb will light when an electric current passes through it. In addition, the electric circuit schema might contain references to other schemas describing electricity in general, everyday occurrences of electric circuits, the functions of power sources, switches, resistors, and so on. Schemas can be specific (the schema for the circuit in a person's living room) or general (the schema for a typical living room circuit, related to, but different from the specific schema for the person's living room circuit).

The general schemas might be considered to be models or prototypes of the real thing. For example, a person's model or general schema for a typical living room circuit might consist of one or more wall plugs (two at each outlet) placed around the room about one foot above the floor. In this person's general schema, the wall plugs are active and provide electricity to anything that is plugged into them. The person's schema might also state that the living room ceiling lights are on a circuit also, but one that is separate from the wall plugs. In other words, this living room circuit description is a typical scenario, and until the person receives information to the contrary, she will refer to this circuit schema whenever something needs to be plugged in, even if she is in an unfamiliar living room.

General schemas are useful in most instances, but also can influence a person's perception of reality. The specific schemas do not always follow the rules of the general schema, and unless a person has learned about the specific schema, the differences may cause problems for him. Consider the example of a person in his friend's house helping clean up the living room. He needs to plug in the vacuum cleaner, and, using the living room circuit schema described above, he looks around the room and finds a likely outlet. Upon plugging in the vacuum and flipping the switch, he is surprised to find that the vacuum does not turn on. At that point, he checks to make sure the plug is securely in the wall and tries the vacuum again. The vacuum still does not work. He decides that either the vacuum or the wall outlet is faulty and looks for another outlet. Not finding one, he asks his friend if she has had a problem with her vacuum recently. Receiving a negative reply, he asks about the wall outlet and is told that it is controlled by a switch near the door. When the switch is turned on, the vacuum works perfectly.

In the example above, the person's general schema of a living room circuit was helpful in finding a place to plug in the vacuum. The schema was incomplete, however, because it did not contain information about wall sockets controlled by switches. This caused the person's perception of reality to be influenced to the extent that he believed that either the vacuum or the wall socket was faulty. After the person had the experience with the wall switch, this new knowledge most likely was added to his schema of living room circuits. Adding to a schema in this manner is an important part of each person's learning process.

In his description of the learning process, Piaget (1964) proposes two phases that can occur during a student's schema modification. These phases are:

1. Assimilation. During assimilation, students tend to interpret external events directly into their own existing schemas and focus only on those aspects of events that are relevant to their schemas. According to Piaget (1964), students cannot view external events from perspectives other than their own. This was the case in the example above, when the person had difficulty making the vacuum work by relying on his incomplete existing schema.
2. Accommodation. During the accommodation phase, students are in a state of disequilibrium because their existing schema has been challenged by disconfirming evidence or opposing viewpoints. If the evidence is strong enough, it motivates the students to search for a more adequate schema. They must replace or reorganize their schemas so that they can defend them properly. As noted in the example above, the person's existing schema for the living room circuit was challenged and eventually modified when new evidence about wall switches was presented.

Norman (1982) expands on Piaget's (1964) ideas by dividing the accommodation phase into two separate modes, structuring and tuning. Thus, Norman's (1982) three learning modes are:

1. Accretion. This is the addition of new knowledge to existing memory schemas and is directly related to Piaget's (1964) assimilation.
2. Structuring. This is the formation of new conceptual structures. The existing schemas no longer suffice and new schemas must be formed. Norman (1982) states that this mode occurs infrequently and usually entails great effort and struggle. More evidence of the difficulty of this mode is presented below.
3. Tuning. Tuning is making fine adjustments of knowledge to a task; using appropriate knowledge and schemas to go from the general to the specific. This mode is used to gain expertise in a certain area by adjusting existing knowledge to the specific task at hand.

In an educational setting, schemas play an important role. If new knowledge can be linked appropriately to a person's existing schema (or prior knowledge), this linking can assist greatly in understanding what is being taught (Anderson & Smith, 1984; Anderson, Spiro & Anderson, 1978). Unfortunately, when a student begins her studies of science, it is often the case that her preexisting knowledge structures, or schemas, are inconsistent with what she has to learn (Cohen, Eylon, & Ganiel, 1983; Driver & Easley, 1978). These inconsistent schemas, called preconceptions here, are developed in most children before they study science formally and help children to understand the world around them. To the student, these preexisting schemas are not incorrect conceptions, but valuable tools that may have helped her cope with physical reality for several years.

A number of studies have demonstrated that students are unwilling to give up their preconceptions easily. For example, Champagne, Klopfer and Anderson (1980) surveyed beginning college physics students to determine their belief in the proposition, "Heavier objects fall faster than lighter objects." They found that 80% of those surveyed believed that (all other things being equal) heavier objects fall significantly faster than lighter ones. The results were particularly surprising to Champagne, Klopfer & Anderson (1980) because 70% of the students in the sample had studied high school physics--some for two years. Furthermore, students in the sample who had studied high school physics did not score significantly better than those who had not.

In a further demonstration of the persistence of the heavier-faster belief mentioned above, Champagne, Gunstone, & Klopfer (1985) had a number of junior high school students predict how fast a heavy and light object would fall. The objects were blocks of the same dimensions--the heavier one made of aluminum and the lighter one made of plastic. Many of the students predicted that the heavier block would fall faster, and justified their predictions by stating that Galileo proved the general principle that heavier objects fall faster. When the blocks were dropped and fell at the same rate, the students were surprised, but tried to explain away the evidence by arguing that the experiment was flawed. Some insisted that the blocks really weighed the same, and others thought that the blocks should be dropped from a greater height in order to detect the difference in speeds.

In another example of persistent preconceptions, diSessa (1982) examined the beliefs of sixth grade students about force and motion by using a computer simulation called the "dynaturtle". The dynaturtle could be maneuvered on the computer screen by giving it "kicks" in the direction that the head was pointing. The head could be turned either right or left in 30° increments. The dynaturtle operated in a frictionless environment and obeyed Newton's laws of motion. Therefore, any "kick" given perpendicular to the dynaturtle's direction of travel would send it off at an angle of something other than 90°. In other words, students found that they could not make the dynaturtle turn directly right or left simply by kicking it in either of those directions. This finding surprised almost all of them, yet, rather than accept that they had incorrect preconceptions about force and motion, the students complained vigorously that the simulation was programmed incorrectly.

Fredette and Clement (1981) found persistent preconceptions about electric circuits even among university freshman studying engineering. The authors were interested in discovering how many of the students held the "short-circuit preconception", made evident when students seem to disregard a wire connecting the two leads coming from the battery. The wire in question causes a short in the circuit, therefore, not allowing current to pass through the electrical components. It is important to note that before participating in the experiment, each student had been exposed via lecture, laboratory, and homework questions to the role which resistors and capacitors play in electric circuits. During individual interviews, 15 students were shown a drawing of an electric circuit containing a battery, a resistor and a capacitor. The components were connected in such a manner as to cause a short circuit. When the students were asked to convert the drawings to electrical schematics, five of the students were unable to interpret the circuit diagram correctly, leaving out of their drawing the essential wire that caused the short circuit. Thus, over 30% of the students still held the short-circuit preconception, even after they had taken formal college courses on electricity.

In a study of children's understanding of electricity (described in more detail below), Shipstone (1984) found that over one-fourth of the students who had studied physics on the high school level still believed that current was used up in the components of an electric circuit. In another study reported in the same article, Shipstone (1984) showed that even students studying to become physics teachers had difficulty giving up some of their preconceptions of electric circuits. Of the 18 prospective teachers studied, seven of them still believed that information about a change of state of an electrical component is transmitted only in the direction in which the current is flowing.

In an attempt to learn new information, then, the student may not be willing to abandon the old schema so readily. Instead he may be using his preconceptions to interpret the new information, quite likely giving it a rational and even a sophisticated meaning which differs from or conflicts with the meaning intended by his teacher (Nussbaum, 1979; Nussbaum & Novick, 1982b). A Peanuts cartoon used in Champagne (1985), illustrates this point very well. In the cartoon, Sally is writing definitions of metric measurements, with Charlie Brown looking on. In the first three panels, she writes "Ten milligrams equals one centigram. Ten decigrams equals one gram. Ten grams equals one grampa." In the last panel, Sally has stopped writing, and Charlie Brown says, "Keep going. I can hardly wait to see what comes next."

As Champagne (1985) points out, "learning is more a process of refining existing knowledge than the simple accretion of new knowledge." In fact, Gunstone, Champagne and Klopfer (1981) and Champagne and Klopfer (1982) demonstrated that students' schemas influence (1) their understanding of science texts and lectures, (2) their observations of physics experiments; and, (3) their interpretations of the observations.

Electric Circuits

In dealing with electric circuits specifically, Shipstone (1984) studied a group of secondary school students who were in physics courses in the United Kingdom. All of the students included in the research had studied electric circuits in the year in which they were tested. The students were given two diagrams of a simple direct current circuit and asked to respond to questions about the circuits and their components. From the responses to the questions, Shipstone (1984) was able to distinguish four models of current flow held by the students, one of which was the correct scientific model.

Osborne (1983) found similar models present in California elementary students who had little or no formal teaching in electric current. The 22 students in the California study were 9-12 years old, of average or above average intelligence (but none were identified as gifted), were native born middle class background and were willing to express their opinions. Each of the students was given a battery, a light bulb and two wires. At that point, they were asked to try to make the light bulb glow. After their initial attempts, whether successful or not, the students were given an "almost completed" circuit, consisting of a board containing a battery and a bulb, each with two wires connected properly. The wires had bare ends and were placed so that the ends could be easily connected together to allow the bulb to light. The students who were unsuccessful in their first attempt at lighting the bulb were told to use the circuit on the board as a model to build their own. Finally, each student was shown a set of diagrams modelling possible ways current can flow in a circuit. The students stated which one they believed was the true model.

Taking Shipstone's (1984) and Osborne's (1983) results together, the following five models of children's ideas on electric current seem to be prevalent:

1. <u>Sink model</u>. In this model, only one connection is necessary between the battery and the component. Since there is no return path to the battery, the current is completely used up within the component. This model is most prevalent among novices (Fredette & Lochhead, 1980),
2. <u>Clashing currents model</u>. In this model, current leaves the battery at both terminals, meets (clashes) at the circuit elements, and is used up within them.
3. <u>Unidirectional without conservation model</u>. Here, current travels in one direction around the circuit and is shared among the components. The current becomes gradually weakened as it goes, so that later components receive less. Less (or no) current exists in the return path to the battery. This model is also called time dependent reasoning by Riley, et al. (1981), and sequential reasoning by Closset (1983). This model and the sink model (#1 above) have been included in a more general "source-consumer" model by Maichle (1981) and Shipstone (1988). In the source-consumer model, something is stored in the battery, travels from there to an electrical component, such as a lamp, and is used up to make the lamp light.

4. Unidirectional with sharing model. Current travels in one direction around the circuit, is shared equally among the components, but is completely used up in the circuit. In this model, equal lamps glow with the same brightness, but no current returns to the battery.
5. Unidirectional with conservation (the scientific model). Equal current exists in all parts of the circuit, including the wires connected to the battery.

Several studies have shown that as students grow older, the number of the preconceptions of electric current they hold tends to decrease, but many preconceptions are still widespread even after formal training in electricity. In the study by Shipstone (1984), described above, almost 30% of the students at the high school level still held to model 3 above (unidirectional without conservation). Fredette and Lochhead (1980) found that over 30% of college-level engineering students thought a light bulb connected using the sink model (number 1 above) would light. This number is not much better than the number of elementary school students (over 50%) who held the sink model in a study by Osborne (1983).

Dupin and Johsua (1987) describe one way in which some of the above preconceptions in the understanding of electric circuits might come about. The authors state that since the students have no way of seeing what is going on in a wire they might use their previous experience with fluids to imagine or create in their minds the "metaphor of moving fluid". As a fluid flowing through a pipe encounters something that uses it (a faucet for example), the fluid flows out of the faucet and thus does not return to its source, even if the pipe is circular. The authors contend that the students might extend this metaphor to an electric circuit and thus conceptualize that current is used up in a light bulb in the same way that the water is used up. With this idea in mind, the students think that the current cannot return to its source (the battery). One can see that the use of the fluid metaphor can easily result in the student maintaining the sink model or the unidirectional without conservation model.

The Role of Declarative Knowledge

In addition to conflicts caused by preconceptions, the understanding of an electric circuit could be inhibited by the lack of adequate prior knowledge of the electrical components or their function. Champagne, Klopfer, and Chaiklin (1984) describe such prior knowledge as declarative knowledge about the concepts involved in physical science learning situations. In the case of electricity, declarative knowledge consists of relationships between the principles and procedures of circuits and their components, and the application of these principles and procedures to specific situations. Champagne et al. (1984) argue that, in general, physical science principles are applicable to a wide range of situations, but that the application of those principles varies as the situations vary. Consider, for example, the light bulb found in a flashlight. The principle used in making the light bulb light is that current must travel from the battery to the bulb, pass through the bulb and then return to the battery. In the specific case of the flashlight bulb, the base is used both as an electrical connection and a way to secure the bulb into place. Ding and Andre (1988) and Shipstone (1988) both point out that this declarative knowledge is not taught explicitly, so that many students only perceive the base as serving the latter function. Since the students do not realize that there are two points of contact on the bulb, this lack of knowledge could inhibit the retrieval of the proper schema for electric current flow. Thus, even if the students possessed the correct scientific model of an electric circuit, they would be unable to apply that model because of the lack of declarative knowledge about the light bulb. Shipstone (1988) emphasizes that if students are to use this type of bulb for experiments, its construction must be explained early on, noting that over 90% of the students using a festoon bulb (a linear bulb with two distinct contacts) recognized correctly the connections necessary to make the bulb light.

Assisting Conceptual Change

Effective instruction in science, thus, involves developing effective methods to help overcome these incorrect preconceptions, and providing for the development of relevant schemas. Posner, Strike, Hewson and Gertzog (1982) developed a model of conceptual change based on Piaget's (1964) assimilation and accommodation phases mentioned earlier. Posner et al. (1982) approach learning from the aspect of a change in a student's conceptions rather than simply adding new knowledge to what is already there. They suggest that four conditions must exist in order for a student to acquire a new schema, especially if the new schema conflicts with the student's preexisting schema. For instruction to overcome a preconception, it must address each of the following explicitly:

1. The student must become dissatisfied with his current structure or conception. He must realize that what he believes somehow does not fit reality.
2. The new conception must be understandable to the student, even though he might not believe it at first. For example, in the "heavier-faster" experiment described earlier, the students were able to understand what happened when the two blocks were dropped, but many did not believe that the blocks fell at the same rate.
3. The new conception must be plausible; potentially true and believable. Using the "heavier-faster" experiment as an example again, the student must be able see that it is possible for the two blocks to fall at the same speed.
4. The new conception must be fruitful. There must be a convincing reason for the student to abandon his old ideas for the new one. Sometimes getting a good grade is reason enough to abandon the old ideas, but most students need to see some practical application of the new conception before they are willing to adopt the new schema.

Using Revised Text

Roth (1985) built on Posner et al.'s (1982) ideas, and using the four steps just described, developed text that discussed photosynthesis and at the same time explicitly addressed students' preconceptions. This text and two other commercially available texts were used in a study of 18 middle school students. The students were given a pretest and then randomly assigned to one of three groups, with each group of students reading a different text. The reading was done over a period of three days, after which all three groups were given the same posttest. To help her determine each student's reading strategy, Roth also interviewed the students individually after each day's reading. Their reading strategies were grouped into the following six categories:

1. Overreliance on prior real-world knowledge.
2. Overreliance on isolated words in the text.
3. Overreliance on facts in the text--using an additive notion of learning, usually just memorizing facts.
4. Separating disciplinary knowledge and real-world knowledge as two distinct equally sensible worlds of knowledge.
5. Overreliance on prior knowledge to make "sense" of the disciplinary view of the text.
6. Using text knowledge to change real-world ideas (preconceptions). This is the proper strategy.

During the experiment, those students using the revised text not only showed a significant change in their reading strategy, but also in their conceptions of photosynthesis. Based on the posttest scores, these same students also mastered a significantly greater number of scientific conceptions.

Hands-on Experience

Fredette and Clement (1981) and Shipstone (1988) both suggest an application phase of specifically directed, hands-on experience with physical objects as the best method to bring about change in a schema. Osborne (1983) describes just such an experiment where each student tried to connect a light bulb first, and subsequently, the instructor guided the unsuccessful students through an "almost complete circuit" (bulb and battery connected to wires, with the wires from each ready to be connected together). Finally, the students were asked to describe their ideas of the current flow and an ammeter was used to test their ideas.

The students using this method showed a significant change in their conception of current in an electric circuit.

Computer Simulations

As computer simulations have become more popular in the classroom over the past few years, the simulations have proven to be safe, economical, and perhaps most importantly, have shown the ability to stretch or compress time according to the student's needs. Several researchers, including Hartley (1988), have stressed the importance of being able to use the simulations to simplify the design of a physical system by "stripping off extraneous or elaborate features while still retaining validity. Hence, students are able to focus on the main attributes of the model" (p 60).

An example of such a simulation is reported by Hooper (1986), who investigated a simulation of computer memory operations. In this simulation, students performed specified tasks on the model as an initial experience in a beginning programming course. The simulation was designed to operate just as a generalized version of computer memory does, but with a much slower speed (of course) and a graphic display giving the user a "window" into each memory cell's contents. The use of the simulation helped students concentrate only on computer memory operations, without other programming variables involved. Hooper (1986) reported that students using the simulation employed more sophisticated algorithms during their programming than did students who were not exposed to the model.

Other computer simulations that help simplify real world tasks are the popular flight simulators available for most microcomputers today. Most of the simulators offer the user various levels of sophistication, starting at a beginning mode, where the only requirement is to use the stick to steer. In the beginning mode, the student is free to concentrate on just one aspect of aircraft flight. From there, the levels of difficulty increase until, in the "reality" mode, the pilot must send and receive radio messages and respond to changes in the weather and flight patterns of other aircraft.

In addition to the advantages of simplicity, time, expense and safety, simulations offer the learner more control over the model, allowing her to choose the most appropriate input parameter values for each experiment. This gives the learner the opportunity to try more examples and experiment more freely with the simulated environment than she would be able to do with the physical equipment.

Rivers and Vockell (1987) support the fact that computer simulations allow students to solve more problems than they can in traditional lab settings. In their study, several science simulations were used by high school students to supplement their science textbooks. The students showing the best overall improvement in problem-solving ability were those using guided simulations, pointing to the fact that the teacher, the text and/or the simulation should help the student progress step by step through the learning process.

The ability of the student to use the simulation as a tool to create many examples could prove to be the real power of a simulation in helping to overcome preconceptions. White and Frederiksen (1987) state explicitly that students need many examples presented in the proper sequence in order to break down the barriers of previous preconceptions. In a promising study, White and Frederiksen (1987) have shown the value of using examples and guided problem solving in their intelligent simulation. This simulation, called QUEST, helps students solve problems in circuit building and fault finding by providing causal qualitative explanations. White and Frederiksen (1987) contend that students need training in the qualitative aspects of a circuit (e.g., Will the light bulb light?) before they can be expected to apply properly the quantitative formulas concerning voltage, resistance and current. In QUEST, each student's level of instruction is determined by his previous performance, and then he is guided through increasingly sophisticated problems and examples as he masters the previous ones. QUEST has knowledge of both functional and structural properties of the circuit under consideration; therefore, as a change is introduced into the circuit, QUEST changes the state of each component and works out a conductive path and current flow. Explanations are always available for each action that is taken and the causal links are highlighted during the explanation.

In a preliminary study using QUEST, White and Frederiksen (1987) used seven high school students with no formal instruction in circuit theory as subjects. The students were given a set of circuit problems as a pretest, and asked to explain the behavior of each circuit as the states of devices were manipulated. All of the students exhibited serious preconceptions about circuit behavior and lacked key electrical concepts. None of them had any experience with troubleshooting. After five hours (one hour a day for five days) of working with QUEST on an individual basis, all seven students were able to make accurate model-based predictions about circuit behavior and could troubleshoot correctly in series circuits.

Zietsman and Hewson (1986) produced a microcomputer simulation on velocity that was used successfully to correct students' preconceptions. Their simulation included a diagnostic portion to attempt to determine whether the student held a common preconception in this domain, and another portion that used Posner et al.'s (1982) conceptual change strategy to help the student acquire the new schema.

In order for simulations to be the most effective, the student must be able to use them at the proper time in her training. According to Thomas and Boysen (1985), computer based instruction can be used effectively to help lay a foundation for proper student schemas prior to formal classroom instruction on a concept. In the authors' view, a model of the concept should be introduced, usually by means of a computer simulation, and the student should be guided through sets of problems with the specific goals of the formal instruction in mind. All this is done with the simulation before the student receives the formal classroom instruction. This "pre-instruction" helps the student gain an intuitive feel for the concept, thus building a cognitive framework for the formal instruction. Thomas and Boysen (1985) emphasize that this kind of simulation is rarely "stand alone" and should be used as a foundation of the instruction to follow.

In a different but related application of the computer in science teaching, Linn (1986) created computerized "lab partners", making record keeping and graphing easy and automatic. With the computer attached to the physical experiment, students were able to see temperature being graphed as the experiment proceeded. Having the computer take care of the record-keeping helped the students see the change in temperature as it was happening by focusing the students' attention on the physical activity rather than the book work. As with a good simulation, this program took away the tedious part of activity, keeping the students' interest on the experiment itself.

Summary

Overcoming incorrect science preconceptions is a formidable task, often requiring students to completely change the beliefs they have held for many years. Within the last few years, specially designed text has been successful in some areas in overcoming these preconceptions. Computer simulations are also showing great promise in science teaching by adding economy and ease of use to providing examples of physical realities. In order to be successful, the use of both of these media must be carefully planned to target specific preconceptions. The study reported herein combines text and a computer simulation in an attempt to capitalize on the advantages of both media.

Explanation of Dissertation Format

This dissertation is written in a format that allows for the inclusion of a paper to be submitted to a scholarly journal. This is done in lieu of the chapter format, but includes the same content. Following is the paper to be submitted.

OVERCOMING STUDENT PRECONCEPTIONS ABOUT SIMPLE SERIES CIRCUITS: PROMOTING CONCEPTUAL CHANGE WITH TEXT MANIPULATIONS AND A MICROCOMPUTER SIMULATION

INTRODUCTION

Most students encountering a science topic in an educational setting already have informal ideas that have been developed through everyday experience with the subject (Champagne, Gunstone & Klopfer, 1985). These informal ideas in science learning have been called such things as "misconceptions" (Fredette & Clement, 1981), "naive conceptions" (Champagne, Gunstone & Klopfer, 1983), "children's science" (Osborne, 1981), "alternative frameworks" (Driver & Easley, 1978), "alternative conceptions" (Zeitsman & Hewson, 1986), and "preconceptions" (Ausubel, Novak & Hanesian, 1978). Although the term "misconception" is the most prevalent in the literature, the word seems to carry an error connotation. Not all informal ideas that students have are erroneous, and those that are, sometimes provide "creative constructions which are useful first-order theories in the student's daily life" (Fredette & Clement, 1981, p. 280). Therefore, the word "preconceptions" has been chosen to represent those informal ideas. These preconceptions are quite widespread among students in many areas of science, and they also are very resistant to change. Preconceptions affect the students' subsequent learning (Nussbaum & Novick, 1982a; Driver & Easley, 1978); Ausubel, Novak and Hanesian (1978) point out that "unlearning of preconceptions might prove to be the most determinative single factor in the acquisition and retention of subject-matter knowledge" (p. 372).

In general, preconceptions refer to the previously developed ideas and beliefs that learners bring to their formal study of science. Over the past ten years, researchers have documented students' previously existing conceptions in many diverse areas including light and vision (Anderson & Smith, 1986), the human circulatory system (Arnaudin & Mintzes, 1986), photosynthesis (Roth, 1985), air and gasses (Nussbaum & Novick, 1982b; Sere, 1986), mechanics (Clement, 1987), and electric circuits (Fredette & Lochhead, 1980; Shipstone, 1988). Students observe and learn about each of these areas of study long before they receive formal training on the subject. For this reason, students develop ideas and beliefs over years of casual observation of the scientific phenomenon involved, and such ideas often are not in agreement with the scientific theory (Cohen, Eylon, & Ganiel, 1983; Driver & Easley, 1978). Although the students' beliefs may be in direct conflict with accepted scientific theory, Driver and Easley (1978) state that many students hold on to their incorrect preconceptions tenaciously. The authors suggest that "in learning about the physical world, alternative interpretations seem to be the product of pupils' imaginative efforts to explain events and abstract communalitdes they see between them" (p. 62). Nussbaum and Novick (1982a) observe that preconceptions are "not a matter of 'not understanding' but of 'understanding differently'..." (p. 184).

Schema Theory and Science Learning

To understand how preconceptions affect the student, one must first understand something about schema theory. Norman (1982) describes schemas as "organized packets of knowledge gathered together to represent single units of self-contained knowledge" (p. 54). Norman (1982) states that schemas may contain both knowledge and rules for using knowledge. The rules state relationships among otherwise isolated facts, creating a structure that is useful in explaining a person's view of the world. A person's schema for an electric circuit might contain information describing the flow of electricity, the physical characteristics of a battery, the brightness of light bulbs, and series or parallel connections of the electrical components. This information is tied together by relationships among each of the facts. For example, the flow of electricity and the brightness of bulbs might be related by a rule that states that the bulb will light when an electric current passes through it. In addition, the electric circuit schema might contain references to other schemas describing electricity in general, everyday occurrences of electric circuits, the functions of power sources, switches, resistors, and so on. Schemas can be specific (the schema for the circuit in a person's living room) or general (the schema for a typical living room circuit, related to, but different from the specific schema for the person's living room circuit).

The general schemas might be considered to be models or prototypes of the real thing. For example, a person's model or general schema for a typical living room circuit might consist of one or more wall plugs (two at each outlet) placed around the room about one foot above the floor. In this person's general schema, the wall plugs are active and provide electricity to anything that is plugged into them. The person's schema might also state that the living room ceiling lights are on a circuit also, but one that is separate from the wall plugs. In other words, this living room circuit description is a typical scenario, and until the person receives information to the contrary, she will refer to this circuit schema whenever something needs to be plugged in, even if she is in an unfamiliar living room.

General schemas are useful in most instances, but also can influence a person's perception of reality. The specific schemas do not always follow the rules of the general schema, and unless a person has learned about the specific schema, the differences may cause problems for him. The general schema of a living room circuit might be helpful in finding a place to plug in a lamp, but may cause problems if a wall plug does not work unless a switch is turned on. If a person does not know about the wall switch, it could cause his perception of reality to be influenced to the extent that he believes that the lamp is faulty when it does not turn on. When the person finds out about the wall switch, this new knowledge most likely will be added to his schema of living room circuits. Adding to a schema in this manner is an important part of each person's learning process.

In his description of the learning process, Piaget (1964) proposes two phases that can occur during students' schema modification. These phases are assimilation or the interpretation of external events directly into the students' own existing schemas; and accommodation, the replacement or reorganization of the students' schemas so that they can defend them properly.

Norman (1982) expands on Piaget's (1964) ideas by dividing the accommodation phase into two separate modes, structuring and tuning. Thus, Norman's (1982) three learning modes are:

1. Accretion. This is the addition of new knowledge to existing memory schemas and is directly related to Piaget's (1964) assimilation.
2. Structuring. This is the formation of new conceptual structures. The existing schemas no longer suffice and new schemas must be formed. Norman (1982) states that this mode occurs infrequently and usually entails great effort and struggle. More evidence of the difficulty of this mode is presented below.
3. Tuning. Tuning is making fine adjustments of knowledge to a task; using appropriate knowledge and schemas to go from the general to the specific. This mode is used to gain expertise in a certain area by adjusting existing knowledge to the specific task at hand.

In an educational setting, schemas play an important role. If new knowledge can be linked appropriately to a person's existing schema (or prior knowledge), this linking can assist greatly in understanding what is being taught (Anderson & Smith, 1984; Anderson, Spiro & Anderson, 1978). Unfortunately, when a student begins her studies of science, it is often the case that her preexisting knowledge structures, or schemas, are inconsistent with what she has to learn (Cohen, Eylon, & Ganiel, 1983; Driver & Easley, 1978). These inconsistent schemas, called preconceptions here, are developed in most children before they study science formally and help children to understand the world around them. To the student, these preexisting schemas are not incorrect conceptions, but valuable tools that have helped her cope with physical reality for several years.

A number of studies have demonstrated that students are unwilling to give up their preconceptions easily. For example, Champagne, Klopfer and Anderson (1980) surveyed beginning college physics students to determine their belief in the proposition, "Heavier objects fall faster than lighter objects." They found that 80% of those surveyed believed that (all other things being equal) heavier objects fall significantly faster than lighter ones. The results were particularly surprising to Champagne, Klopfer and Anderson (1980) because 70% of the students in the sample had studied high school physics--some for two years.

In a further demonstration of the persistence of the heavier-faster belief mentioned above, Champagne, Gunstone, and Klopfer (1985) had a number of junior high school students predict how fast a heavy and light object would fall. Many of the students predicted that the heavier block would fall faster, and justified their predictions by stating that Galileo proved the general principle that heavier objects fall faster. When the blocks were dropped and fell at the same rate, the students were surprised, but tried to explain away the evidence by arguing that the experiment was flawed. Some insisted that the blocks really weighed the same, and others thought that the blocks should be dropped from a greater height in order to detect the difference in speeds.

In another example of persistent preconceptions, diSessa (1982) examined the beliefs of sixth grade students about force and motion by using a computer simulation called the "dynaturtle". The dynaturtle operated in a frictionless environment and could be maneuvered on the computer screen by giving it "kicks" in the direction that the head was pointing. Because the dynaturtle followed the laws of Newtonian physics, the students found that they could not make the dynaturtle turn directly right or left with one 90° kick. Instead of modifying what they believed, many students argued vigorously that the simulation was programmed incorrectly.

Fredette and Clement (1981) found persistent preconceptions about electric circuits even among university freshman studying engineering. The authors were interested in discovering how many of the students held the "short-circuit preconception", made evident when students seem to disregard a wire connecting the two leads coming from the battery. During individual interviews, students were asked to convert drawings of an electric circuit to electrical schematics. Over 30% of the students left out the shorting wire in their schematic, still holding to the short-circuit preconception, even after they had taken formal college courses on electricity.

In a study of children's understanding of electricity, Shipstone (1984) found that over one-fourth of the students who had studied physics on the high school level still believed that current was used up in the components of an electric circuit. In another study reported in the same article, Shipstone (1984) showed that even students studying to become physics teachers had difficulty giving up some of their preconceptions of electric circuits.

In an attempt to learn new information, then, a student may not be willing to abandon his old schema so readily. Instead he may be using his preconceptions to interpret the new information, quite likely giving it a rational and even a sophisticated meaning which differs from or conflicts with the meaning intended by his teacher (Nussbaum, 1979; Nussbaum & Novick, 1982b). A Peanuts cartoon used in Champagne (1985), illustrates this point very well. In the cartoon, Sally is writing definitions of metric measurements, with Charlie Brown looking on. In the first three panels, she writes "Ten milligrams equals one centigram. Ten decigrams equals one gram. Ten grams equals one grampa." In the last panel, Sally has stopped writing, and Charlie Brown says, "Keep going. I can hardly wait to see what comes next."

As Champagne (1985) points out, "learning is more a process of refining existing knowledge than the simple accretion of new knowledge." In fact, Gunstone, Champagne and Klopfer (1981) and Champagne and Klopfer (1982) demonstrated that students' schemas influence (1) their understanding of science texts and lectures, (2) their observations of physics experiments; and, (3) their interpretations of the observations.

Electric Circuits

In dealing with electric circuits specifically, Shipstone (1984) studied a group of secondary school students who were in physics courses in the United Kingdom. He was able to distinguish four models of current flow held by the students, one of which was the correct scientific model. Osborne (1983) found similar models present in California elementary students who had little or no formal teaching in electric current.

Taking Shipstone's (1984) and Osborne's (1983) results together, the following five models of children's ideas on electric current seem to be prevalent:

1. Sink model. In this model, only one connection is necessary between the battery and the component. Since there is no return path to the battery, the current is completely used up within the component. This model is most prevalent among novices (Fredette & Lochhead, 1980),
2. Clashing currents model. In this model, current leaves the battery at both terminals, meets (clashes) at the circuit elements, and is used up within them.
3. Unidirectional without conservation model. Here, current travels in one direction around the circuit and is shared among the components. The current becomes gradually weakened as it goes, so that later components receive less. Less (or no) current exists in the return path to the battery. This model is also called time dependent reasoning by Riley et al. (1981), and sequential reasoning by Closset (1983). This model and the sink model (#1 above) have been included in a more general "source-consumer" model by Maichle (1981) and Shipstone (1988). In the source-consumer model, something is stored in the battery, travels from there to an electrical component, such as a lamp, and is used up to make the lamp light.
4. Unidirectional with sharing model. Current travels in one direction around the circuit, is shared equally among the components, but is completely used up in the circuit. In this model, equal lamps glow with the same brightness, but no current returns to the battery.
5. Unidirectional with conservation (the scientific model). Equal current exists in all parts of the circuit, including the wires connected to the battery.

Several studies have shown that as students grow older, the number of the preconceptions of electric current they hold tends to decrease, but many preconceptions are still widespread even after formal training in electricity. In the study by Shipstone (1984), described above, almost 30% of the students at the high school level still held to model 3 above (unidirectional without conservation). Fredette and Lochhead (1980) found that over 30% of college-level engineering students thought a light bulb connected using the sink model (number 1 above) would light. This number is not much better than the number of elementary school students (over 50%) who held the sink model in a study by Osborne (1983).

Dupin and Johsua (1987) describe one way in which some of the above preconceptions in the understanding of electric circuits might come about. The authors state that since the students have no way of seeing what is going on in a wire they might use their previous experience with fluids to imagine or create in their minds the "metaphor of moving fluid". As a fluid flowing through a pipe encounters something that uses it (a faucet for example), the fluid flows out of the faucet and thus does not return to its source, even if the pipe is circular. The authors contend that the students might extend this metaphor to an electric circuit and thus conceptualize that current is used up in a light bulb in the same way that the water is used up. With this idea in mind, the students think that the current cannot return to its source (the battery). One can see that the use of the fluid metaphor can easily result in the student maintaining the sink model or the unidirectional without conservation model.

The Role of Declarative Knowledge

In addition to conflicts caused by preconceptions, the understanding of an electric circuit could be inhibited by the lack of adequate prior knowledge of the electrical components or their function. Champagne, Klopfer, and Chaiklin (1984) describe such prior knowledge as declarative knowledge about the concepts involved in physical science learning situations. In the case of electricity, declarative knowledge consists of relationships between the principles and procedures of circuits and their components, and the application of these principles and procedures to specific situations. Champagne et al. (1984) argue that, in general, physical science principles are applicable to a wide range of situations, but that the application of those principles varies as the situations vary. Consider, for example, the light bulb found in a flashlight. The principle used in making the light bulb light is that current must travel from the battery to the bulb, pass through the bulb and then return to the battery. In the specific case of the flashlight bulb, the base is used both as an electrical connection and a way to secure the bulb into place. Ding and Andre (1988) and Shipstone (1988) both point out that this declarative knowledge is not taught explicitly, so that many students only perceive the base as serving the latter function. Since the students do not realize that there are two points of contact on the bulb, this lack of knowledge could inhibit the retrieval of the proper schema for electric current flow. Thus, even if the students possessed the correct scientific model of an electric circuit, they would be unable to apply that model because of the lack of declarative knowledge about the light bulb.

Assisting Conceptual Change

Effective instruction in science, thus, involves developing effective methods to help overcome these incorrect preconceptions, and providing for the development of relevant schemas. Posner, Strike, Hewson and Gertzog (1982) developed a model of conceptual change based on Piaget's (1964) assimilation and accommodation phases mentioned earlier. Posner et al. (1982) approach learning from the aspect of a change in a student's conceptions rather than simply adding new knowledge to what is already there. They suggest that four conditions must exist in order for a student to acquire a new schema, especially if the new schema conflicts with the student's preexisting schema. For instruction to overcome a preconception, it must address each of the following explicitly:

1. The student must become dissatisfied with his current structure or conception. He must realize that what he believes somehow does not fit reality.
2. The new conception must be understandable to the student, even though he might not believe it at first. For example, in the "heavier-faster" experiment described earlier, the students were able to understand what happened when the two blocks were dropped, but many did not believe that the blocks fell at the same rate.

3. The new conception must be plausible; potentially true and believable. Using the "heavier-faster" experiment as an example again, the student must be able see that it is possible for the two blocks to fall at the same speed.
4. The new conception must be fruitful. There must be a convincing reason for the student to abandon his old ideas for the new one. Sometimes getting a good grade is reason enough to abandon the old ideas, but most students need to see some practical application of the new conception before they are willing to adopt the new schema.

Using Revised Text

Roth (1985) built on Posner et al.'s (1982) ideas, and using the four steps just described, developed text that discussed photosynthesis and at the same time explicitly addressed students' preconceptions. This text and two other commercially available texts were used in a study of 18 middle school students. Those students using the revised text showed a significant change in their study strategy and in their conceptions of photosynthesis.

Hands-on Experience

Fredette and Clement (1981) and Shipstone (1988) both suggest an application phase of specifically directed, hands-on experience with physical objects as the best method to bring about change in a schema. Osborne (1983) describes just such an experiment where each student tried to connect a light bulb first, and subsequently, the instructor guided the unsuccessful students through an "almost complete circuit" (bulb and battery connected to wires, with the wires from each ready to be connected together). Finally, the students were asked to describe their ideas of the current flow and an ammeter was used to test their ideas. The students using this method showed a significant change in their conception of current in an electric circuit.

Computer Simulations

As computer simulations have become more popular in the classroom over the past few years, many of the simulations have proven to be safe, economical, and perhaps most importantly, have shown the ability to stretch or compress time according to the student's needs. Although not all simulations have been successful in assisting in the learning process, some have shown real promise in supporting classroom activities or overcoming specific preconceptions. The simulations showing the most promise are those used with the guidance of the teacher or the text (Rivers & Vockell, 1987). The discussion below is limited to guided simulations that have been successful in the classroom.

Several researchers, including Hartley (1988), have stressed the importance of being able to use the simulations to simplify the design of a physical system by "stripping off extraneous or elaborate features while still retaining validity. Hence, students are able to focus on the main attributes of the model" (p 60). An example of such a simulation is reported by Hooper (1986), who investigated a simulation of computer memory operations. In this simulation, students performed specified tasks on the model as an initial experience in a beginning programming course. The simulation was designed to operate just as a generalized version of computer memory does, but with a much slower speed (of course) and a graphic display giving the user a "window" into each memory cell's contents. The use of the simulation helped students concentrate only on computer memory operations, without other programming variables involved. Hooper (1986) reported that students using the simulation employed more sophisticated algorithms during their programming than did students who were not exposed to the model.

In addition to the advantages of simplicity, time, expense and safety, simulations offer the learner more control over the model, allowing her to choose the most appropriate input parameter values for each experiment. This gives the learner the opportunity to try more examples and experiment more freely with the simulated environment than she would be able to do with the physical equipment.

Rivers and Vockell (1987) support the fact that computer simulations allow students to solve more problems than they can in traditional lab settings. In their study, several science simulations were used by high school students to supplement their science textbooks. The students showing the best overall improvement in problem-solving ability were those using guided simulations, pointing to the fact that the teacher, the text and/or the simulation should help the student progress step by step through the learning process.

The ability of the student to use the simulation as a tool to create many examples could prove to be the real power of a simulation in helping to overcome preconceptions. White and Frederiksen (1987) state explicitly that students need many examples presented in the proper sequence in order to break down the barriers of previous preconceptions. In a promising study, White and Frederiksen (1987) have shown the value of using examples and guided problem solving in their intelligent simulation. This simulation, called QUEST, helps students solve problems in circuit building and fault finding by providing causal qualitative explanations. QUEST has knowledge of both functional and structural properties of the circuit under consideration; therefore, as a change is introduced into the circuit, QUEST changes the state of each component and works out a conductive path and current flow. Explanations are always available for each action that is taken and the causal links are highlighted during the explanation.

In a preliminary study using QUEST, White and Frederiksen (1987) used seven high school students with no formal instruction in circuit theory as subjects. All of the students exhibited serious preconceptions about circuit behavior and lacked key electrical concepts. None of them had any experience with troubleshooting. After five hours (one hour a day for five days) of working with QUEST on an individual basis, all seven students were able to make accurate model-based predictions about circuit behavior and could troubleshoot correctly in series circuits.

Zietsman and Hewson (1986) produced a microcomputer simulation on velocity that was used successfully to correct students' preconceptions. Their simulation included a diagnostic portion to attempt to determine whether the student held a common preconception in this domain, and another portion that used Posner et al.'s (1982) conceptual change strategy to help the student acquire the new schema.

In order for simulations to be the most effective, the students must be able to use them at the proper time in their training. According to Thomas and Hooper (1989), computer based instruction can be used before formal instruction to help "set the cognitive or affective stage for future learning" (p. 2). The authors call such instruction "experiencing", based on a taxonomy of instructional use of computers proposed by Thomas and Boysen (1984).

In using an experiencing simulation to support proper student schemas about a concept, Thomas and Hooper (1989) state that students usually are presented with a desired goal and use the simulation to perform actions they believe will achieve the goal. If the desired goal is achieved, the students will assume their ideas about the concept are correct; if not, the students will question their ideas and be more inclined to search for better ones. In other words, this "pre-instruction" does not present new knowledge, but helps the students use their existing knowledge to test their own ideas about a concept. Therefore, to get the maximum benefit from the experiencing activity, it should be directed toward the specific goals of the formal instruction that is to follow.

Purpose

To this point, it has been shown that preconceptions exist in the form of incomplete or inconsistent schemas in almost every area of science. Overcoming incorrect preconceptions is a formidable task and one that has been addressed only recently in research on science learning. The use of text designed to promote conceptual change has been very helpful in overcoming preconceptions, as has the presentation of many examples through laboratory experiments or computer simulations. Because of their success separately, it seems reasonable to assume that a computer simulation used with text designed to promote conceptual change would not only be feasible, but would greatly enhance a student's study of a scientific domain. In order to be successful, however, the use of both of these media must be carefully planned to target specific preconceptions. The study reported herein combines text and a computer simulation in an attempt to capitalize on the advantages of both media.

The purpose of this study was to assess the effectiveness of a microcomputer simulation used in conjunction with text designed to promote conceptual change in helping to overcome students' preconceptions in electric circuits. Although initially, this may appear to be a media comparison study, it is in fact a study comparing different teaching methods. The methods vary from the use of traditional text to the use of specially designed text in conjunction with a computer simulation. The traditional text was modified using the format described in Roth (1985), covering basic instruction on simple direct current electric circuits. The simulation allowed the students to build and test any of the circuits described in the text. The text and simulation are described in more detail below.

Hypotheses

The hypotheses are:

1. Students using the simulation or the conceptual change designed text (CCDT) will perform significantly better on the conceptual questions on the posttest that deal with serial circuits than will all other groups.
2. Students using the conceptual change designed text alone will perform significantly better on the conceptual questions on the posttest that deal with serial circuits than will those using the traditional text alone.

METHOD

Subjects

One hundred four students (47 male and 57 female) enrolled in introductory psychology courses at Iowa State University participated in the study. Students signed up on a voluntary basis and received extra credit points in their class by participating in the study. Because the study lasted one hour a day for three days, the extra credit was given only if the student participated in all three sessions. All student information was kept confidential and each student was free to leave at any time during the experiment without penalty. Students signed up for the experiment on two sets of sheets which instructed the students to go to one of two different rooms. The sheets did not mention any difference between the rooms. The sign-up sheets also listed the following restrictions on those who should sign up to participate:

1. The students were not to have taken any college level physics, computer engineering or electrical engineering courses.
2. The students were to be native English speakers.
3. The students were not to have participated in another similar study on electricity.

Of the 104 students who participated, only 83 (36 male and 47 female) could be used in the analyses. Data from the following students were eliminated for these reasons:

- Seven students had previously taken college physics or electrical engineering courses. Of these seven, four were in the group that used the simulation during the study of the conceptual change designed text (CCDT), two were in the group that used the simulation during the study of the traditional text and one was in the group that studied the traditional text only.
- Seven students did not complete all three sessions. Of these seven, one was in the group that used the simulation before studying the traditional text, two were in the group that used the simulation before studying the CCDT, two were in the group that

used the simulation during the study of the CCDT, one was in the group that studied the traditional text only and one was in the group that studied the CCDT only.

- Seven students finished the simulation, but left the session before studying the text. These seven were in the group that was to use the simulation before studying the CCDT.

Materials

Traditional text

The traditional text was adapted from Wang (1989), who combined portions of two commercially available texts: Murphy, Hollon and Zitzewitz (1986) and Ramsey, Gabriel, McGuirk, Phillips, and Watenpaugh (1986). These texts cover basic electricity concepts and are designed to be used at the middle school/junior high school level and the high school level respectively. The complete traditional text, in the form of two booklets given to one of the treatment groups, is included as Appendix A.

Text designed to promote conceptual change

The conceptual change designed text (CCDT) incorporated the principles used by Roth (1985), was based upon Posner et al.'s (1982) model of conceptual change instruction and was adapted from Wang (1989). The CCDT was formulated by adding to the traditional text and was designed to elicit first the students' preconceptions by presenting the students with circuit diagrams and asking questions like the following:

"Do you think the bulb in this circuit will light? Why or why not?"

"How does the electricity cause the bulb to light?"

Students were asked to respond to the questions by writing in spaces provided on the booklet.

The CCDT then challenged the five typical preconceptions of electric current flow discussed previously. These preconceptions were the sink model, the clashing currents model, the unidirectional without conservation model, the unidirectional with sharing model, and the unidirectional with conservation (scientific) model. In addition, the CCDT addressed the short circuit preconception, also discussed previously. The CCDT described the preconceptions and provided descriptive evidence that those preconceptions led to incorrect predictions. These descriptions were intended to produce dissatisfaction and prepare students so that they would find the text explanation of current flow both intelligible and plausible. Only after all typical student preconceptions had been ruled out did the text provide the correct scientific explanation of electrical concepts. The complete CCDT, in the form of two booklets given to one of the treatment groups, is included as Appendix B.

For the purposes of this study, only the series portions of the texts taken from Wang (1989) (with the addition of the short circuit preconception) were used. To reduce the amount of study time per session, each series portion was further divided into two sections; the first section dealt with basic electricity concepts and the second dealt with the measurement of current and voltage.

Simulation

The microcomputer simulation was developed using HyperCard on an Apple Macintosh computer and was run on each of 25 Macintosh Plus computers. The simulation provided the ability to design and test any of the circuits mentioned in the traditional text and the CCDT. All students had their own copy of the simulation, and were able to access HyperCard through an AppleShare Network.

The screens of the HyperCard circuit stack and a complete listing of the HyperTalk script are contained in Appendix C. A short description of the stack's operation is given below.

When students started using the stack, they could choose to do any or all of the following activities:

1. Go through a short introduction on how to the use of the Macintosh mouse.
2. Go through a short tutorial on the circuit simulation.

3. Start the simulation itself.

The mouse introduction lasted about three minutes and was necessary because many of the students were unfamiliar with the Macintosh and its user interface.

The simulation tutorial followed directly after the mouse introduction and lasted from five to ten minutes, depending on how quickly the student was able to grasp the concepts. The tutorial gave the student the opportunity to add three parts to an existing circuit and provided practice using the mouse pointer in a controlled situation.

When the students chose to start the simulation, they were presented with a screen containing an area to build a circuit, and buttons that could be used to create circuit parts. Figure 1 shows the circuit screen and is a copy of the reference sheet given to each student using the simulation. The buttons used to create parts each contained an icon representing one of the range of electrical parts available. When one of these buttons was clicked, a new part would appear and the student could place the new part anywhere in the circuit area. The parts were moved around the circuit area by clicking on the part to be moved and then clicking at the new position. An evaluation of the circuit would be initiated when parts were added to complete a circuit, or when parts were taken away from a previously complete circuit.

Study booklets

Each of the six treatment groups received a different study booklet. The complete text of the booklets is contained in Appendices A, B, D, E, and F (Appendix C contains the script for the circuit simulation). The booklets for those students not using the simulation contained the traditional text or CCDT as described above (Appendices A and B). Appendix D is a copy of the problems given to the students who used the simulation before studying either the traditional text or the CCDT. Appendices E and F contain a copy of the booklets given to the students who used the simulation during their study of the appropriate text.

For those groups using the simulation, instructions on its use were included in the booklet. Instructions were also added at appropriate places telling the subjects to try to build

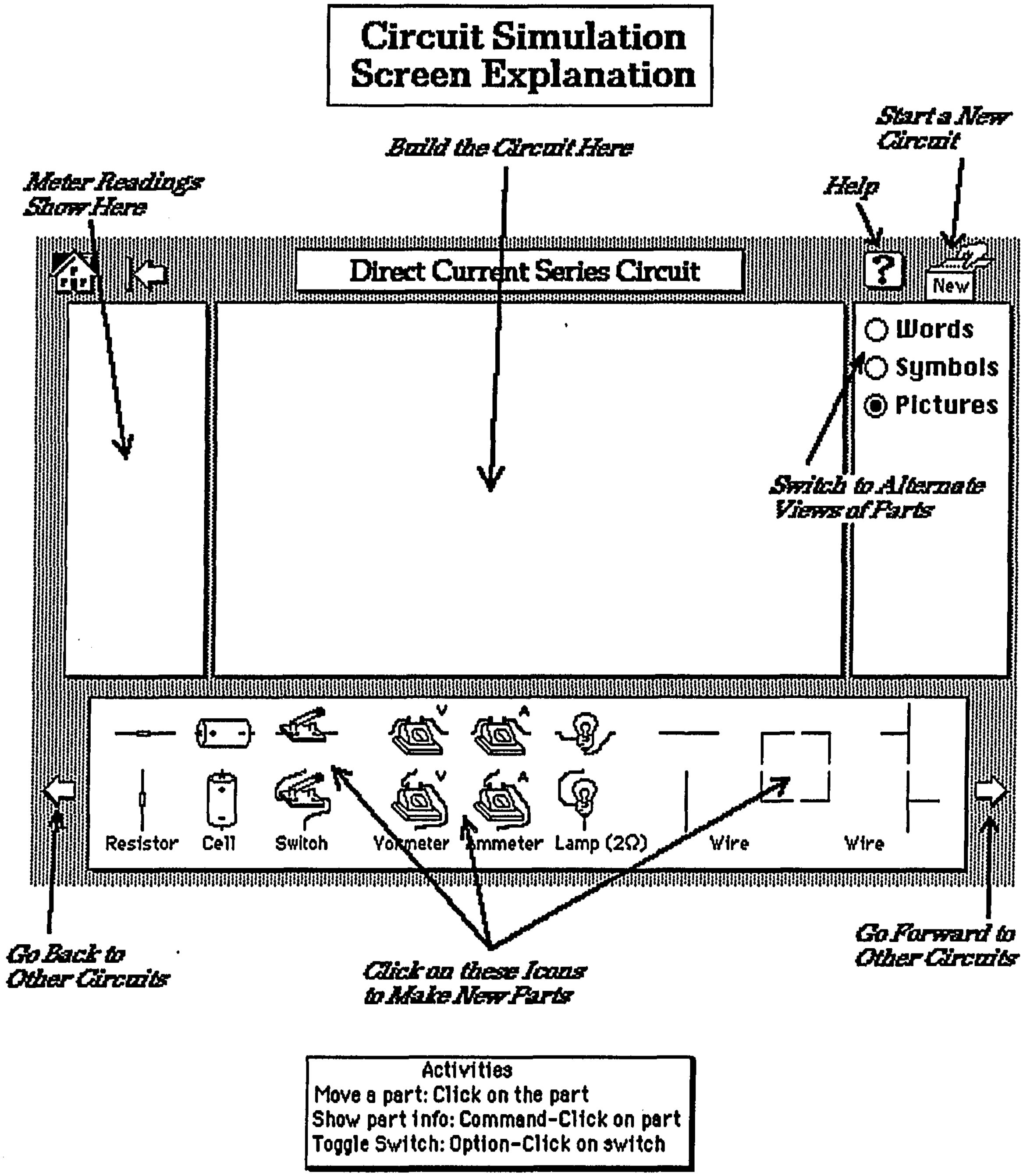

Figure 1. Circuit simulation screen with added explanations as given to each subject

specific circuits using the computer simulation. More specifically, the two treatment groups using the simulation before studying were given eight circuits (four each day) to build and test before they were told to read the traditional text or CCDT. The other two treatment groups were given booklets with instructions added at appropriate places in the traditional text or CCDT, telling the subjects to try to build and test the circuit currently being studied.

Posttest

A posttest was given to the students and was designed to measure their understanding of basic concepts of electricity. The complete posttest is included as Appendix G. The test contained 66 items and was in a multiple choice format. There were two main parts in the test: a diagram part and a calculation part. The diagram part consisted of 18 diagrams of complete circuits, series circuits, short circuits, and terminals on a light bulb.

Four types of questions were included in the test and covered the following areas:

1. 26 questions covering serial circuit concepts (conceptual serial).
2. 8 questions covering parallel circuit concepts (conceptual parallel).
3. 22 questions requiring calculations in serial circuits only.
4. 10 questions requiring definitions of electric circuit terms.

All questions were designed to test students' understanding of the calculations and conceptions of resistance, current, or voltage in both one element simple circuits and multi-element series circuits. All items were randomly arranged.

The scores from the conceptual serial portion of the test were of particular interest, because they were designed to show which preconceptions the students held. The specific questions in the conceptual serial portion are listed in Appendix I and marked with an asterisk (*) on the test itself (Appendix G). The test did not contain the asterisks when given to the students.

The conceptual serial questions contained six subsets of questions targeted at each of the preconceptions discussed previously. Note that the total number of responses is greater than 26 because some questions had more than one response targeted at a particular preconception. The specific questions and responses are listed in Appendix I and printed in bold on the test itself. The test was <u>not</u> printed this way when given to the students. Following are the preconception models and the number of responses targeted at each.

1. Sink Model--10 responses.
2. Clashing current model--6 responses.
3. Unidirectional without conservation model--3 responses.
4. Unidirectional with sharing model--3 responses.
5. Scientific model--7 responses.
6. Short circuit preconception--4 responses.

It should be noted that the five circuit models (items 1 through 5 above) are arranged from the lowest to the highest model conceptually as discussed in Shipstone (1984). This ordering is important for the analysis and is explained in more detail later. Although the short circuit preconception is not one of the models of current flow, it was targeted in the CCDT and the simulation as a preconception to be overcome. Therefore, scores for the short circuit preconception responses are included in the analysis.

<u>Questionnaire</u>

The questionnaire consisted of 17 multiple choice items concerning the students' gender, major, age and experience in electricity and computers. The questionnaire items were included in the booklet with the posttest (Appendix G) and were used to examine how the students' sex, age, major and background in electricity related to their performance on the posttest. Electricity experience of the students was determined by six questions. Two of the questions dealt with college physics or electrical engineering courses. Students who answered positively to these were eliminated from the analysis. Responses to the other four experience questions were combined to form an experience score which was used as a covariate.

Design

A completely randomized 2 x 2 x 3 factorial experimental design was used. The independent variables were (1) gender, (2) type of text at 2 levels: traditional vs. conceptual change designed text and (2) use of the simulation at 3 levels: prior to reading the text, during the reading of the text, or not at all.

The six treatments consisted of the following:

Of the three groups who studied the traditional text:

a. One used the simulation before reading the text (called the "simulation-before-text" group),

b. One used the simulation during the reading of the text (called the "simulation-during-text" group), and

c. One did not use the simulation at all (called the "text-only" group).

Of the three groups who read the conceptual change designed text (CCDT),

a. One used the simulation before reading the text (called the "simulation-before-CCDT" group),

b. One used the simulation during the reading of the text (called the "simulation-during-CCDT" group), and

c. One did not use the simulation at all (called the "CCDT-only" group).

Procedure

The experiment was conducted in three one-hour sessions, held on three successive days. On the first two days of the study, those students in the four simulation groups used the computer and those in the CCDT-only and text-only groups did not. The students who used the computer were those who had signed up on the sheets directing them to go to the room containing the Macintoshes. The students on the other sheets studied the text only and were in a regular classroom. As was mentioned previously, the sign-up sheets did not mention the difference between the rooms or the use of a computer in the experiment. For the first two days, the computer sessions and text-only sessions were held at different times on the same days. On the last day (during the posttest), the computer was not used and all the students were in the same room at the same time. Activities for each day were as follows:

Day 1. All subjects were assigned randomly to one of the four computer treatments or one of the two text-only treatments. The subjects participated in reading part 1 of the appropriate text (basic electricity concepts) and used the simulation according to the group to which each has been assigned. In the computer treatments, two of the groups used the simulation before studying the text, while the other two groups used the simulation during the study of the text.

Day 2. All subjects studied part 2 of the appropriate text (measuring electricity) and used the simulation if applicable.

Day 3. All subjects completed the same posttest.

RESULTS

Posttest

After the study was completed, it was discovered that, because of typographical errors, the correct answers to two of the posttest questions were not in the list of choices for those questions. Both of these questions required calculations and both were eliminated from the analysis.

Table 1. Reliability figures for the posttest and each of the four subsets of questions scored on the posttest.

Subset	Reliability
Total Posttest	0.8407
Conceptual Serial	0.7889
Conceptual Parallel	0.4493
Calculations	0.7037
Definitions	0.5724

Table 1 shows the reliability figures for the posttest and each of the four subsets mentioned previously. Note that the conceptual parallel questions and the definitions both had low reliability scores. This is understandable, since parallel circuit concepts were not taught during the experiment and definitions were not stressed. Because of this low reliability, the results involving these parts of the test are not considered further. Although the reliability of the calculations section is reasonable, no analysis was done on this section because the performance of the students on calculations was not of interest in this study.

Electricity Experience

Responses to four questions on the questionnaire were used to determine differences in electricity experience among the participants. The analysis showed a negative correlation between gender and electricity experience, ($\underline{r} = -.5859$, $\underline{p} < .001$). Since gender was coded as 1 for male and 2 for female, this indicated that the females had significantly less electricity experience than did the males. An analysis of variance, using electricity experience as the dependent variable, confirmed that the females (M = .45) reported significantly less experience with electricity than did the males [M = 1.58, $F(1, 71) = 35.044$, $p < .001$]. Experience in electrical repairs and electric toys showed the largest disparity between the genders. Over 50% of the males reported doing some electrical repair work, whereas only 2% of the females reported doing so. Over 35% of the males reported building electrical toys as children or adolescents, whereas only 6% of the females reported such activity.

To minimize its influence on the dependent measures, electricity experience was added as a covariate in all subsequent analyses of variance (ANOVA). It should be noted that even though the addition of the covariate caused adjustment of individual scores, and subsequently adjustment of the cell means, it did not change the order of any of the means. Therefore, only the unadjusted means are reported here.

Total Conceptual Serial Score

An ANOVA was run on the mean conceptual serial scores, with the text type, use of simulation, and gender as the independent variables, and electricity experience as a covariate (see Appendix H for the complete listings of cell means and analysis of variance (ANOVA) tables). The mean scores showed that the only significant differences were in the text type variable. Those studying the CCDT (M = 20.59) scored significantly higher than those studying the traditional text [M = 18.67, $F(1, 70) = 5.734$, $p < .05$].

Preconception Models

The conceptual serial questions all contained diagrams and many of them contained responses that were specifically targeted at one or more of the preconception models described previously. Therefore, six more sets of scores were developed using each preconception and the scientific model as keys. The keys, found in Appendix I, were constructed by recording how people would answer each question if they were to have the specific preconception. Thus, each of these scores shows the degree to which the students believe in the preconception. In other words, the higher the score, the more the student is likely to exhibit the specific preconception.

ANOVA's were run on each of the preconception means, with text type, use of simulation and gender as the independent variables, and electricity experience as a covariate. Complete listings of cell means and analysis of variance (ANOVA) tables for these results are found in Appendix H.

Sink and Clashing Current Models

Analysis of the scores for the questions covering the sink and clashing current models showed no significant differences among any of the groups.

Unidirectional Without Conservation Model

The mean scores for the unidirectional without conservation responses showed that those studying the CCDT ($M = .51$) held this preconception significantly less than did those using the traditional text [$M = .98$, $F(1, 70) = 7.816$, $p < .01$]. Differences were also found among the groups using the simulation, $F(2, 70) = 5.404$, $p < .01$. A Tukey test revealed that the simulation-during groups ($M = .46$) held the preconception significantly less than did the no-simulation groups ($M = 1.13$). The scores for this model's responses were the only ones showing differences between the genders, with the females ($M = .57$) holding to the preconception significantly less than the males [$M = 1.03$, $F(1, 70) = 4.823$, $p < .04$]. There was also an interaction effect between text type and simulation, $F(2, 70) = 3.859$, $p < .03$. One set of simple effects tests revealed that, of the groups using the traditional text, both the simulation-before groups ($M = .71$) and the simulation-during groups ($M = .36$) held the preconception significantly less than did the no-simulation groups ($M = 1.87$). Another set of simple effects tests showed that, of the subjects not using the simulation, the CCDT group ($M = .47$) held to this preconception significantly less than did the traditional-text group ($M = 1.87$).

Unidirectional With Sharing Model

Analysis of the mean scores on the unidirectional with sharing responses showed differences among the groups using the simulation, $F(2, 70) = 5.621, p < .01$. A Tukey test revealed that the no-simulation group ($M = .22$) held to this model significantly less than did the simulation-before group ($M = .74$) and the simulation-during group ($M = .71$).

Scientific Model

The mean scores on scientific model responses show that those studying the CCDT ($M = 4.68$) held this model significantly more than did those studying the traditional text [$M = 3.13$, $F(1, 70) = 15.183, p < .001$]. Differences were also found among the groups using the simulation, $F(2, 70) = 5.860, p < .01$. A Tukey test revealed that those in the simulation-before groups ($M = 4.37$) held this model significantly more than did those in the no-simulation groups ($M = 3.06$).

Short Circuit Preconception

Differences were found among the text type and the simulation variables in the short circuit preconception scores. Those using the traditional text ($M = 1.33$) held to this preconception significantly more than did those using the CCDT [$M = .68$, $F(1, 70) = 7.934$, $p < .01$]. Differences were also found among the groups using the simulation, $F(2, 70) = 6.784, p < .01$. A Tukey test showed that those in the no-simulation groups ($M = 1.53$) held to this preconception much more than did those in simulation-before groups ($M = .59$).

Assigning Model Classifications

Although the results above are encouraging, an analysis of variance of the model scores only showed that there were significant differences in the scores of the subjects on some of the models. It did not show which models the students held. The question remained as to whether those not holding to the unidirectional without conservation model or the unidirectional with sharing model held to a lower or to a higher model. Further analysis was necessary to complete the picture.

To better understand where they were in their development of proper electric circuit conceptions, the students were assigned to models on the basis of their scores on each of the five preconception model response keys. This assignment was made in the following manner:

1. All preconception model raw scores were converted to z-scores, using the grand mean and standard deviation for those scores.
2. For each student, the model with the highest of the five z-scores was assigned to that student. In case of a tie, the lowest model was used.
3. The students each were given a number from 1 through 5 (sink model through scientific model), representing the model they held.

This assignment allowed analysis of the distribution of preconception models in each treatment group. It also allowed the calculation of model means for each treatment group, with a higher mean representing movement toward a higher conceptual model.

Although this model classification assignment method facilitates assignment of each student to a model, it has some imperfections. A potential problem stems from the fact that the total number of items determining each model differs widely. For example, the total items for the sink model key are ten, but only three items assess the unidirectional without conservation model. One can see that missing one item among the unidirectional without conservation items would make a much greater difference in the z-score than would missing one among the sink model items.

Because of this problem, an alternative method was developed in which a criterion was set for each model. A student then was assigned to a particular model only if the criterion was met for that model. Using this method, 23 subjects could not be classified. This created a problem, in that eliminating 23 of the subjects from the analysis would leave a sample that would be too small for proper statistical analysis. However, the pattern of results using this criterion method were similar to the pattern using the z-score assignment method. Therefore, only the analysis involving the z-score method is discussed.

Model Classification Analysis

Because of the low frequencies in some of the cells, it was necessary to combine model classifications 1 and 2 into one "Low" classification, and 3 and 4 into one "Medium" classification. Model classification 5 (the scientific model) was called the "High" classification. A chi-square analysis using text type and these combined model classifications showed a significant dependency between text type and model classification, $\chi^2(2, N = 83) = 11.36$, $p < .01$. The chi-square frequency table is contained in Appendix H. The analysis shows that there was a significantly higher percentage of subjects using the traditional text in the medium classification and a significantly higher percentage of subjects using the CCDT in the high classification.

A chi-square analysis using simulation and the three model classifications did not show a dependency between these two variables.

An alternative approach to the chi-square analysis would be to treat model classification as a dependent measure. Because the classification is based on a developmental sequence, this analysis is meaningful and has the advantage of not collapsing the data. Therefore, an ANOVA was run using model classification (1 through 5) as the dependent variable and text type, use of simulation and gender as the independent variables. Electricity experience was used as a covariate. The means and ANOVA tables are contained in Appendix H. The results showed that the mean model classification was significantly higher for the groups that studied the CCDT ($M = 3.65$) than it was for the groups studying the traditional text [$M = 3.17$, $F(2,70) = 3.878$, $p = .05$]. It was also found that the mean model classification was significantly higher for the simulation-before groups ($M = 3.81$) and the simulation-during groups ($M = 3.71$), than it was for the no-simulation groups [$M = 2.78$), $F(2, 70) = 6.511$, $p < .01$].

DISCUSSION

Posttest

In general, the posttest was designed to assess the students' qualitative and quantitative understanding of simple electric circuit concepts. It is important that the construction of the test items be valid and that the critical portions of the test be reliable in order to discuss meaningfully the results of the data analysis above. The critical conceptual items were constructed by using recommendations presented in the literature for such items (e.g., White & Frederiksen, 1987), and are similar in format to other tests developed to assess misconceptions (Halloun & Hestines, 1985; Shipstone, 1984; White, 1988). In addition, the reliability of the overall test (.84) and the conceptual serial portion (.78) show that students tended to answer consistently across the set of test items. These reliabilities are typical for research of this type. These facts support the use of the posttest and the conceptual serial portion in comparing the groups of students in this study.

Although the text and simulation dealt strictly with series circuits, some questions dealing with parallel circuits were included in the posttest. These questions were of a qualitative nature and were included to study possible transfer effects from series circuit concepts to parallel circuit concepts. However, the low reliability of the parallel portions of the posttest suggests that students were primarily guessing and had learned little about parallel circuits.

Traditional Text

The traditional text used in this study (Ramsey et al., 1986) is widely used in secondary schools across the United States. It was introduced in the late 1970's and has undergone several revisions. As with many texts designed for beginning students, attempts to simplify complex physical phenomena have resulted in the introduction of errors[1] of oversimplification into the text's description of physical concepts. For the most part, these errors are typical of

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[1]The errors in the text were pointed out by Dr. Francis Peterson.

introductory middle and high school texts. Because the traditional text and the conceptual change text both contained the same errors, no advantage was provided to any one group. The key issue of this study is whether the additional instructional features (conceptual change text and simulation) help improve student learning; consequently, these oversimplifications in the original passages are irrelevant to the hypotheses that were investigated. It is also important to point out that Wang (1989) compared pretest-posttest performance of students who read only the traditional text. These students improved in both their conceptual understanding and ability to solve quantitative circuit problems. Thus, while the text does contain some oversimplification errors, it also does teach the material of critical interest in this study.

The results of the statistical analysis confirm results obtained by Wang (1989); the students studying the CCDT scored significantly better overall on the questions involving serial circuit concepts. Since this was the main goal of the CCDT, it shows that the changes made to the traditional text were effective in overcoming preconceptions about simple series circuits. This is especially encouraging because of the type of subjects used in the study. All subjects included in the analysis were novices and most were not highly motivated to learn about electricity. The CCDT manipulations and the simulation would be likely to have greater effects on students who were studying electricity in actual classes.

Simulation

Although no formal measurements were taken on specific aspects of the HyperCard simulation, informal observations showed that it proved to be easy to use, versatile and an improvement over electric circuit simulations for the Apple II. One of the most important aspects of the simulation was that it was developed on a computer that is easy to use. The Macintosh's mouse and object oriented interface allowed even students not familiar with computers and electric circuits to build simulated circuits after only ten minutes of practice.

One potential advantage of this simulation is its ability to present a circuit in three different formats. This feature may be an instructionally important aspect for those students who need to see a particular circuit in more than one way. The simulation allows students to shift to alternative forms of the circuit components (symbols, pictures and words). This feature may be especially important when examples from the text are presented using electrical symbols rather than drawings of the components. Students having difficulty understanding the symbols could build the circuit given, then switch to pictures to gain a better meaning for the actual circuit, or to words to remind themselves of the actual value (in volts or ohms) of the components.

It should be noted that although the simulation represented correctly the changes of states in electric circuits, it did not duplicate every aspect of electrical circuits. Indeed, the purpose of the simulation was to eliminate information not relevant on an introductory level (as emphasized by Hartley, 1988), thus allowing the student to gain an understanding of the qualitative aspects of electric circuits first. For this reason, the simulation did not include complicated phenomena such as the variance in resistance that components experience as they reach operating temperature.

Because of its ease of use, it is somewhat disappointing that there were no differences in the overall scores for those using the simulation. It was hypothesized that those using the simulation before studying the text would score significantly higher than those using the simulation during study and those using no simulation at all. This was not the case for the overall scores. There could be many reasons why no differences were found. Perhaps the most important is that there was not enough time for those using the simulation to sufficiently explore the questions they were given. Almost all students using the simulation spent the entire hour each day and many did not complete all the problems in time to study the text as much as those who did not use the simulation. A second reason is that the subjects might not have been sufficiently motivated to want to spend extra time in exploring the circuits using the simulation. Finally, the simulation was somewhat slow because of memory limitations on the computers and the way HyperCard interprets its programming language. Analysis of each circuit took an average of 30 seconds. The slow speed caused frustration on the part of several students, who might have done more if the simulation was able to respond more quickly.

The results of the scores on the targeted questions are very encouraging. Since the goal of the text and the use of the simulation was to overcome the incorrect preconceptions and replace them with the scientific model, the scores on the specific responses show that the goal was met at least in part.

Sink Model and Clashing Currents Model

For the questions targeted at these two lower level models, there were no significant differences found among the text groups or the simulation groups. In other words, the means for all groups on these responses were about the same. The failure to find significant differences may be due to a floor effect, since the scores in all the groups were very low for both these models. For example, with 10 responses in the sink model response key, the grand mean was less than 1. This may be an indication that many students reaching the college level do not hold to either of these two models.

Unidirectional Without Conservation Model

Text type

The higher mean scores for those students using the traditional text indicated that the students using the CCDT chose the responses targeted at this model fewer times. Since the chi-square showed the greatest contribution to the text type/model dependency was in this and the next higher model, it can be determined that those using the traditional text were more likely to hold to models 3 and 4, and those using the CCDT were more likely to hold to model 5. These findings indicate that the CCDT was an important factor in helping the students overcome this incorrect preconceptions.

Simulation

Since the mean scores for this model were lower for those using the simulation, this was an indication that those using the simulation probably held to this model less than those students who did not use the simulation. Although the chi-square did not show a relationship between use of simulation and model held, the mean model classification was higher for those in both the simulation-before and the simulation-during groups. This could mean that those students not using the simulation were more likely to hold to a lower model than those who used the simulation. It seems, then, that the simulation was also successful in helping the students overcome this preconception.

Unidirectional With Sharing Model

It is interesting that those using the simulation held to the unidirectional with sharing model more than did the other groups. This seems to be a negative finding, until one looks at the model classification distribution; 75% of those not using the simulation were in a model lower than this one, whereas, for those in the simulation-before and the simulation-during groups, only 33% were in a lower model. In other words, the simulation groups held to this model more than did the no-simulation groups because most of the students in the no-simulation groups were in a lower model classification.

Scientific Model

The mean for the CCDT group was over one and one-half points higher than the mean for those studying the traditional text. A similar result was found between the groups using the simulation before and the groups not using the simulation. The differences among the groups on this model are very encouraging; both the CCDT and the simulation were successful in overcoming incorrect preconceptions and moving the students toward the correct scientific model.

Model Classification

Of all the findings, those concerning model classification are probably the most important, because they show the distribution of the students according to which model they held at the time of the posttest. Both the chi-square and the ANOVA's on mean model classification showed that those using the CCDT and the simulation were more likely to be classified in a higher model than were the other groups. In other words, the model classification analysis confirms that both the CCDT and the simulation assisted in moving the students toward the correct scientific model more than did traditional text or study without using the simulation.

Recommendations To Better Overcome Preconceptions

In this study, probably the greatest hinderance to the students using the simulation was the lack of time. During actual classroom use of materials such as those used in the study, students should be given sufficient opportunity to become familiar with the computer and the simulation before working on formal activities. If students use the computer and the simulation regularly, they will become more comfortable with them, and be more inclined to experiment freely with the circuit problems.

Not only should students be given more time on the computer, but the simulation should be modified to evaluate circuits more quickly. Even though the simulation used in this study explained each step during circuit evaluation, it was slower than many of the students thought it should be. The slow response time caused some of the students to became frustrated waiting for results. One way to speed up the simulation would be to compile external routines and attach them to HyperCard. (In an informal test of this recommendation, after the study had been completed, one of the frequently used routines was compiled as an external function. With the new compiled routine attached to the HyperCard simulation, a typical circuit was evaluated 50% faster.)

Implications of the Study

This study supports and expands upon studies mentioned earlier in the introduction. It has shown that novices at the college level still hold incorrect preconceptions of simple series circuits and that many of these preconceptions can be overcome through specific training. The training is effective if it elicits and confronts each preconception and guides the student through experiments with an electric circuit simulation. The simulation must be easy to use and flexible enough to allow the student to produce many examples of the circuits in the text.

For educators, the challenge now is to consider current physics curricula to determine if the texts used should be changed to incorporate the ideas of Posner et al. (1982). The evidence seems to warrant this type of change in order to overcome the preconceptions held by students at many levels of physics education. In addition to changes to current texts, educators should consider a much wider use of simulations, especially in the physics curricula. As suggested by Shipstone (1988) and supported in this experiment, some type of "hands-on" experience, such as using a simulation, is a excellent way to test one's understanding of what is being taught. Finally, this study supports the views of White and Fredericksen (1987), in that students need to begin at the qualitative level in their study of electric circuits.

CONCLUSION

The combination of text and a computer simulation was effective in overcoming several specific preconceptions about electric circuits. It was necessary that the text be very specific and that the students be guided through the use of the simulation. Because of the specificity of the training, much research must be done into the incorrect preconceptions held in any area of physics before training can be developed to overcome these preconceptions. It is important that the preconceptions be pointed out specifically and that students get a chance to see the scientific model demonstrated clearly. To get the maximum benefit from their study, students should be allowed to experiment with their ideas of physical phenomena through the use of computer simulations.

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APPENDIX A.

TRADITIONAL TEXT

ELECTRIC CIRCUITS

Electrical energy is not something used only by scientists and engineers. Today, almost everyone uses electricity. You are familiar with many different kinds of electric appliances. Twist a knob or push a button, and a radio or television set begins to play. Flip a switch, and an electric light or a fan is turned on. Each of these appliances works by using electrical energy. Do you know how the electricity causes those appliances to work? You will find out in this section.

THE PATH OF AN ELECTRIC CURRENT

What do switching on a light and turning on a faucet have in common? Opening the faucet lets water flow from the pipe. Turning on an electric light switch permits electrons to flow through the wires. Water will not flow in the pipe, however, unless a force is present to move it. That force could be supplied by gravity causing the water to flow down hill. A pump could also supply the energy needed to move the water. Electrons flowing through a conductor also need a force to cause them to move.

About the year 1800, an Italian scientist named Alessandro Volta discovered a way to make electrons flow through a conductor. Volta found that a combination of two different metals and salt water could make electrons move through a conductor. A chemical reaction between the metals and the salt solution caused the electrons to move. This arrangement of two materials together with a solution causing a flow of electrons is called an electrochemical cell. An automobile battery is made up of several electrochemical cells.

Electrical energy in the battery is changed into chemical energy and stored in the cells. Later, the cells in the battery can change the stored chemical energy back into electricity.

An ordinary flashlight battery is also a kind of electrochemical cell. It is often called a dry cell because it does not contain a liquid. A moist chemical mixture is used instead of the liquid.

Chemical changes taking place inside the dry cell cause part of the cell to build up a supply of extra electrons. This part of the cell is called the negative terminal (-). Another part of the cell lacks a normal supply of electrons. This part of the cell is called the positive terminal (+). Wires can be attached easily to the negative and positive terminals of a cell or battery.

THE NATURE OF ELECTRIC CIRCUITS

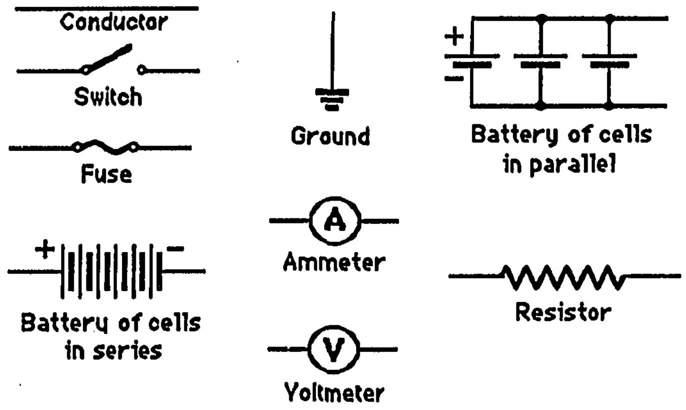
If you connect a wire or other conductor between the negative and positive terminals of a cell, the extra electrons at the negative terminal will have a path to get to the positive terminal where electrons are lacking. Electrons will immediately start to flow between the two terminals. You have made an electric circuit. An electric circuit is a complete path allowing electrons to flow and produce an electric current.

When you plug a lamp into an electric outlet and turn on the switch, you are completing an electric circuit. The two parts of the plug and a pair of wires provide a complete circuit. An electric current can then flow through the lamp that is plugged into the outlet.

Electrons repel each other because they all carry a negative charge. An electron in a wire repels other electrons in the wire. Electrons all along the wire pass along this movement from one to the next. This effect travels rapidly along the wire. This is what is meant when electrons are said to "flow" along a conductor.

KINDS OF CIRCUITS

An electric circuit is made up of several parts. There must be a source of electrons to be moved through the circuit. Conductors, usually wires, are needed to connect all the parts. These parts include switches and the appliance to be operated, a light for example (see Figure 1). Illustrated are some of the symbols used to describe parts of electric circuit diagrams.



Symbols Used in Diagrams of Electric Circuits

Figure 1

These items can be connected one after another. This arrangement is called a series circuit. In a series circuit, all parts of an electric circuit are connected one after another. See Fig. 2. In a series circuit, there is only one path the electrons can follow. A series circuit can cause some problems. Suppose, for example, that light bulbs are arranged in a series circuit. If one bulb fails, the circuit is broken and all the bulbs go out. No part of a series circuit can be switched off without turning off the whole thing. If the lights in a house were connected in series, they would all have to be on or off at the same time.

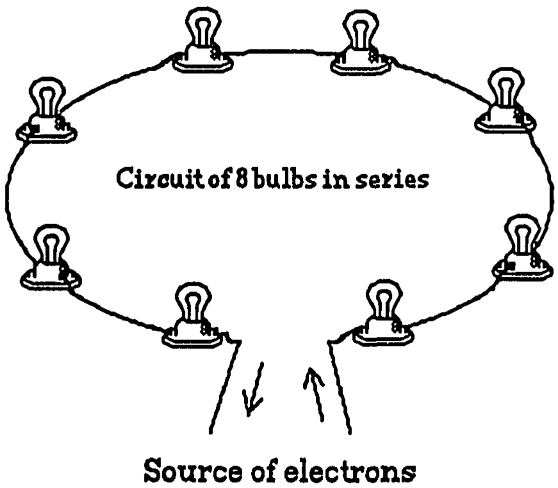


Figure 2

Another way to connect the parts of a circuit is shown in Fig. 3. This arrangement is called a parallel circuit. In a parallel circuit, the different paths are on separate branches. Each branch of a parallel circuit can be switched off without affecting the other branches. The different circuits in a house are arranged in a parallel. In this way, many appliances can be used at the same time. They do not all have to be on at the same time.

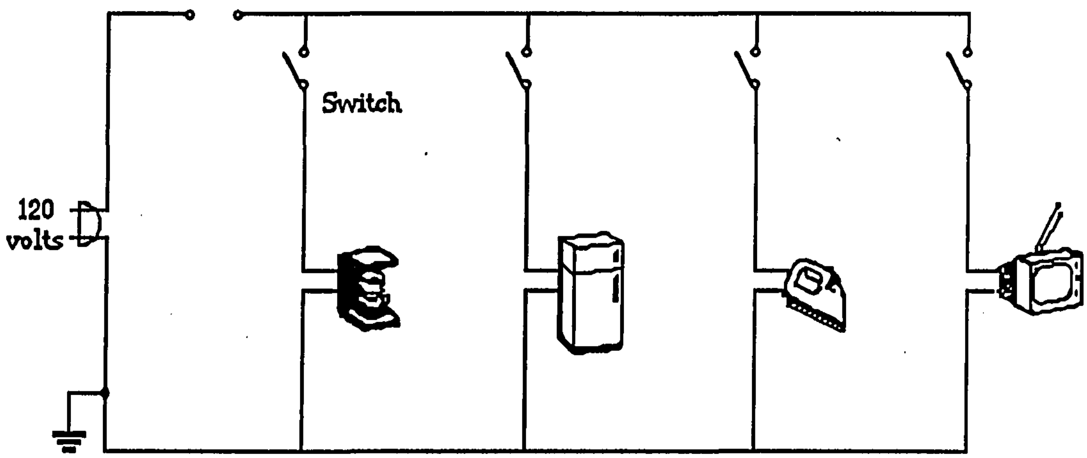


Figure 3

SHORT CIRCUIT

Have you ever used an electric appliance only to be startled by a shower of sparks, and a room plunged into sudden darkness? What caused this to happen?

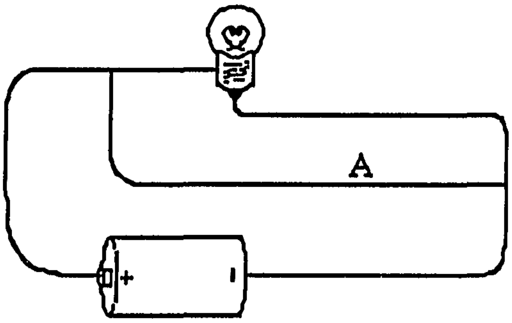


Figure 4

This is a short circuit phenomenon. The short circuit happens whenever the terminals of a cell are connected so the current does not flow through a resistance. See Figure 4. The resistance is any part of the circuit that does not allow current to flow easily. In Figure 4, the resistance is the filament of the light bulb. Another example would be the heating coil in a toaster. Both offer resistance in a circuit. When the current does not flow through some kind of resistance like the filament of a light bulb or the heating coil in a toaster, the circuit will most likely be burnt.

A short circuit is both dangerous and wasteful. It is dangerous because a short circuit can heat the wires and possibly start a fire. It is wasteful because the electrical energy is being converted to heat energy in the circuit itself, instead of being converted to energy in a useful appliance.

This is the end of the first section of the text. After you feel you have studied this booklet carefully, please return it to the proctor and you may leave. Remember to come to the proper room at the designated time tomorrow. Thank you.

Yesterday, you studied about the parts of an electric circuit and how they can be connected together. Since you will be using some electrical symbols in this section, Figure 1 from the first section has been inserted below for reference. You may also review the booklet that you studied yesterday. The proctor has it at the front.

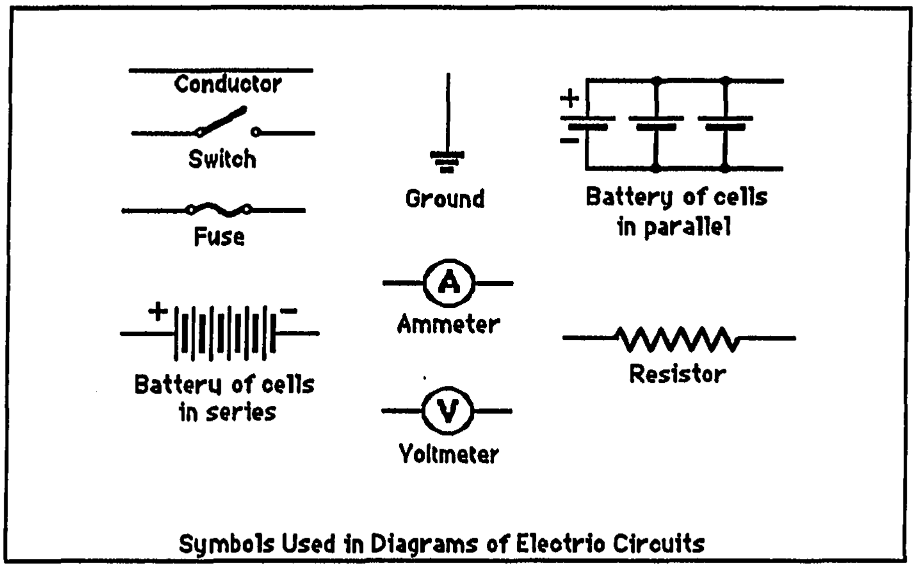


Figure 1

MEASURING ELECTRICITY

The water behind a dam has potential energy. It gained this energy by being lifted above sea level. A dry cell also has potential energy stored in it. This energy cannot be used until the dry cell is connected to an electric circuit. Then the flow of electrons in the circuit releases some of the energy of the cell. How could you find out how much potential energy is stored in a dry cell? You would need some way to measure this energy. The potential energy of water trapped behind a dam is determined by the height of the water behind the dam. In the same way, the potential energy (E) of electrons in a dry cell is measured in volts (V). A volt measures the potential of electrons to do work. We can use volts to measure the amount of work done if electrons move between two points in an electric circuit. This is often called the potential difference or electromotive force. If we compare the flow of electrons to water running down a hill, then voltage is a measure of how high the hill is. An ordinary flashlight battery gives 1.5 volts of energy. This would compare to water held behind a low dam. The 1.5 V battery is also similar to water flowing down a low hill. A larger battery gives 6 volts of energy. This would be like water behind a high dam. The 6 V battery is also similar to water flowing down a higher hill. In other words the 6-V battery has the potential to do four times as much work as the 1.5-V cell. A 6-V battery pushes the electrons harder than a 1.5-V battery.

The voltage of an electric circuit can be measured by an instrument called a voltmeter. A voltmeter can be attached to an electric circuit. Then the voltage of the circuit can be read on the dial of the voltmeter. A voltmeter can also be used in an automobile. This voltmeter tells the driver if there is enough voltage in the car's electrical system to run the starter, lights, and other parts of the car.

For most electric circuits, we want to know not only the voltage, or how hard the electrons are pushed, but also how many electrons are flowing. This is called the current (I). To measure the amount of current, we use amperes (am-pirz). An ampere (A) measures the amount of charge moving past a point in a circuit in one second. Am ampere is often called "amp" for short. Measurement of both voltage and amperage describes the behavior of an electric current. For example, a circuit may have high voltage with low amperage. This would be like a very narrow but swiftly flowing stream. On the other hand, a circuit with high amperage but low voltage would be like a wide but slow moving river.

The amount of current in a circuit can be measured by attaching a meter called an ammeter to the circuit. An ammeter in a car tells whether the battery is being charged (electrons flowing in) or drained (electrons flowing out).

A voltmeter and an ammeter each has a coil of wire in a magnetic field. When a current flows through the coil, the coil moves a pointer on a scale. The scale shows the number of volts or amperes. In an ampere, all the current flows through the coil. In a voltmeter, a small current that is proportional to the voltage flows through the coil.

Suppose that water is flowing through a wide pipe. Suddenly, the pipe becomes much narrower. What will happen to the amount of water that can flow through the pipe? The flow of water will slow down because the pipe becomes narrower. When water flows through pipes, the size or shape of the pipe can change the ease with which the water moves. This is also true of electrons. When electrons move through any material, they meet resistance (rih-zis-tunts). Resistance (R) is the term used for all conditions that limit the flow of electrons in an electric circuit. For example, a light bulb adds resistance to an electric circuit.

The amount of current that flows in a particular electric circuit is also affected by the voltage. Again, think of water flowing through a pipe. The amount of water that will pass through the pipe is affected by the force pushing the water. Suppose that the water flows through a narrow pipe. Less water could then pass through the pipe. The narrow pipe has the same effect on the flow of water as resistance in an electric circuit has on the flow of electrons. If electrons flow through a part of the circuit where the resistance is high, then the amount of current flowing through the entire circuit is reduced. Resistance is measured in ohms. A resistance of one ohm means a potential of one volt per one ampere of current.

OHM'S LAW

The voltage, current, and resistance in an electric circuit are related to each other by a rule known as Ohm's law. This relationship was discovered by a German schoolteacher. Georg Ohm, in the early 1800's. Ohm experimented with electric circuits on wires having different amounts of resistance. He discovered a general rule that describes the relationship among voltage, current, and resistance in a circuit. This rule, now known as Ohm's law, can be written as follows:

$$I = \frac{E}{R} \qquad \text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

For example, an automobile with a 12-V battery has headlights whose resistance is 4 ohms. When the lights are on, the current needed is:

$$I = \frac{E}{R} = \frac{12\ V}{4\ ohms} = 3\ A$$

Most automobile batteries can supply 3 amperes of current for only a few hours. Thus, a battery can run down if the headlights are left on for several hours while the engine is not running.

By rearranging the terms, the preceding equation can also be written;

volts = amperes x ohms or ohms = $\frac{\text{volts}}{\text{amperes}}$

$$E = IR \qquad R = \frac{E}{I}$$

SERIES CIRCUITS

When resistors are connected in series, all current travels through each resistor, one after the other. The electric current in the circuit passes through each lamp (resistance) in succession. The current through each resistance is the same. The current flowing in a series circuit is the same everywhere along the wire. To determine the current in the circuit, the effective resistance of the circuit must be found. The effective resistance is the resistance of a single resistor that could replace all the resistors in the circuit. The single resistor would have the same current through it as the resistors it replaced. To find the effective resistance, Ohm's law is applied to the circuit as a whole and to its parts. The total voltage across the three resistors is equal to the potential difference across the generator, 120 V. The total voltage across the three resistors is also equal to the sum of the voltage across the individual resistors. That is,

$$V = V_1 + V_2 + V_3$$

According to Ohm's law, the voltage across R is given by $V_1 = IR_1$, where I is the current through the circuit. Therefore,

$$V = IR_1 + IR_2 + IR_3$$

$$V = I\,(R_1 + R_2 + R_3)$$

If the three resistors were replaced by a single resistor with resistance R, the voltage across R could be found using Ohm's law: V=IR. Comparing this equation with the one above shows that in a series circuit the following holds:

$$R = R_1 + R_2 + R_3$$

The effective resistance, R, of resistors in series is the sum of the resistances. Note that the resistance of R is larger than that of any one of the resistors.

The current through a series circuit is found by calculating the effective resistance R, and then using Ohm's law in the form of I = V/R.

Example--Current in a Series Circuit

Four 15-ohm resistors are connected in series to a 30-V battery. What is the current in the circuit?

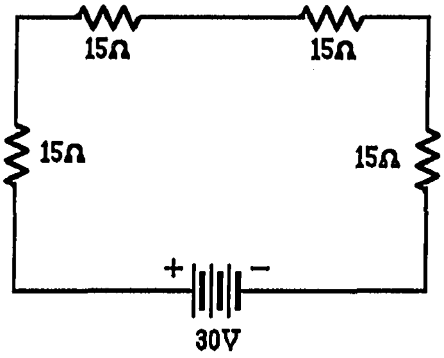


Figure 5

$R = R_1 + R_2 + R_3 + R_4$

$= 15 + 15 + 15 + 15 = 60$ ohms

Then apply Ohm's law to the circuit.

$$I = \frac{V}{R} = \frac{30\ V}{60\ ohms} = 0.5\ A$$

EXAMPLE--Voltage Drops in a Series Circuit

A 5.0 ohm resistor and a 10.0 ohm resistor are connected in series and placed across a 45.0-V potential difference.

a. What is the effective resistance of the circuit?
b. What is the current through the circuit?
c. What is the voltage across each resistor?
d. What is the total voltage across the circuit?

Given: $R_1 = 5.0$ ohms
$R_2 = 10.0$ ohms
$V = 45.0$ V

Unknowns: R, I, V_1, V_2,
Basic equation: $V = IR$

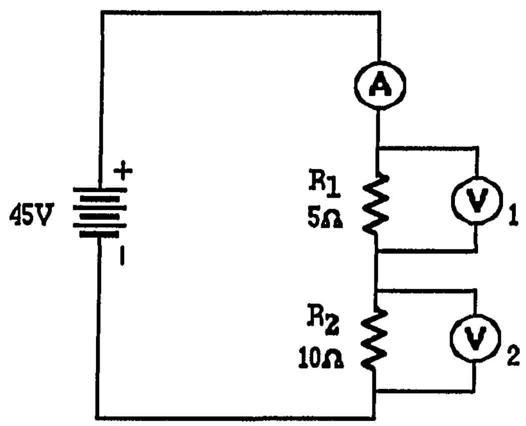


Figure 6

Solution:

a. $R = R_1 + R_2$

$= 5.0 + 10.0 = 15.0$ ohms

b. $I = \frac{V}{R} = \frac{45.0\ V}{15.0\ ohms} = 3.00\ A$

c. The voltage across R_1 is

$V_1 = IR_1 = (3.00\ A)\ (5.0\ ohms) = 15\ V$

The voltage across R_2 is

$V_2 = IR_2$

$= (3.00\ A)\ (10.0\ ohms) = 30.0\ V$

d. $V = V_1 + V_2$

$= 15\ V + 30.0\ V = 45\ V$

An important application of series resistors is the voltage divider. The voltage divider is designed to obtain a desired voltage from a battery that supplies a larger voltage. Consider the circuit in Figure 22. Two resistors, R_1 and R_2 are connected in series across a battery of voltage V. The effective resistance of the circuit is $R=R_1 + R_2$. The current, I, is given by $I = V/R=V/(R_1 + R_2)$. The desired voltage drop, V_2,is the voltage drop across resistor R_2. According to Ohm's law, V_2 equals IR_2. Replacing I by its equivalent calculated by the equation above gives

$$V_2 = IR_2 = \left(\frac{V}{R_1 + R_2}\right) \times R_2 = \frac{VR_2}{R_1 + R_2}.$$

EXAMPLE--Voltage Divider

A 9.0 V battery and two resistors, $R_1 = 400$ ohms and $R_2 = 500$ ohms, are connected as a voltage divider. What is the voltage across R_2?

Given: $V = 9.0$ V
$R_1 = 400$ ohms
$R_2 = 500$ ohms

Unknown: V_2

Basic equation: $V_2 = \frac{VR_2}{R_1 + R_2}$

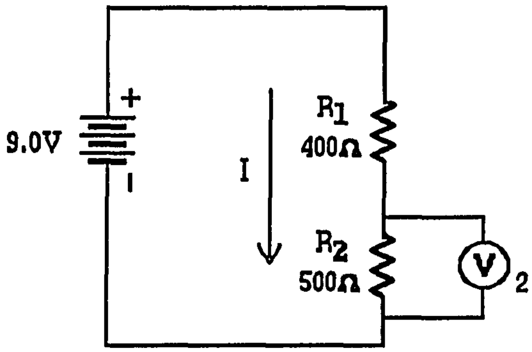


Figure 7

Solution:

$$V_2 = \frac{VR_2}{R_1 + R_2} = \frac{(9\ V)\ (500\ ohms)}{400\ ohms + 500\ ohms} = 5\ V$$

This is the end of the second section of the text. After you feel you have studied this booklet carefully, please return it to the proctor and you may leave. Remember to come to the proper room at the designated time tomorrow. Thank you.

APPENDIX B.

TEXT DESIGNED TO PROMOTE CONCEPTUAL CHANGE

ELECTRIC CIRCUITS

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THE PATH OF AN ELECTRIC CURRENT

What do switching on a light and turning on a faucet have in common? Opening the faucet lets water flow from the pipe. Turning on an electric light switch permits electrons to flow through the wires. Water will not flow in the pipe, however, unless a force is present to move it. That force could be supplied by gravity causing the water to flow down hill. A pump could also supply the energy needed to move the water. Electrons flowing through a conductor also need a force to cause them to move.

About the year 1800, an Italian scientist named Alessandro Volta discovered a way to make electrons flow through a conductor. Volta found that combination of two different metals and salt water could make electrons move through a conductor. A chemical reaction between the metals and the salt solution caused the electrons to move. This arrangement of two materials together with a solution causing a flow of electrons is called an electrochemical cell. An automobile battery is made up of several electrochemical cells.

Electrical energy in the battery is changed into chemical energy and stored in the cells. Later, the cells in the battery can change the stored chemical energy back into electricity.

An ordinary flashlight battery is also a kind of electrochemical cell. It is often called a dry cell because it does not contain a liquid. A moist chemical mixture is used instead of the liquid.

Chemical changes taking place inside the dry cell cause part of the cell to build up a supply of extra electrons. This part of the cell is called the negative terminal (-). Another part of the cell lacks a normal supply of electrons. This part of the cell is called the positive terminal (+). Wires can be attached easily to the negative and positive terminals of a cell or battery.

IDEAS ABOUT ELECTRIC CIRCUITS

Suppose you have a flashlight bulb connected to a battery with wires. The bulb is lit. How does electricity cause this to happen? Before you read any more, write your description of how you think electricity makes the bulb light.

Different students give a number of different answers.

Some students believe that only one wire is needed between the battery and the bulb. They think that bulbs in Figure 1 and Figure 2 would light.

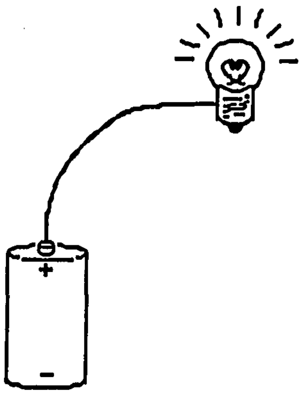


Figure 1

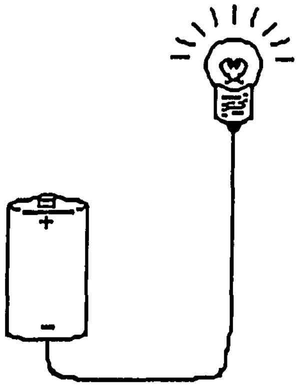


Figure 2

This view is called the "sink theory" of electricity, which states that electricity can leave a battery and go to an electrical device through a single wire, and not return to the battery.

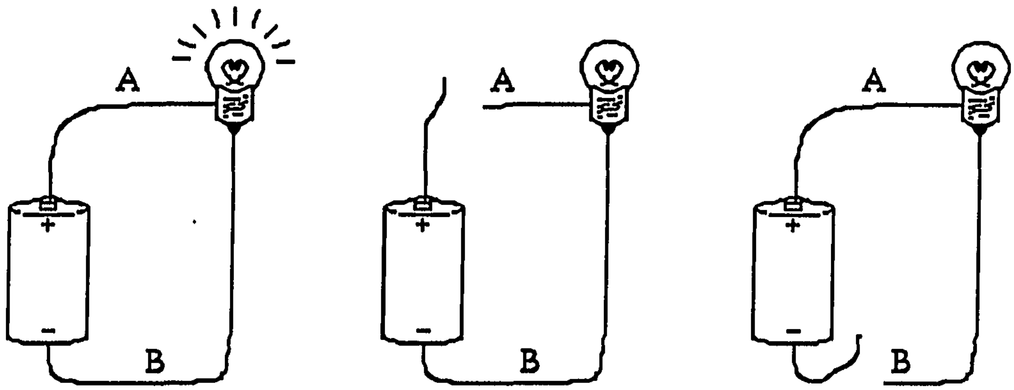
Do you think these students are right? Why do you think the students are right or wrong? Take a minute and answer these questions for Figure 1 and Figure 2.

Question 1. Will the bulb in Figure 1 light?
yes   no   (circle one)

Question 2. Will the bulb in Figure 2 light?
yes   no   (circle one).

Students who believe the "sink theory" are incorrect. The "sink theory" is wrong. How can we prove that this view is wrong?

Let's experimentally connect two wires, one light bulb, and a battery to form an electric circuit as illustrated in Figure 3.



Both wires connected
Bulb lit

Wire A disconnected
Bulb not lit

Wire B disconnected
Bulb not lit

Figure 3a

Figure 3b

Figure 3c

When the wires are connected as in Figure 3, the bulb lights. Now let's disconnect wire A as in Figure 3b. When wire A is disconnected, the light bulb does not light. Similarly, when wire B is disconnected as in Figure 3c, the light bulb will not light. Only when both wire A and wire B are connected does the light bulb light as in Figure 3a. This experiment proves that the "sink theory" is wrong and the bulb or other electrical device will not work unless there are two electrical pathways from the source of electricity (battery) to the device.

Other students who know that two wires or pathways are needed believe that the bulb lights because positive electricity leaves the positive side of the battery and negative electricity leaves the negative side of the battery. When the opposite currents meet at the wire, they clash and cause the bulb to light. The idea these students have is that electricity flows in two directions in an electrical circuit and meets at the device. See Figure 4.

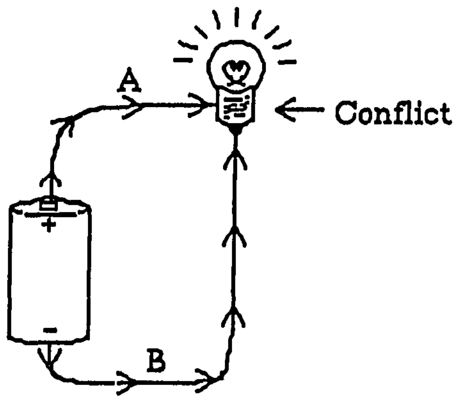


Figure 4

This view is called the clashing current view. It states that the conflict of both positive and negative "currents" cause the bulb to light.

Do you think these students are right? Why do you think the students are right or wrong? Take a minute and answer these questions for Figure 4.

Write your answers here.

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These students are incorrect. The clashing current view is wrong. How can we prove that this view is wrong?

Let's experimentally connect three wires, two light bulbs, and a battery to form an electric circuit. See Figure 5.

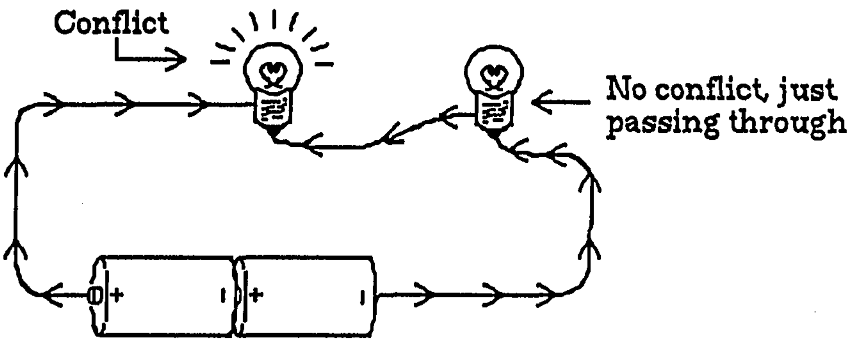


Figure 5

According to the clashing current view, positive electricity flows only until it meets negative electricity and vice versa. The clashing currents view predicts that bulb 1 would light but bulb 2 would not light because bulb 1 has both positive and negative electricity clashing while bulb 2 has only negative electricity passing through it.

When we connect this circuit, we find that both bulbs light as in Figure 6. This proves that the clashing current view is wrong. Electricity does not flow in opposite directions from both the positive terminal and the negative terminal of the battery simultaneously and meet at the electrical device. Electricity moves from one terminal to the other terminal of the battery. This is illustrated in Figure 6.

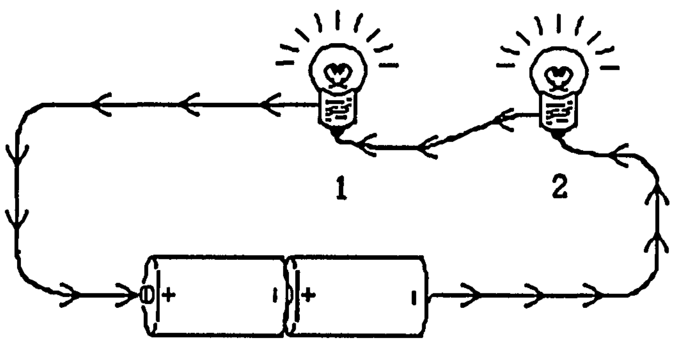


Figure 6

How does electricity move in a circuit? Read the following section to find the answer.

THE NATURE OF ELECTRIC CIRCUITS

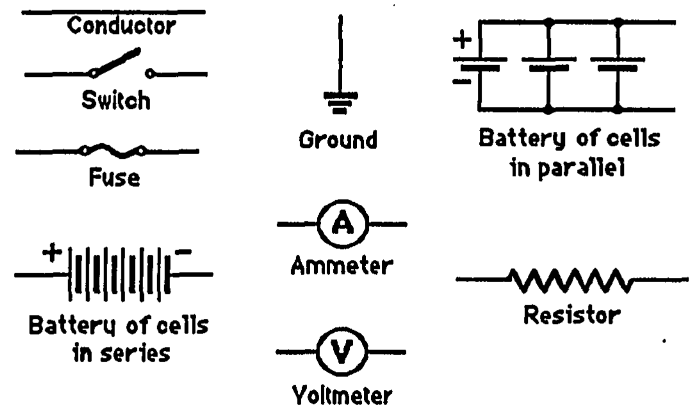
If you connect a wire or other conductor between the negative and positive terminals of a cell, the extra electrons at the negative terminal will have a path to get to the positive terminal where electrons are lacking. Electrons will immediately start to flow between the two terminals. You have made an electric circuit. An electric circuit is a complete path allowing electrons to flow and produce an electric current.

When you plug a lamp into an electric outlet and turn on the switch, you are completing an electric circuit. The two parts of the plug and a pair of wires provide a complete circuit. An electric current can then flow through the lamp that is plugged into the outlet.

Electrons repel each other because they all carry a negative charge. An electron in a wire repels other electrons in the wire. Electrons all along the wire pass along this movement from one to the next. This effect travels rapidly along the wire. This is what is meant when electrons are said to "flow" along a conductor.

KINDS OF CIRCUITS

An electric circuit is made up of several parts. There must be a source of electrons to be moved through the circuit. Conductors, usually wires, are needed to connect all the parts. These parts include switches and the appliance to be operated, a light for example. See Figure 7. Illustrated are some of the symbols used to illustrate parts of electric circuit diagrams.



Symbols Used in Diagrams of Electric Circuits

Figure 7

These items can be connected one after another. This arrangement is called a series circuit. In a series circuit, all parts of an electric circuit are connected one after another. See Fig. 8. In a series circuit, there is only one path the electrons can follow. A series circuit can cause some problems. Suppose, for example, that light bulbs are arranged in a series circuit. If one bulb fails, the circuit is broken and all the bulbs go out. No part of a series circuit can be switched off without turning off the whole thing. If the lights in a house were connected in series, they would all have to be on or off at the same time.

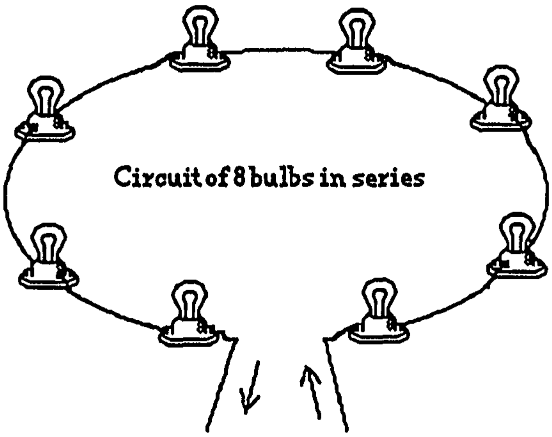


Figure 8

Another way to connect the parts of a circuit is shown in Fig. 9. This arrangement is called a parallel circuit. In a parallel circuit, the different paths are on separate branches. Each branch of a parallel circuit can be switched off without affecting the other branches The different circuits in a house are arranged in a parallel. In this way, many appliances can be used at the same time. They do not all have to be on at the same time.

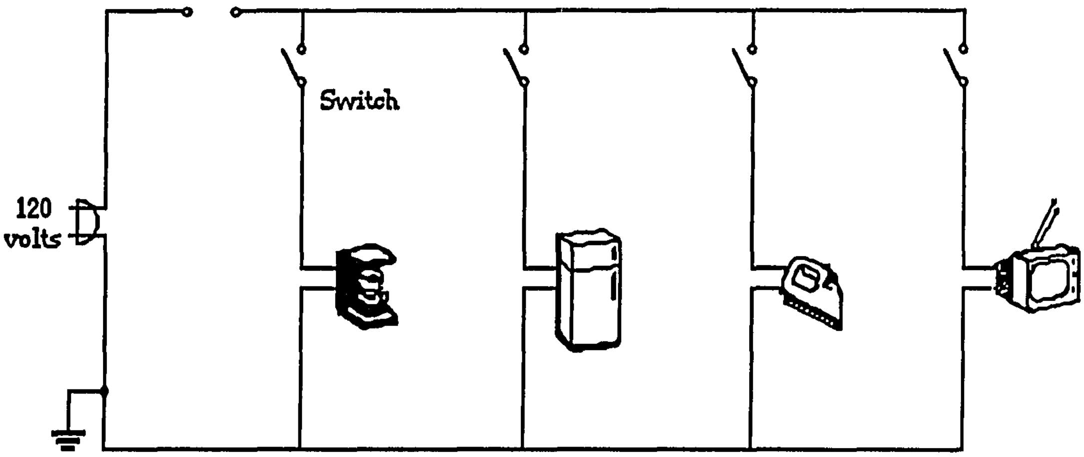


Figure 9

Now look at Figure 10. Try to answer whether the light bulb will light in Figure 10 below. Why do you think so? How does the electricity cause the bulb to light, if it does? If it does not, why not?

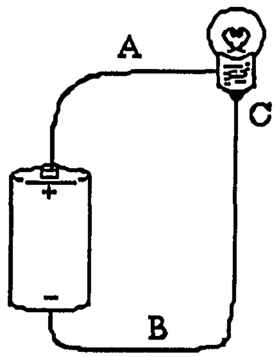


Figure 10

Write your answers here.

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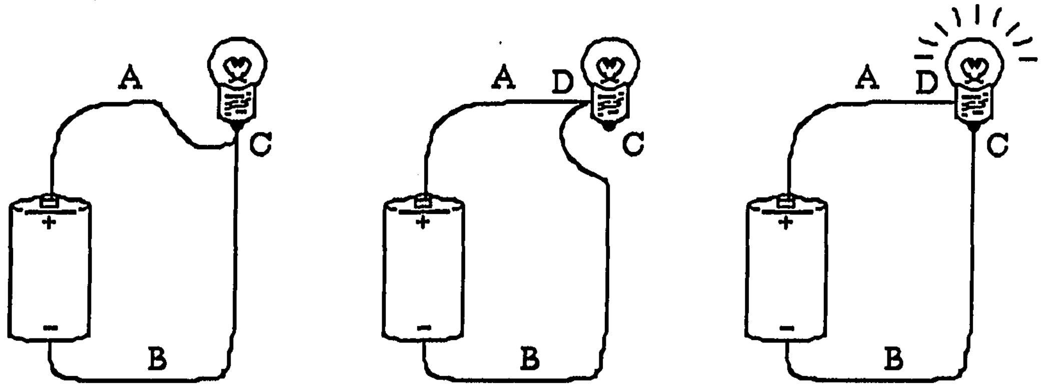
Let's experimentally connect a circuit based on Figure 10 . Both wire A and wire B are connected at point C at the side of the bulb as in Figure 11a, or the bottom of the bulb as in Figure 11b. The result is that the light bulb does not light. But when we move wire A from point C to point D at the lower side of the bulb as illustrated in Figure 11c, we will see that the light bulb lights.



Bulb not lit — Bulb not lit — Bulb lit

Figure 11a — Figure 11b — Figure 11c

If you review this section, you can recall that when the electricity moves from negative terminal to the positive terminal of the battery, the light bulb will light. In other words, the light bulb will light only when there is electricity passing through it from the negative side to the positive side. If we look at Figure 11a and 11b, we can see that the electricity can not pass through the light bulb because both wire A and wire B are connected at the one point (point c). But in figure 11c, the electricity can flow from the negative side (point C) of the bulb to the positive side (point D). The current passing through the bulb causes it to light.

SHORT CIRCUIT

Have you ever used an electric appliance only to be startled by a shower of sparks, and a room plunged into sudden darkness? What caused this to happen?

Let's look at the Figure 12 below. Do you think the light bulb will light? Why do you think so? If the wire A is cut, do you think the light bulb will light? Why do you think so?

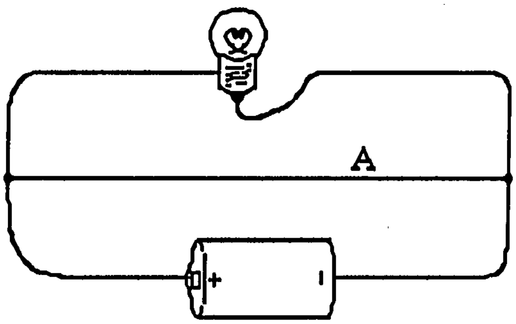


Figure 12a

Write your answers here.

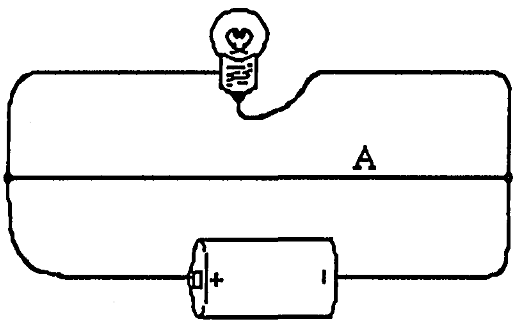
____

____

____

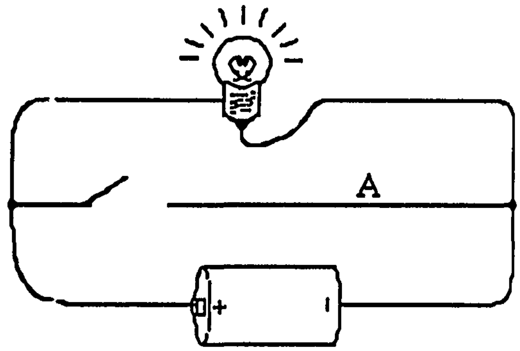
____

Let's test your answers. experimentally connect a circuit as in 12a. The light bulb does not light. Then, let's cut the wire A and see what will happen. The light bulb lights. Do you understand why the light bulb will light only when wire A is cut? This is the short-circuit phenomenon. Wire A causes a short circuit. Like water flowing down-hill, electricity will seek the path of least resistance. The light bulb has a lot of resistance, while wire A has almost none. Given a chance, the electricity will flow through wire A rather than through the light bulb (See Figure 12b). Thus, the light bulb will not light. A short circuit is a pathway with very low or no resistance that completes an electrical circuit.



Wire A connected
Bulb not lit

Figure 12 b



Wire A disconnected
Bulb lit

Figure 12c

Short circuits are dangerous. The low resistance of a short circuit allows so much electricity to flow through the wire that the wire can heat up and cause a fire. Even if the wire does not get hot enough to cause a fire, it can discharge a battery quickly.

This is the end of the first section of the text. After you feel you have studied this booklet carefully, please return it to the proctor and you may leave. Remember to come to the proper room at the designated time tomorrow. Thank you.

Yesterday, you studied about the parts of an electric circuit and how they can be connected together. Since you will be using some electrical symbols in this section, Figure 7 from the first section has been inserted below for reference. You may also review the booklet that you studied yesterday. The proctor has it at the front.

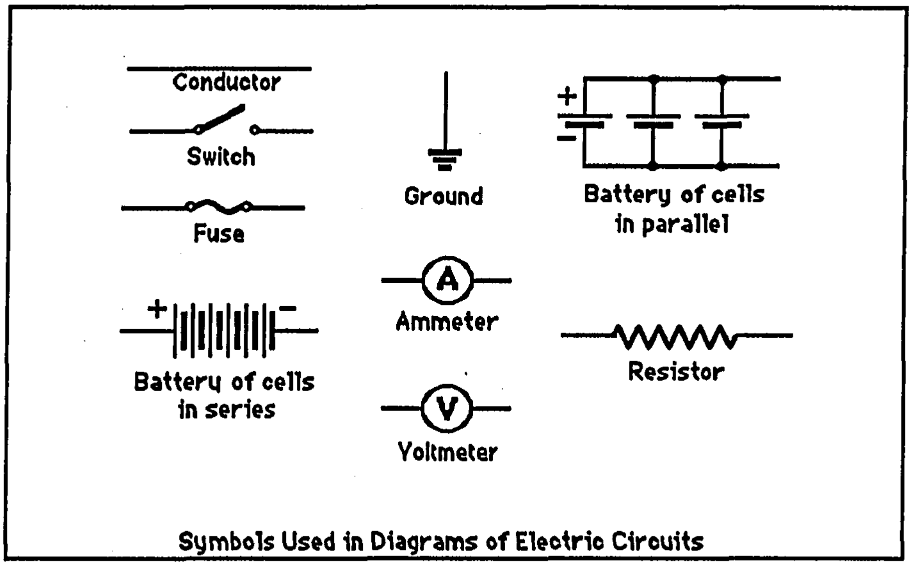


Figure 7

MEASURING ELECTRICITY

Electromotive force and current.

We have seen that the same current flows through electrical devices in a circuit. If current is not used up by electrical devices in a circuit, what is? We all know that "electricity" gets used up when we leave a flashlight on; we say that the battery has died. If devices don't use up current, what do they use up?

Batteries are chemical/electrical devices that cause negative elements of electricity to be drawn to one end or "pole" of the battery and the other end or pole to thus become positive. When a pathway or wire is connected between poles of the battery, the difference between the positive and negative ends causes negative elements to flow towards the positive and reduce the difference. This difference between the positive and negative sides of a battery is called the electromotive force of the battery. The stronger the battery, the greater is its electromotive force.

Electrical devices such as wires, light bulbs, buzzers, bells, and radios, provide pathways by which electricity can flow between the positive and negative ends of the battery. However, they are not perfect pathways. They resist the flow of electricity. Wires have very little resistance, they resist the flow of electricity very little. (So little in fact that we will consider the resistance 0 in the simple problems we will deal with.) Light bulbs have a lot of resistance, they resist the flow of electricity much more than wires. A good way of thinking about resistance is thinking about your running on different surfaces. If you run on a hard concrete street, the street resists your running very little and you can run fast with relatively little effort. If you run on a soft sandy beach or in ankle deep soft snow, it is harder to run. If you run in waist-deep water, you have to work very hard to move at all.

Electromotive force and resistance interact to produce or cause current. A particular device, such as a light bulb, has a particular amount of resistance. If a battery that has only a little bit of electromotive force is connected to the device, no current will flow because the electromotive force is not great enough to overcome the resistance (sort of like being stuck hip deep in snow). If a stronger battery is connected and its electromotive force is great enough to overcome the resistance of the device, a current will flow. If an even stronger battery is connected a greater current will flow.

When you add multiple devices in a simple circuit, you increase the resistance and the current flow is less, but all the devices get the same amount of current. As the electrical force passes each device, however, the electromotive force loses some of its strength. It is the electromotive force, or emf, that each device uses up. The amount of Emf used is measured with a device called a voltmeter.

In a circuit, each device, like a light bulb, uses up some electromotive force. Look at Figure 13. Remembering that current flows from negative to positive, you can see that the emf is less after each device.

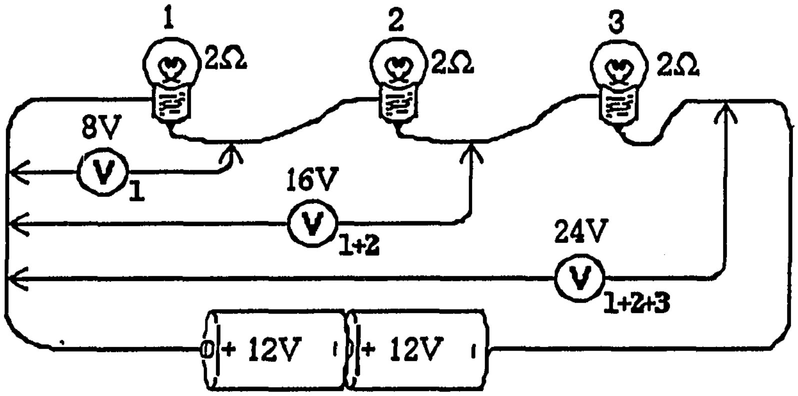


Figure 13

Another way to think of a battery's electromotive force (emf) is as potential energy. What is potential energy? The water behind a dam has potential energy. It gained this energy by being lifted above sea level. A battery also has potential energy stored in it. This energy cannot be used until the battery is connected to an electric circuit. Then the flow of electrons in the circuit releases some of the energy of the cell. How could you find out how much potential energy is stored in a battery? You would need some way to measure this energy. The potential energy of water trapped behind a dam is determined by the height of the water behind the dam. In the same way, the potential energy (E) of electrons in a battery is measured in volts (V). A volt measures the potential of electrons to do work. We can use volts to measure the amount of work done if electrons move between two points in an electric circuit. This is also called the potential difference or as we explained above, electromotive force (emf). If we compare the flow of electrons to water running down a hill, then voltage is a measure of how high the hill is. An ordinary flashlight battery gives 1.5 volts of energy. This would compare to water held behind a low dam. The 1.5 V battery is also similar to water flowing down a low hill. A larger battery gives 6 volts of energy. This would be like water behind a high dam. The 6 V battery is also similar to water flowing down a higher hill. In other words the 6-V battery has the potential to do four times as much work as the 1.5-V cell. A 6-V battery pushes the electrons harder than a 1.5-V battery.

The voltage of an electric circuit can be measured by an instrument called a voltmeter. A voltmeter can be attached to an electric circuit (see Figure 13 above). Then the voltage of the circuit can be read on the dial of the voltmeter. A voltmeter can also be used in an automobile. This voltmeter tells the driver if there is enough voltage in the car's electrical system to run the starter, lights, and other parts of the car.

For most electric circuits, we want to know not only the voltage, or how hard the electrons are pushed, but also how many electrons are flowing. This is called the current (I). To measure the amount of current, we use amperes (am-purz). An ampere (A) measures the amount of charge moving past a point in a circuit in one second. An ampere is often called "amp" for short. Measurement of both voltage and amperage describes the behavior of an electric current. For example, a circuit may have high voltage with low amperage. This would be like a very narrow but swiftly flowing stream. On the other hand, a circuit with high amperage but low voltage would be like a wide but slow moving river.

The amount of current in a circuit can be measured by attaching a device called an ammeter to the circuit. An ammeter in a car tells whether the battery is being charged (electrons flowing in) or drained (electrons flowing out).

A voltmeter and an ammeter both have a coil of wire in a magnetic field. When a current flows through the coil, the coil moves a pointer on a scale. The scale shows the number of volts or amperes. In an ammeter, all the current flows through the coil. In a voltmeter, a small current that is proportional to the voltage flows through the coil.

Suppose that water is flowing through a wide pipe. Suddenly, the pipe becomes much narrower. What will happen to the amount of water that can flow through the pipe? The flow of water will slow down because the pipe becomes narrower. When water flows through pipes, the size or shape of the pipe can change the ease with which the water moves. This is also true of electrons. When electrons move through any material, they meet resistance (rih-zis-tunts). Resistance, (R) is the term used for all conditions that limit the flow of electrons in an electric circuit. For example, a light bulb adds resistance to an electric circuit.

The amount of current that flows in a particular electric circuit is also affected by the voltage. Again, think of water flowing through a pipe. The amount of water that will pass through the pipe is affected by the force pushing the water. Suppose that the water flows through a narrow pipe. Less water could then pass through the pipe. The narrow pipe has the same effect on the flow of water as resistance in an electric circuit has on the flow of electrons. If electrons flow through a part of the circuit where the resistance is high, then the amount of current flowing through the entire circuit is reduced. Resistance is measured in ohms (Ω). A resistance of one ohm ($1\ \Omega$) means a potential of one volt per one ampere of current.

OHM'S LAW

The voltage, current, and resistance in an electric circuit are related to each other by a rule known as Ohm's law. This relationship was discovered by a German schoolteacher, Georg Ohm, in the early 1800's. Ohm experimented with electric circuits using wires with different amounts of resistance. He discovered a general rule that describes the relationship among voltage, current, and resistance in a circuit. This rule, now known as Ohm's law, is written below.

$$I = \frac{E}{R} \qquad \text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

For example, an automobile with a 12-V battery has headlights whose resistance is 4 ohms. When the lights are on, the current needed is:

$$I = \frac{E}{R} = \frac{12\text{ V}}{4\text{ ohms}} = 3\text{ A}$$

Most automobile batteries can supply 3 amperes of current for only a few hours. Thus, a battery can run down if the headlights are left on for several hours while the engine is not running.

By rearranging the terms, the preceding equation can also be written;

volts = amperes x ohms

$$E = IR$$

or

$$\text{ohms} = \frac{\text{volts}}{\text{amperes}}$$

$$R = \frac{E}{I}$$

SERIES CIRCUITS

Now we are going to consider more complex circuits. Before you read any more, describe how you think electricity moves in the Figure 14 circuit below. Specifically, what do you think about the brightness of four bulbs. Will they have the same brightness? Which one will be brightest? Which one will shine least? Why or why not?

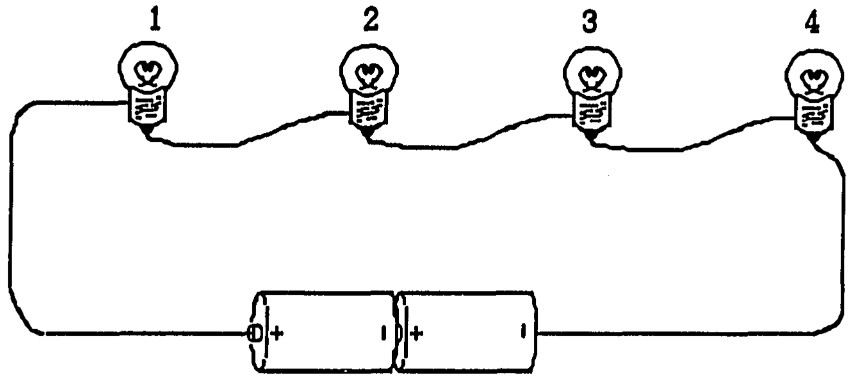


Figure 14

Write your answers here.

Before studying electricity, different students believe many different things about a circuit like Figure 14.

Some students think that later devices in a circuit receive less electricity than devices earlier in the circuit. If they think that electricity flows from positive to negative, some students believe that the bulb 1 will glow most brightly and bulb 4 will glow least brightly as illustrated in Figure 15. Other students, who think electricity flows from negative to positive, believe that bulb 4 will glow most brightly and bulb 1 least brightly as illustrated in Figure 16. These students believe that each electrical device uses up some of the electrical current and later devices receive less.

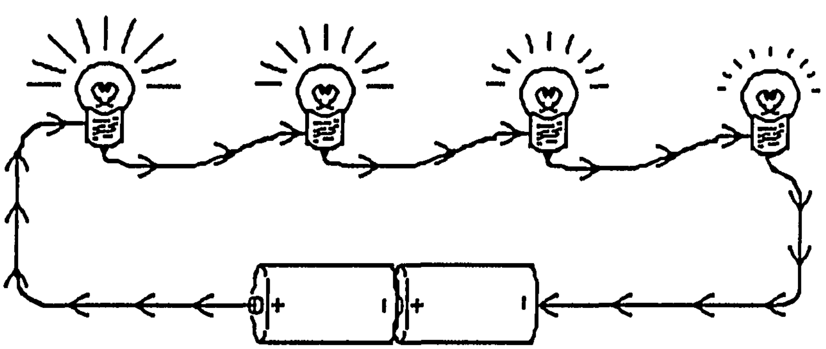


Figure 15

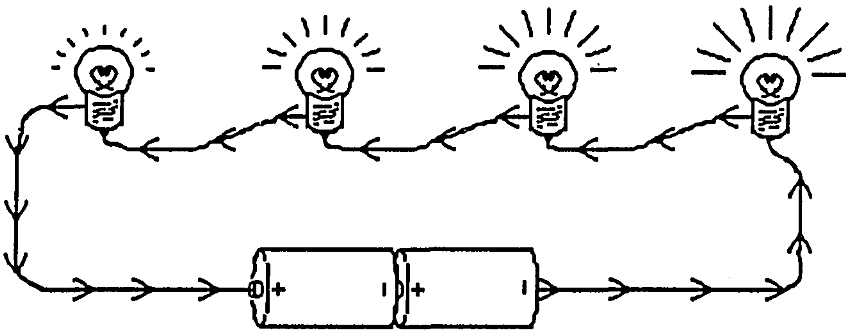


Figure 16

We can test these students' beliefs by hooking up a circuit like that illustrated in Figure 14. In Figure 17 below, we have represented what would actually happen. Assuming they were all the same, all the lights would glow the same amount. This experiment indicates that all the lights receive the same amount of current.

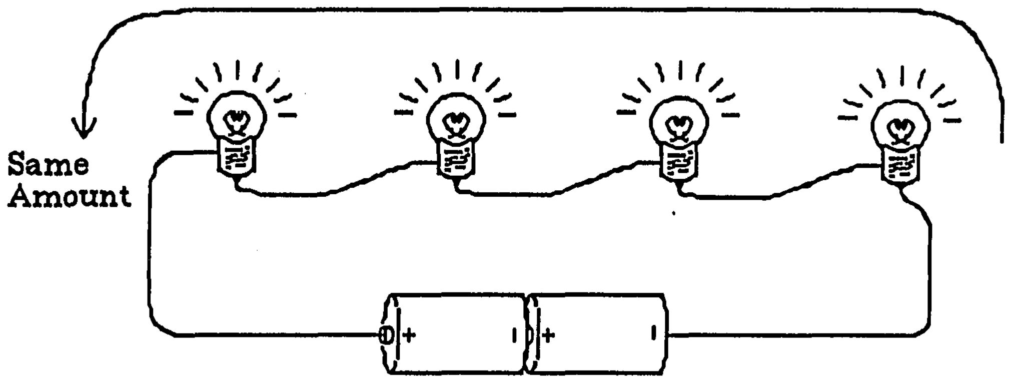


Figure 17

Some students believe that the electrical devices in a circuit share the current equally, but that the amount of current flowing back to the battery is less than the amount of current flowing out to the devices. That is, they believe that while the devices share the current, they use some of it up, so less current must go back to the battery. This view is shown in Figure 18.

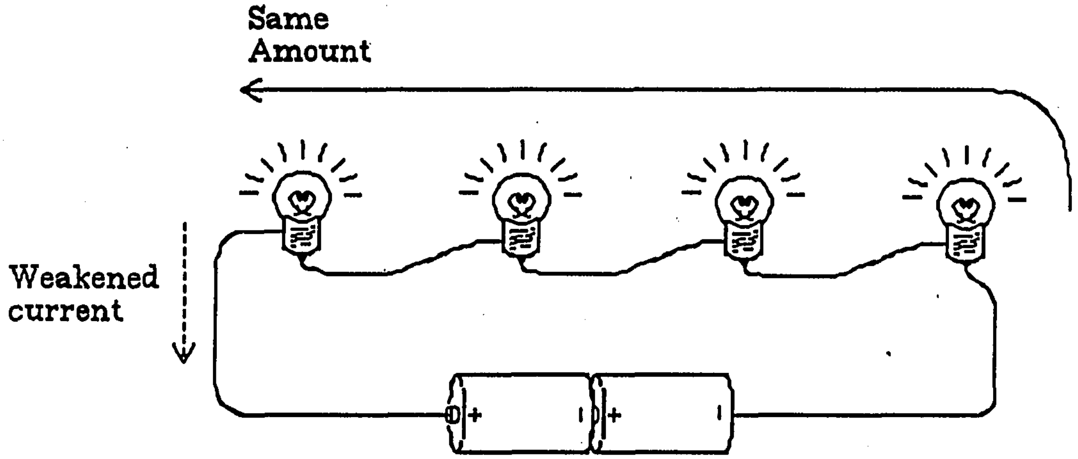


Figure 18

Remember that we can measure the current in a circuit with a device called an ammeter. We can use ammeters to test these students' belief. In Figure 19, we have added in ammeters. As you can see, the amount of current measured by each ammeter is the same, regardless of where it is placed in this kind of circuit. This experiment indicates that, in a series circuit, each device receives the same amount of current and that the amount of current flowing back to the battery is the same as the amount flowing out.

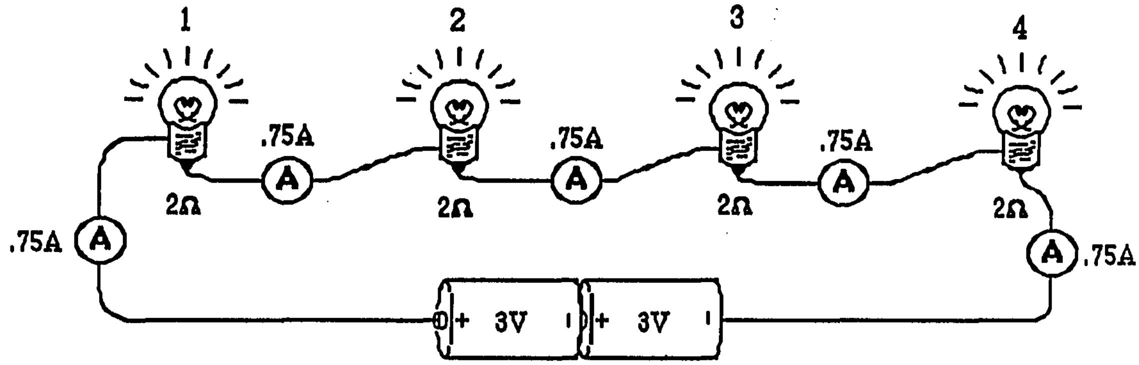


Figure 19

When resistors are connected in series, all current travels through each resistor, one after the other. The electric current in the circuit passes through each lamp (resistance) in succession. The current through each resistance is the same. The current flowing in a series circuit is the same everywhere along the wire. To determine the current in the circuit, the effective resistance of the circuit must be found. The effective resistance is the resistance of a single resistor that could replace all the resistors in the circuit. The single resistor would have the same current through it as the resistors it replaced. To find the effective resistance, Ohm's law is applied to the circuit as a whole and to its parts. The total voltage across the three resistors is equal to the potential difference across the generator, 120 V. The total voltage across the three resistors is also equal to the sum of the voltage across the individual resistors. That is,

$$V = V_1 + V_2 + V_3$$

According to Ohm's law the voltage across R, is given by $V_1 = IR_1$ where I is the current through he circuit, Therefore,

$$V = IR_1 + IR_2 + IR_3$$

$$V = I(R_1 + R_2 + R_3)$$

If the three resistors were replaced by a single resistor with resistance R, the voltage across R could be found using Ohm's law: V=IR. Comparing this equation with the one above shows that in a series circuit

$$R = R_1 + R_2 + R_3$$

The effective resistance, R, of resistors in series is the sum of the resistances. Note that the resistance of R is larger than that of any one of the resistors.

The current through a series circuit is found by calculating the effective resistance R, and then using Ohm's law in the form of I = V/R.

Example--Current in a Series Circuit

Four 15-ohm resistors are connected in series to a 30-V battery. What is the current in the circuit?

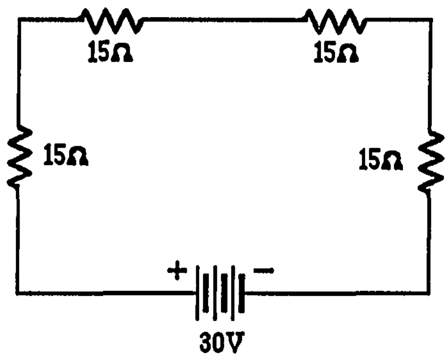


Figure 20

$$R = R_1 + R_2 + R_3 + R_4$$

$$= 15 + 15 + 15 + 15 = 60 \text{ ohms}$$

Then apply Ohm's law to the circuit.

$$I = \frac{V}{R} = \frac{30 \text{ V}}{60 \text{ ohms}} = 0.5 \text{ A}$$

EXAMPLE--Voltage Drops in a Series Circuit

A 5.0 ohm resistor and a 10.0 ohm resistor are connected in series and placed across a 45.0-V potential difference.

a. What is the effective resistance of the circuit?
b. What is the current through the circuit?
c. What is the voltage across each resistor?
d. What is the total voltage across the circuit?

Given: $R_1 = 5.0$ ohm
$R_2 = 10.0$ ohm
$V = 45.0$ V

Unknowns: R, I, V_1, V_2,
Basic equation: $V = IR$

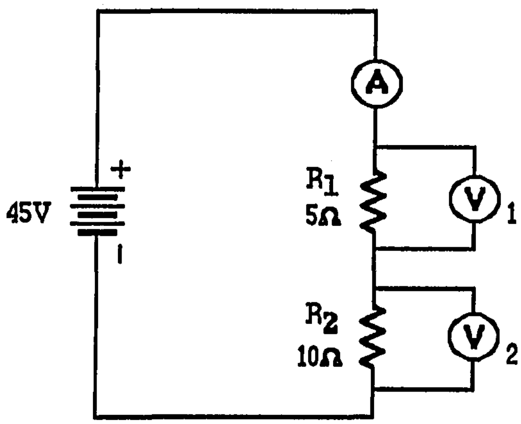


Figure 21

Solution:

a. $R = R_1 + R_2$

$= 5.0 + 10.0 = 15.0$ (ohm)

b. $I = \frac{V}{R} = \frac{45.0\ V}{15.0\ ohms} = 3.00\ A$

c. The voltage across R_1 is

$V_1 = IR_1 = (3.00\ A)\ (5.0\ ohms) = 15\ V$

The voltage across R_2 is

$V_2 = IR_2$

$= (3.00\ A)\ (10.0\ ohms) = 30.0\ V$

d. $V = V_1 + V_2$

$= 15\ V + 30.0\ V = 45\ V$

An important application of series resistors is the voltage divider. The voltage divider is designed to obtain a desired voltage from a battery that supplies a larger voltage. Consider the circuit in Figure 22. Two resistors, R_1 and R_2 are connected in series across a battery of voltage V. The effective resistance of the circuit is $R=R_1 + R_2$. The current, I, is given by $I = V/R=V/(R_1 + R_2)$. The desired voltage drop, V_2,is the voltage drop across resistor R_2. According to Ohm's law, V_2 equals IR_2. Replacing I by its equivalent calculated by the equation above gives the following:

$$V_2 = IR_2 = \left(\frac{V}{R_1 + R_2}\right) \times R_2 = \frac{VR_2}{R_1 + R_2}$$

EXAMPLE--Voltage Divider

A 9.0 V battery and two resistors, R_1 = 400 ohms and R_2 = 500 ohms, are connected as a voltage divider. What is the voltage across R_2?

Given: V = 9.0 V   Unknown: V_2
R_1 = 400 ohms
R_2 = 500 ohms   Basic equation: $V_2 = \frac{VR_2}{R_1 + R_2}$

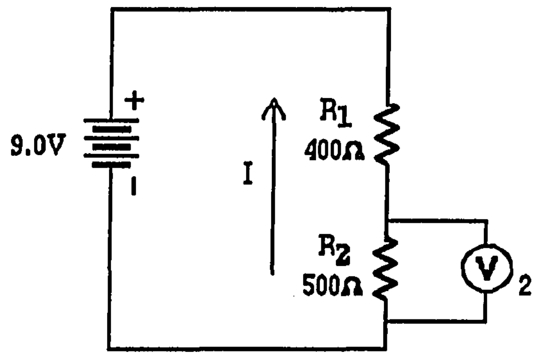


Figure 22

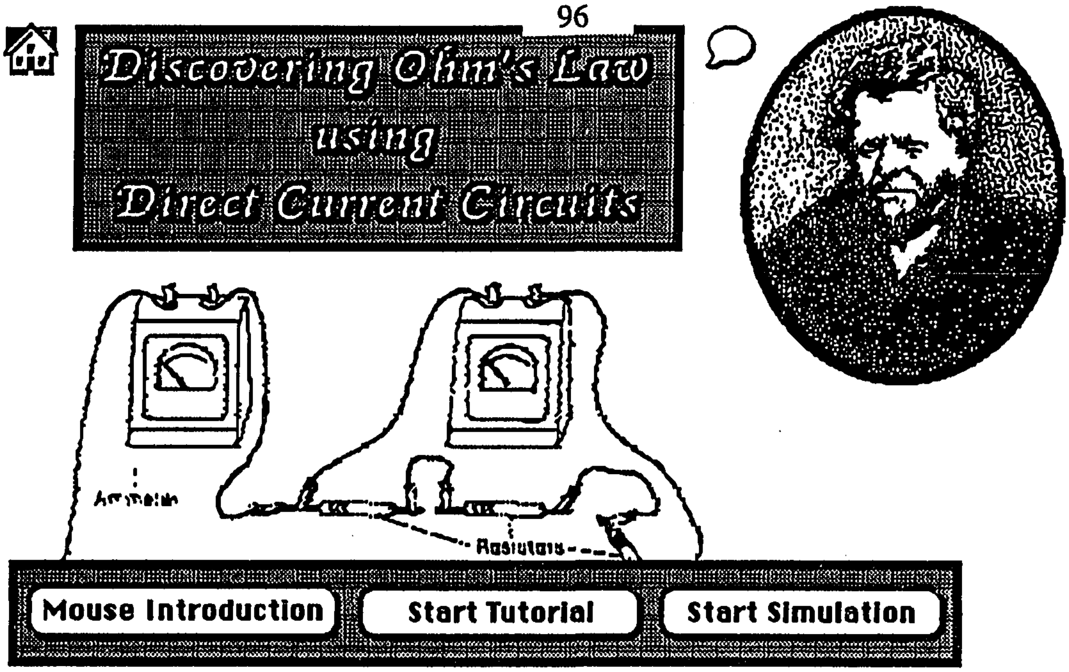
Solution:

$$V_2 = \frac{VR_2}{R_1 + R_2} = \frac{(9\ V)\ (500\ ohms)}{400\ ohms + 500\ ohms} = 5\ V$$

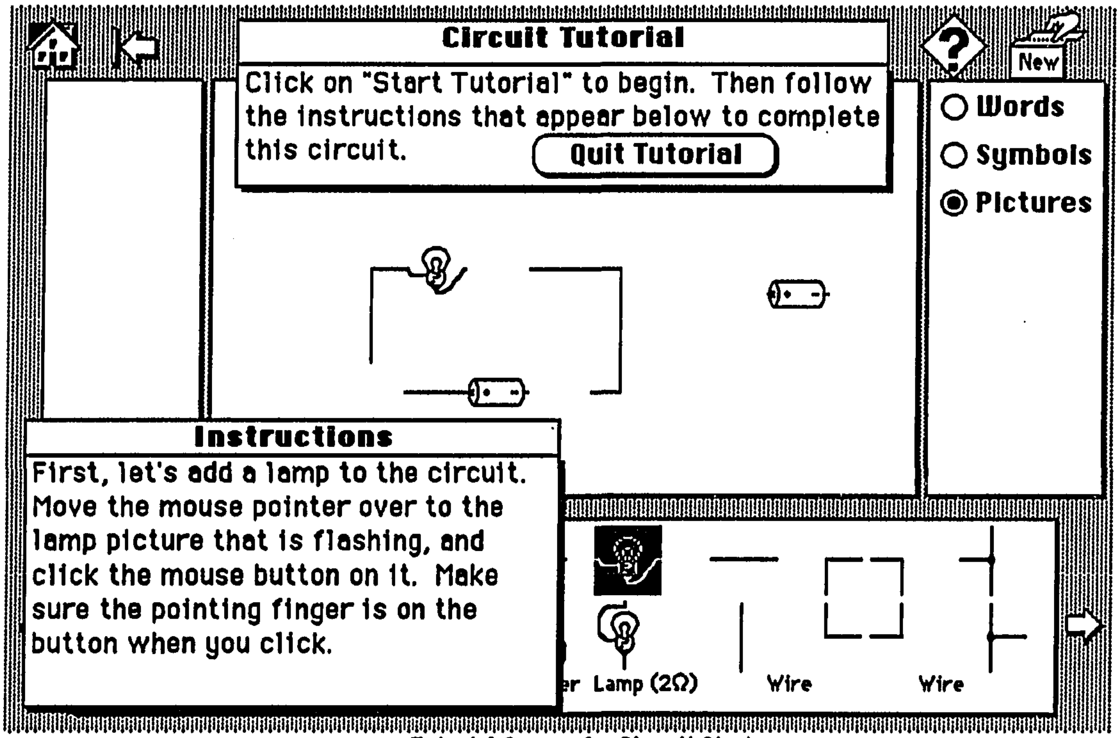
This is the end of the second section of the text. After you feel you have studied this booklet carefully, please return it to the proctor and you may leave. Remember to come to the proper room at the designated time tomorrow. Thank you.

APPENDIX C.

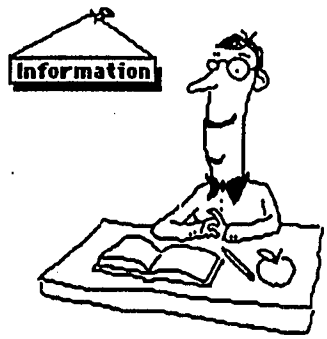
CIRCUIT STACK SCREENS AND SCRIPT



Title Screen for Circuit Stack

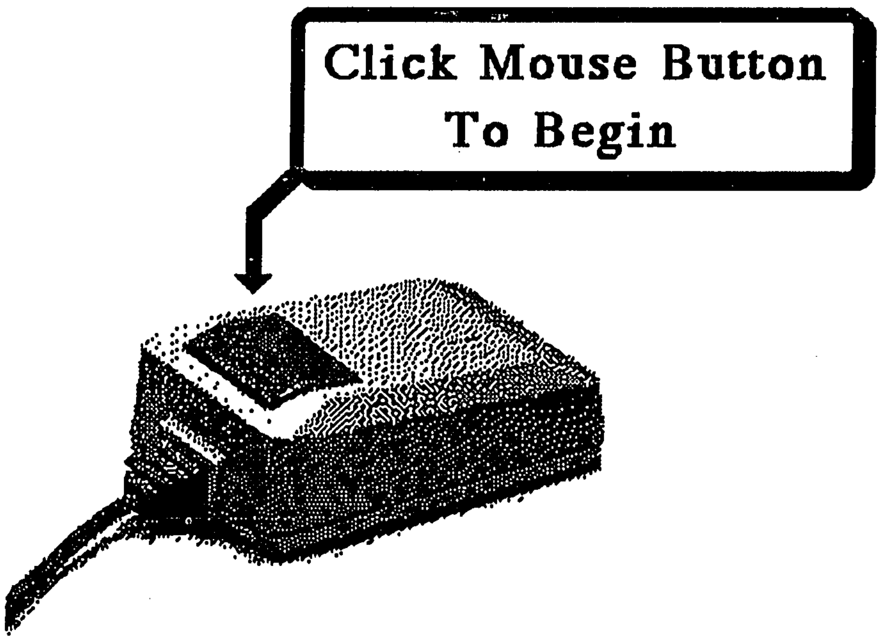


Tutorial Screen for Circuit Stack

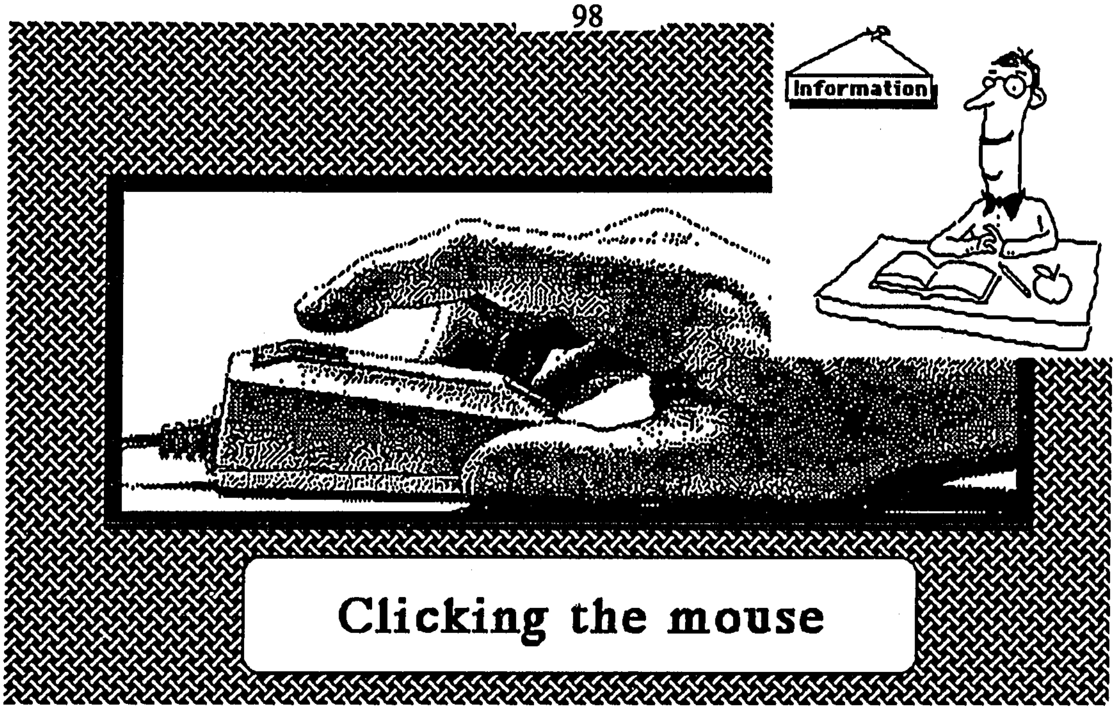


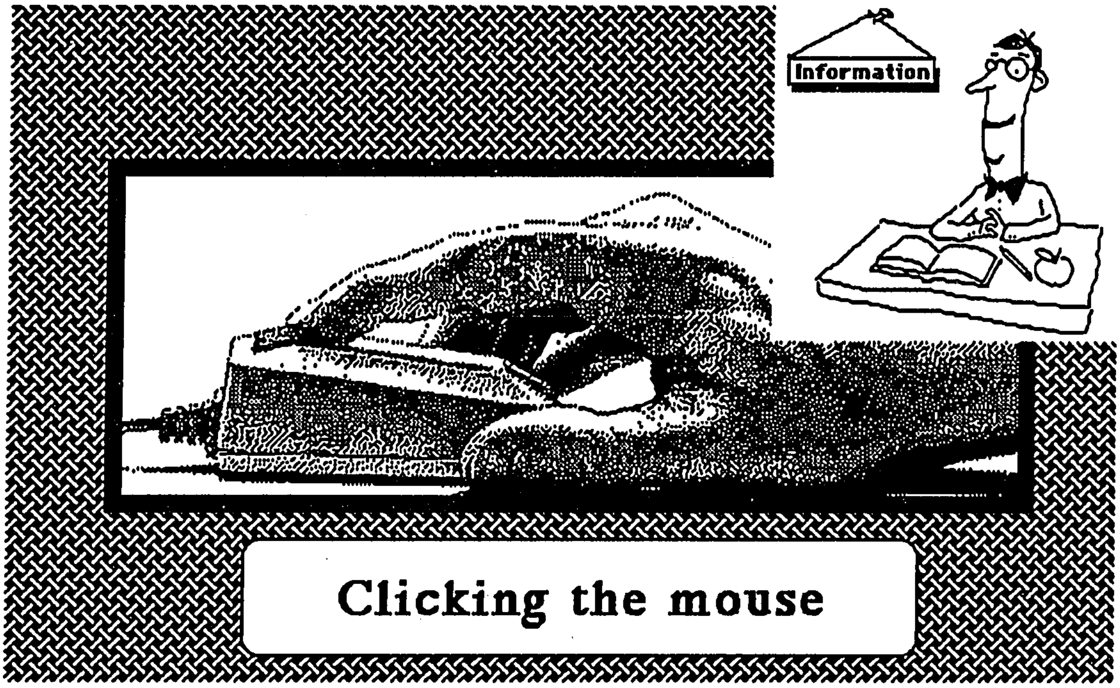
To use the electric circuit simulation, you will need

'Mouse Training'

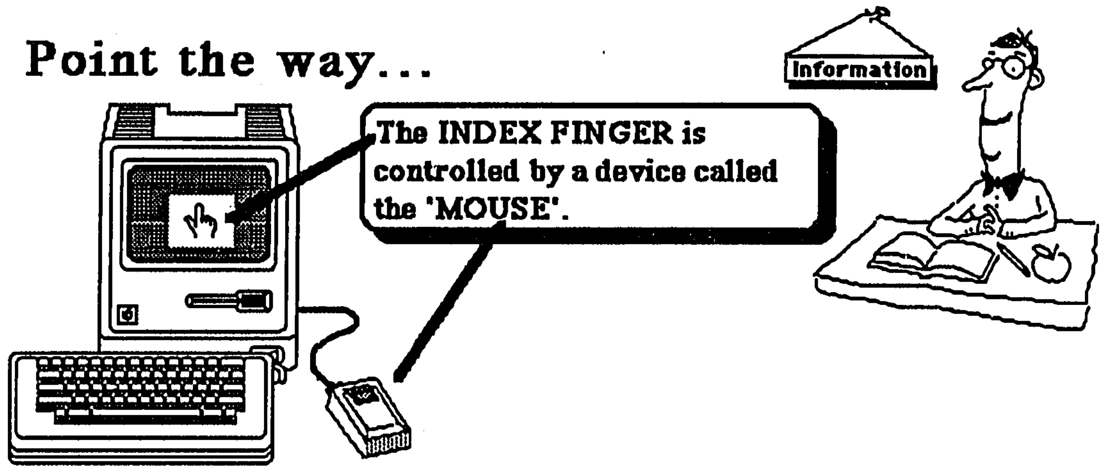


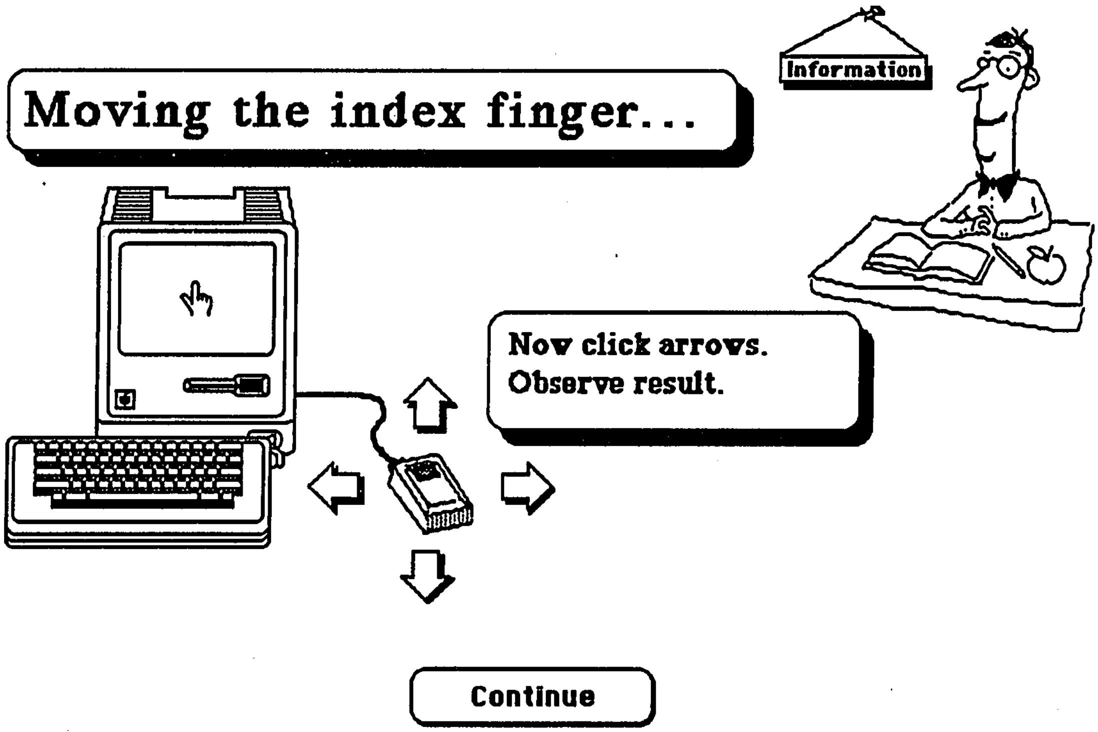
Mouse Instruction Screens



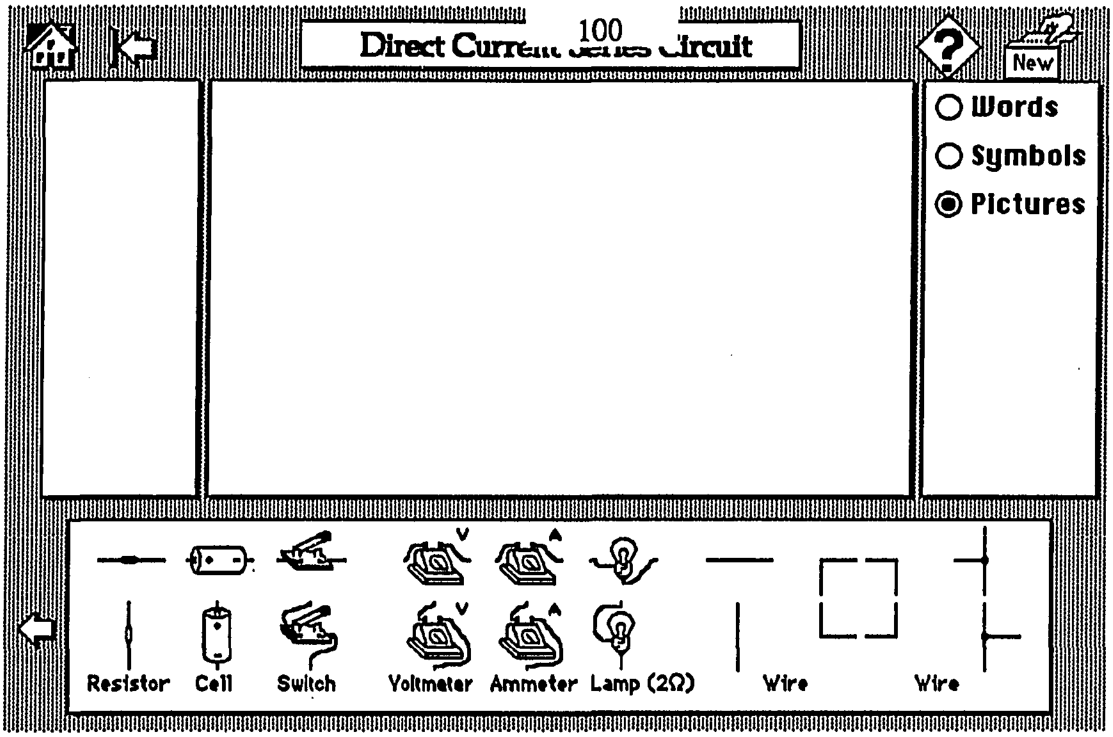


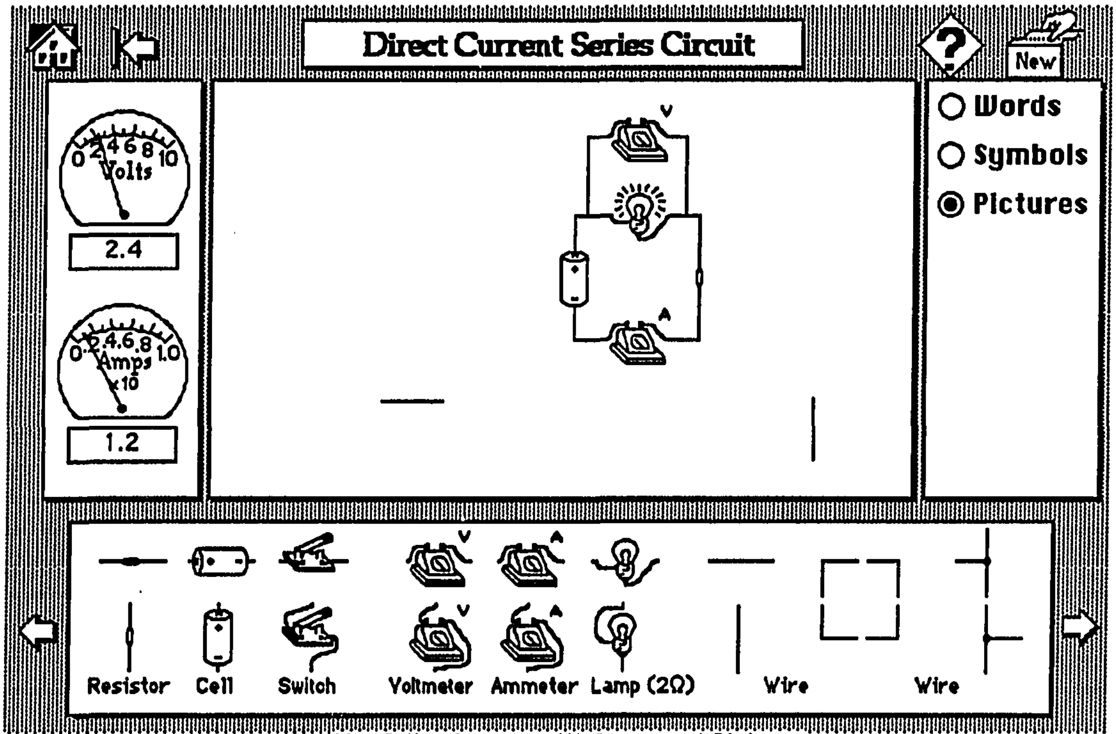
Mouse Training Screens (cont'd)



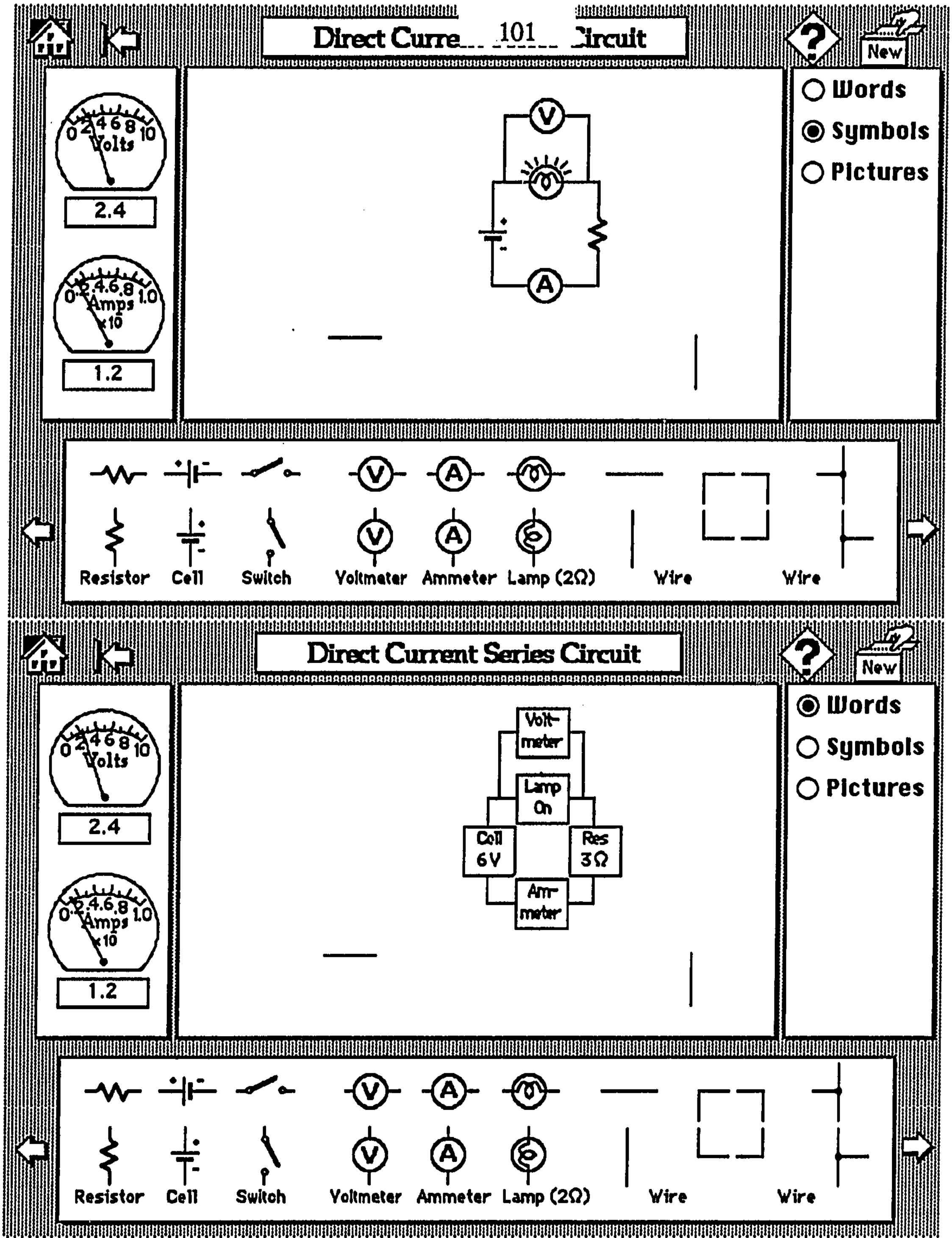


Mouse Training Screens (cont'd)





Simulation Screens with Component Pictures



Circuit Simulation with Component Symbols and Words

SCRIPTS FOR STACK: Circuit

```
=========================================================

**   STACK   SCRIPT   ***********************************
--Notes:
-- Each device (button) in the circuit has a device table (field)
-- associated with it. The button and the field are given the same
-- name when they are created. The table contains the following
-- entries:
--   Line 1. Device type (e.g., Switch, Lamp, Cell); blank for wire.
--   Line 2. Device state and/or, if applicable, voltage or resistance.
--   Line 3. Adjacent part. (see below)
--   Line 4. Adjacent part. (see below)
--    The adjacent parts are placed in lines 3 and 4 of each device
--     table in the following order:
--        left then right for horizontal parts
--        top then bottom for vertical parts
--        clockwise for corner wires
--  Line 5. Internal conductivity change due to a recent state change.
--     Either Yes or No, if yes, triggers evaluation of other device
--     states, then changed to no after the evaluation.

on evaluateCircuit deviceName
  global recording
  global deviceDirection  --Keeps track of the direction of search
   -- around the circuit
  --This handler is called when the internal conductivity of a device
  -- in the circuit changes. The handler starts from a device whose
  -- conductivity changed or from anywhere in the circuit where a part
  -- was removed, and finds subsequent devices in the circuit
  -- that can change states (everything except wires). It then sends
  -- a message to the device (button) to evaluate its state. The
  -- handler continues around the circuit until it comes back to the
  -- first device or until there is no connection.
  --Update conductivity-change line in device table
  lock screen
  --Check to see if the device coming in is a wire. If it is, then
  -- find the next device whose state can change.
  if ("wire" is in deviceName) or ("Switch" is in deviceName) then
    put firstDeviceAfter(deviceName) into deviceName
  end if
  if deviceName = "None" then exit evaluateCircuit
  if recording then
    put the date && the long time && "Evaluating Circuit" ¬
    after bg fld "Student Activities"
  end if
```

```
--If there's a voltmeter in the circuit, it must evaluate its state
if the visible of cd fld "Voltmeter Mask" is false then
  send evaluateState to cd btn "Voltmeter"
end if
--First device must evaluate its state
send evaluateState to cd btn deviceName
put deviceName into firstDevice
--Start the search going left or up
if char 1 of deviceName = "H" then
  put "left" into deviceDirection
else
  put "up" into deviceDirection
end if
put nextDeviceAfter(deviceName) into nextDevice
repeat until (nextDevice = firstDevice) or (nextDevice = "None")
  send evaluateState to cd btn nextDevice
  put nextDevice into deviceName
  put nextDeviceAfter(deviceName) into nextDevice
end repeat
--If the next device comes back "None", there is a break in the
--  circuit. The handler then has to start at the first device and
--  check the opposite way in the circuit to make sure that all
--  devices had a chance to evaluate themselves.
if nextDevice = "None" then  --Check the opposite way
  --First check to see if there is a voltmeter present
  if the visible of card fld "Voltmeter Mask" is false then
    -- Zero out the voltmeter because the circuit is broken
    send zeroVoltmeter to bg fld "Voltmeter Reading"
  end if
  if char 1 of firstDevice = "H" then
    put "right" into deviceDirection
  else
    put "down" into deviceDirection
  end if
  put nextDeviceAfter(firstDevice) into nextDevice
  repeat until (nextDevice = "None")  --Keep going until the break
    send evaluateState to cd btn nextDevice
    put nextDevice into deviceName
    put nextDeviceAfter(deviceName) into nextDevice
  end repeat
end if
unlock screen
hide message box
if recording then
  put return after bg fld "student activities"
end if
```

```
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
end evaluateCircuit

function firstDeviceAfter deviceName
  global deviceDirection
  --Check for a corner wire and get a different part to start with
  if char 1 of deviceName = "C" then
     --Set the search direction differently for corners
    if "-TR" is in word one of deviceName then
       put "right" into deviceDirection
    else if "-BR" is in word one of deviceName then
      put "down" into deviceDirection
    else if "-BL" is in word one of deviceName then
      put "left" into deviceDirection
    else if "-TL" is in word one of deviceName then
      put "up" into deviceDirection
    end if
  end if  --End of check for corner
  --if "-M" is in deviceName then
  --Start the search going left or up to get first device whose state
  --  can change
  if char 1 of deviceName = "H" then
    put "left" into deviceDirection
  else if char 1 of deviceName = "V" then
    put "up" into deviceDirection
  end if
  put nextDeviceAfter(deviceName) into nextDevice
  if nextDevice = "None" then
   --No connection or no changeable device; Check the other way
   if char 1 of deviceName = "C" then
      --Set the search direction differently for corners
    if "-TR" is in word one of deviceName then
      put "up" into deviceDirection
    else if "-BR" is in word one of deviceName then
      put "right" into deviceDirection
    else if "-BL" is in word one of deviceName then
      put "down" into deviceDirection
    else if "-TL" is in word one of deviceName then
      put "left" into deviceDirection
    end if
   end if  --End of check for corner
   if char 1 of deviceName = "H" then
     put "right" into deviceDirection
```

```
    else if char 1 of deviceName = "V" then
      put "down" into deviceDirection
    end if
    put nextDeviceAfter(deviceName) into nextDevice
    return nextDevice
  else
    return nextDevice
  end if
end firstDeviceAfter

function nextDeviceAfter partName
  global deviceDirection, direction
  --This function finds the next device (other than a wire) in the
  -- circuit. It returns the name of the device, or "None" if it
  -- finds that there is a circuit fault (no connection). It uses
  -- global variable "deviceDirection" to keep track of the search
  -- direction, since other handlers use the global variable
  -- "direction".
  put deviceDirection into direction
  put partName into firstPart
  put nextPartAfter(partName) into partName
  repeat while "Wire" is in word 1 of partName ¬
    and (partName ≠ firstPart) --Check for circuit of just wires
    put nextPartAfter(partName) into partName
  end repeat
  put direction into deviceDirection
  if ("Card" is in word 1 of partName) or (partName = firstPart) then
    return "None"
  else
    return partName
  end if
end nextDeviceAfter

function goodPaths partName
  --Not only does this function look for good paths to and from the
  -- battery, it also calculates circuit resistance and circuit
  -- voltage in the process.
  global direction, circuitResistance, circuitVoltage
  put 0 into circuitResistance
  put 0 into circuitVoltage
  put "Looking for good paths to and from battery" --, starting with " ¬
    --& partname --***
  put "False" into cellFound
  if char 1 of partName = "H" then
    put "left" into direction
  else
```

```
    put "up" into direction
  end if
   put partName into firstPart
  repeat
    --Find a path to the Cell (either side).  Also works if a cell is
    --  the incoming part
    --Meanwhile, calculate circuit resistance and voltage
    if "Cell" is in word 1 of partName then
   end if
    if "resistor" is in word 1 of partName then  --Get the resistance
     put word 1 of line 2 of cd fld partName into devResistance
     add devResistance to circuitResistance
    else if "cell" is in word 1 of partName then  --Get the voltage
     --Found a good path to the cell.
     --Later add determination of the pole reached.
     --Later a check will have to be put in here for a discharged
     --  battery and a check to see if this is the positive side
     put "True" into cellFound
     put word 1 of line 2 of cd fld partName into devVoltage
    add devVoltage to circuitVoltage
    else if "lamp" is in word 1 of partName then  --Lamps are 2Ω
     add 2 to circuitResistance
   end if
    put nextPartAfter(partName) into partName
    if faultAt(partName) then return "False"
    --Finding a middle wire means a possible parallel circuit
    if "-M" is in partName then
      put direction into oldDirection
      if shortCircuitAt(partName) then
       return "False"
    else
       put oldDirection into direction
    end if
   end if
    --Check for a fault or not finding a cell in the circuit
    if (partName = firstPart) then
     return cellFound
   end if
  end repeat
end goodPaths

function shortCircuitAt wireName
  global direction
  if "-ML" is in wireName then
    put "right" into direction
 else
```

```
    put "left" into direction
  end if
  put line 5 of cd fld wireName into partName
  repeat
    if ("Lamp" is in partName) or ("Resistor" is in partName) or ¬
    ("Cell" is in partName) or (faultAt(partName)) then
      return "False"
    end if
    if "-M" is in partName then
      return "True"
    end if
    put nextPartAfter(partName) into partName
  end repeat
end shortCircuitAt

function faultAt partName
  --Check for switch fault (switch open)
  if ("Switch" is in word 1 of partName) then
    if (line 2 of cd fld partName = "Open") then
      return "True"
    end if
  end if
  --Next check for circuit fault (no connection)
  if (word 1 of partName = "card") then
    return "True"
  end if
  --Check for middle wire (three connections)
  if "-M" is in partName then
    put 0 into connections
    if not ("Card" is in line 3 of cd fld partName) then
      add 1 to connections
    end if
    if not ("Card" is in line 4 of cd fld partName) then
      add 1 to connections
    end if
    if not ("Card" is in line 5 of cd fld partName) then
      add 1 to connections
    end if
    if connections < 2 then
      return "True"
    end if
  end if
  return "False"
end faultAt

function nextPartAfter partName
```

```
global direction
--Direction must be set to the direction around the circuit before
-- calling this function
get timelapse("Do it") --Display the Clock cursor with moving hand
put char 1 of partName into partType
if partType = "C" then  --Corner Wire changes the direction
  if direction = "left" then
    if "BL-" is in word 1 of partName then
      put "up" into direction
      return line 4 of cd fld partName
  else
      put "down" into direction
      return line 3 of cd fld partName
  end if
  else if direction = "right" then
    if "TR-" is in word 1 of partName then
      put "down" into direction
      return line 4 of cd fld partName
    else   --Bottom Right
      put "up" into direction
      return line 3 of cd fld partName
  end if
  else if direction = "up" then
    if "TL-" is in word 1 of partName then
      put "right" into direction
      return line 4 of cd fld partName
    else   --Top Right
      put "left" into direction
      return line 3 of cd fld partName
  end if
  else  --Down
    if "BL-" is in word 1 of partName then
      put "right" into direction
      return line 3 of cd fld partName
    else  --Bottom Right
      put "left" into direction
      return line 4 of cd fld partName
  end if
 end if
else  --The following is for all horizontal & vertical parts
  if direction = "left" or direction = "up" then
    return line 3 of cd fld partName
  else if direction = "right" or direction = "down" then
    return line 4 of cd fld partName
 end if
end if
```

```
end nextPartAfter

function timelapse string
  --This function shows the clock cursor with moving hand
  global loop
  if string <> "Do it" then return(string) -- if called by mistake.
  add 1 to loop
  if loop = 1 then set cursor to pos1
  if loop = 2 then set cursor to pos2
  if loop = 3 then set cursor to pos3
  if loop = 4 then set cursor to pos4
  if loop = 5 then set cursor to pos5
  if loop = 6 then set cursor to pos6
  if loop = 7 then set cursor to pos7
  if loop = 8 then
    set cursor to pos8
    put 0 into loop
  end if
  return("Do it")
end timelapse

on openStack
  global recording
  hide message box
  hide menubar
  set cantDelete of this stack to true
  -- The following flag is set to true if you want the user's activites
  --   recorded in the bg fld "Student Activities"
  put "True" into recording
end openStack

on openCard
end openCard

on newCard
  -- cover up the meter drawings by copying opaque masks to the card
  show bg fld "Voltmeter Mask"
  show bg fld "Ammeter Mask"
  set cursor to watch
  lock screen
  hide message box
  hide bg fld "Voltage x10 Mask"
  hide bg fld "Amperage x10 Mask"
  show bg fld "Digital Ammeter Reading"
  select bg fld "Digital Ammeter Reading"
  doMenu "Copy Field"
```

```
    doMenu "Paste Field"
    hide bg fld "Digital Ammeter Reading"
    show bg fld "Digital Voltmeter Reading"
    select bg fld "Digital Voltmeter Reading"
    doMenu "Copy Field"
    doMenu "Paste Field"
    hide bg fld "Digital Voltmeter Reading"
    select bg fld "Voltmeter Mask"
    doMenu "Copy Field"
    doMenu "Paste Field"
    hide bg fld "Voltmeter Mask"
    select bg fld "Ammeter Mask"
    doMenu "Copy Field"
    doMenu "Paste Field"
    hide bg fld "Ammeter Mask"
  choose browse tool
  set the hilite of bg btn "Words" to false
  set the hilite of bg btn "Symbols" to false
  set the hilite of bg btn "Pictures" to true
  put "false" into line 1 of bg fld "Button Values"
  put "false" into line 2 of bg fld "Button Values"
  put "true" into line 3 of bg fld "Button Values"
  send setBgPictures to bg btn "Pictures"
  put "To move the part:" & return & "  Click where you" & ¬
  "  want to put it." into bg fld "Moving Instructions"
  put "Cancel" into bg fld "Cancel Move"
  put "To measure the voltage of a part of the circuit:" & return & ¬
  "  Click the mouse on both" & return & ¬
  "  sides of the part you want" & return & "  to measure." into ¬
   bg field "Voltmeter Instructions"
  put "Cancel" into bg fld "Cancel Voltmeter Move"
  show bg fld "Voltage x10 Mask"
  show bg fld "Amperage x10 Mask"
  put "Digital Only" into cd fld "Digital Ammeter Reading"
  put "Digital Only" into cd fld "Digital Voltmeter Reading"
  hide cd fld "Digital Ammeter Reading"
  hide cd fld "Digital Voltmeter Reading"
  unlock screen
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
end newCard
```

```
**   BACKGROUND   #1:   Circuit   **************************************
```

```
on openBackground
  push recent cd
end openBackground

on mouseDown
  global targetName
  put the short name of the target into targetName
   --put the clickLoc
end mouseDown

on updateRightPos partName, oldLoc, newLoc
  global targetName
  --Don't update old location if it's in the parts bin
  if not (oldLoc is within "29,242,486,333") then
   --Check to see what is to the right of the old location
    click at (item 1 of oldLoc + 30),(item 2 of oldLoc)
   put targetName into oldAdjName
    --Only update old location if there's a part there
   if word 1 of oldAdjName ≠ "card" then
     if "BR-" is in word 1 of oldAdjName then
        --The bottom right corner wire order is Top in 3, Left in 4
       put the short name of this cd into line 4 of cd fld oldAdjName
     else if "-MR" is in word 1 of oldAdjName then
        --The middle right wire uses line 5 for what's on the left
       put the short name of this cd into line 5 of cd fld oldAdjName
    else
       put the short name of this cd into line 3 of cd fld oldAdjName
    end if
  end if
 end if
 --Check to see what is to the right of the new location
 click at (item 1 of newLoc + 30),(item 2 of newLoc)
 put targetName into newAdjName
 if "BL-" is in word 1 of partName then
   --The bottom left corner wire order is Right in 3, Top in 4
  put newAdjName into line 3 of cd fld partName
 else if "-ML" is in word 1 of partName then
   --The middle left wire uses line 5 for what's on the right
  put newAdjName into line 5 of cd fld partName
else
  put newAdjName into line 4 of cd fld partName
end if
if word 1 of newAdjName ≠ "card" then
  if "BR-" is in word 1 of newAdjName then
     --The bottom right corner wire order is Top in 3, Left in 4
    put partName into line 4 of cd fld newAdjName
```

```
    else if "-MR" is in word 1 of newAdjName then
      --The middle right wire uses line 5 for what's on the left
      put partName into line 5 of cd fld newAdjName
    else
      put partName into line 3 of cd fld newAdjName
    end if
  end if
end updateRightPos

on updateLeftPos partName, oldLoc, newLoc
  global targetName
  --Don't update old location if it's in the parts bin
  if not (oldLoc is within "29,242,486,333") then
    --Check to see what is to the left of the old location
    click at (item 1 of oldLoc - 30),(item 2 of oldLoc)
    put targetName into oldAdjName
    --Only update old location if there's a part there
    if word 1 of oldAdjName ≠ "card" then
      if "BL-" is in word 1 of oldAdjName then
        --The bottom left corner wire order is Right in 3, Top in 4
        put the short name of this cd into line 3 of cd fld oldAdjName
      else if "-ML" is in word 1 of oldAdjName then
        --The middle left wire uses line 5 for what's on the right
        put the short name of this cd into line 5 of cd fld oldAdjName
      else
        put the short name of this cd into line 4 of cd fld oldAdjName
      end if
    end if
  end if
  --Check to see what is to the left of the old location
  click at (item 1 of newLoc - 30),(item 2 of newLoc)
  put targetName into newAdjName
  if "BR-" is in word 1 of partName then
    --The bottom right corner wire order is Top in 3, Left in 4
    put newAdjName into line 4 of cd fld partName
  else if "-MR" is in word 1 of partName then
    --The middle right wire uses line 5 for what's on the left
    put newAdjName into line 5 of cd fld partName
  else
    put newAdjName into line 3 of cd fld partName
  end if
  --Only update new location if there's a part there
  if word 1 of newAdjName ≠ "card" then
    if "BL-" is in word 1 of newAdjName then
      --The bottom left corner wire order is Right in 3, Top in 4
      put partName into line 3 of cd fld newAdjName
```

```
    else if "-ML" is in word 1 of newAdjName then
      --The middle left wire uses line 5 for what's on the right
      put partName into line 5 of cd fld newAdjName
    else
      put partName into line 4 of cd fld newAdjName
    end if
  end if
end updateLeftPos

on updateTopPos partName, oldLoc, newLoc
  global targetName
  --Don't update old location if it's in the parts bin
  if not (oldLoc is within "29,242,486,333") then
    --Check to see what is on the top of the old location
    click at (item 1 of oldLoc),(item 2 of oldLoc - 30)
    put targetName into oldAdjName
    --Only update old location if there's a part there
    if word 1 of oldAdjName ≠ "card" then
      if "TL-" is in word 1 of oldAdjName then
        --The top left corner wire order is Bottom in 3, Right in 4
        put the short name of this cd into line 3 of cd fld oldAdjName
      else
        put the short name of this cd into line 4 of ¬
        cd fld oldAdjName
      end if
    end if
  end if
  --Check to see what is on the top of the new location
  click at (item 1 of newLoc),(item 2 of newLoc - 30)
  put targetName into newAdjName
  if "BL-" is in word 1 of partName then
    --The bottom left corner wire order is Right in 3, Top in 4
    put newAdjName into line 4 of cd fld partName
  else
    put newAdjName into line 3 of cd fld partName
  end if
  if word 1 of newAdjName ≠ "card" then
    if "TL-" is in word 1 of newAdjName then
      --The top left corner wire order is Bottom in 3, Right in 4
      put partName into line 3 of cd fld newAdjName
    else
      put partName into line 4 of cd fld newAdjName
    end if
  end if
end updateTopPos
```

```
on updateBottomPos partName, oldLoc, newLoc
  global targetName
  --Don't update old location if it's in the parts bin
  if not (oldLoc is within "29,242,486,333") then
    --Check to see what is on the bottom of the old location
    click at (item 1 of oldLoc),(item 2 of oldLoc + 30)
    put targetName into oldAdjName
    if word 1 of oldAdjName ≠ "card" then
      if "BL-" is in word 1 of oldAdjName then
        --The bottom left corner wire order is Right in 3, Top in 4
        put the short name of this cd into line 4 of ¬
        cd fld oldAdjName
      else
        put the short name of this cd into line 3 of ¬
        cd fld oldAdjName
      end if
    end if
  end if
  --Check to see what is on the bottom of the old location
  click at (item 1 of newLoc),(item 2 of newLoc + 30)
  put targetName into newAdjName
  if "TL-" is in word 1 of partname then
    --The top left corner wire order is Bottom in 3, Right in 4
    put newAdjName into line 3 of cd fld partName
  else
    put newAdjName into line 4 of cd fld partName
  end if
  if word 1 of newAdjName ≠ "card" then
    if "BL-" is in word 1 of newAdjName then
      --The bottom left corner wire order is Right in 3, Top in 4
      put partname into line 4 of cd fld newAdjName
    else
      put partName into line 3 of cd fld targetName
    end if
  end if
end updateBottomPos

on updateAdjParts partName, oldLoc, newLoc
  --1. Update the adjacent parts at the old location with "card"
  --2. Put into the individual part info field of a part,
  --   the name of the parts that are adjacent it
  --3. Update the adjacent parts at the new location with the partname.
  --The partNames are placed in lines 3 and 4 of each part info field
  --  (and line 5 for middle wires) in the following order:
  --     left then right for horizontal
  --     top then bottom for vertical (then right/left for middle wires)
```

```
  --     clockwise for corners
  if "H-" is in word 1 of partName then
    updateRightPos partName, oldLoc, newLoc
    updateLeftPos partName, oldLoc, newLoc
  else if "V-" is in word 1 of partName then
    updateTopPos partName, oldLoc, newLoc
    updateBottomPos partName, oldLoc, newLoc
    if "-ML" is in word 1 of partName then
      updateRightPos partName, oldLoc, newLoc
    else if "-MR" is in word 1 of partName then
      updateLeftPos partName, oldLoc, newLoc
    end if
  else if "TR-" is in word 1 of partName then
    updateLeftPos partName, oldLoc, newLoc
    updateBottomPos partName, oldLoc, newLoc
  else if "BR-" is in word 1 of partName then
    updateTopPos partName, oldLoc, newLoc
    updateLeftPos partName, oldLoc, newLoc
  else if "BL-" is in word 1 of partName then
    updateRightPos partName, oldLoc, newLoc
    updateTopPos partName, oldLoc, newLoc
  else if "TL-" is in word 1 of partName then
    updateBottomPos partName, oldLoc, newLoc
    updateRightPos partName, oldLoc, newLoc
  end if
end updateAdjParts

on makeNewPart partName
  set cursor to wait
  lock screen
  -- Copy part button to card
  put partName && "Template" into templateName
  show bg btn templateName
  select bg btn templateName
  doMenu "Copy Button"
  doMenu "Paste Button"
  hide bg btn templateName
  -- Copy part field to card
  show bg fld "Property Template"
  select bg fld "Property Template"
  doMenu "Copy Field"
  doMenu "Paste Field"
  hide bg fld "Property Template"
  choose browse tool
  -- Name the new card button and field, which are also the highest
  --    numbered card button and field
```

```
  put the number of cd btns into newButtonNumber
  put the number of cd flds into newFieldNumber
  put partName && the id of cd btn newButtonNumber into newPartName
  set the name of cd btn newButtonNumber to newPartName
  set the name of cd fld newFieldNumber to newPartName
  -- Check to see if symbols, pics or words are showing and set new
  --   part accordingly, except for wires which are always the same
  hide cd fld newPartName
  if the hilite of bg btn "Pictures" is true then
    send setPicture to cd btn newPartName
  else
    if the hilite of bg btn "Symbols" is true then
      send setSymbol to cd btn newPartName
    else
      send setWord to cd btn newPartName
    end if
  end if
  set the loc of cd fld newPartName to the loc of cd btn newPartName
  set the style of cd btn newPartName to shadow
  unlock screen
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
end makeNewPart

on turnOn buttonNo, groupID
  global cardChanged
  put "True" into cardChanged
  if groupID = "radioGroup1" then
    put the number of bg btn "Pictures" into start
    put the number of bg btn "Words" into finish
  end if
  repeat with counter = start to finish
    if buttonNo = counter then
      set hilite of bg btn counter to true
    else
      set hilite of bg btn counter to false
    end if
  end repeat
end turnOn

on movePart partName  --Note: Can't delete a part right now
  -- This handler takes one parameter:
  --   1. The short name of the part (button) to be moved
  global targetName, partsAround, needCircuitEval, finished, evalPart
```

```
global recording
set cursor to arrow
put "False" into finished
unlock screen
put word 2 of partName into partNumber
put char 1 of partName into partType
--This very tight loop traps all user mouseClicks that occured
--  during the handler's execution
repeat until the mouseClick is false
end repeat
-- Show field with instructions
show bg fld "Moving Instructions"
show bg fld "Cancel Move"
-- Get and save the mouse click
wait until the mouseClick
put the clickLoc into partLoc
hide bg fld "Moving Instructions"
hide bg fld "Cancel Move"
if partLoc is within the rect of bg fld "Cancel Move" then
  exit movePart
end if
set cursor to wait
lock screen
--if the part is being moved out of the circuit, and there are
--  partnames in both lines 3 & 4 of the part field, it will probably
--  make a difference in the evaluation of the circuit. If so, set
--  a flag that says to evaluate the circuit after the part is moved.
if (line 3 of cd fld partName is empty) or ¬
(line 4 of cd fld partName is empty) or ¬
("card" is in line 3 of cd fld partName) or ¬
("card" is in line 4 of cd fld partName) then
  put "False" into needCircuitEval
else
  put "True" into needCircuitEval
   --Circuit evaluation starts with this part
  put line 3 of cd fld partName into evalPart
end if
-- Part must be placed in the proper area on the card
if not (partLoc is within "96,37,417,208") then
beep
 answer "Part cannot be placed outside circuit area." ¬
 with "Cancel" or "Try Again"
 if it = "Cancel" then
   exit movePart
else
  movePart partName
```

```
    exit movePart
  end if
 end if
 click at partLoc
 -- Part cannot be placed on top of another
 if not("Card" is in targetName) then
  beep
   answer "Part cannot be placed on top of another." ¬
    with "Cancel" or "Try Again"
   if it = "Cancel" then
     exit movePart
  else
    movePart partName
     exit movePart
  end if
end if
                -------------------------
 put 0 into partsAround
put the loc of cd btn partName into oldLoc
 -- Set up adjacent click positions
 put partLoc into bottomPosition
 put partLoc into topPosition
 put partLoc into rightPosition
 put partLoc into leftPosition
 put (item 1 of rightPosition + 30) into item 1 of rightPosition
 put (item 1 of leftPosition - 30) into item 1 of leftPosition
 put (item 2 of bottomPosition + 30) into item 2 of bottomPosition
 put (item 2 of topPosition - 30) into item 2 of topPosition
 -- Check for adjacent parts at all 4 positions around part's new loc
 checkRightPos partName, oldLoc, rightPosition
 if finished then exit movePart
checkLeftPos partName, oldLoc, leftPosition
 if finished then exit movePart
checkTopPos partName, oldLoc, topPosition
 if finished then exit movePart
checkBottomPos partName, oldLoc, bottomPosition
 if finished then exit movePart
-- Beep if none of the parts around it fit with the one being moved
if partsAround > 0 then
 beep
   answer "Part will not fit here." with "Cancel" or "Try Again"
  if recording then
    put the date && the long time && quote & partName & quote && ¬
      "placed incorrectly." & return into bg fld "Student Activities"
  end if
  if it = "Cancel" then
```

```
      exit movePart
    else
      movePart partName
      exit movePart
    end if
  else
    placePart partName, partLoc
    updateAdjParts partName, oldLoc, partLoc
    --Check to see if the part was moved out of the circuit
    if needCircuitEval then
      unlock screen
      evaluateCircuit evalPart
    end if
  end if
  unlock screen
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
end movePart

on checkRightPos partName, oldLoc, rightPosition
  global partsAround, targetName, needCircuitEval, finished, evalPart
  put "False" into finished
  put char 1 of partName into partType
  click at rightPosition  -- Check to the right
  if word 1 of targetName ≠ "card" then
    put targetName into tempName
    put (partsAround + 1) into partsAround
    put char 1 of tempName into tempType
    if ((partType is "H" or tempType is "H") or¬
    (partType is "C" and tempType is "C")) and ¬
    horizPartsFit(partName, tempName) then
      -- Get the adjacent part location
      put the loc of cd btn tempName into newLoc
      put (item 1 of newLoc - 29) into item 1 of newLoc
      -- Only place the part if no other part is there
      click at newLoc
      if word 1 of targetName = "card" then
        -- Put new part 1 button-width left of adjacent part
        placePart partName, newLoc
        updateAdjParts partName, oldLoc, newLoc
        --Check to see if the part is being moved next to two others
        if (not("card" is in line 3 of cd fld partName) and ¬
        not("card" is in line 4 of cd fld partName)) then
        unlock screen
```

```
          evaluateCircuit partName  --check for state changes
          put "False" into needCircuitEval
        end if
        if needCircuitEval then
          unlock screen
          evaluateCircuit evalPart  --check for state changes
        end if
        put "True" into finished
      end if
    end if
  end if
end checkRightPos

on checkLeftPos partName, oldLoc, leftPosition
  global partsAround, targetName, needCircuitEval, finished, evalPart
  put "False" into finished
  put char 1 of partName into partType
  click at leftPosition  -- Check to the left
  if word 1 of targetName ≠ "card" then
    put targetName into tempName
    put (partsAround + 1) into partsAround
    put char 1 of tempName into tempType
    if ((partType is "H" or tempType is "H") or¬
    (partType is "C" and tempType is "C")) and ¬
    horizPartsFit(tempName, partName) then
      -- Get the adjacent part location
      put the loc of cd btn tempName into newLoc
      put (item 1 of newLoc + 29) into item 1 of newLoc
      -- Only place the part if no other part is there
      click at newLoc
      if word 1 of targetName = "card" then
          -- Put new part 1 button-width right of adjacent part
        placePart partName, newLoc
        updateAdjParts partName, oldLoc, newLoc
        --Check to see if the part is being moved next to two others
        if (not("card" is in line 3 of cd fld partName) and ¬
        not("card" is in line 4 of cd fld partName)) then
          unlock screen
          evaluateCircuit partName  --check for state changes
          put "False" into needCircuitEval
        end if
        if needCircuitEval then
          unlock screen
          evaluateCircuit evalPart  --check for state changes
        end if
        put "True" into finished
```

```
      end if
    end if
  end if
end checkLeftPos

on checkTopPos partName, oldLoc, topPosition
  global partsAround, targetName, needCircuitEval, finished, evalPart
  put "False" into finished
  put char 1 of partName into partType
  click at topPosition  -- Check above
  if word 1 of targetName ≠ "card" then
   put targetName into tempName
     put (partsAround + 1) into partsAround
   put char 1 of tempName into tempType
    if ((partType is "V" or tempType is "V") or¬
   (partType is "C" and tempType is "C")) and ¬
    vertPartsFit(tempName, partName) then
      -- Get the adjacent part location
    put the loc of cd btn tempName into newLoc
     put (item 2 of newLoc + 29) into item 2 of newLoc
      -- Only place the part if no other part is there
    click at newLoc
     if word 1 of targetName = "card" then
         -- Put new part 1 button-width below adjacent part
      placePart partName, newLoc
      updateAdjParts partName, oldLoc, newLoc
       --Check to see if the part is being moved next to two others
        if (not("card" is in line 3 of cd fld partName) and ¬
        not("card" is in line 4 of cd fld partName)) then
        unlock screen
          evaluateCircuit partName  --check for state changes
         put "False" into needCircuitEval
      end if
       if needCircuitEval then
        unlock screen
          evaluateCircuit evalPart  --check for state changes
      end if
       put "True" into finished
    end if
  end if
 end if
end checkTopPos

on checkBottomPos partName, oldLoc, bottomPosition
  global partsAround, targetName, needCircuitEval, finished, evalPart
  put "False" into finished
```

```
  put char 1 of partName into partType
  click at bottomPosition -- Check below
  if word 1 of targetName ≠ "card" then
    put targetName into tempName
    put (partsAround + 1) into partsAround
    put char 1 of tempName into tempType
    if ((partType is "V" or tempType is "V") or¬
    (partType is "C" and tempType is "C")) and ¬
    vertPartsFit(partName, tempName) then
      put the loc of cd btn tempName into newLoc
      put (item 2 of newLoc - 29) into item 2 of newLoc
      -- Only place the part if no other part is there
      click at newLoc
      if word 1 of targetName = "card" then
        -- Put new part 1 button-width above adjacent part
        placePart partName, newLoc
        updateAdjParts partName, oldLoc, newLoc
        --Check to see if the part is being moved next to two others
        if (not("card" is in line 3 of cd fld partName) and ¬
        not("card" is in line 4 of cd fld partName)) then
          unlock screen
          evaluateCircuit partName --check for state changes
          put "False" into needCircuitEval
        end if
        if needCircuitEval then
          unlock screen
          evaluateCircuit evalPart --check for state changes
        end if
        put "True" into finished
      end if
    end if
  end if
end checkBottomPos

on placePart partName, partLoc
  global recording
  -- This handler takes two parameters:
  --  1. The short name of the part (button) to be placed
  --  2. The location where the part is to be placed
  if recording then
    put the date && the long time && quote & partName & quote after ¬
    bg fld "Student Activities"
    if "Cell" is in partName or "Res" is in partName then
      put "=" & line 2 of cd fld partName after ¬
      bg fld "Student Activities"
    end if
```

```
    put "  " & partLoc & return after ¬
    bg fld "Student Activities"
  end if
  set the style of cd btn partName to transparent
  set the loc of cd btn partName to partLoc
  set the loc of cd fld partName to partLoc
end placePart

function horizPartsFit leftPartName, rightPartName
  put char 1 of leftPartName into leftPartType
  put char 1 of rightPartName into rightPartType
  -- Left Corner (on left) fits Right Corner (on right)
  if (leftPartType is "C") and (rightPartType is "C") then
    if ("L-" is in word 1 of leftPartName) and ¬
    ("R-" is in word 1 of rightPartName) then
      return "True"
  else
      return "False"
  end if
 else
    -- Two horizontal parts fit
    if leftPartType = rightPartType then
      return "True"
  end if
 end if
 if (leftPartType is "H") and (rightPartType is "C") then
    -- Horizontal (on left) fits Right Corner (on right)
   if "R-" is in word 1 of rightPartName then
     return "True"
  else
     return "False"
  end if
 end if
 if (leftPartType is "C") and (rightPartType is "H") then
    -- Left Corner (on left) fits horizontal (on right)
   if "L-" is in word 1 of leftPartName then
     return "True"
  else
     return "False"
  end if
 end if
 if ("-ML" is in word 1 of leftPartName) and ¬
 (rightPartType is "H") then
   -- Middle Left (on left) fits horizontal (on right)
   return "True"
end if
```

```
  if ("-MR" is in word 1 of rightPartName) and ¬
  (leftPartType is "H") then
    -- Middle Right (on right) fits horizontal (on left)
    return "True"
  end if
  return "False"
end horizPartsFit

function vertPartsFit topPartName, bottomPartName
  put char 1 of topPartName into topPartType
  put char 1 of bottomPartName into bottomPartType
  -- Top Corner (on top) fits Bottom Corner (on bottom)
  if (topPartType is "C") and (bottomPartType is "C") then
    if ("-T" is in word 1 of topPartName) and ¬
    ("-B" is in word 1 of bottomPartName) then
      return "True"
    else
      return "False"
    end if
  else
    -- Two vertical parts fit
    if topPartType = bottomPartType then
      return "True"
    end if
  end if
  -- Vertical (on top) fits Bottom Corner (on bottom)
  if (topPartType is "V") and (bottomPartType is "C") then
    if "-B" is in word 1 of bottomPartName then
      return "True"
    else
      return "False"
    end if
  end if
  -- Top Corner (on top) fits Vertical (on bottom)
  if (topPartType is "C") and (bottomPartType is "V") then
    if "-T" is in word 1 of topPartName then
      return "True"
    else
      return "False"
    end if
  end if
  return "False"
end vertPartsFit

on openCard
  set cursor to watch
```

```
  lock screen
  if line 1 of bg fld "Button Values" ≠ "" then
    put the number of bg btn "Pictures" into firstButton
    repeat with x = 0 to 2
      if line (x + 1) of bg fld "Button Values" = "true" then
        send mouseUp to bg btn (firstButton + x)
      end if
    end repeat
  end if
  hide message box
  hide bg fld "Parts Help"
  hide bg fld "Circuit Help"
  hide bg fld "Meter Help"
  hide bg btn "Symbols Help"
  hide bg fld "Activities Help"

  -- check the readings on the meters and set the scales accordingly
  if item 1 of bg fld "Voltmeter Reading" > 10 then
    hide bg fld "Voltage x10 Mask"
  else
    show bg fld "Voltage x10 Mask"
  end if
  if item 1 of bg fld "Ammeter Reading" > 1 then
    hide bg fld "Amperage x10 Mask"
  else
    show bg fld "Amperage x10 Mask"
  end if
  --This very tight loop traps all user mouseClicks that occured
  -- during the handler's execution
  repeat until the mouseClick is false
  end repeat
  unlock screen
  pass openCard
end openCard

on closeCard
  set cursor to watch
  put the number of bg btn "Pictures" into firstButton
  repeat with x = 0 to 2
    put hilite of bg btn (firstButton + x) into ¬
    line x + 1 of bg fld "Button Values"
  end repeat
  --This very tight loop traps all user mouseClicks that occured
  -- during the handler's execution
  repeat until the mouseClick is false
  end repeat
```

```
 pass closeCard
end closeCard

** BKGND #1, FIELD #2: Ammeter Reading
*************************************

on zeroAmmeter
  set cursor to watch
  lock screen
  if the heapspace > 200000 then
    hide cd fld "Digital Ammeter Reading"
    -- erase the ammeter needle
    choose select tool
      drag from 17,193 to 80,132
    doMenu "Clear Picture"
    choose brush tool
    set brush to 28
    set pattern to 12
    -- draw zeroed-out Ammeter Needle
      drag from 52,188 to 31,156
    choose browse tool
  else
    show cd fld "Digital Ammeter Reading"
  end if
  show bkgnd field "Amperage x10 Mask"
  put 0 into bkgnd field "Ammeter Reading"
  unlock screen
end zeroAmmeter

on calcAmperage --ammeter
  global deviceDirection, circuitResistance, circuitVoltage
  --Circuit resistance and voltage are calculated in the function
  --  goodPaths.  Using these two figures, calculate
  --  the current.  Update the ammeter reading (field and needle).
  -- calculate amperage, which must not be greater than 10

  if (circuitVoltage = 0) and (circuitResistance = 0) then
    put 0 into amperage
    exit calcAmperage
  else
    put (circuitVoltage / circuitResistance) into amperage
  end if

  if amperage > 10 then
    send zeroAmmeter to bg fld "Ammeter Reading"
    answer "Resistance too low - sizzled meters!" with "Try Again"
    exit calcAmperage
```

```
end if

if amperage > 1 then
  hide bkgnd field "Amperage x10 Mask"
  put amperage / 10 into reading
else
  show bkgnd field "Amperage x10 Mask"
  put amperage into reading
end if

set cursor to watch
lock screen
if the heapspace > 200000 then
  hide cd fld "Digital Ammeter Reading"
  -- erase the ammeter needle
 choose select tool
   drag from 17,193 to 80,132
  doMenu "Clear Picture"

  -- draw the ammeter needle
 choose brush tool
 set brush to 28
 if reading ≤ 0 then
    drag from 52,188 to 31,156
 else if reading < .1 then
      drag from 52,188 to 30+(round(10*reading*(34-31))),156
 else if reading < .2 then
      drag from 52,188 to 34+(round(10*(reading-.1)*(38-34))),153
 else if reading < .3 then
      drag from 52,188 to 38+(round(10*(reading-.2)*(43-38))),150
 else if reading < .4 then
      drag from 52,188 to 43+(round(10*(reading-.3)*(47-43))),149
 else if reading < .5 then
      drag from 52,188 to 47+(round(10*(reading-.4)*(52-47))),148
 else if reading < .6 then
      drag from 52,188 to 52+(round(10*(reading-.5)*(57-52))),146
 else if reading < .7 then
      drag from 52,188 to 57+(round(10*(reading-.6)*(62-57))),147
 else if reading < .8 then
      drag from 52,188 to 62+(round(10*(reading-.7)*(66-62))),149
 else if reading < .9 then
      drag from 52,188 to 66+(round(10*(reading-.8)*(70-66))),150
 else if reading < 1 then
      drag from 52,188 to 70+(round(10*(reading-.9)*(75-70))),153
else
   drag from 52,188 to 75,156
```

```
    end if
    choose browse tool
  else
    show cd fld "Digital Ammeter Reading"
  end if
  put amperage into bg fld "Ammeter Reading"
  unlock screen
  --This very tight loop traps all user mouseClicks that occured
  -- during the handler's execution
  repeat until the mouseClick is false
  end repeat
end calcAmperage

** BKGND #1, FIELD #3: Voltmeter Reading
*************************************

on zeroVoltmeter
  -- erase the voltmeter needle
  set cursor to watch
  lock screen
  if the heapspace > 200000 then
    hide cd fld "Digital Voltmeter Reading"
    choose select tool
    drag from 17,103 to 80,42
    doMenu "Clear Picture"
    choose brush tool
    set brush to 28
    set pattern to 12
    -- draw zeroed-out Voltmeter Needle
    drag from 52,98 to 31,66
    choose browse tool
  else
    show cd fld "Digital Voltmeter Reading"
  end if
  show bkgnd field "Voltage x10 Mask"
  put 0 into bkgnd field "Voltmeter Reading"
  unlock screen
end zeroVoltmeter

on calcVoltage resistance
  global deviceDirection, circuitResistance, circuitVoltage
  put "Calculating voltage drop."
  --Circuit resistance and voltage are calculated in the function
  -- goodPaths. Using these two figures, calculate
  -- the voltage drop. Update the ammeter reading (field and needle).
  --put "circuit resistance = " & circuitResistance && ¬
  --"circuit voltage = " & circuitVoltage --***
```

```
  --wait until the mouseClick --***
 if (circuitVoltage = 0) and (resistance = 0) then
  send zeroVoltmeter to bg fld "Voltmeter Reading"
  exit calcVoltage
else
   put ((circuitVoltage * resistance) / (circuitResistance)) into ¬
 voltage
end if
 --put "voltage = " & voltage --***
 --wait until the mouseClick --***
if voltage > 100 then
  send zeroVoltmeter to bg fld "Voltmeter Reading"
  answer "Voltage too high - sizzled meters!" with "Try Again"
 exit calcVoltage
end if

if voltage > 10 then
  hide bkgnd field "Voltage x10 Mask"
  put voltage / 10 into reading
else
  show bkgnd field "Voltage x10 Mask"
  put voltage into reading
end if

-- erase the voltmeter needle
set cursor to watch
lock screen
if the heapspace > 200000 then
  hide cd fld "Digital Voltmeter Reading"
 choose select tool
  drag from 17,103 to 80,42
  doMenu "Clear Picture"

  -- draw the voltmeter needle
 choose brush tool
 set brush to 28
 if reading ≤ 0 then
    drag from 52,98 to 31,66
 else if reading < 1 then
      drag from 52,98 to 30+(round(reading*(34-31))),66
 else if reading < 2 then
      drag from 52,98 to 34+(round((reading-1)*(38-34))),63
 else if reading < 3 then
      drag from 52,98 to 38+(round((reading-2)*(43-38))),60
 else if reading < 4 then
      drag from 52,98 to 43+(round((reading-3)*(47-43))),59
```

```
    else if reading < 5 then
         drag from 52,98 to 47+(round((reading-4)*(52-47))),58
    else if reading < 6 then
         drag from 52,98 to 52+(round((reading-5)*(57-52))),56
    else if reading < 7 then
         drag from 52,98 to 57+(round((reading-6)*(62-57))),57
    else if reading < 8 then
         drag from 52,98 to 62+(round((reading-7)*(66-62))),59
    else if reading < 9 then
         drag from 52,98 to 66+(round((reading-8)*(70-66))),60
    else if reading < 10 then
         drag from 52,98 to 70+(round((reading-9)*(75-70))),63
   else
      drag from 52,98 to 75,46
   end if
   choose browse tool
  else
    show cd fld "Digital Voltmeter Reading"
  end if
  put voltage into bg fld "Voltmeter Reading"
  unlock screen
  --This very tight loop traps all user mouseClicks that occured
  -- during the handler's execution
  repeat until the mouseClick is false
  end repeat
end calcVoltage

** BKGND #1, FIELD #7: Meter Help *************************************
on mouseUp
  send mouseUp to bg btn "Help"
end mouseUp

** BKGND #1, FIELD #8: Circuit Help *************************************
on mouseUp
  send mouseUp to bg btn "Help"
end mouseUp

** BKGND #1, FIELD #12: Activities Help
****************************************
on mouseUp
  send mouseUp to bg btn "Help"
end mouseUp

** BKGND #1, FIELD #13: Property Template
*************************************
on mouseUp
```

```
  send mouseUp to cd btn the short name of me
end mouseUp

** BKGND #1, BUTTON #1: Next ************************************
on mouseUp
  lock screen
  go to next card
  unlock screen with visual effect wipe left
end mouseUp

** BKGND #1, BUTTON #2: Prev ************************************
on mouseUp
  lock screen
  go to previous card
  unlock screen with visual effect wipe right
end mouseUp

** BKGND #1, BUTTON #3: H-Resistor ************************************
on mouseUp
  put "a" into resistance
  --Make sure only numbers come in
  repeat until resistance < 10000
    ask "What resistance would you like?"
    if it is empty then exit mouseUp
    put word 1 of it into resistance
    if resistance > 10000 then
      answer "Please enter only numbers."
    end if
  end repeat

  makeNewPart the short name of me
  put the number of cd flds into newFieldNumber
  put "Res" into line 1 of cd fld newFieldNumber
  put resistance && "Ω" into line 2 of card field newFieldNumber
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd fld newFieldNumber
end mouseUp

on setPicture
  set the icon of me to "H-Resistor Picture"
end setPicture
```

```
on setSymbol
  set the icon of me to "H-Resistor Symbol"
end setSymbol

on setWord
end setWord

** BKGND #1, BUTTON #4: H-Switch ***************************************
on mouseUp
  makeNewPart "H-Switch"
  put the number of cd flds into newFieldNumber
  put "Switch" into line 1 of cd fld newFieldNumber
  put "Open" into line 2 of cd fld newFieldNumber
  --This very tight loop traps all user mouseClicks that occured
  -- during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd fld newFieldNumber
end mouseUp

on setPicture
  set the icon of me to "H-OpenSwitch Picture"
end setPicture

on setSymbol
  set the icon of me to "H-OpenSwitch Symbol"
end setSymbol

on setWord
end setWord

** BKGND #1, BUTTON #5: V-Voltmeter
****************************************
on mouseUp
  global targetName, direction, finished, recording
  set cursor to arrow
  -- Show field with instructions for placing voltmeter
  show bg field "Voltmeter Instructions"
  show bg fld "Cancel Voltmeter Move"
  -- Get and save the two mouse clicks
  lock screen
  show bg btn "Click Marker 1"
  wait until the mouseClick
  if the clickLoc is within the rect of ¬
  bg fld "Cancel Voltmeter Move" then
```

```
    hide bg btn "Click Marker 1"
    hide bg field "Voltmeter Instructions"
    hide bg field "Cancel Voltmeter Move"
    exit mouseUp
  else
    put the clickLoc into wireOne
    set the loc of bg btn "Click Marker 1" to wireOne
  end if
  unlock screen
  set cursor to arrow
  lock screen
  show bg btn "Click Marker 2"
  wait until the mouseClick
  if the clickLoc is within the rect of ¬
  bg fld "Cancel Voltmeter Move" then
    hide bg btn "Click Marker 1"
    hide bg btn "Click Marker 2"
    hide bg field "Voltmeter Instructions"
    hide bg field "Cancel Voltmeter Move"
    exit mouseUp
  else
    put the clickLoc into wireTwo
    set the loc of bg btn "Click Marker 2" to wireTwo
  end if
  unlock screen
  hide bg field "Voltmeter Instructions"
  hide bg field "Cancel Voltmeter Move"
  lock screen
  hide bg btn "Click Marker 1"
  hide bg btn "Click Marker 2"
  click at wireOne
  put targetName into partOne
  click at wireTwo
  put targetName into partTwo
  if word 1 of partOne = "card" or word 1 of partTwo = "Card" then
    answer "Both mouse clicks must be on the circuit." with ¬
    "Cancel" or "Try Again"
    if it = "Cancel" then
      exit mouseUp
    else
      send mouseUp to me
      exit mouseUp
    end if
  end if
  -- check to see if a voltmeter has been made already. It isn't
  --  an H- or V- part, because it can change by just changing the
```

```
 -- Icon
 set cursor to watch
 if the visible of card field "Voltmeter Mask" is true then
   makeNewVoltmeter
   unlock screen
else
   put "Preparing to place Voltmeter."
   lock screen
   if "Top" is in line 5 of cd fld "Voltmeter" ¬
   or "Bottom" is in line 5 of cd fld "Voltmeter" then
     click at the loc of cd btn "V-Voltmeter-Wire 1"
     put targetName into firstPart
     click at the loc of cd btn "V-Voltmeter-Wire 2"
    put targetName into secondPart
   else if "Right" is in line 5 of cd fld "Voltmeter" or ¬
   "Left" is in line 5 of cd fld "Voltmeter" then
     click at the loc of cd btn "H-Voltmeter-Wire 1"
     put targetName into firstPart
     click at the loc of cd btn "H-Voltmeter-Wire 2"
    put targetName into secondPart
  end if
end if
lock screen
if the heapspace > 175000 then
   -- this sequence erases part of the voltmeter wires
  choose select tool
   drag from 110,32 to 399,235
  doMenu "Clear Picture"
  choose browse tool
end if
unlock screen
-- Find out where the clicks were on the circuit (Top, Bot, Lft or Rt)
--  This will determine whether to add to or subtract from col or row
-- Check to see if both mouse clicks are on the same
--   side of the circuit
-- First check horizontally (row coordinates match) or if on one part
--   it is horizontal
if ((item 2 of the loc of cd btn partOne = ¬
item 2 of the loc of cd btn partTwo)) and ¬
not("V-" is in partOne) and not("V-" is in partTwo) then
   --Voltmeter is to be horizontal
  put "False" into finished
  placeHorizVoltmeter partOne, partTwo, wireOne, wireTwo
 unlock screen
  if finished then
   exit mouseUp
```

```
    end if
   else if (item 1 of the loc of cd btn partOne) = ¬
   (item 1 of the loc of cd btn partTwo) and ¬
   not("H-" is in partOne) and not("H-" is in partTwo) then
     --Voltmeter is to be vertical
    put "False" into finished
    placeVertVoltmeter partOne, partTwo, wireOne, wireTwo
    unlock screen
    if finished then
     exit mouseUp
    end if
  else     -- One or both mouse clicks were not on the circuit
   doMenu "Undo"
    answer "Both clicks must be on one side of the circuit" with "Cancel" or ¬
    "Try Again"
    unlock screen
   hide message box
    if it = "Cancel" then
     exit mouseUp
   else
    send mouseUp to me
     exit mouseUp
   end if
  end if
  --This very tight loop traps all user mouseClicks that occured
  -- during the handler's execution
  repeat until the mouseClick is false
  end repeat
  unlock screen
  if recording then
    put the date && the long time && "Moving Voltmeter" after ¬
    bg fld "Student Activities"
  end if
  send evaluateState to cd btn "Voltmeter"
  hide message box
  if recording then
    put return after bg fld "Student Activities"
  end if
end mouseUp

on makeNewVoltmeter
  --If a voltmeter is not available yet,
  --  make four wire buttons (both H- & V-) to hook the
  --  voltmeter to the circuit
  put "Making new Voltmeter now."
  lock screen
```

```
-- Copy V-wires to card
show bg btn "V-Voltmeter-Wire 1 Template"
select bg btn "V-Voltmeter-Wire 1 Template"
doMenu "Copy Button"
doMenu "Paste Button"
put the number of cd btns into newButtonNumber
set the name of cd btn newButtonNumber to "V-Voltmeter-Wire 1"
hide bg btn "V-Voltmeter-Wire 1 Template"
show bg btn "V-Voltmeter-Wire 2 Template"
select bg btn "V-Voltmeter-Wire 2 Template"
doMenu "Copy Button"
doMenu "Paste Button"
put the number of cd btns into newButtonNumber
set the name of cd btn newButtonNumber to "V-Voltmeter-Wire 2"
hide bg btn "V-Voltmeter-Wire 2 Template"
-- Copy H-wires to card
show bg btn "H-Voltmeter-Wire 1 Template"
select bg btn "H-Voltmeter-Wire 1 Template"
doMenu "Copy Button"
doMenu "Paste Button"
put the number of cd btns into newButtonNumber
set the name of cd btn newButtonNumber to "H-Voltmeter-Wire 1"
hide bg btn "H-Voltmeter-Wire 1 Template"
show bg btn "H-Voltmeter-Wire 2 Template"
select bg btn "H-Voltmeter-Wire 2 Template"
doMenu "Copy Button"
doMenu "Paste Button"
put the number of cd btns into newButtonNumber
set the name of cd btn newButtonNumber to "H-Voltmeter-Wire 2"
hide bg btn "H-Voltmeter-Wire 2 Template"
--hide all the voltmeter wire buttons until two are needed
hide cd btn "H-Voltmeter-Wire 1"
hide cd btn "H-Voltmeter-Wire 2"
hide cd btn "V-Voltmeter-Wire 1"
hide cd btn "V-Voltmeter-Wire 2"
--Zero out voltmeter reading
send zeroVoltmeter to bg fld "Voltmeter Reading"
makeNewPart "Voltmeter"
put the number of cd flds into newFieldNumber
put the number of cd btns into newButtonNumber
set the name of cd btn newButtonNumber to "Voltmeter"
set the name of cd fld newFieldNumber to "Voltmeter"
hide card field "Voltmeter Mask"
put "Volt-" & return & "meter" into cd fld newFieldNumber
unlock screen
put "Voltmeter successfully made."
```

```
end makeNewVoltmeter

on placeHorizVoltmeter partOne, partTwo, wireOne, wireTwo
  global finished, direction
  -- Voltmeter goes horizontal, so set the voltmeter icon to horizontal
  put the icon of cd btn "Voltmeter" into iconNumber
  put iconNumber - 12188 into iconDir
  if iconDir = 0 or iconDir = 20 then
    --Change to or keep the horizontal voltmeter
    set the icon of cd btn "Voltmeter" to (iconNumber + 1)
  end if
  -- Now make sure the left voltmeter wire goes on first and that
  --  partOne is on the left
  if item 1 of wireOne > item 1 of wireTwo then
    -- wireOne is on the right, so put it on the left
    put item 1 of wireOne into temp
    put item 1 of wireTwo into item 1 of wireOne
    put temp into item 1 of wireTwo
    put partOne into temp
    put partTwo into partOne
    put temp into partTwo
  end if
  -- Find midpoint between voltmeter wires to determine voltmeter loc
  put (trunc((item 1 of wireTwo - item 1 of wireOne)/2)) + ¬
  (item 1 of wireOne) into ¬
  voltmeterCol
  -- Search through circuit until a corner wire is found.  Then we
  --  will be able to tell which side of the circuit we're on.
  put partOne into partName
  put "left" into direction
  repeat until "C-" is in word one of partName
    put nextPartAfter(partName) into nextPart
    if nextPart = "None" then
      -- the circuit isn't complete, so stop search and give message
      answer "Circuit should be complete to place voltmeter."
      put "True" into finished
      exit placeHorizVoltmeter
    else
      put nextPart into partName
    end if
  end repeat
  if "-T" is in word one of partName then
    -- The voltmeter goes on top of the circuit
    -- subtract from part row to get loc for voltmeter wires & voltmeter
    put "Top" into line 5 of cd fld "Voltmeter"
    put (item 2 of the loc of cd btn partOne - 13) into wireRow
```

```
    put voltmeterCol & "," & (wireRow - 16) into voltmeterPos
    -- Set the direction for the search for resistance later
   if "C" is in word one of partOne then
     put up into searchDirection
   else
     put right into searchDirection
   end if
  else
   -- The voltmeter goes on the bottom of the circuit
   -- add to part row to get loc for voltmeter wires & voltmeter
   put "Bottom" into line 5 of cd fld "Voltmeter"
   put (item 2 of the loc of cd btn partOne + 12) into wireRow
    put voltmeterCol & "," & (wireRow + 16) into voltmeterPos
   if "C" is in word one of partOne then
     put down into searchDirection
   else
     put right into searchDirection
   end if
  end if
  -- Put the two voltmeter wire buttons next to the part of the
  --  circuit that was clicked on
  hide cd btn "H-Voltmeter-Wire 1"
  hide cd btn "H-Voltmeter-Wire 2"
  show cd btn "V-Voltmeter-Wire 1"
  show cd btn "V-Voltmeter-Wire 2"
  set the loc of cd btn "V-Voltmeter-Wire 1" to ¬
  (item 1 of wireOne),wireRow
  set the loc of cd btn "V-Voltmeter-Wire 2" to ¬
  (item 1 of wireTwo),wireRow
  placePart "Voltmeter", voltmeterPos
 if the heapspace > 175000 then
  choose brush tool
   set brush to 28
   -- Draw lines from the wires to the voltmeter
   drag from (item 1 of wireOne-1),(item 2 of wireOne) to ¬
    (item 1 of wireOne-1),(item 2 of voltmeterPos-1)
   drag from (item 1 of wireOne-1),(item 2 of voltmeterPos-1) to ¬
    (item 1 of voltmeterPos-15),(item 2 of voltmeterPos-1)
   drag from (item 1 of voltmeterPos+15),(item 2 of voltmeterPos-1) to ¬
    (item 1 of wireTwo-1),(item 2 of voltmeterPos-1)
   drag from (item 1 of wireTwo-1),(item 2 of voltmeterPos-1) to ¬
    (item 1 of wireTwo-1),(item 2 of wireTwo)
  choose browse tool
 end if
 -- Determine what devices are in between the voltmeter wires and
 --  calculate the voltage drop
```

```
  -- The direction for finding the next part is set earlier when it
  -- is determined whether we are on top or bottom of the circuit
  put partOne into adjPart
  put searchDirection into direction
  put 0 into resistance
  repeat while adjPart ≠ partTwo
    if item 1 of the loc of cd btn adjPart > item 1 of wireOne and ¬
    item 1 of the loc of cd btn adjPart < item 1 of wireTwo then
      -- Add the resistance of each part if its location is between
      -- the two voltmeter wires
      if line 1 of cd fld adjPart = "Lamp" then
        add 2 to resistance
      else if "Ω" is in line 2 of cd fld adjPart then
        add word 1 of line 2 of cd fld adjPart to resistance
      end if
    end if
    put nextPartAfter (adjPart) into adjPart
  end repeat
  if item 1 of the loc of cd btn adjPart > item 1 of wireOne and ¬
  item 1 of the loc of cd btn adjPart < item 1 of wireTwo then
    -- Add the resistance of the last part if its location is between
    -- the two voltmeter wires
    if line 1 of cd fld adjPart = "Lamp" then
      add 2 to resistance
    else if "Ω" is in line 2 of cd fld adjPart then
      add word 1 of line 2 of cd fld adjPart to resistance
    end if
  end if
end placeHorizVoltmeter

on placeVertVoltmeter partOne, partTwo, wireOne, wireTwo
  global finished, direction
  -- Voltmeter goes vertical, so set the voltmeter icon to vertical
  put the icon of cd btn "Voltmeter" into iconNumber
  put iconNumber - 12188 into iconDir
  if iconDir = 1 or iconDir = 21 then
    --Change to or keep the vertical voltmeter if horizontal
    set the icon of cd btn "Voltmeter" to (iconNumber - 1)
  end if
  -- Now make sure the top voltmeter wire goes on first and that
  -- partOne is on the top
  if item 2 of wireOne > item 2 of wireTwo then
    -- wireOne is on the bottom, so put it on the top
    put item 2 of wireOne into temp
    put item 2 of wireTwo into item 2 of wireOne
    put temp into item 2 of wireTwo
```

```
put partOne into temp
put partTwo into partOne
put temp into partTwo
end if
-- Find midpoint between voltmeter wires to determine voltmeter loc
put (trunc((item 2 of wireTwo - item 2 of wireOne)/2)) + ¬
(item 2 of wireOne) into ¬
voltmeterRow
-- Search through circuit until a corner wire is found. Then we
-- will be able to tell which side of the circuit we're on.
put partOne into partName
put "up" into direction
repeat until "C" is in word one of partName
  put nextPartAfter(partName) into nextPart
  if nextPart = "None" then
    -- the circuit isn't complete, so stop search and give message
    answer "Circuit should be complete to place voltmeter."
    put "True" into finished
    exit placeVertVoltmeter
  else
    put nextPart into partName
  end if
end repeat
if "L-" is in word one of partName then
  -- The voltmeter goes on the left of the circuit
  -- subtract from part col to get loc for voltmeter wires & voltmeter
  put "Left" into line 5 of cd fld "Voltmeter"
  put (item 1 of the loc of cd btn partOne - 13) into wireCol
  put (wireCol - 16) & "," & voltmeterRow into voltmeterPos
  -- Set the direction for the search for resistance later
  if "C" is in word one of partOne then
    put left into searchDirection
  else
    put down into searchDirection
  end if
else
  -- The voltmeter goes on the right of the circuit
  -- add to part col to get loc for voltmeter wires & voltmeter
  put "Right" into line 5 of cd fld "Voltmeter"
  put (item 1 of the loc of cd btn partOne + 12) into wireCol
  put (wireCol + 16) & "," & voltmeterRow into voltmeterPos
  if "C" is in word one of partOne then
    put right into searchDirection
  else
    put down into searchDirection
  end if
```

```
end if
-- Put the two voltmeter wire buttons next to the part of the
--  circuit that was clicked on
hide cd btn "V-Voltmeter-Wire 1"
hide cd btn "V-Voltmeter-Wire 2"
show cd btn "H-Voltmeter-Wire 1"
show cd btn "H-Voltmeter-Wire 2"
set the loc of cd btn "H-Voltmeter-Wire 1" to ¬
wireCol, (item 2 of wireOne)
set the loc of cd btn "H-Voltmeter-Wire 2" to ¬
wireCol, (item 2 of wireTwo)
placePart "Voltmeter", voltmeterPos
if the heapspace > 175000 then
 choose brush tool
 set brush to 28
  -- Draw lines from the wires to the voltmeter
  drag from (item 1 of wireOne),(item 2 of wireOne-1) to ¬
   (item 1 of voltmeterPos-1),(item 2 of wireOne-1)
  drag from (item 1 of voltmeterPos-1),(item 2 of wireOne-1) to ¬
   (item 1 of voltmeterPos-1),(item 2 of voltmeterPos-15)
  drag from (item 1 of voltmeterPos-1),(item 2 of voltmeterPos+15) to ¬
   (item 1 of voltmeterPos-1),(item 2 of wireTwo-1)
  drag from (item 1 of voltmeterPos-1),(item 2 of wireTwo-1) to ¬
  (item 1 of wireTwo),(item 2 of wireTwo-1)
 -- Determine what devices are in between the voltmeter wires and
 --  calculate the voltage drop
 --  The direction for finding the next part is set earlier when it
 --  is determined whether we are on the left or right of the circuit
 choose browse tool
end if
put partOne into adjPart
put searchDirection into direction
put 0 into resistance
repeat while adjPart ≠ partTwo
 if item 2 of the loc of cd btn adjPart > item 2 of wireOne and ¬
 item 2 of the loc of cd btn adjPart < item 2 of wireTwo then
   -- Add the resistance of each part if its location is between
   --  the two voltmeter wires
   if line 1 of cd fld adjPart = "Lamp" then
    add 2 to resistance
   else if "Ω" is in line 2 of cd fld adjPart then
    add word 1 of line 2 of cd fld adjPart to resistance
  end if
 end if
  put nextPartAfter (adjPart) into adjPart
end repeat
```

```
  if item 2 of the loc of cd btn adjPart > item 2 of wireOne and ¬
  item 2 of the loc of cd btn adjPart < item 2 of wireTwo then
    -- Add the resistance of the last part if its location is between
    --  the two voltmeter wires
    if line 1 of cd fld adjPart = "Lamp" then
     add 2 to resistance
    else if "Ω" is in line 2 of cd fld adjPart then
      add word 1 of line 2 of cd fld adjPart to resistance
    end if
  end if
end placeVertVoltmeter

on setPicture
  set the icon of me to "V-Voltmeter Picture"
end setPicture

on setSymbol
  set the icon of me to "V-Voltmeter Symbol"
end setSymbol

on setWord
end setWord

** BKGND #1, BUTTON #6: V-Ammeter
***************************************
on mouseUp
  -- check to see if an ammeter has been made already
  if the visible of card field "Ammeter Mask" is true then
    --Zero out ammeter reading
    send zeroAmmeter to bg fld "Ammeter Reading"
  end if
  -- make a new ammeter if one isn't present
  makeNewPart the short name of me
  hide card field "Ammeter Mask"
  put the number of cd flds into newFieldNumber
  put "Am-" & return & "meter" into cd fld newFieldNumber
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd fld newFieldNumber
end mouseUp

on setPicture
  set the icon of me to "V-Ammeter Picture"
```

```
end setPicture

on setSymbol
  set the icon of me to "V-Ammeter Symbol"
end setSymbol

on setWord
end setWord

** BKGND #1, BUTTON #7: V-Resistor *************************************
on mouseUp
  put "a" into resistance
  --Make sure only numbers come in
  repeat until resistance < 10000
    ask "What resistance would you like?"
    if it is empty then exit mouseUp
    put word 1 of it into resistance
    if resistance > 10000 then
      answer "Please enter only numbers."
    end if
  end repeat
  makeNewPart the short name of me
  put the number of cd flds into newFieldNumber
  put "Res" into line 1 of cd fld newFieldNumber
  put resistance && "Ω" into line 2 of card field newFieldNumber
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd fld newFieldNumber
end mouseUp

on setPicture
  set the icon of me to "V-Resistor Picture"
end setPicture

on setSymbol
  set the icon of me to "V-Resistor Symbol"
end setSymbol

on setWord
end setWord

** BKGND #1, BUTTON #8: V-Cell *************************************
on mouseUp
```

```
  put "a" into voltage
  --Make sure only numbers come in
  repeat until voltage < 10000
    ask "What voltage would you like?"
    if it is empty then exit mouseUp
    put word 1 of it into voltage
    if voltage > 10000 then
      answer "Please enter only numbers."
    end if
  end repeat
  makeNewPart the short name of me, vertical
  put the number of cd flds into newFieldNumber
  put "Cell" into line 1 of cd fld newFieldNumber
  put voltage && "V" into line 2 of card field newFieldNumber
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd fld newFieldNumber
end mouseUp

on setPicture
  set the icon of me to "V-Cell Picture"
end setPicture

on setSymbol
  set the icon of me to "V-Cell Symbol"
end setSymbol

on setWord
end setWord

** BKGND #1, BUTTON #9: New Circuit
****************************************

on mouseUp
  answer "Start a new circuit card." with "Cancel" or "OK"
  if it = "OK" then
    lock screen
    send closeCard to this card
    doMenu "New Card"
    unlock screen with dissolve
  end if
end mouseUp

** BKGND #1, BUTTON #10: New Button
****************************************
```

```
on mouseUp
end mouseUp


** BKGND #1, BUTTON #11: Home ****************************************
on mouseUp
  answer "Do you really want to leave this stack?" with "Yes" or "No"
  if it = "Yes" then
    visual effect iris close
   go "Home"
  end if
end mouseUp

** BKGND #1, BUTTON #12: Help ****************************************
on mouseUp
  set visible of bkgnd field "Parts Help" to not the visible ¬
  of bkgnd field "Parts Help"
  if the visible of bkgnd field "Parts Help" is true then
    Put "Click on a part in this bin and your own part will appear." ¬
    into bkgnd field "Parts Help"
  end if
  set visible of bkgnd field "Circuit Help" to not the visible ¬
  of bkgnd field "Circuit Help"
  if the visible of bkgnd field "Circuit Help" is true then
    Put "Add each part to the circuit." ¬
    into bkgnd field "Circuit Help"
  end if
  set visible of bkgnd field "Meter Help" to not the visible ¬
  of bkgnd field "Meter Help"
  if the visible of bkgnd field "Meter Help" is true then
    Put "Record the meter readings you get." ¬
    into bkgnd field "Meter Help"
  end if
  set visible of bkgnd field "Activities Help" to not the visible ¬
  of bkgnd field "Activities Help"
  if the visible of bkgnd field "Activities Help" is true then
    put "                    Activities" & return & ¬
    "Move a part: Shift-Click on part" & return & ¬
    "Show part info: Command-Click on part" & return & ¬
    "Toggle Switch: Option-Click on switch" ¬
    into bkgnd field "Activities Help"
  end if
  set visible of bkgnd button "Symbols Help" to not the visible ¬
  of bkgnd button "Symbols Help"
end mouseUp
```

```
** BKGND #1, BUTTON #13: Symbols Help
***************************************
on mouseUp
  push this card
  visual iris open
  go to card id 6362
end mouseUp


** BKGND #1, BUTTON #14: H-Ammeter
***************************************
on mouseUp
  -- check to see if an ammeter has been made already
  if the visible of card field "Ammeter Mask" is true then
     --Zero out ammeter reading
    send zeroAmmeter to bg fld "Ammeter Reading"
  end if
  -- make a new ammeter if one isn't present
  makeNewPart the short name of me
  hide card field "Ammeter Mask"
  put the number of cd flds into newFieldNumber
  put "Am-" & return & "meter" into cd fld newFieldNumber
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd fld newFieldNumber
end mouseUp

on setPicture
  set the icon of me to "H-Ammeter Picture"
end setPicture

on setSymbol
  set the icon of me to "H-Ammeter Symbol"
end setSymbol

on setWord
end setWord

** BKGND #1, BUTTON #15: H-Voltmeter
***************************************
on mouseUp
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
```

```
  repeat until the mouseClick is false
  end repeat
  send mouseUp to bg btn "V-Voltmeter"
end mouseUp

on setPicture
  set the icon of me to "H-Voltmeter Picture"
end setPicture

on setSymbol
  set the icon of me to "H-Voltmeter Symbol"
end setSymbol

on setWord
end setWord
```

** BKGND #1, BUTTON #16: V-Switch
****

```
on mouseUp
  makeNewPart "V-Switch"
  put the number of cd flds into newFieldNumber
  put "Switch" into line 1 of cd fld newFieldNumber
  put "Open" into line 2 of cd fld newFieldNumber
  --This very tight loop traps all user mouseClicks that occured
  -- during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd fld newFieldNumber
end mouseUp

on setPicture
  set the icon of me to "V-OpenSwitch Picture"
end setPicture

on setSymbol
  set the icon of me to "V-OpenSwitch Symbol"
end setSymbol

on setWord
end setWord
```

** BKGND #1, BUTTON #17: H-Lamp
****

```
on mouseUp
  makeNewPart the short name of me
```

```
  put the number of cd flds into newFieldNumber
  put "Lamp" into line 1 of cd fld newFieldNumber
  put "Off" into line 2 of cd fld newFieldNumber
  --This very tight loop traps all user mouseClicks that occured
  -- during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd fld newFieldNumber
end mouseUp

on setPicture
  set the icon of me to "H-LampOff Picture"
end setPicture

on setSymbol
  set the icon of me to "H-LampOff Symbol"
end setSymbol

on setWord
end setWord

** BKGND #1, BUTTON #18: V-Lamp
******************************************

on mouseUp
  makeNewPart the short name of me, vertical
  put the number of cd flds into newFieldNumber
  put "Lamp" into line 1 of cd fld newFieldNumber
  put "Off" into line 2 of cd fld newFieldNumber
  --This very tight loop traps all user mouseClicks that occured
  -- during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd fld newFieldNumber
end mouseUp

on setPicture
  set the icon of me to "V-LampOff Picture"
end setPicture

on setSymbol
  set the icon of me to "V-LampOff Symbol"
end setSymbol

on setWord
```

```
end setWord

** BKGND #1, BUTTON #19: H-Wire
****************************************
on mouseUp
  makeNewPart the short name of me
  put the number of cd btns into newButtonNumber
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd btn newButtonNumber
end mouseUp

** BKGND #1, BUTTON #20: V-Wire
****************************************
on mouseUp
  makeNewPart the short name of me, vertical
  put the number of cd btns into newButtonNumber
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd btn newButtonNumber
end mouseUp

** BKGND #1, BUTTON #21: C-BL-Wire
*************************************
on mouseUp
  makeNewPart the short name of me
  put the number of cd btns into newButtonNumber
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd btn newButtonNumber
end mouseUp

** BKGND #1, BUTTON #22: C-TL-Wire
*************************************
on mouseUp
  makeNewPart the short name of me
  put the number of cd btns into newButtonNumber
```

```
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd btn newButtonNumber
end mouseUp
```

** BKGND #1, BUTTON #23: C-TR-Wire
****

```
on mouseUp
  makeNewPart the short name of me
  put the number of cd btns into newButtonNumber
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd btn newButtonNumber
end mouseUp
```

** BKGND #1, BUTTON #24: H-Cell
****

```
on mouseUp
  put "a" into voltage
  --Make sure only numbers come in
  repeat until voltage < 10000
    ask "What voltage would you like?"
    if it is empty then exit mouseUp
    put word 1 of it into voltage
    if voltage > 10000 then
      answer "Please enter only numbers."
    end if
  end repeat
  makeNewPart the short name of me, horizontal
  put the number of cd flds into newFieldNumber
  put "Cell" into line 1 of cd fld newFieldNumber
  put voltage && "V" into line 2 of card field newFieldNumber
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd fld newFieldNumber
end mouseUp
```

```
on setPicture
  set the icon of me to "H-Cell Picture"
end setPicture

on setSymbol
  set the icon of me to "H-Cell Symbol"
end setSymbol

on setWord
end setWord
```

** BKGND #1, BUTTON #25: C-BR-Wire
* *

```
on mouseUp
  makeNewPart the short name of me
  put the number of cd btns into newButtonNumber
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd btn newButtonNumber
end mouseUp
```

** BKGND #1, BUTTON #26: H-Resistor Template
* *

```
on setPicture
  hide cd fld the short name of me
   set the icon of me to "H-Resistor Picture" --12201
end setPicture

on setSymbol
  hide cd fld the short name of me
   set the icon of me to "H-Resistor Symbol" --12181
end setSymbol

on setWord
  show cd fld the short name of me
end setWord

on mouseUp
  set the style of me to transparent
  if the lockScreen is false then
    movePart the short name of me
  end if
end mouseUp
```

```
on mouseDown
  set the style of me to opaque
  if the commandKey is down then
    show cd fld the short name of me
    set the hilite of me to false
    wait while the mouse is down
    hide cd fld the short name of me
  end if
  pass mouseDown
end mouseDown

on evaluateState
  global recording
  if recording then
    put ", " & quote & the short name of me & quote & "=" & ¬
    line 2 of cd fld the short name of me after ¬
     bg fld "Student Activities"
  end if
end evaluateState
```

** BKGND #1, BUTTON #27: V-Resistor Template
****

```
on setPicture
  hide cd fld the short name of me
  set the icon of me to "V-Resistor Picture" --12200
end setPicture

on setSymbol
  hide cd fld the short name of me
  set the icon of me to "V-Resistor Symbol" --12180
end setSymbol

on setWord
  show cd fld the short name of me
end setWord

on mouseUp
  set the style of me to transparent
  if the lockScreen is false then
    movePart the short name of me
  end if
end mouseUp

on mouseDown
  set the style of me to opaque
```

```
  if the commandKey is down then
    show cd fld the short name of me
    set the hilite of me to false
    wait while the mouse is down
    hide cd fld the short name of me
  end if
  pass mouseDown
end mouseDown

on evaluateState
  global recording
  if recording then
    put ", " & quote & the short name of me & quote & "=" & ¬
    line 2 of cd fld the short name of me after ¬
    bg fld "Student Activities"
  end if
end evaluateState

** BKGND #1, BUTTON #28: V-Cell Template
************************************
on evaluateState
  global recording
  --Might have to add something here to check for dead battery
  --  when the simulation reaches a higher level
  if recording then
    put ", " & quote & the short name of me & quote & "=" & ¬
    line 2 of cd fld the short name of me after ¬
    bg fld "Student Activities"
  end if
end evaluateState

on setPicture
  hide cd fld the short name of me
  set the icon of me to "V-Cell Picture" --12206
end setPicture

on setSymbol
  hide cd fld the short name of me
  set the icon of me to "V-Cell Symbol" --12186
end setSymbol

on setWord
  show cd fld the short name of me
end setWord

on mouseUp
```

```
  set the style of me to transparent
  if the lockScreen is false then
    movePart the short name of me
  end if
end mouseUp

on mouseDown
  set the style of me to opaque
  if the commandKey is down then
    show cd fld the short name of me
    set the hilite of me to false
    wait while the mouse is down
    hide cd fld the short name of me
  end if
  pass mouseDown
end mouseDown

** BKGND #1, BUTTON #29: H-Cell Template
**************************************
on evaluateState
  global recording
  --Might have to add something here to check for dead battery
  --  when the simulation reaches a higher level
  if recording then
    put ", " & quote & the short name of me & quote & "=" & ¬
    line 2 of cd fld the short name of me after ¬
    bg fld "Student Activities"
  end if
end evaluateState

on setPicture
  hide cd fld the short name of me
  set the icon of me to "H-Cell Picture" --12207
end setPicture

on setSymbol
  hide cd fld the short name of me
  set the icon of me to "H-Cell Symbol" --12187
end setSymbol

on setWord
  show cd fld the short name of me
end setWord

on mouseUp
  set the style of me to transparent
```

```
  if the lockScreen is false then
    movePart the short name of me
  end if
end mouseUp

on mouseDown
  set the style of me to opaque
  if the commandKey is down then
    show cd fld the short name of me
    set the hilite of me to false
    wait while the mouse is down
    hide cd fld the short name of me
  end if
  pass mouseDown
end mouseDown
```

** BKGND #1, BUTTON #30: H-Switch Template
****

```
on evaluateState
  --Will there ever be anything internal that will change a switch's
  --  state?
end evaluateState

on setPicture
  hide cd fld the short name of me
  put the icon of me into iconNumber
  if iconNumber is 12204 or iconNumber is 12205 then --Picture
    exit setPicture
  end if
  set the icon of me to (iconNumber + 20)
end setPicture

on setSymbol
  hide cd fld the short name of me
  put the icon of me into iconNumber
  if iconNumber is 12184 or iconNumber is 12185 then
    exit setSymbol
  end if
  set the icon of me to (iconNumber - 20)
end setSymbol

on setWord
  show cd fld the short name of me
end setWord

on mouseUp
```

```
set the style of me to transparent
if the lockScreen is false and the optionKey is up then
  movePart the short name of me
else if the optionKey is down then
  put the icon of me into iconNumber
   put (iconNumber - 12184) into switchState
  -- Toggle between open and closed switch
   if (switchState = 0) or (switchState = 20) then  --if the switch is
    set the icon of me to (iconNumber + 1)  -- open, close it
   put "Closed" into line 2 of cd fld the short name of me
  else                          -- if the switch is closed, then
    set the icon of me to (iconNumber - 1)   -- open it
   put "Open" into line 2 of cd fld the short name of me
  end if
   --Internal conductivity has changed
  put "Yes" into line 5 of cd fld the short name of me
  --Send a message through the circuit that the state has changed.
  --  Of course, if the switch is not hooked to anything, then
  --  the message will stop pretty quick. The message should travel
   --  along the wire looking for devices (like a light bulb or a bell)
  --  whose state could be changed by closing a switch . When one
  --  of these is reached, it's state should be evaluated by looking
  --  for good feed and return paths to the battery.
  evaluateCircuit the short name of me
 end if
 --This very tight loop traps all user mouseClicks that occured
 --  during the handler's execution
 repeat until the mouseClick is false
 end repeat
end mouseUp

on mouseDown
 set the style of me to opaque
 if the commandKey is down then
  show cd fld the short name of me
   set the hilite of me to false
   wait while the mouse is down
  hide cd fld the short name of me
 end if
 pass mouseDown
end mouseDown

** BKGND #1, BUTTON #31: V-Switch Template
**********************************

on evaluateState
  --Will there ever be anything internal that will change a switch's
```

```
  -- state?
end evaluateState

on setPicture
  hide cd fld the short name of me
  put the icon of me into iconNumber
   if iconNumber is 12202 or iconNumber is 12203 then --Picture
     exit setPicture
  end if
  set the icon of me to (iconNumber + 20)
end setPicture

on setSymbol
  hide cd fld the short name of me
  put the icon of me into iconNumber
   if iconNumber is 12182 or iconNumber is 12183 then --Symbol
     exit setSymbol
  end if
  set the icon of me to (iconNumber - 20)
end setSymbol

on setWord
  show cd fld the short name of me
end setWord

on mouseUp
  set the style of me to transparent
  if the lockScreen is false and the optionKey is up then
    movePart the short name of me
  else if the optionKey is down then
    put the icon of me into iconNumber
      put (iconNumber - 12182) into switchState
    -- Toggle between open and closed switch
      if (switchState = 0) or (switchState = 20) then  --if the switch is
       set the icon of me to (iconNumber + 1)   -- open, close it
      put "Closed" into line 2 of cd fld the short name of me
    else                          -- if the switch is closed, then
       set the icon of me to (iconNumber - 1)   -- open it
      put "Open" into line 2 of cd fld the short name of me
    end if
     --Internal conductivity has changed
    put "Yes" into line 5 of cd fld the short name of me
    --Send a message through the circuit that the state has changed.
    --  Of course, if the switch is not hooked to anything, then
    --  the message will stop pretty quick.  The message should travel
    --   along the wire looking for devices (like a light bulb or a bell)
```

```
    -- whose state could be changed by closing a switch . When one
    -- of these is reached, it's state should be evaluated by looking
    -- for good feed and return paths to the battery.
    evaluateCircuit the short name of me
  end if
  --This very tight loop traps all user mouseClicks that occured
  -- during the handler's execution
  repeat until the mouseClick is false
  end repeat
end mouseUp

on mouseDown
  set the style of me to opaque
  if the commandKey is down then
    show cd fld the short name of me
    set the hilite of me to false
    wait while the mouse is down
    hide cd fld the short name of me
  end if
  pass mouseDown
end mouseDown
```

** BKGND #1, BUTTON #32: V-Wire Template
****

```
on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseDown
  set the style of me to opaque
  pass mouseDown
end mouseDown

on mouseUp
  if the lockScreen is false then
    movePart the short name of me
  end if
  set the style of me to transparent
end mouseUp
```

** BKGND #1, BUTTON #33: H-Wire Template
****

```
on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseDown
  set the style of me to opaque
  pass mouseDown
end mouseDown

on mouseUp
  if the lockScreen is false then
    movePart the short name of me
  end if
  set the style of me to transparent
end mouseUp

** BKGND #1, BUTTON #34: Pictures
******************************************
on mouseUp
  if the lockScreen is false then
    turnOn the number of me,radioGroup1
    set cursor to watch
    lock screen
    repeat with x = 1 to the number of cd buttons
      send setPicture to cd btn x
    end repeat
    setBgPictures
    unlock screen
  end if
end mouseUp

on setBgPictures
  send setPicture to bg btn "h-resistor"
  send setPicture to bg btn "v-resistor"
  send setPicture to bg btn "h-ammeter"
  send setPicture to bg btn "v-ammeter"
  send setPicture to bg btn "h-voltmeter"
  send setPicture to bg btn "v-voltmeter"
  send setPicture to bg btn "h-Switch"
  send setPicture to bg btn "v-Switch"
  send setPicture to bg btn "h-lamp"
```

```
  send setPicture to bg btn "v-lamp"
  send setPicture to bg btn "h-cell"
  send setPicture to bg btn "v-cell"
end setBgPictures
```

** BKGND #1, BUTTON #35: Symbols
****

```
on mouseUp
  if the lockScreen is false then
    turnOn the number of me,radioGroup1
    set cursor to watch
    lock screen
    repeat with x = 1 to the number of cd buttons
      send setSymbol to cd btn x
    end repeat
    setBgSymbols
    unlock screen
  end if
end mouseUp

on setBgSymbols
  send setSymbol to bg btn "h-resistor"
  send setSymbol to bg btn "v-resistor"
  send setSymbol to bg btn "h-ammeter"
  send setSymbol to bg btn "v-ammeter"
  send setSymbol to bg btn "h-voltmeter"
  send setSymbol to bg btn "v-voltmeter"
  send setSymbol to bg btn "h-Switch"
  send setSymbol to bg btn "v-Switch"
  send setSymbol to bg btn "h-lamp"
  send setSymbol to bg btn "v-lamp"
  send setSymbol to bg btn "h-cell"
  send setSymbol to bg btn "v-cell"
end setBgSymbols
```

** BKGND #1, BUTTON #36: Words
****

```
on mouseUp
  if the lockScreen is false then
    turnOn the number of me,radioGroup1
    set cursor to watch
    lock screen
    repeat with x = 1 to the number of cd buttons
      send setWord to cd btn x
    end repeat
    unlock screen
```

```
  end if
end mouseUp

** BKGND #1, BUTTON #37: V-Lamp Template
*********************************
on evaluateState
  global recording
  put "Evaluating state of lamp."
  wait 1 second
  put the icon of me into iconNumber
  put (iconNumber - 12192) into bulbState --0 or 20 = off, 1 or 21 = on
  --Check to see if paths to battery exist from each side of device
  if goodPaths(the short name of me) then
    -- Turn the bulb on or leave it on
    if (bulbState = 0) or (bulbState = 20) then   --if the bulb is off
      set the icon of me to (the icon of me + 1)  -- turn it on
      put "On" into line 2 of cd fld the short name of me
      if recording then
        put ", " & quote & the short name of me & quote & "->ON" after ¬
        bg fld "Student Activities"
      end if
    end if
  else -- Turn the bulb off or leave it off
    if (bulbState = 1) or (bulbState = 21) then   --if the bulb is on
      set the icon of me to (iconNumber - 1)      -- turn it off
      put "Off" into line 2 of cd fld the short name of me
      if recording then
        put ", " & quote & the short name of me & quote & "->OFF" after ¬
        bg fld "Student Activities"
      end if
    end if
  end if
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
end evaluateState

on setPicture
  hide cd fld the short name of me
  put the icon of me into iconNumber
  if iconNumber is 12212 or iconNumber is 12213 then
    exit setPicture
  end if
  set the icon of me to (iconNumber + 20)
end setPicture
```

```
on setSymbol
  hide cd fld the short name of me
  put the icon of me into iconNumber
  if iconNumber is 12192 or iconNumber is 12193 then
    exit setSymbol
  end if
  set the icon of me to (iconNumber - 20)
end setSymbol

on setWord
  show cd fld the short name of me
end setWord

on mouseUp
  if the lockScreen is false then
    movePart the short name of me
    --if a lighted bulb has been moved out of the circuit, it should
    --  be turned off.
    put the icon of me into iconNumber
     put (iconNumber - 12192) into bulbState --0 or 20=off, 1 or 21=on
     if ((bulbState = 1) or (bulbState = 21)) and ¬
    (("card" is in line 3 of cd fld the short name of me) or¬
    ("card" is in line 4 of cd fld the short name of me)) then
       --if the bulb is on, turn it off
      set the icon of me to (iconNumber - 1)
      put "Off" into line 2 of cd fld the short name of me
    end if
  end if
end mouseUp

on mouseDown
  if the commandKey is down then
    show cd fld the short name of me
    set the hilite of me to false
    wait while the mouse is down
    hide cd fld the short name of me
  end if
  pass mouseDown
end mouseDown

** BKGND #1, BUTTON #38: C-TR-Wire Template
*********************************
on setSymbol
end setSymbol
```

```
on setPicture
end setPicture

on setWord
end setWord

on mouseDown
  set the style of me to opaque
  pass mouseDown
end mouseDown

on mouseUp
  if the lockScreen is false then
    movePart the short name of me
  end if
  set the style of me to transparent
end mouseUp

** BKGND #1, BUTTON #39: C-TL-Wire Template
**********************************

on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseDown
  set the style of me to opaque
  pass mouseDown
end mouseDown

on mouseUp
  if the lockScreen is false then
    movePart the short name of me
  end if
  set the style of me to transparent
end mouseUp

** BKGND #1, BUTTON #40: C-BL-Wire Template
**********************************

on setSymbol
end setSymbol
```

```
on setPicture
end setPicture

on setWord
end setWord

on mouseDown
  set the style of me to opaque
  pass mouseDown
end mouseDown

on mouseUp
  if the lockScreen is false then
    movePart the short name of me
  end if
  set the style of me to transparent
end mouseUp

** BKGND #1, BUTTON #41: C-BR-Wire
******************************************

on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseDown
  set the style of me to opaque
  pass mouseDown
end mouseDown

on mouseUp
  if the lockScreen is false then
    movePart the short name of me
  end if
  set the style of me to transparent
end mouseUp

** BKGND #1, BUTTON #42: H-Ammeter Template
**********************************

on evaluateState
  global recording
  put "Evaluating state of ammeter."
```

```
    wait 1 second
    --Check to see if paths to battery exist from each side of device
    if goodPaths(the short name of me) then
      --Calculate the circuit amperage
      send calcAmperage to bg fld "Ammeter Reading"
      --This very tight loop traps all user mouseClicks that occured
      --  during the handler's execution
      if recording then
        put ", " & quote & the short name of me & quote & "=" & ¬
        bg fld "Ammeter Reading" && "Amps" after ¬
        bg fld "Student Activities"
      end if
      repeat until the mouseClick is false
      end repeat
    else
      -- Zero out the ammeter or leave it zeroed out.
      if bg fld "Ammeter Reading" = 0 then
        exit evaluateState
      else
        send zeroAmmeter to bg fld "Ammeter Reading"
      end if
    end if
  end evaluateState

  on mouseUp
    global deleted
    if the lockScreen is false then
      put "False" into deleted
      movePart the short name of me
      --If a non-zero ammeter has been moved out of the circuit, it should
      --  be zeroed out.
      --Check the ammeter reading field.  If it is non-zero, then zero it
      --  out if there is no connection on one side of the ammeter.
      if deleted then  --Check to see if the user deleted the part
        show cd fld "Ammeter Mask"
      else
        if bg fld "Ammeter Reading" ≠ 0 and ¬
        (("card" is in line 3 of cd fld the short name of me) or ¬
        ("card" is in line 4 of cd fld the short name of me)) then
          --The meter is non-zero, so zero it out
          send zeroAmmeter to bg fld "Ammeter Reading"
        end if
      end if
    end if
  end mouseUp
```

```
on mouseDown
  if the commandKey is down then
    show cd fld the short name of me
    set the hilite of me to false
    wait while the mouse is down
    hide cd fld the short name of me
  end if
  pass mouseDown
end mouseDown

on setPicture
  hide cd fld the short name of me
  set the icon of me to "H-Ammeter Picture"
end setPicture

on setSymbol
  hide cd fld the short name of me
  set the icon of me to "H-Ammeter Symbol"
end setSymbol

on setWord
  show cd fld the short name of me
end setWord
```

** BKGND #1, BUTTON #43: V-Voltmeter-Wire 2 Template
****

```
on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseUp
  global targetName
  click at (item 1 of the loc of me+8), (item 2 of the loc of me-15)
  if "Card" is in word 1 of targetName then
    click at (item 1 of the loc of me+8), (item 2 of the loc of me+15)
  end if
end mouseUp
```

** BKGND #1, BUTTON #44: H-Voltmeter-Wire 2 Template
****

```
on setSymbol
```

```
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseUp
  global targetName
   click at (item 1 of the loc of me+15), (item 2 of the loc of me + 8)
   if "Card" is in word 1 of targetName then
     click at (item 1 of the loc of me-15), (item 2 of the loc of me + 8)
  end if
end mouseUp

** BKGND #1, BUTTON #45: Voltmeter Template
**********************************

on evaluateState
  global targetName, direction, recording
  put "Evaluating state of voltmeter."
  set cursor to watch
  lock screen
  --The position of the voltmeter on the circuit is in line 5 of its
  --  card field
  if "Top" is in line 5 of cd fld the short name of me ¬
  or "Bottom" is in line 5 of cd fld the short name of me then
     put the loc of cd btn "V-Voltmeter-Wire 1" into wireOne
     put the loc of cd btn "V-Voltmeter-Wire 2" into wireTwo
    click at wireOne
    put targetName into partOne
    click at wireTwo
    put targetName into partTwo
    if "Top" is in line 5 of cd fld the short name of me then
      if "C" is in word one of partOne then --Check for corner wire
        put up into searchDirection
     else
        put right into searchDirection
     end if
  else
     if "C" is in word one of partOne then  --Check for corner wire
       put down into searchDirection
     else
        put right into searchDirection
     end if
  end if
```

```
-- Determine what devices are in between the voltmeter wires and
-- calculate the voltage drop
-- The direction for finding the next part is set earlier when it
-- is determined whether we are on top or bottom of the circuit
put partOne into adjPart
put searchDirection into direction
put 0 into resistance
put "Calculating resistance between voltmeter wires."
repeat while adjPart ≠ partTwo
  if "Card" is in adjPart then
    --Circuit is broken
    send zeroVoltmeter to bg fld "Voltmeter Reading"
    --This very tight loop traps all user mouseClicks that occured
    -- during the handler's execution
    repeat until the mouseClick is false
    end repeat
    if recording then
      put ", " & quote & the short name of me & quote & "=" & ¬
      bg fld "Voltmeter Reading" && "Volts" after ¬
      bg fld "Student Activities"
    end if
    exit evaluateState
  end if
  if item 1 of the loc of cd btn adjPart > item 1 of wireOne and ¬
  item 1 of the loc of cd btn adjPart < item 1 of wireTwo then
    -- Add the resistance of each part if its location is between
    -- the two voltmeter wires
    if line 1 of cd fld adjPart = "Lamp" then
      add 2 to resistance
    else if "Ω" is in line 2 of cd fld adjPart then
      add word 1 of line 2 of cd fld adjPart to resistance
    end if
  end if
  put nextPartAfter (adjPart) into adjPart
end repeat
if item 1 of the loc of cd btn adjPart > item 1 of wireOne and ¬
item 1 of the loc of cd btn adjPart < item 1 of wireTwo then
  -- Add the resistance of the last part if its location is between
  -- the two voltmeter wires
  if line 1 of cd fld adjPart = "Lamp" then
    add 2 to resistance
  else if "Ω" is in line 2 of cd fld adjPart then
    add word 1 of line 2 of cd fld adjPart to resistance
  end if
end if
else if "Right" is in line 5 of cd fld the short name of me or ¬
```

```
"Left" is in line 5 of cd fld the short name of me then
  put the loc of cd btn "H-Voltmeter-Wire 1" into wireOne
  put the loc of cd btn "H-Voltmeter-Wire 2" into wireTwo
 click at wireOne
 put targetName into partOne
 click at wireTwo
 put targetName into partTwo
 if "Right" is in line 5 of cd fld the short name of me then
   if "C" is in word one of partOne then
     put right into searchDirection
  else
    put down into searchDirection
  end if
else
  if "C" is in word one of partOne then
     put left into searchDirection
  else
    put down into searchDirection
  end if
end if
 -- Determine what devices are in between the voltmeter wires and
 --  calculate the voltage drop
 --  The direction for finding the next part is set earlier when it
 --  is determined whether we are on the left or right of the circuit
 put partOne into adjPart
 put searchDirection into direction
 put "Calculating resistance between voltmeter wires."
 put 0 into resistance
 repeat while adjPart ≠ partTwo
  if "Card" is in adjPart then
     --Circuit is broken
    send zeroVoltmeter to bg fld "Voltmeter Reading"
     --This very tight loop traps all user mouseClicks that occured
     --  during the handler's execution
    if recording then
      put ", " & quote & the short name of me & quote & "=" & ¬
       bg fld "Voltmeter Reading" && "Volts" after ¬
      bg fld "Student Activities"
    end if
    repeat until the mouseClick is false
   end repeat
   exit evaluateState
 end if
 if item 2 of the loc of cd btn adjPart > item 2 of wireOne and ¬
 item 2 of the loc of cd btn adjPart < item 2 of wireTwo then
   -- Add the resistance of each part if its location is between
```

```
        -- the two voltmeter wires
       if line 1 of cd fld adjPart = "Lamp" then
       add 2 to resistance
       else if "Ω" is in line 2 of cd fld adjPart then
        add word 1 of line 2 of cd fld adjPart to resistance
      end if
    end if
      put nextPartAfter (adjPart) into adjPart
  end repeat
  if item 2 of the loc of cd btn adjPart > item 2 of wireOne and ¬
  item 2 of the loc of cd btn adjPart < item 2 of wireTwo then
    -- Add the resistance of the last part if its location is between
    -- the two voltmeter wires
    if line 1 of cd fld adjPart = "Lamp" then
     add 2 to resistance
    else if "Ω" is in line 2 of cd fld adjPart then
     add word 1 of line 2 of cd fld adjPart to resistance
    end if
  end if
end if
put partOne into centerPart
--Find a good part (not a corner) to start search for good paths
if "C-" is in word 1 of centerPart then
  --Check adjacent parts. If both are corners, then zero meter and
  -- exit, otherwise put the one that isn't a corner into centerpart
  if "C-" is in line 3 of cd fld centerPart then
    if "C-" is in line 4 of cd fld centerPart then
      --Nothing is in between the voltmeter wires
     send zeroVoltmeter to bg fld "Voltmeter Reading"
      --This very tight loop traps all user mouseClicks that occured
      -- during the handler's execution
     if recording then
      put ", " & quote & the short name of me & quote & "=" & ¬
       bg fld "Voltmeter Reading" && "Volts" after ¬
       bg fld "Student Activities"
    end if
     repeat until the mouseClick is false
    end repeat
    exit evaluateState
  else
     put line 4 of cd fld centerPart into centerPart
  end if
else
   put line 3 of cd fld centerPart into centerPart
 end if
end if
```

```
  if "Card" is in centerPart then
     -- if the circuit is broken, zero meter and exit
    send zeroVoltmeter to bg fld "Voltmeter Reading"
     --This very tight loop traps all user mouseClicks that occured
     --  during the handler's execution
    if recording then
      put ", " & quote & the short name of me & quote & "=" & ¬
       bg fld "Voltmeter Reading" && "Volts" after ¬
       bg fld "Student Activities"
    end if
    repeat until the mouseClick is false
    end repeat
    exit evaluateState
  end if
  unlock screen
  --See if the voltmeter has a good path to the battery
  if goodpaths(centerPart) then
    put "calcVoltage" && quote & resistance & quote into voltMessage
    send voltMessage to bg fld "Voltmeter Reading"
  else
    send zeroVoltmeter to bg fld "Voltmeter Reading"
  end if
  if recording then
    put ", " & quote & the short name of me & quote & "=" & ¬
     bg fld "Voltmeter Reading" && "Volts" after ¬
     bg fld "Student Activities"
  end if
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
end evaluateState

on mouseUp
  if the lockScreen is false then
    send mouseUp to bg btn "V-Voltmeter"
  end if
end mouseUp

on setPicture
  hide cd fld the short name of me
  put the icon of me into iconNumber
  put iconNumber - 12188 into iconType
  if iconType = 0 or iconType = 1 then
    --Change to or keep voltmeter picture
    set the icon of cd btn the short name of me to (iconNumber + 20)
```

```
  end if
 end setPicture

 on setSymbol
  hide cd fld the short name of me
  put the icon of me into iconNumber
  put iconNumber - 12188 into iconType
  if iconType = 20 or iconType = 21 then
    --Change to or keep voltmeter symbol
    set the icon of cd btn the short name of me to (iconNumber - 20)
  end if
 end setSymbol

 on setWord
  show cd fld the short name of me
 end setWord

 on mouseDown
  if the commandKey is down then
    show cd fld the short name of me
    set the hilite of me to false
    wait while the mouse is down
    hide cd fld the short name of me
  end if
  pass mouseDown
 end mouseDown
```

** BKGND #1, BUTTON #46: V-Voltmeter-Wire 1 Template
* *

```
on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseUp
  global targetName
  click at (item 1 of the loc of me-8), (item 2 of the loc of me-15)
  if "Card" is in word 1 of targetName then
    click at (item 1 of the loc of me-8), (item 2 of the loc of me+15)
  end if
end mouseUp
```

** BKGND #1, BUTTON #47: H-Voltmeter-Wire 1 Template
****

```
on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseUp
  global targetName
  click at (item 1 of the loc of me+15), (item 2 of the loc of me - 8)
  if "Card" is in word 1 of targetName then
    click at (item 1 of the loc of me-15), (item 2 of the loc of me - 8)
  end if
end mouseUp
```

** BKGND #1, BUTTON #48: V-MR-Wire
****

```
on mouseUp
  makeNewPart the short name of me
  put the number of cd btns into newButtonNumber
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd btn newButtonNumber
end mouseUp
```

** BKGND #1, BUTTON #49: V-ML-Wire
****

```
on mouseUp
  makeNewPart the short name of me
  put the number of cd btns into newButtonNumber
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart the short name of cd btn newButtonNumber
end mouseUp
```

** BKGND #1, BUTTON #50: V-ML-Wire Template
****

```
on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseDown
  set the style of me to opaque
  pass mouseDown
end mouseDown

on mouseUp
  if the lockScreen is false then
    movePart the short name of me
  end if
  set the style of me to transparent
end mouseUp
```

** BKGND #1, BUTTON #51: V-MR-Wire Template
****

```
on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseDown
  set the style of me to opaque
  pass mouseDown
end mouseDown

on mouseUp
  if the lockScreen is false then
    movePart the short name of me
  end if
  set the style of me to transparent
end mouseUp
```

** BKGND #1, BUTTON #52: V-Ammeter Template
****

```
on evaluateState
  global recording
  put "Evaluating state of ammeter."
  wait 1 second
  --Check to see if paths to battery exist from each side of device
  if goodPaths(the short name of me) then
    --Calculate the circuit amperage
    send calcAmperage to bg fld "Ammeter Reading"
    --This very tight loop traps all user mouseClicks that occured
    --  during the handler's execution
    if recording then
      put ", " & quote & the short name of me & quote & "=" & ¬
      bg fld "Ammeter Reading" && "Amps" after ¬
      bg fld "Student Activities"
    end if
    repeat until the mouseClick is false
    end repeat
  else
    -- Zero out the ammeter or leave it zeroed out.
    if bg fld "Ammeter Reading" = 0 then
      exit evaluateState
    else
      send zeroAmmeter to bg fld "Ammeter Reading"
    end if
  end if
end evaluateState

on mouseUp
  global deleted
  if the lockScreen is false then
    put "False" into deleted
    movePart the short name of me
    --If a non-zero ammeter has been moved out of the circuit, it should
    --  be zeroed out.
    --Check the ammeter reading field.  If it is non-zero, then zero it
    --  out if there is no connection on one side of the ammeter.
    if deleted then  --Check to see if the user deleted the part
      show cd fld "Ammeter Mask"
    else
      if bg fld "Ammeter Reading" ≠ 0 and ¬
      (("card" is in line 3 of cd fld the short name of me) or ¬
      ("card" is in line 4 of cd fld the short name of me)) then
        --The meter is non-zero, so zero it out
        send zeroAmmeter to bg fld "Ammeter Reading"
```

```
      end if
    end if
  end if
end mouseUp

on mouseDown
  if the commandKey is down then
    show cd fld the short name of me
    set the hilite of me to false
    wait while the mouse is down
    hide cd fld the short name of me
  end if
  pass mouseDown
end mouseDown

on setPicture
  hide cd fld the short name of me
  set the icon of me to "V-Ammeter Picture"
end setPicture

on setSymbol
  hide cd fld the short name of me
  set the icon of me to "V-Ammeter Symbol"
end setSymbol

on setWord
  show cd fld the short name of me
end setWord
```

** BKGND #1, BUTTON #53: H-Lamp Template
****

```
on evaluateState
  global recording
  put "Evaluating state of lamp."
  wait 1 second
  put the icon of me into iconNumber
  put (iconNumber - 12194) into bulbState --0 or 20 = off, 1 or 21 = on
  --Check to see if paths to battery exist from each side of device
  if goodPaths(the short name of me) then
    -- Turn the bulb on or leave it on
    if (bulbState = 0) or (bulbState = 20) then    --if the bulb is off
      set the icon of me to (the icon of me + 1)  -- turn it on
      put "On" into line 2 of cd fld the short name of me
      if recording then
        put ", " & quote & the short name of me & quote & "->ON" after ¬
        bg fld "Student Activities"
```

```
      end if
    end if
  else -- Turn the bulb off or leave it off
    if (bulbState = 1) or (bulbState = 21) then    --if the bulb is on
      set the icon of me to (iconNumber - 1)       -- turn it off
      put "Off" into line 2 of cd fld the short name of me
      if recording then
        put ", " & quote & the short name of me & quote & "->OFF" after ¬
        bg fld "Student Activities"
      end if
    end if
  end if
  --This very tight loop traps all user mouseClicks that occured
  -- during the handler's execution
  repeat until the mouseClick is false
  end repeat
end evaluateState

on setPicture
  hide cd fld the short name of me
  put the icon of me into iconNumber
  if iconNumber is 12214 or iconNumber is 12215 then
    exit setPicture
  end if
  set the icon of me to (iconNumber + 20)
end setPicture

on setSymbol
  hide cd fld the short name of me
  put the icon of me into iconNumber
  if iconNumber is 12194 or iconNumber is 12195 then
    exit setSymbol
  end if
  set the icon of me to (iconNumber - 20)
end setSymbol

on setWord
  show cd fld the short name of me
end setWord

on mouseUp
  if the lockScreen is false then
    movePart the short name of me
    --If a lighted bulb has been moved out of the circuit, it should
    -- be turned off.
    put the icon of me into iconNumber
```

```
      put (iconNumber - 12194) into bulbState --0 or 20=off, 1 or 21=on
      if ((bulbState = 1) or (bulbState = 21)) and ¬
     (("card" is in line 3 of cd fld the short name of me) or¬
     ("card" is in line 4 of cd fld the short name of me)) then
        --if the bulb is on, turn it off
       set the icon of me to (iconNumber - 1)
       put "Off" into line 2 of cd fld the short name of me
    end if
  end if
end mouseUp

on mouseDown
  if the commandKey is down then
    show cd fld the short name of me
    set the hilite of me to false
    wait while the mouse is down
    hide cd fld the short name of me
  end if
  pass mouseDown
end mouseDown
```

** BKGND #1, BUTTON #54: Click Marker 1
****

```
on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseUp
  global targetName
  click at (item 1 of the loc of me+8), (item 2 of the loc of me-15)
  if "Card" is in word 1 of targetName then
    click at (item 1 of the loc of me+8), (item 2 of the loc of me+15)
  end if
end mouseUp
```

** BKGND #1, BUTTON #55: Click Marker 2
****

```
on setSymbol
end setSymbol

on setPicture
```

```
end setPicture

on setWord
end setWord

on mouseUp
  global targetName
  click at (item 1 of the loc of me+8), (item 2 of the loc of me-15)
  if "Card" is in word 1 of targetName then
    click at (item 1 of the loc of me+8), (item 2 of the loc of me+15)
  end if
end mouseUp

** CARD #1: Title Card ************************************************
on openCard
  hide card field "Ohm Info"
end openCard

** CARD #1, FIELD #1: Ohm Info *******************************************
on mouseUp
  hide card field "Ohm Info"
end mouseUp

** CARD #1, FIELD #2: About **********************************************
on mouseUp
  hide card field "About"
end mouseUp

** CARD #1, BUTTON #1: Start Simulation **********************************
on mouseUp
  if the shiftKey is down then
    lock screen
    go to card id 8095
    hide bkgnd field "Parts Help"
    hide bkgnd field "Circuit Help"
    hide bkgnd field "Meter Help"
    hide bkgnd button "Symbols Help"
    unlock screen with visual effect dissolve
  end if
end mouseUp

** CARD #1, BUTTON #2: Ohm's Button
****************************************
on mouseUp
  set visible of card field "Ohm Info" to not the visible of ¬
  card field "Ohm Info"
```

```
end mouseUp

** CARD #1, BUTTON #3: Home
*******************************************
on mouseUp
  visual effect iris close
  go "Home"
end mouseUp

** CARD #1, BUTTON #4: About
*******************************************
on mouseDown
  set visible of card field "About" to not the visible of card field "About"
end mouseDown

** CARD #1, BUTTON #5: Mouse Introduction
********************************
on mouseUp
  --if the shiftKey is down then
  set cursor to "None"
  --unlock screen with iris open slowly to black
  --wait 3 seconds
  Visual effect iris open slowly
  go to card id 11583
  wait 3 seconds
  visual effect barn door open very slowly
  go to next card
  repeat 5 times
    go to next card
     play "Click"
    go to previous card
  end repeat

  visual effect iris open slowly to black
  go to cd "Begin"
  --end if
end mouseUp

** CARD #1, BUTTON #6: Start Tutorial ************************************
on mouseUp
  --if the shiftKey is down then
  lock screen
  go to card id 4604
  hide bkgnd field "Parts Help"
  hide bkgnd field "Circuit Help"
  hide bkgnd field "Meter Help"
```

```
    hide bkgnd button "Symbols Help"
    unlock screen with visual effect dissolve
    --end if
end mouseUp

** CARD #2: Start Mouse Training ****************************************
on openCard
  hide menubar
  set cursor to "None"
  unlock screen with wipe left very slowly
  wait 3 seconds
end openCard

** CARD #5: Begin **************************************************
on openCard
  unlock screen with iris open to black
  hide menubar
  set cursor to "None"
  repeat until the mouseClick
    set cursor to "none"
    set hilite of cd btn "Arrow" to true
    wait 15
    set hilite of cd btn "Arrow" to false
    wait 15
  end repeat
  visual effect iris open slowly to black
  go to next card
end openCard

** CARD #6: Mouse1 ***********************************************
on openCard
  set cursor to "None"
  unlock screen with iris open
  wait 6 seconds
  visual effect iris open
  go to next card
end openCard

** CARD #7: Mouse2 *********************************************
on openCard
  global counter,firstTime
  put true into firstTime
  put empty into counter
  hide cd fld "Watch It Field"
end openCard
```

```
on move
  global firstTime
  if firstTime <> false then
    --play "Continue"
    repeat 5 times
      set hilite of card button "Continue" to true
      wait 15
      set hilite of card button "Continue" to false
      wait 15
    end repeat
  end if
  put false into firstTime
end move

on up
  global counter
  put counter + 1 into counter
  set hilite of card button "Hand" to true
  get the location of cd btn "Hand"
  put it into begin
  put it into finish
  subtract 15 from item 2 of finish
  select cd btn "Hand"
  set dragSpeed to 5
  drag from begin to finish
  choose browse tool
  show cd btn "Hand" at begin
  set hilite of card button "Hand" to false
  if counter > 1 then move
end up

on Right
  global counter
  put counter + 1 into counter
  set hilite of card button "Hand" to true
  get the location of cd btn "Hand"
  put it into begin
  put it into finish
  add 20 to item 1 of finish
  select cd btn "Hand"
  set dragSpeed to 5
  drag from begin to finish
  choose browse tool
  show cd btn "Hand" at begin
  set hilite of card button "Hand" to false
  if counter > 1 then move
```

```
end Right

on Left
  global counter
  put counter + 1 into counter
  set hilite of card button "Hand" to true
  get the location of cd btn "Hand"
  put it into begin
  put it into finish
  subtract 20 from item 1 of finish
  select cd btn "Hand"
  set dragSpeed to 5
  drag from begin to finish
  choose browse tool
  show cd btn "Hand" at begin
  set hilite of card button "Hand" to false
  if counter > 1 then move
end Left

on Down
  global counter
  put counter + 1 into counter
  set hilite of card button "Hand" to true
  get the location of cd btn "Hand"
  put it into begin
  put it into finish
  add 15 to item 2 of finish
  select cd btn "Hand"
  set dragSpeed to 5
  drag from begin to finish
  choose browse tool
  show cd btn "Hand" at begin
  set hilite of card button "Hand" to false
  if counter > 1 then move
end Down

** CARD #7, BUTTON #1: Up
******************************************

on mouseUp
  play "Click"
  set hilite of cd btn "Up" to true
  show cd fld "Watch It Field"
  up
  set hilite of cd btn "Up" to false
  hide cd fld "Watch It Field"
end mouseUp
```

```
** CARD #7, BUTTON #2: Right
*********************************************
on mouseUp
  play "Click"
  set hilite of cd btn "Right" to true
  show cd fld "Watch It Field"
  Right
  set hilite of cd btn "Right" to false
  hide cd fld "Watch It Field"
end mouseUp

** CARD #7, BUTTON #3: Left *******************************************
on mouseUp
  play "Click"
  set hilite of cd btn "Left" to true
  show cd fld "Watch It Field"
  Left
  set hilite of cd btn "Left" to false
  hide cd fld "Watch It Field"
end mouseUp

** CARD #7, BUTTON #4: Down
*********************************************
on mouseUp
  play "Click"
  set hilite of cd btn "Down" to true
  show cd fld "Watch It Field"
  Down
  set hilite of cd btn "Down" to false
  hide cd fld "Watch It Field"
end mouseUp

** CARD #7, BUTTON #6: Continue ****************************************
on mouseUp
  play "Click"
  visual effect dissolve slowly to black
  visual effect dissolve slowly to card
  go to card id 4604
end mouseUp

** CARD #8, BUTTON #1: Return
*********************************************
on mouseUp
  visual effect iris close
  pop card
```

```
end mouseUp

** CARD #8, BUTTON #2: Next
*******************************************
on mouseUp
  visual effect wipe left
  go to next card
  hide bkgnd field "Parts Help"
  hide bkgnd field "Circuit Help"
  hide bkgnd field "Meter Help"
  hide bkgnd button "Symbols Help"
end mouseUp

** CARD #8, BUTTON #3: Prev
*******************************************
on mouseUp
  visual effect wipe right
  go to previous card
end mouseUp

** CARD #8, BUTTON #4: Home *******************************************
on mouseUp
  visual effect iris close
  go "Home"
end mouseUp

** CARD #9: Sample Circuit *******************************************
on openCard
  hide bg btn "Prev"
  show bg btn "Next"
  pass openCard
end openCard

on closeCard
  show bg btn "Prev"
  pass closeCard
end closeCard

** CARD #9, BUTTON #16: Circuit Cover *************************************
on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
```

```
end setWord

on mouseUp
  answer "Start a new circuit card." with "Cancel" or "OK"
  if it = "OK" then
    lock screen
    doMenu "New Card"
    unlock screen with dissolve
  end if
end mouseUp

**   CARD   #10:   Tutorial   ****************************************
on openCard
  set cursor to watch
  lock screen
  if line 1 of bg fld "Button Values" ≠ "" then
    put the number of bg btn "Pictures" into firstButton
    repeat with x = 0 to 2
      if line (x + 1) of bg fld "Button Values" = "true" then
        send mouseUp to bg btn (firstButton + x)
      end if
    end repeat
  end if
  hide bg fld "Parts Help"
  hide bg fld "Circuit Help"
  hide bg fld "Meter Help"
  hide bg btn "Symbols Help"
  hide bg fld "Activities Help"

  -- check the readings on the meters and set the scales accordingly
  if item 1 of bg fld "Voltmeter Reading" > 10 then
    hide bg fld "Voltage x10 Mask"
  else
    show bg fld "Voltage x10 Mask"
  end if
  if item 1 of bg fld "Ammeter Reading" > 1 then
    hide bg fld "Amperage x10 Mask"
  else
    show bg fld "Amperage x10 Mask"
  end if
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  set cantModify of this stack to true
  hide message box
```

```
  put empty into cd fld "Instructions"
  show cd btn "Tutorial Mask"
  hide cd btn "Quit Tutorial"
  unlock screen
end openCard

on closeCard
  set cursor to wait
  set cantModify of this stack to false
  hide cd fld "Instructions"
  hide cd fld "Instructions Title"
  put the number of bg btn "Pictures" into firstButton
  repeat with x = 0 to 2
    if the short name of bg btn (firstButton + x) is "Pictures" then
      put "true" into line x + 1 of bg fld "Button Values"
    else
      put "false" into ¬
      line x + 1 of bg fld "Button Values"
    end if
  end repeat
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
end closeCard

on tutorial
  global targetName
  hide message box
  put empty into cd fld "Instructions"
  put (item 1 of topLeft of cd fld "Instructions" + 2) & "," & ¬
  (item 2 of topLeft of cd fld "Instructions" + 2)  into instructLoc
  --Display instructions to add lamp to circuit and have user click on
  --  the lamp
  set cursor to none
  click at instructLoc
  type "First, let's add a lamp to the circuit.  " & ¬
  "Move the mouse pointer over to the lamp picture " & ¬
  "that is flashing, and click the mouse button on it.  " & ¬
  "Make sure the pointing finger is on the button when you click."
  set cursor to hand
  repeat
    repeat until the mouseClick
      set hilite of cd btn "H-Lamp" to true
      wait 15
      set hilite of cd btn "H-Lamp" to false
```

```
      wait 15
    end repeat
     if the clickLoc is within the rect of cd btn "Quit Tutorial" then
      send mouseUp to cd btn "Quit Tutorial"
       exit tutorial
    end if
     if the clickLoc is within the rect of bg btn "H-Lamp" then
       put empty into cd fld "instructions"
       --Prompt the user to click at the top of the circuit to
      --  place the lamp.
      set cursor to none
       click at instructLoc
      type "Good.  You have just started creating a lamp that you " &¬
      "can use in the circuit.  After a few seconds your " &¬
       "lamp will appear.  Follow the instructions at the right " &¬
      "and move the lamp to the top of the circuit right next to " &¬
      "the other lamp."
     set cursor to hand
      click at the loc of cd btn "H-Lamp"
     unlock screen
      exit repeat
   else
      answer "Please click on the flashing lamp button."
   end if
  end repeat
end tutorial

on checkCell
  unlock screen
  put (item 1 of topLeft of cd fld "Instructions" + 2) & "," & ¬
  (item 2 of topLeft of cd fld "instructions" + 2)  into instructLoc
  if the loc of cd btn "H-Cell 64" is "255,183" then
    put empty into cd fld "Instructions"
    --Tell the user to go on to building circuits.
   set cursor to none
    click at instructLoc
   type "Very Good.  Now you're ready to build some circuits of your " &¬
   "own.  Click on the 'New' button at the top " &¬
    "right and start working on your booklet. "
   set cursor to hand
 else
   answer "Please move the battery to the circuit."
 end if
end checkCell
```

** CARD #10, BUTTON #7: Start Tutorial ************************************

```
on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseUp
  lock screen
  hide cd btn "Tutorial Mask"
  show cd fld "Instructions"
  show cd fld "Instructions Title"
  put empty into cd fld "Instructions"
  show cd btn "Quit Tutorial"
  unlock screen with dissolve slowly
  tutorial
end mouseUp

** CARD #10, BUTTON #9: Quit Tutorial ***********************************
on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseUp
  hide cd fld "Instructions"
  hide cd fld "Instructions Title"
  hide message box
  answer "Start a new circuit card." with "Cancel" or "OK"
  if it = "OK" then
    lock screen
    send closeCard to this card
    doMenu "New Card"
    unlock screen with dissolve
  end if
  hide me
end mouseUp

** CARD #10, BUTTON #10: H-Cell 64
****************************************
```

```
on evaluateState
  --Might have to add something here to check for dead battery
  --  when the simulation reaches a higher level
end evaluateState

on setPicture
  hide cd fld the short name of me
   set the icon of me to "H-Cell Picture" --12207
end setPicture

on setSymbol
  hide cd fld the short name of me
   set the icon of me to "H-Cell Symbol" --12187
end setSymbol

on setWord
  show cd fld the short name of me
end setWord

on mouseUp
  set the style of me to transparent
  if the lockscreen is false then
    movePart the short name of me
    checkCell
  end if
end mouseUp

on mouseDown
  set the style of me to opaque
  if the commandKey is down then
    show cd fld the short name of me
    set the hilite of me to false
    wait while the mouse is down
    hide cd fld the short name of me
  end if
  pass mouseDown
end mouseDown

** CARD #10, BUTTON #13: Tutorial Mask  **********************************
on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
```

```
end setWord

on mouseUp
  answer "Please click on the 'Start Tutorial' Button."
end mouseUp

**  CARD  #10,  BUTTON  #14:  H-Lamp     ***************************************
on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on checkLamp
 unlock screen
  put (item 1 of topLeft of cd fld "Instructions" + 2) & "," & ¬
  (item 2 of topLeft of cd fld "Instructions" + 2)  into instructLoc
  if the loc of cd btn "H-Lamp 95" is "226,125" then
    -- Now add a corner wire to complete the circuit
    put empty into cd fld "Instructions"
    --Prompt the user to click on the lower left corner
   set cursor to none
    click at instructLoc
   type "OK.  Now let's add a left corner wire to " &¬
   "the circuit.  Move the mouse pointer to the bottom " &¬
   "left corner wire and click on it.  After a few seconds, your " &¬
   "corner wire will appear and you can move it to the circuit."
   set cursor to hand
   repeat
     wait until the mouseClick
     if the clickLoc is within the rect of cd btn "Quit Tutorial" then
      send mouseUp to cd btn "Quit Tutorial"
      exit checkLamp
    end if
     if the clickLoc is within the rect of cd btn "C-BL-Wire" then
       click at the loc of cd btn "C-BL-Wire"
      exit repeat
   else
       answer "You must click on the lower left corner wire."
    end if
  end repeat
else
  put empty into cd fld "Instructions"
```

```
    set cursor to none
    click at instructLoc
    type "Well, you didn't get the lamp moved to the proper " &¬
    "place in the circuit.  In order to move the lamp now, " &¬
    "simply click on it.  Follow the instructions to put " &¬
    "it into the circuit right next to the other lamp."
    set cursor to hand
  end if
end checkLamp

on mouseUp
  set the cursor to wait
  wait 3 seconds
  show cd btn "H-Lamp 95"
  --This very tight loop traps all user mouseClicks that occured
  --  during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart "H-Lamp 95"
  checkLamp
end mouseUp

on setPicture
  set the icon of me to "H-LampOff Picture"
end setPicture

on setSymbol
  set the icon of me to "H-LampOff Symbol"
end setSymbol

on setWord
end setWord

** CARD #10, BUTTON #15: C-BL-Wire
**************************************

on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseUp
```

```
  set the cursor to wait
  wait 3 seconds
  show cd btn "C-BL-Wire 99"
  --This very tight loop traps all user mouseClicks that occured
  -- during the handler's execution
  repeat until the mouseClick is false
  end repeat
  --Allow the part to be moved immediately to the circuit
  movePart "C-BL-Wire 99"
  checkWire
end mouseUp

on checkWire
  unlock screen
  put (item 1 of topLeft of cd fld "Instructions" + 2) & "," & ¬
  (item 2 of topLeft of cd fld "Instructions" + 2) into instructLoc
  if the loc of cd btn "c-bl-wire 99" is "168,183" then
    -- Finally add the battery to the circuit
    put empty into cd fld "Instructions"
    --Prompt the user to click on the lower left corner
    set cursor to none
    click at instructLoc
    type "Great. Finally, let's move the battery that's already " &¬
    "created into the place at the bottom of the circuit right next " &¬
    "to the other battery. To move a part that is already created, " &¬
    "just click on the part. Try it now."
    set cursor to hand
  else
    put empty into cd fld "Instructions"
    set cursor to none
    click at instructLoc
    type "Well, you didn't get the wire moved to the proper " &¬
    "place in the circuit. In order to move the wire now, " &¬
    "just click on it. Follow the instructions to put " &¬
    "it in the lower left hand corner of the circuit."
    set cursor to hand
  end if
end checkWire

** CARD #10, BUTTON #16: H-Lamp 95
*************************************

on checkLamp
  unlock screen
  put (item 1 of topLeft of cd fld "Instructions" + 2) & "," & ¬
  (item 2 of topLeft of cd fld "Instructions" + 2) into instructLoc
  if the loc of me is "226,125" then
```

```
-- Now add a corner wire to complete the circuit
put empty into cd fld "instructions"
--Prompt the user to click on the lower left corner
click at instructLoc
type "OK.  Now let's add a left corner wire to " &¬
"the circuit.  Move the mouse pointer to the bottom " &¬
"left corner wire and click on it.  After a few seconds, your " &¬
"corner wire will appear and you can move it to the circuit."
repeat
  wait until the mouseClick
  if the clickLoc is within the rect of cd btn "Quit Tutorial" then
    send mouseUp to cd btn "Quit Tutorial"
    exit checkLamp
  end if
  if the clickLoc is within the rect of cd btn "C-BL-Wire" then
    click at the loc of cd btn "C-BL-Wire"
    exit repeat
  else
    answer "You must click on the lower left corner wire."
  end if
end repeat
else
  put empty into cd fld "instructions"
  click at instructLoc
  type "Well, you didn't get the lamp moved to the proper " &¬
  "place in the circuit.  In order to move the lamp now, " &¬
  "simply click on it.  Follow the instructions to put " &¬
  "it into the circuit right next to the other lamp."
end if
end checkLamp

on evaluateState
  put "Evaluating state of lamp."
  wait 2 seconds
  put the icon of me into iconNumber
  put (iconNumber - 12194) into bulbState --0 or 20 = off, 1 or 21 = on
  --Check to see if paths to battery exist from each side of device
  if goodPaths(the short name of me) then
    -- Turn the bulb on or leave it on
    if (bulbState = 0) or (bulbState = 20) then   --if the bulb is off
      set the icon of me to (the icon of me + 1)  -- turn it on
      put "On" into line 2 of cd fld the short name of me
    end if
  else -- Turn the bulb off or leave it off
    if (bulbState = 1) or (bulbState = 21) then   --if the bulb is on
      set the icon of me to (iconNumber - 1)       -- turn it off
```

```
      put "Off" into line 2 of cd fld the short name of me
    end if
  end if
end evaluateState

on setPicture
  hide cd fld the short name of me
  put the icon of me into iconNumber
  if iconNumber is 12214 or iconNumber is 12215 then
    exit setPicture
  end if
  set the icon of me to (iconNumber + 20)
end setPicture

on setSymbol
  hide cd fld the short name of me
  put the icon of me into iconNumber
  if iconNumber is 12194 or iconNumber is 12195 then
    exit setSymbol
  end if
  set the icon of me to (iconNumber - 20)
end setSymbol

on setWord
  show cd fld the short name of me
end setWord

on mouseUp
  if the lockScreen is false then
    movePart the short name of me
    --If a lighted bulb has been moved out of the circuit, it should
    --  be turned off.
    put the icon of me into iconNumber
    put (iconNumber - 12194) into bulbState --0 or 20=off, 1 or 21=on
    if ((bulbState = 1) or (bulbState = 21)) and ¬
    (("card" is in line 3 of cd fld the short name of me) or¬
    ("card" is in line 4 of cd fld the short name of me)) then
      --if the bulb is on, turn it off
      set the icon of me to (iconNumber - 1)
      put "Off" into line 2 of cd fld the short name of me
    end if
    checklamp
  end if
end mouseUp

on mouseDown
```

```
  if the commandKey is down then
    show cd fld the short name of me
    set the hilite of me to false
    wait while the mouse is down
    hide cd fld the short name of me
  end if
  pass mouseDown
end mouseDown

** CARD #10, BUTTON #17: C-BL-Wire 99
*************************************
on checkWire
  unlock screen
  put (item 1 of topLeft of cd fld "Instructions" + 2) & "," & ¬
  (item 2 of topLeft of cd fld "Instructions" + 2)  into instructLoc
  if the loc of me is "168,183" then
    -- Finally add the battery to the circuit
    put empty into cd fld "Instructions"
    --Prompt the user to click on the lower left corner
    click at instructLoc
    type "Great.  Finally, let's move the battery that's already " &¬
    "created into the place at the bottom of the circuit right next " &¬
    "to the other battery.  To move a part that is already created, " &¬
    "just click on that part.  Try it now."
  else
    put empty into cd fld "Instructions"
    click at instructLoc
    type "Well, you didn't get the wire moved to the proper " &¬
    "place in the circuit.  In order to move the wire now, " &¬
    "just click on the it.  Follow the instructions to put " &¬
    "it in the lower left hand corner of the circuit."
  end if
end checkWire

on setSymbol
end setSymbol

on setPicture
end setPicture

on setWord
end setWord

on mouseDown
  set the style of me to opaque
  pass mouseDown
```

```
end mouseDown

on mouseUp
  if the lockScreen is false then
    movePart the short name of me
    checkWire
  end if
  set the style of me to transparent
end mouseUp

** CARD #11: Last Card ***********************************************
on openCard
  hide bg btn "next"
  show bg btn "prev"
  pass openCard
end openCard

on closeCard
  show bg btn "next"
  pass closeCard
end closeCard
```

APPENDIX D.

PROBLEMS FOR STUDENTS USING THE SIMULATION BEFORE STUDYING THE TEXT OR CCDT

THE SIMULATED ELECTRIC CIRCUIT

To help you get acquainted with electric circuits, you will be able to use a microcomputer simulation of an electric circuit developed with HyperCard on the Apple Macintosh. You will be given problems to work on and example circuits to build. The goal is to allow you to see how a real circuit behaves, without having to bring in and teach you about all the equipment a real circuit requires. Working with the simulation should help you develop a foundation upon which to build in your study of the text later.

It is not necessary that you have previous experience with the Macintosh or any other microcomputer to use the simulation. The first few minutes of this session will be spent in helping you become familiar with the Macintosh and in using the mouse. After you have learned how to use the mouse, go on to study the text.

To activate the computer program, hold down one of the "Shift" keys and then push (or click) on the mouse button once. The computer will instruct you from there. After you are finished with the introductory portion, a screen containing pictures of electrical parts will appear. This is the screen you will use to build your circuits. You should have received a printed copy of the simulation screen. Please refer to it as you read the following instructions.

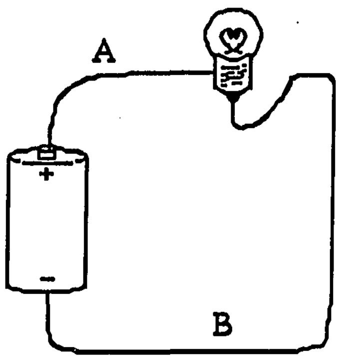
Each time you build a new circuit, you should go through the following general procedure:

1. Click on the small picture that says "New" by putting the small hand (pointer) on the picture and pressing the mouse button once. This will give you a clean circuit area to work with.
2. Near the bottom of the screen are pictures of electrical parts. Click on any of the parts that you need. In a few seconds, a new part will appear, and you will be asked to click on the area of the screen where you want to put the part.
3. Continue to create and place the parts you need until you have built the circuit the way you want it.
4. During the process of building the circuit, you may want to move some of the parts you have already created. If so, simply click the pointer on the part you want to move. You will be asked to click on the area of the screen where you want to put the part. If you are trying to move a part and you hear a "Beep", that means that you are trying to move the part to the wrong place on the screen. Make sure you are clicking on the circuit area and that you are not trying to put the part too close to another part that can't connect with it.

If you have any questions on how to use the simulation, the proctor will be glad to help you. You may now go on to the exercises.

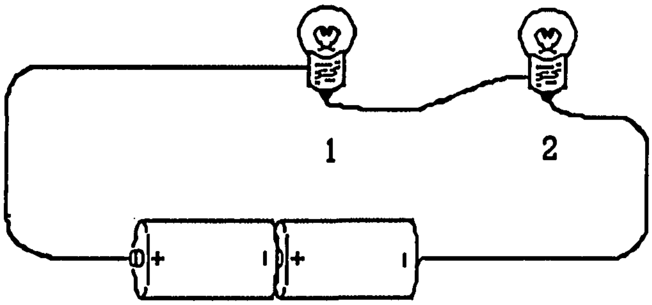
PRE-STUDY EXERCISES

Exercise 1. Use the simulation to build the circuit in the figure below. You may give the battery anywhere from 3 to 12 volts. What happens when the circuit is completed? Try removing a piece of wire A and write down what happens. Now put back the piece of wire A and remove a piece of wire B. What happens?



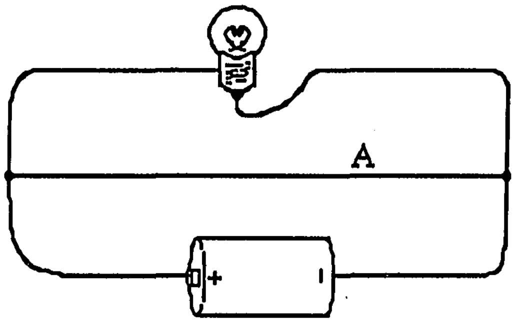
Write your answers here.

Exercise 2. Build a new circuit with two batteries and two light bulbs as shown in the figure below. Give the batteries anywhere from 3 to 12 volts. What do you notice about the two light bulbs when the circuit is completed?



Write your answers below.

Exercise 3. Using the computer simulation, build a circuit like the one in the figure below. You may give the battery anywhere from 3 to 12 volts. Does the light bulb light? If not, try to change the circuit (without adding any other parts) so that the light bulb lights. Were you successful? If so, what did you change, and why do you think the circuit works that way?



Write your answers here.

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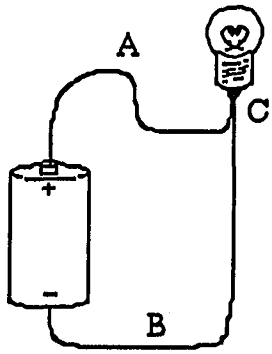
Exercise 4. In the figure below, you can see that both wire A and wire B are connected at point C on the light bulb. Using the simulation, is it possible to build a circuit like the one in this figure? If it is, build it and tell how you did it and whether the light bulb lit. If it isn't possible, write down why you think the simulation was made so it couldn't be done.



Write your answers here.

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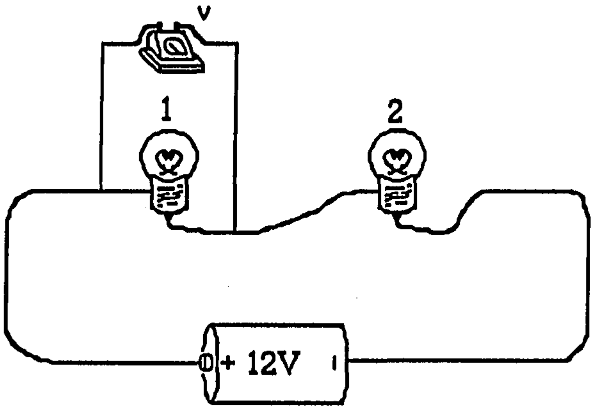
Exercise 5. Using the computer simulation, build a circuit like the one in the figure below. The battery should be 12 volts. Use the voltmeter to measure the voltage across bulb 1. Record the reading that you get. Replace the current battery with a new one so that the voltage across bulb 1 is exactly one-half of what it was with the 12 volt battery. What voltage did you give the battery? Record below the voltages that you gave to the batteries and the voltmeter reading that you got with each new voltage.



Voltage of Battery Voltmeter Reading

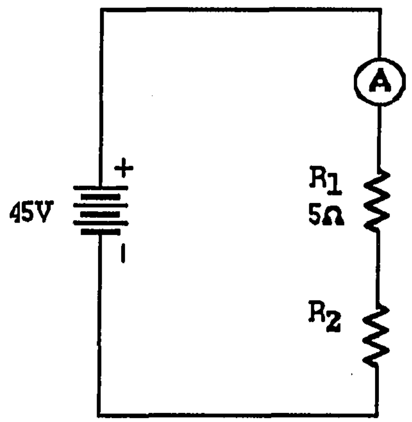
Exercise 6. Use the same circuit that you built for Exercise 5 for this exercise. Measure the current of the circuit with an ammeter placed in different parts of the circuit. Record the readings that you get.

Position of ammeter in circuit. Ammeter Reading

Exercise 7. Use the same circuit that you built for Exercise 5 for this exercise. Now can you replace the battery in the circuit with a new one, so that the new ammeter reading is twice as much as the readings you got in Exercise 6? If you can, what voltage did you give the new battery? Record the voltages that you try and the readings you get with each new voltage.

Voltage of Battery	Ammeter Reading

Exercise 8. Using the simulation, build the circuit in the figure below. You will have to click on the round button labelled "Symbols" to make the parts appear as electrical symbols instead of pictures. Use a 45 volt battery and a 5-ohm resistor for R_1. Now, try to add R_2 with a resistance that will make the ammeter read 3 amps. Record the resistances that you try and the ammeter readings that you get with each resistance.



Resistance of R_2	Ammeter Reading

This is the end of the exercises using the computer simulation. Now you should go on to study the attached text.

APPENDIX E.

BOOKLETS FOR STUDENTS USING THE SIMULATION DURING THE STUDY OF THE TRADITIONAL TEXT

ELECTRIC CIRCUITS

Electrical energy is not something used only by scientists and engineers. Today, almost everyone uses electricity. You are familiar with many different kinds of electric appliances. Twist a knob or push a button, and a radio or television set begins to play. Flip a switch, and an electric light or a fan is turned on. Each of these appliances works by using electrical energy. Do you know how the electricity causes those appliances to work? You will find out in this section.

THE PATH OF AN ELECTRIC CURRENT

What do switching on a light and turning on a faucet have in common? Opening the faucet lets water flow from the pipe. Turning on an electric light switch permits electrons to flow through the wires. Water will not flow in the pipe, however, unless a force is present to move it. That force could be supplied by gravity causing the water to flow down hill. A pump could also supply the energy needed to move the water. Electrons flowing through a conductor also need a force to cause them to move.

About the year 1800, an Italian scientist named Alessandro Volta discovered a way to make electrons flow through a conductor. Volta found that combination of two different metals and salt water could make electrons move through a conductor. A chemical reaction between the metals and the salt solution caused the electrons to move. This arrangement of two materials together with a solution causing a flow of electrons is called an electrochemical cell. An automobile battery is made up of several electrochemical cells.

Electrical energy in the battery is changed into chemical energy and stored in the cells. Later, the cells in the battery can change the stored chemical energy back into electricity.

An ordinary flashlight battery is also a kind of electrochemical cell. It is often called a dry cell because it does not contain a liquid. A moist chemical mixture is used instead of the liquid.

Chemical changes taking place inside the dry cell cause part of the cell to build up a supply of extra electrons. This part of the cell is called the negative terminal (-). Another part of the cell lacks a normal supply of electrons. This part of the cell is called the positive terminal (+). Wires can be attached easily to the negative and positive terminals of a cell or battery.

THE NATURE OF ELECTRIC CIRCUITS

If you connect a wire or other conductor between the negative and positive terminals of a cell, the extra electrons at the negative terminal will have a path to get to the positive terminal where electrons are lacking. Electrons will immediately start to flow between the two terminals. You have made an electric circuit. An electric circuit is a complete path allowing electrons to flow and produce an electric current.

When you plug a lamp into an electric outlet and turn on the switch, you are completing an electric circuit. The two parts of the plug and a pair of wires provide a complete circuit. An electric current can then flow through the lamp that is plugged into the outlet.

Electrons repel each other because they all carry a negative charge. An electron in a wire repels other electrons in the wire. Electrons all along the wire pass along this movement from one to the next. This effect travels rapidly along the wire. This is what is meant when electrons are said to "flow" along a conductor.

KINDS OF CIRCUITS

An electric circuit is made up of several parts. There must be a source of electrons to be moved through the circuit. Conductors, usually wires, are needed to connect all the parts. These parts include switches and the appliance to be operated, a light for example. See Figure 7. Illustrated are some of the symbols used to illustrate parts of electric circuit diagrams.

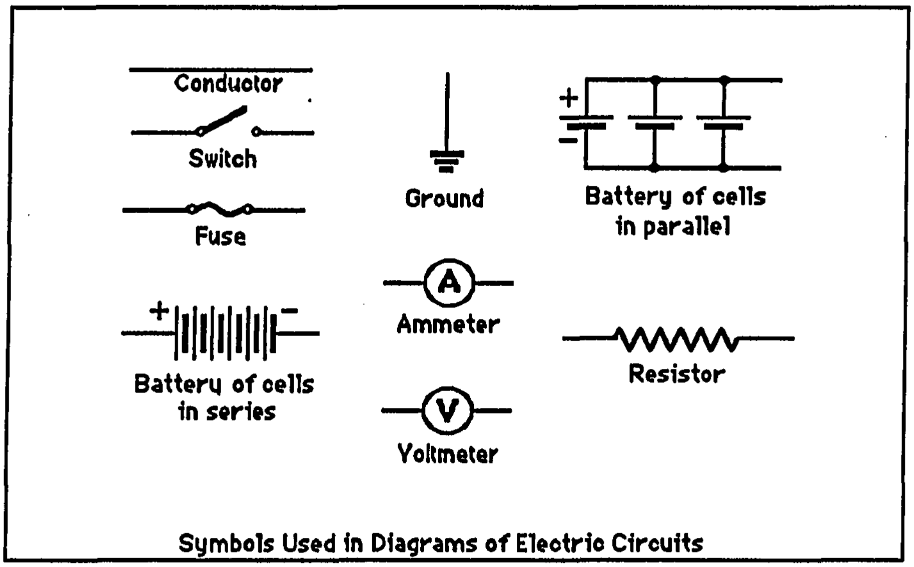


Figure 1

These items can be connected one after another. This arrangement is called a series circuit. In a series circuit, all parts of an electric circuit are connected one after another as shown in Figure 2. In a series circuit, there is only one path the electrons can follow. A series circuit can cause some problems. Suppose, for example, that light bulbs are arranged in a series circuit. If one bulb fails, the circuit is broken and all the bulbs go out. No part of a series circuit can be switched off without turning off the whole thing. If the lights in a house were connected in series, they would all have to be on or off at the same time.

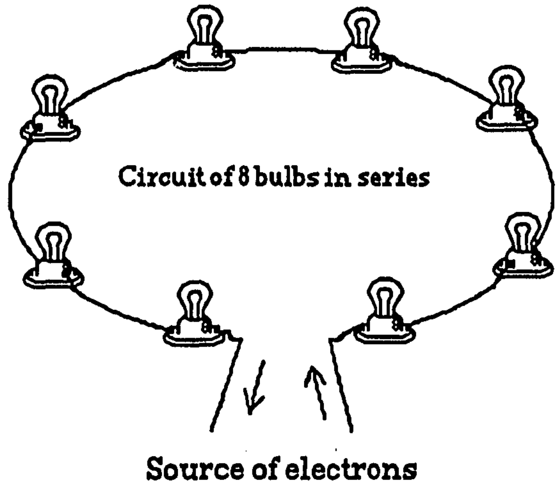


Figure 2a

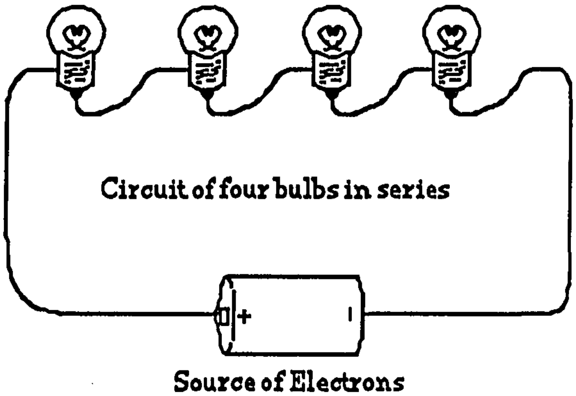


Figure 2b

At this point, you should use the computer simulation to try to build a series circuit like the one in 2b above. You can use one 6 volt battery as the source of electrons. What happens to all the lights if the circuit is broken at any point?
Write your answer here. ____

Another way to connect the parts of a circuit is shown in Fig. 3 (next page). This arrangement is called a parallel circuit. In a parallel circuit, the different paths are on separate branches. Each branch of a parallel circuit can be switched off without affecting the other branches The different circuits in a house are arranged in a parallel. In this way, many appliances can be used at the same time. They do not all have to be on at the same time.

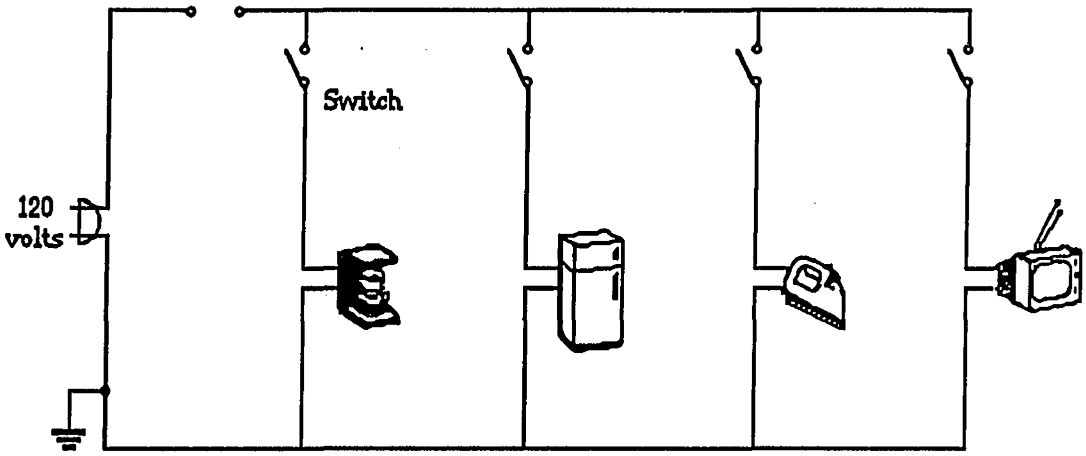


Figure 3

SHORT CIRCUIT

Have you ever used an electric appliance only to be startled by a shower of sparks, and a room plunged into sudden darkness? What caused this to happen?

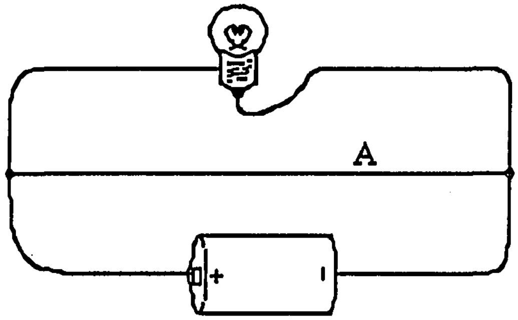


Figure 4

This is a short circuit phenomenon. The short circuit happens whenever the terminals of a cell are connected so the current does not flow through a resistance. See Figure 4.

Resistance in a circuit is any part that does not allow current to flow easily. In Figure 4, the resistance is the filament of the light bulb. Another example would be the heating coil in a toaster. Both offer resistance in a circuit. When the current does not flow through some kind of resistance like the filament of a light bulb or the heating coil in a toaster, the circuit will most likely be burnt.

At this point, you should use the computer simulation to try to build a circuit with a short like the one in Figure 4. Use one light bulb and a 3 volt battery. Is the light bulb on or off when the circuit looks like the one in Figure 4? Can you find a way to make the light bulb light without adding any more parts to the circuit?

Write your answers below.

____

____

A short circuit is both dangerous and wasteful. It is dangerous because a short circuit can heat the wires and possibly start a fire. It is wasteful because the electrical energy is being converted to heat energy in the circuit itself, instead of being converted to energy in a useful appliance.

This is the end of the first section of the text. After you feel you have studied this booklet carefully, please return it to the proctor and you may leave. Remember to come to the proper room at the designated time tomorrow. Thank you.

Yesterday, you studied about the parts of an electric circuit and how they can be connected together. Since you will be using some electrical symbols in this section, Figure 1 from the first section has been inserted below for reference. You may also review the booklet that you studied yesterday. The proctor has it at the front.

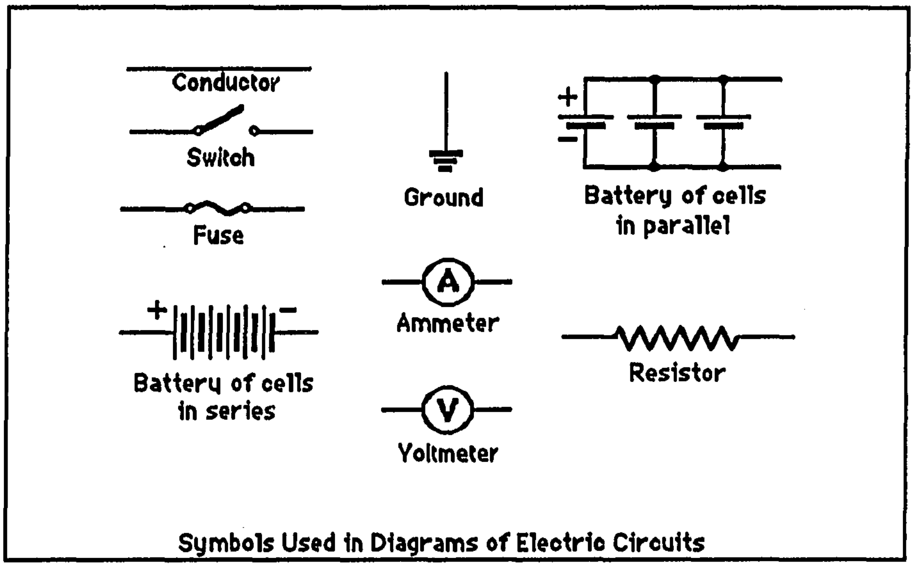


Figure 1

MEASURING ELECTRICITY

The water behind a dam has potential energy. It gained this energy by being lifted above sea level. A dry cell also has potential energy stored in it. This energy cannot be used until the dry cell is connected to an electric circuit. Then the flow of electrons in the circuit releases some of the energy of the cell. How could you find out how much potential energy is stored in a dry cell? You would need some way to measure this energy. The potential energy of water trapped behind a dam is determined by the height of the water behind the dam. In the same way, the potential energy (E) of electrons in a dry cell is measured in volts (V). A volt measures the potential of electrons to do work. We can use volts to measure the amount of work done if electrons move between two points in an electric circuit. This is often called the potential difference or electromotive force. If we compare the flow of electrons to water running down a hill, then voltage is a measure of how high the hill is. An ordinary flashlight battery gives 1.5 volts of energy. This would compare to water held behind a low dam. The 1.5 V battery is also similar to water flowing down a low hill. A larger battery gives 6 volts of energy. This would be like water behind a high dam. The 6 V battery is also similar to water flowing down a higher hill. In other words the 6-V battery has the potential to do four times as much work as the 1.5-V cell. A 6-V battery pushes the electrons harder than a 1.5-V battery.

The voltage of an electric circuit can be measured by an instrument called a voltmeter. A voltmeter can be attached to an electric circuit. Then the voltage of the circuit can be read on the dial of the voltmeter. A voltmeter can also be used in an automobile. This voltmeter tells the driver if there is enough voltage in the car's electrical system to run the starter, lights, and other parts of the car.

For most electric circuits, we want to know not only the voltage, or how hard the electrons are pushed, but also how many electrons are flowing. This is called the current (I). To measure the amount of current, we use amperes (am-pirz). An ampere (A) measures the amount of charge moving past a point in a circuit in one second. Am ampere is often called "amp" for short. Measurement of both voltage and amperage describes the behavior of an electric current. For example, a circuit may have high voltage with low amperage. This would be like a very narrow but swiftly flowing stream. On the other hand, a circuit with high amperage but low voltage would be like a wide but slow moving river.

The amount of current in a circuit can be measured by attaching a meter called an ammeter to the circuit. An ammeter in a car tells whether the battery is being charged (electrons flowing in) or drained (electrons flowing out).

A voltmeter and an ammeter each has a coil of wire in a magnetic field. When a current flows through the coil, the coil moves a pointer on a scale. The scale shows the number of volts or amperes. In an ampere, all the current flows through the coil. In a voltmeter, a small current that is proportional to the voltage flows through the coil.

Suppose that water is flowing through a wide pipe. Suddenly, the pipe becomes much narrower. What will happen to the amount of water that can flow through the pipe? The flow of water will slow down because the pipe becomes narrower. When water flows through pipes, the size or shape of the pipe can change the ease with which the water moves. This is also true of electrons. When electrons move through any material, they meet resistance (rih-zis-tunts). Resistance, (R) is the term used for all conditions that limit the flow of electrons in an electric circuit. For example, a light bulb adds resistance to an electric circuit.

The amount of current that flows in a particular electric circuit is also affected by the voltage. Again, think of water flowing through a pipe. The amount of water that will pass through the pipe is affected by the force pushing the water. Suppose that the water flows through a narrow pipe. Less water could then pass through the pipe. The narrow pipe has the same effect on the flow of water as resistance in an electric circuit has on the flow of electrons. If electrons flow through a part of the circuit where the resistance is high, then the amount of current flowing through the entire circuit is reduced. Resistance is measured in ohms. A resistance of one ohm means a potential of one volt per one ampere of current.

OHM'S LAW

The voltage, current, and resistance in an electric circuit are related to each other by a rule known as Ohm's law. This relationship was discovered by a German schoolteacher. Georg Ohm, in the early 1800's. Ohm experimented with electric circuits on wires having different amounts of resistance. He discovered a general rule that describes the relationship among voltage, current, and resistance in a circuit. This rule, now known as Ohm's law, can be written as

$$I = \frac{E}{R} \qquad \text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

For example, an automobile with a 12-V battery has headlights whose resistance is 4 ohms. When the lights are on, the current needed is:

$$I = \frac{E}{R} = \frac{12\ V}{4\ ohms} = 3\ A$$

Most automobile batteries can supply 3 amperes of current for only a few hours. Thus, a battery can run down if the headlights are left on for several hours while the engine is not running.

By rearranging the terms, the preceding equation can also be written;

volts = amperes x ohms or $\text{ohms} = \frac{\text{volts}}{\text{amperes}}$

$$E = IR \qquad\qquad R = \frac{E}{I}$$

SERIES CIRCUITS

When resistors are connected in series, all current travels through each resistor, one after the other. The electric current in the circuit passes through each lamp (resistance) in succession. The current through each resistance is the same. The current flowing in a series circuit is the same everywhere along the wire. To determine the current in the circuit, the effective resistance of the circuit must be found. The effective resistance is the resistance of a single resistor that could replace all the resistors in the circuit. The single resistor would have the same current through it as the resistors it replaced. To find the effective resistance, Ohm's law is applied to the circuit as a whole and to its parts. The total voltage across the three resistors is equal to the potential difference across the generator, 120 V. The total voltage across the three resistors is also equal to the sum of the voltage across the individual resistors. That is,

$$V = V_1 + V_2 + V_3$$

According to Ohm's law, the voltage across R is given by $V_1 = IR_1$, where I is the current through the circuit. Therefore,

$$V = IR_1 + IR_2 + IR_3$$

$$V = I(R_1 + R_2 + R_3)$$

If the three resistors were replaced by a single resistor with resistance R, the voltage across R could be found using Ohm's law: V=IR. Comparing this equation with the one above shows that in a series circuit

$$R = R_1 + R_2 + R_3$$

The effective resistance, R, of resistors in series is the sum of the resistances. Note that the resistance of R is larger than that of any one of the resistors.

The current through a series circuit is found by calculating the effective resistance R, and then using Ohm's law in the form of I = V/R.

Example--Current in a Series Circuit

Four 15-ohm resistors are connected in series to a 30-V battery. What is the current in the circuit?

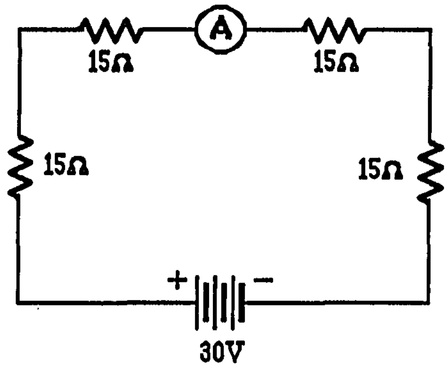


Figure 5

Using the computer simulation, build the circuit in Figure 5. Does the ammeter reading match the result of the calculations below? What happens if the ammeter is moved to a different part of the circuit? Does the reading change?

Write your answers below.

$$R = R_1 + R_2 + R_3 + R_4$$

$$= 15 + 15 + 15 + 15 = 60 \text{ ohms}$$

Then apply Ohm's law to the circuit.

$$I = \frac{V}{R} = \frac{30\text{ V}}{60\text{ ohms}} = 0.5\text{ A}$$

EXAMPLE--Voltage Drops in a Series Circuit

A 5.0 ohm resistor and a 10.0 ohm resistor are connected in series and placed across a 45.0-V potential difference.

a. What is the effective resistance of the circuit?
b. What is the current through the circuit?
c. What is the voltage across each resistor?
d. What is the total voltage across the circuit?

Given: $R_1 = 5.0$ ohms
$R_2 = 10.0$ ohms
$V = 45.0$ V

Unknowns: R, I, V_1, V_2,
Basic equation: $V = IR$

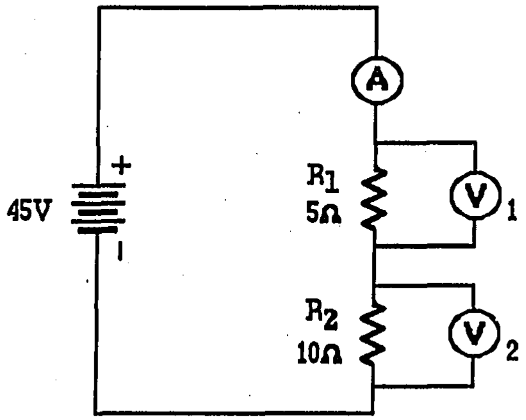


Figure 6

At this point you should use the computer simulation to build the circuit in Figure 6. You will have to take the voltmeter readings one at a time. Write the readings you observe in the space below. Do the readings of the meters match the result of the calculations? What reading do you get by putting a voltmeter connection across both resistors?

Write your answers below.

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Solution:

a. $R = R_1 + R_2$

$= 5.0 + 10.0 = 15.0$ ohms

b. $I = \frac{V}{R} = \frac{45.0\ V}{15.0\ ohms} = 3.00\ A$

c. The voltage across R_1 is

$V_1 = IR_1 = (3.00\ A)\ (5.0\ ohms) = 15\ V$

The voltage across R_2 is

$V_2 = IR_2$

$= (3.00\ A)\ (10.0\ ohms) = 30.0\ V$

d. $V = V_1 + V_2$

$= 15\ V + 30.0\ V = 45\ V$

An important application of series resistors is the voltage divider. The voltage divider is designed to obtain a desired voltage from a battery that supplies a larger voltage. Consider the circuit in Figure 7. Two resistors, R_1 and R_2 are connected in series across a battery of voltage V. The effective resistance of the circuit is $R=R_1 + R_2$. The current, I, is given by $I = V/R=V/(R_1 +R_2)$. The desired voltage drop, V_2,is the voltage drop across resistor R_2. According to Ohm's law, V_2 equals IR_2. Replacing I by its equivalent formula from the equation above gives

$$V_2 = IR_2 = \left(\frac{V}{R_1 + R_2}\right) X\ R_2 = \frac{VR_2}{R_1 + R_2}$$

EXAMPLE--Voltage Divider

A 9.0 V battery and two resistors, $R_1 = 400$ ohms and $R_2 = 500$ ohms, are connected as a voltage divider. What is the voltage across R_2?

Given: V = 9.0 V   Unknown: V_2
$R_1 = 400$ ohms
$R_2 = 500$ ohms   Basic equation: $V_2 = \frac{VR_2}{R_1 + R_2}$

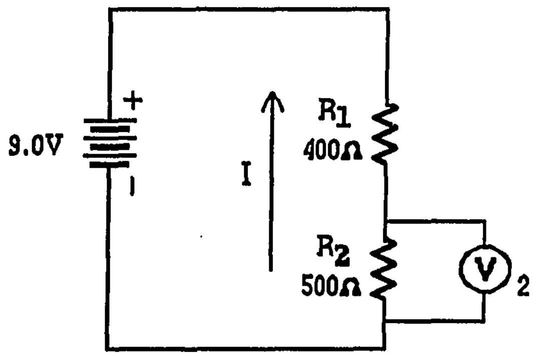

Figure 7

At this point, you should use the computer simulation to build the circuit in Figure 7. Does the voltmeter reading match the result of the calculations? What reading do you get by putting the voltmeter connection across both resistors?

Write your answers below.

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Solution:

$$V_2 = \frac{VR_2}{R_1 + R_2} = \frac{(9\ \text{V})\ (500\ \text{ohms})}{400\ \text{ohms} + 500\ \text{ohms}} = 5\ \text{V}$$

This is the end of the second section of the text. After you feel you have studied this booklet carefully, please return it to the proctor and you may leave. Remember to come to the proper room at the designated time tomorrow. Thank you.

APPENDIX F.

BOOKLETS FOR STUDENTS USING THE SIMULATION DURING THE STUDY OF THE CCDT

ELECTRIC CIRCUITS

Electrical energy is not something used only by scientists and engineers. Today, almost everyone uses electricity. You are familiar with many different kinds of electric appliances. Twist a knob or push a button, and a radio or television set begins to play. Flip a switch, and an electric light or a fan is turned on. Each of these appliances works by using electrical energy. Do you know how the electricity causes those appliances to work? You will find out in this section.

THE PATH OF AN ELECTRIC CURRENT

What do switching on a light and turning on a faucet have in common? Opening the faucet lets water flow from the pipe. Turning on an electric light switch permits electrons to flow through the wires. Water will not flow in the pipe, however, unless a force is present to move it. That force could be supplied by gravity causing the water to flow down hill. A pump could also supply the energy needed to move the water. Electrons flowing through a conductor also need a force to cause them to move.

About the year 1800, an Italian scientist named Alessandro Volta discovered a way to make electrons flow through a conductor. Volta found that combination of two different metals and salt water could make electrons move through a conductor. A chemical reaction between the metals and the salt solution caused the electrons to move. This arrangement of two materials together with a solution causing a flow of electrons is called an electrochemical cell. An automobile battery is made up of several electrochemical cells.

Electrical energy in the battery is changed into chemical energy and stored in the cells. Later, the cells in the battery can change the stored chemical energy back into electricity.

An ordinary flashlight battery is also a kind of electrochemical cell. It is often called a dry cell because it does not contain a liquid. A moist chemical mixture is used instead of the liquid.

Chemical changes taking place inside the dry cell cause part of the cell to build up a supply of extra electrons. This part of the cell is called the negative terminal (-). Another part of the cell lacks a normal supply of electrons. This part of the cell is called the positive terminal (+). Wires can be attached easily to the negative and positive terminals of a cell or battery.

IDEAS ABOUT ELECTRIC CIRCUITS

Suppose you have a flashlight bulb connected to a battery with wires. The bulb is lit. How does electricity cause this to happen? Before you read any more, write your description of how you think electricity makes the bulb light.

Different students give a number of different answers.

Some students believe that only one wire is needed between the battery and the bulb. They think that bulbs in Figure 1 and Figure 2 would light.

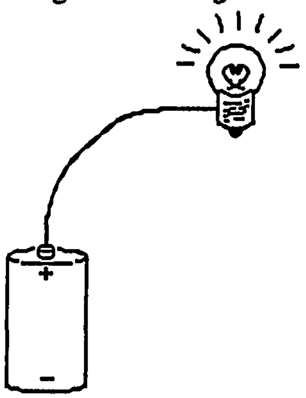

Figure 1

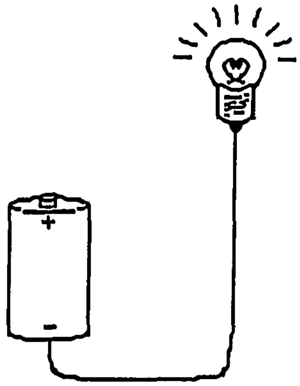

Figure 2

This view is called the "sink theory" of electricity, which states that electricity can leave a battery and go to an electrical device through a single wire, and not return to the battery.

Do you think these students are right? Why do you think the students are right or wrong? Take a minute and answer these questions for Figure 1 and Figure 2.

Question 1. Will the bulb in Figure 1 light?
yes no (circle one)

Question 2. Will the bulb in Figure 2 light?
yes no (circle one).

Students who believe the "sink theory" are incorrect. The "sink theory" is wrong. How can we prove that this view is wrong?

Using the computer simulation, connect wires, one light bulb, and a 3 volt battery to form an electric circuit as illustrated in Figure 3. Does the bulb light? What happens when you remove a piece of wire A? Now replace the piece of wire A and remove a piece of wire B. What happens?

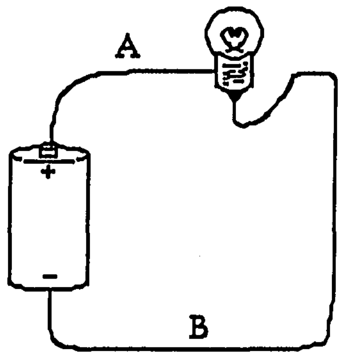

Figure 3

Write your answers below.

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As you saw in the simulation, the bulb lights when the wires are connected as in Figure 3. When wire A was disconnected, the light bulb did not light. Similarly, when wire B was disconnected the light bulb did not light. Only when both wire A and wire B are connected does the light bulb light as in Figure 3. This experiment proves that the "sink theory" is wrong and the bulb or other electrical device will not work unless there are two electrical pathways from the source of electricity (battery) to the device.

Other students who know that two wires or pathways are needed believe that the bulb lights because positive electricity leaves the positive side of the battery and negative electricity leaves the negative side of the battery. When the opposite currents meet at the wire, they clash and cause the bulb to light. The idea these students have is that electricity flows in two directions in an electrical circuit and meets at the device. See Figure 4.

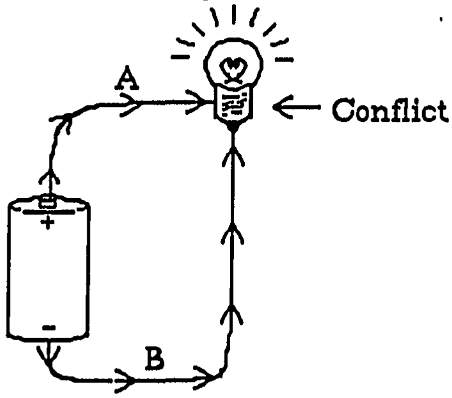

Figure 4

This view is called the clashing current view. It states that the conflict of both positive and negative "electricities" cause the bulb to light.

Do you think these students are right? Why do you think the students are right or wrong? Take a minute and answer these questions for Figure 4.

Write your answers here.

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These students are incorrect. The clashing current view is wrong. How can we prove that this view is wrong?

At this point, starting with a new circuit, use the simulation to connect wires, two light bulbs, and two 3 volt batteries to form the circuit in Figure 5.

According to the clashing current view, positive electricity flows only until it meets negative electricity and vice versa. The clashing currents view predicts that bulb 1 would light but bulb 2 would not light because bulb 1 has both positive and negative electricity clashing while bulb 2 has only negative electricity passing through it.

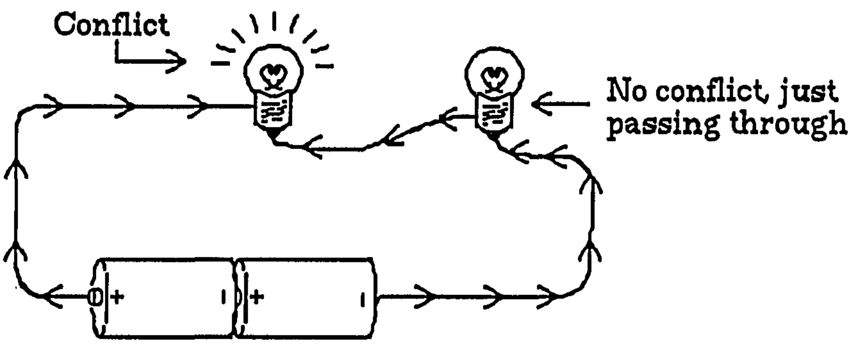


Figure 5

What happened when the circuit was completed in the simulation?

When you connected this circuit, you found that both bulbs lit as in Figure 6. This proves that the clashing current view is wrong. Electricity does not flow in opposite directions from both the positive terminal and the negative terminal of the battery simultaneously and meet at the electrical device. Electricity moves from one terminal to the other terminal of the battery. This is illustrated in Figure 6.

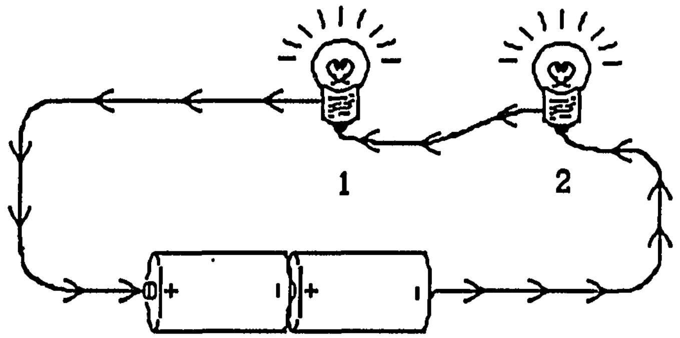


Figure 6

How does electricity move in a circuit? Read the following section to find the answer.

THE NATURE OF ELECTRIC CIRCUITS

If you connect a wire or other conductor between the negative and positive terminals of a cell, the extra electrons at the negative terminal will have a path to get to the positive terminal where electrons are lacking. Electrons will immediately start to flow between the two terminals. You have made an electric circuit. An electric circuit is a complete path allowing electrons to flow and produce an electric current.

When you plug a lamp into an electric outlet and turn on the switch, you are completing an electric circuit. The two parts of the plug and a pair of wires provide a complete circuit. An electric current can then flow through the lamp that is plugged into the outlet.

Electrons repel each other because they all carry a negative charge. An electron in a wire repels other electrons in the wire. Electrons all along the wire pass along this movement from one to the next. This effect travels rapidly along the wire. This is what is meant when electrons are said to "flow" along a conductor.

KINDS OF CIRCUITS

An electric circuit is made up of several parts. There must be a source of electrons to be moved through the circuit. Conductors, usually wires, are needed to connect all the parts. These parts include switches and the appliance to be operated, a light for example. See Figure 7. Illustrated are some of the symbols used to illustrate parts of electric circuit diagrams.

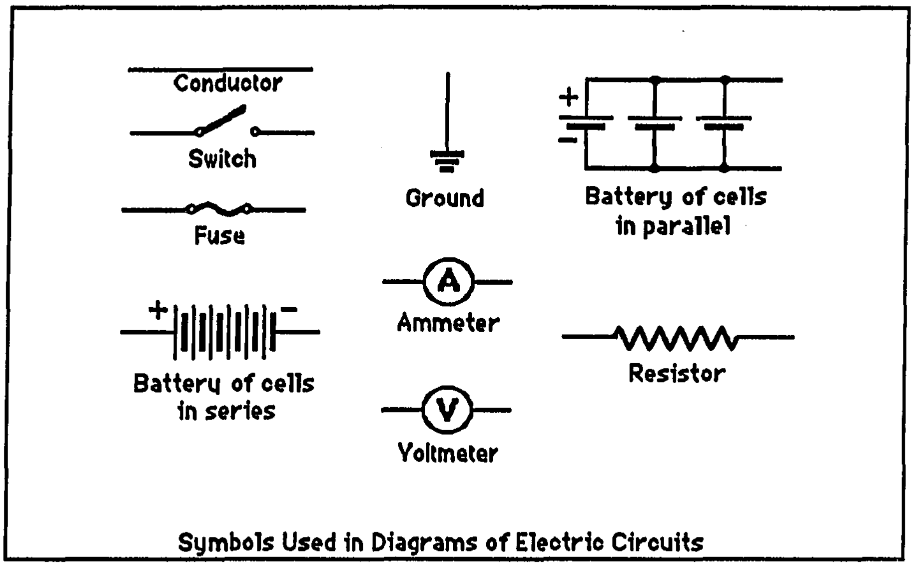


Figure 7

These items can be connected one after another. This arrangement is called a series circuit. In a series circuit, all parts of an electric circuit are connected one after another. See Fig. 8. In a series circuit, there is only one path the electrons can follow. A series circuit can cause some problems. Suppose, for example, that light bulbs are arranged in a series circuit. If one bulb fails, the circuit is broken and all the bulbs go out. No part of a series circuit can be switched off without turning off the whole thing. If the lights in a house were connected in series, they would all have to be on or off at the same time.

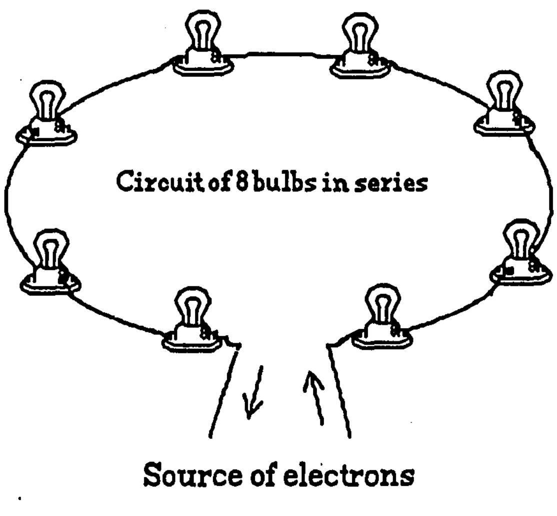


Figure 8

Another way to connect the parts of a circuit is shown in Fig. 9. This arrangement is called a parallel circuit. In a parallel circuit, the different paths are on separate branches. Each branch of a parallel circuit can be switched off without affecting the other branches The different circuits in a house are arranged in a parallel. In this way, many appliances can be used at the same time. They do not all have to be on at the same time.

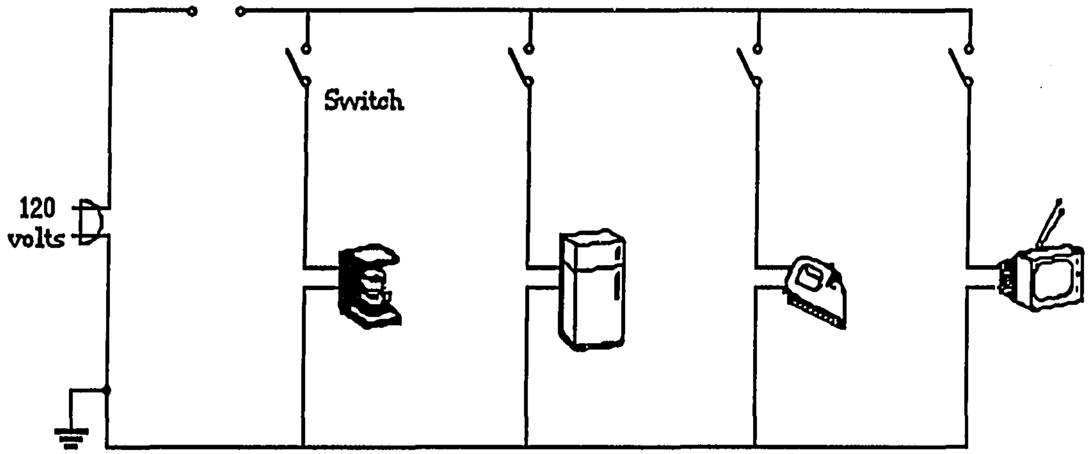


Figure 9

Now look at Figure 10. Try to answer whether the light bulb will light in Figure 10 below. Why do you think so? How does the electricity cause the bulb to light, if it does? If it does not, why not? Look at the light bulbs available in the computer simulation. Using the simulation, is it possible to build a circuit like the one in Figure 10?

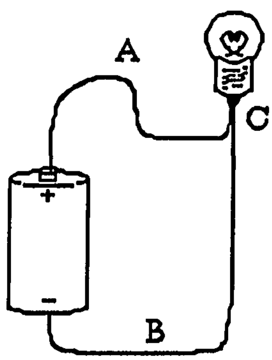
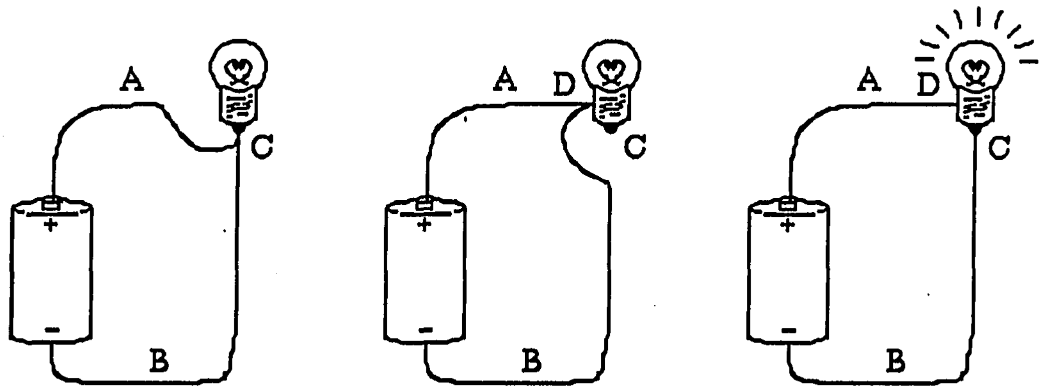


Figure 10

Write your answers here.

If you try to build the circuit in Figure 10 using the computer simulation, you would find it impossible. Why? Because the computer is programmed to know that there must be a wire connected to both parts of the bulb in order for electricity to pass through it. The problem many students face is that they don't know that the part of the light bulb that screws into the socket serves two functions. It holds the light bulb in place and it is also an electrical connection.

In the figures below, both wire A and wire B are connected at point C at the side of the bulb as in Figure 11a, or the bottom of the bulb as in Figure 11b. The result is that the light bulb does not light. As we have seen before, the bulb must be connected as illustrated in Figure 11c, in order for it to light.



Bulb not lit — Bulb not lit — Bulb lit

Figure 11a — Figure 11b — Figure 11c

If you review this section, you will recall that when the electricity moves from negative terminal to the positive terminal of the battery, the light bulb will light. In other words, the light bulb will light only when there is electricity passing through it from the negative side to the positive side. If we look at Figure 11a and 11b, we can see that the electricity can not pass through the light bulb because both wire A and wire B are connected at the one point (point C or D). If you remember that the screw-in portion of the light bulb is also an electrical contact, you will see that in Figure 11c, the electricity can flow from the negative side (point C) of the bulb to the positive side (point D). The current passing through the bulb causes it to light.

SHORT CIRCUIT

Have you ever used an electric appliance only to be startled by a shower of sparks, and a room plunged into sudden darkness? What caused this to happen?

Let's look at the Figure 12 below. Do you think the light bulb will light? Why do you think so? If the wire A is cut, do you think the light bulb will light? Why do you think so?

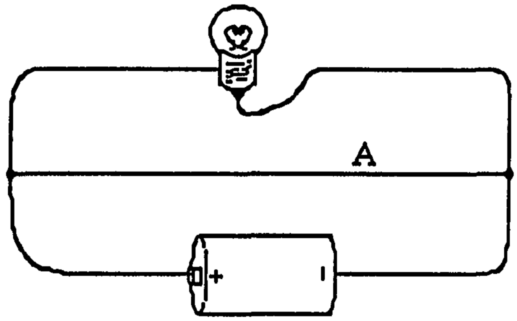


Figure 12

Write down your answers on the following lines.

Let's test your answers. Using the computer simulation, build a circuit like the one in Figure 12. Does the light bulb light? Now remove a piece of wire A and see what happens. Does the light bulb light now?

Write your answers below.

Using the simulation, you saw that the bulb will not light when wire A is in place. But when you removed a piece of wire A the light bulb lit. Do you understand why the light bulb will light only when wire A is cut? This is the short-circuit phenomenon. Wire A causes a short circuit. Like water flowing down-hill, electricity will seek the path of least resistance. The light bulb has a lot of resistance, while wire A has almost none. Given a chance, the electricity will flow through wire A rather than through the light bulb. Thus, the light bulb will not light. A short circuit is a pathway with very low or no resistance that completes an electrical circuit.

Short circuits are dangerous. The low resistance of a short circuit allows so much electricity to flow through the wire that the wire can heat up and cause a fire. Even if the wire does not get hot enough to cause a fire, it can discharge a battery quickly.

This is the end of the first section of the text. After you feel you have studied this booklet carefully, please return it to the proctor and you may leave. Remember to come to the proper room at the designated time tomorrow. Thank you.

Yesterday, you studied about the parts of an electric circuit and how they can be connected together. Since you will be using some electrical symbols in this section, Figure 7 from the first section has been inserted below for reference. You may also review the booklet that you studied yesterday. The proctor has it at the front.

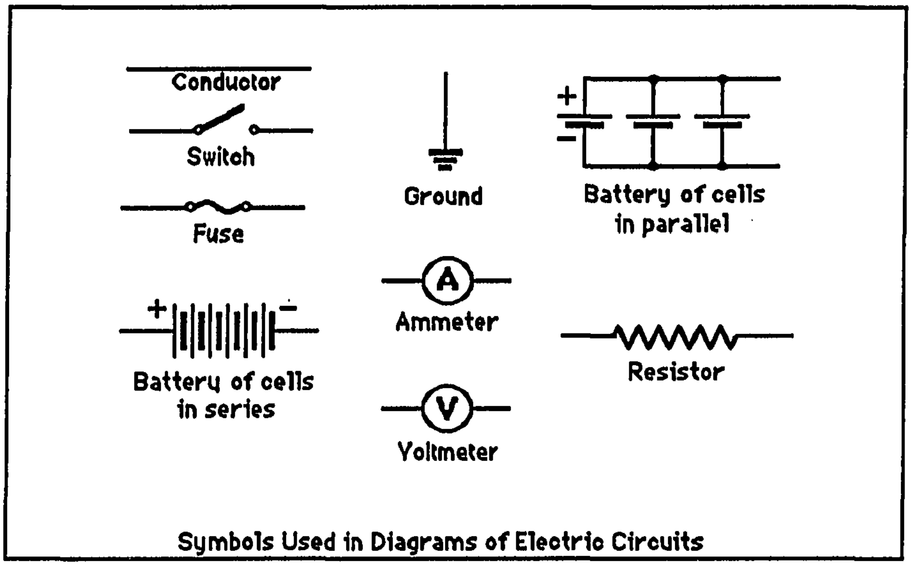


Figure 7

MEASURING ELECTRICITY

We have seen that the same current flows through all electrical devices in a circuit. If current is not used up by electrical devices in a circuit, what is? We all know that "electricity" gets used up when we leave a flashlight on; we say that the battery has died. If devices don't use up current, what do they use up?

Batteries are chemical/electrical devices that cause negative elements of electricity to be drawn to one end or "pole" of the battery and the other end or pole to thus become positive. When a pathway or wire is connected between poles of the battery, the difference between the positive and negative ends causes negative elements to flow towards the positive and reduce the difference. This difference between the positive and negative sides of a battery is called the electromotive force of the battery. The stronger the battery, the greater is its electromotive force.

Electrical devices such as wires, light bulbs, buzzers, bells, and radios, provide pathways by which electricity can flow between the positive and negative ends of the battery. However, they are not perfect pathways. They resist the flow of electricity. Wires have very little resistance, they resist the flow of electricity very little. (So little in fact that we will consider the resistance 0 in the simple problems we will deal with.) Light bulbs have a lot of resistance, they resist the flow of electricity much more than wires. A good way of thinking about resistance is thinking about your running on different surfaces. If you run on a hard concrete street, the street resists your running very little and you can run fast with relatively little effort.

If you run on a soft sandy beach or in ankle deep soft snow, it is harder to run. If you run in waist-deep water, you have to work very hard to move at all.

Electromotive force and resistance interact to produce or cause current. A particular device, such as a light bulb, has a particular amount of resistance. If a battery that has only a little bit of electromotive force is connected to the device, no current will flow because the electromotive force is not great enough to overcome the resistance (sort of like being stuck hip deep in snow). If a stronger battery is connected and its electromotive force is great enough to overcome the resistance of the device, a current will flow. If an even stronger battery is connected a greater current will flow.

When you add multiple devices in a simple circuit, you increase the resistance and the current flow is less, but all the devices get the same amount of current. As the electrical force passes each device, however, the electromotive force loses some of its strength. It is the electromotive force (or emf) that each device uses up. The amount of emf used is measured with a device called a voltmeter.

In a circuit, each device, like a light bulb, uses up some electromotive force. Look at Figure 13. The three voltmeters measure the emf present between the two points where they are connected to the circuit.

Using the computer simulation, create a circuit like the one in Figure 13. Now connect a voltmeter in the three different ways shown. Since the simulation only allows one voltmeter per circuit, you will have to connect it three different times. Write the readings that you get for each connection. Remembering that current flows from negative to positive, what do the readings tell you about the amount of emf after each device?

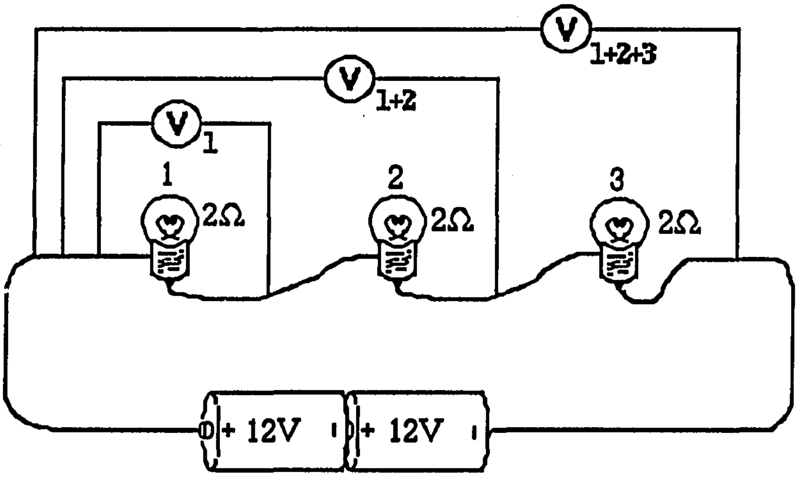


Figure 13

Write your answers below.

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As you measured the emf, you found that it was less after each bulb. This means that some of the emf was being used up by each bulb.

Another way to think of a battery's electromotive force (emf) is as potential energy. What is potential energy? The water behind a dam has potential energy. It gained this energy by being lifted above sea level. A battery also has potential energy stored in it. This energy cannot be used until the battery is connected to an electric circuit. Then the flow of electrons in the circuit releases some of the energy of the cell. How could you find out how much potential energy is stored in a battery? You would need some way to measure this energy. The potential energy of water trapped behind a dam is determined by the height of the water behind the dam. In the same way, the potential energy (E) of electrons in a battery is measured in volts (V). A volt measures the potential of electrons to do work. We can use volts to measure the amount of work done if electrons move between two points in an electric circuit. This is also called the potential difference or as we explained above, electromotive force (emf). If we compare the flow of electrons to water running down a hill, then voltage is a measure of how high the hill is. An ordinary flashlight battery gives 1.5 volts of energy. This would compare to water held behind a low dam. The 1.5 V battery is also similar to water flowing down a low hill. A larger battery gives 6 volts of energy. This would be like water behind a high dam. The 6 V battery is also similar to water flowing down a higher hill. In other words the 6-V battery has the potential to do four times as much work as the 1.5-V cell. A 6-V battery pushes the electrons harder than a 1.5-V battery.

The voltage of an electric circuit can be measured by an instrument called a voltmeter. A voltmeter can be attached to an electric circuit (see Figure 13 above). Then the voltage of the circuit can be read on the dial of the voltmeter. A voltmeter can also be used in an automobile. This voltmeter tells the driver if there is enough voltage in the car's electrical system to run the starter, lights, and other parts of the car.

For most electric circuits, we want to know not only the voltage, or how hard the electrons are pushed, but also how many electrons are flowing. This is called the current (I). To measure the amount of current, we use amperes (am-pirz). An ampere (A) measures the amount of charge moving past a point in a circuit in one second. An ampere is often called "amp" for short. Measurement of both voltage and amperage describes the behavior of an electric current. For example, a circuit may have high voltage with low amperage. This would be like a very narrow but swiftly flowing stream. On the other hand, a circuit with high amperage but low voltage would be like a wide but slow moving river.

The amount of current in a circuit can be measured by attaching a device called an ammeter to the circuit. An ammeter in a car tells whether the battery is being charged (electrons flowing in) or drained (electrons flowing out).

A voltmeter and an ammeter both have a coil of wire in a magnetic field. When a current flows through the coil, the coil moves a pointer on a scale. The scale shows the number of volts or amperes. In an ammeter, all the current flows through the coil. In a voltmeter, a small current that is proportional to the voltage flows through the coil.

Suppose that water is flowing through a wide pipe. Suddenly, the pipe becomes much narrower. What will happen to the amount of water that can flow through the pipe? The flow of water will slow down because the pipe becomes narrower. When water flows through pipes, the size or shape of the pipe can change the ease with which the water moves. This is also true of electrons. When electrons move through any material, they meet resistance (rih-zis-tunts). Resistance, (R) is the term used for all conditions that limit the flow of electrons in an electric circuit. For example, a light bulb adds resistance to an electric circuit.

The amount of current that flows in a particular electric circuit is also affected by the voltage. Again, think of water flowing through a pipe. The amount of water that will pass through the pipe is affected by the force pushing the water. Suppose that the water flows through a narrow pipe. Less water could then pass through the pipe. The narrow pipe has the same effect on the flow of water as resistance in an electric circuit has on the flow of electrons. If electrons flow through a part of the circuit where the resistance is high, then the amount of current flowing through the entire circuit is reduced. Resistance is measured in ohms (Ω). A resistance of one ohm (1 Ω) means a potential of one volt per one ampere of current.

OHM'S LAW

The voltage, current, and resistance in an electric circuit are related to each other by a rule known as Ohm's law. This relationship was discovered by a German schoolteacher, Georg Ohm, in the early 1800's. Ohm experimented with electric circuits using wires with different amounts of resistance. He discovered a general rule that describes the relationship among voltage, current, and resistance in a circuit. This rule, now known as Ohm's law, is written below.

$$I = \frac{E}{R} \qquad \text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

For example, an automobile with a 12-V battery has headlights whose resistance is 4 ohms. When the lights are on, the current needed is:

$$I = \frac{E}{R} = \frac{12\text{ V}}{4\text{ ohms}} = 3\text{ A}$$

Most automobile batteries can supply 3 amperes of current for only a few hours. Thus, a battery can run down if the headlights are left on for several hours while the engine is not running.

By rearranging the terms, the preceding equation can also be written;

volts = amperes x ohms

$$E = IR$$

or

$$\text{ohms} = \frac{\text{volts}}{\text{amperes}}$$

$$R = \frac{E}{I}$$

SERIES CIRCUITS

Now we are going to consider more complex circuits. Before you read any more, describe how you think electricity moves in the Figure 14 circuit below. Specifically, what do you think about the brightness of four bulbs. Will they have the same brightness? Which one will be brightest? Which one will shine least? Why or why not?

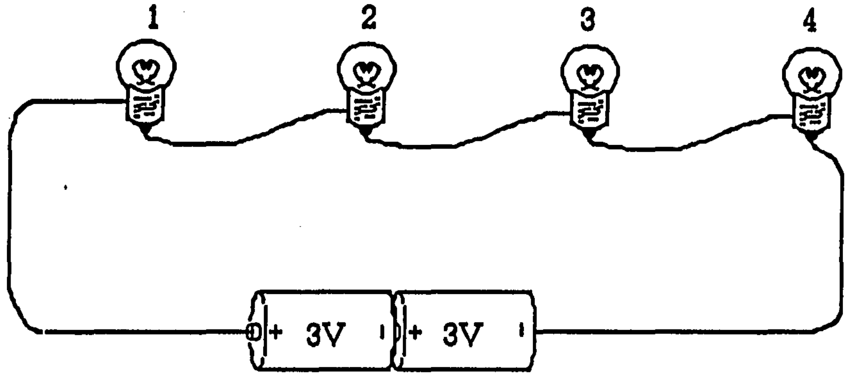


Figure 14

Write your answers here.

Before studying electricity, different students believe many different things about a circuit like Figure 14.

Some students think that later devices in a circuit receive less electricity than devices earlier in the circuit. If they think that electricity flows from positive to negative, some students believe that the bulb 1 will glow most brightly and bulb 4 will glow least brightly as illustrated in Figure 15. Other students, who think electricity flows from negative to positive, believe that bulb 4 will glow most brightly and bulb 1 least brightly as illustrated in Figure 16. These students believe that each electrical device uses up some of the electrical current and later devices receive less.

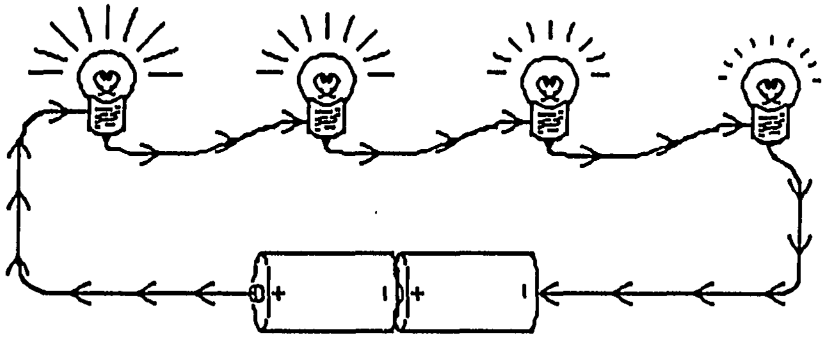


Figure 15

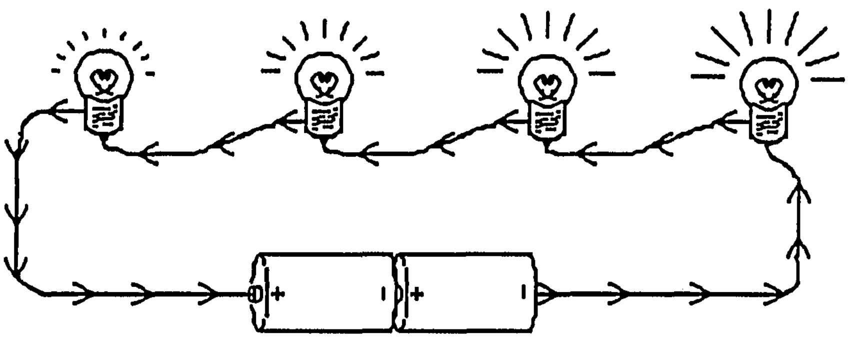


Figure 16

At this point you should test these students' beliefs by using the computer simulation to build a circuit like the one in Figure 14. Use two 3 volt batteries. What did you find out about the brightness of each bulb? ______________________________

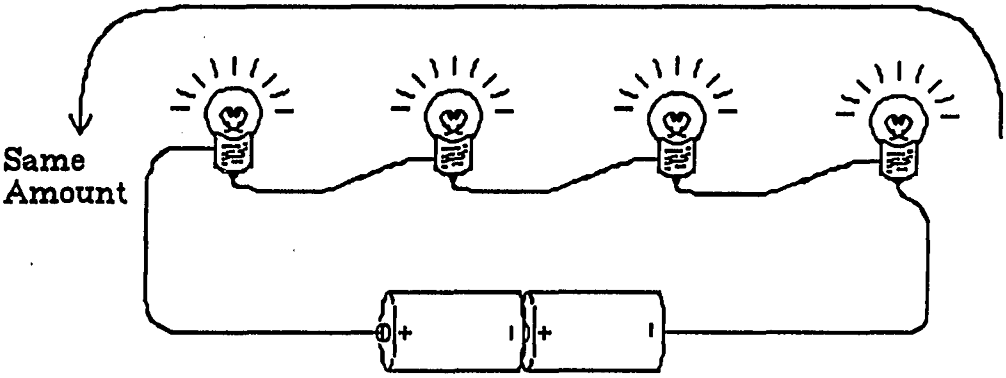


Figure 17

Before we talk about what you found out in your circuit, it is important to point out that all the lights in the simulation have the same resistance (2 Ω). This means that if they glowed at a different intensity, it would be due to different amounts of current flowing through them. You found out, however, that they all the glow the same amount. This experiment indicates that all the lights receive the same amount of current.

Some students believe that the electrical devices in a circuit share the current equally, but that the amount of current flowing back to the battery is less than the amount of current flowing out to the devices. That is, they believe that while the devices share the current, they use some of it up, so less current must go back to the battery. This view is shown in Figure 18.

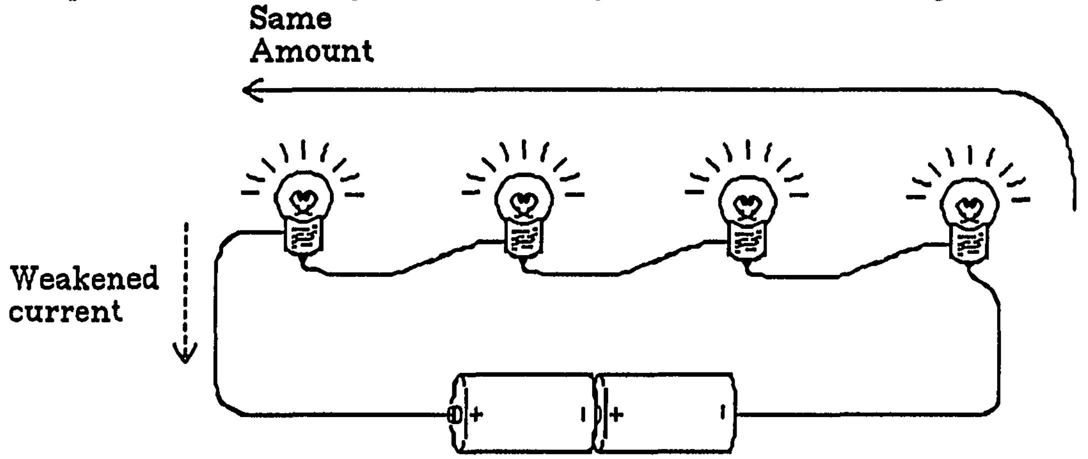


Figure 18

Remember that we can measure the current in a circuit with a device called an ammeter. We can use ammeters to test these students' belief by using the same circuit that you built to test the bulb brightness. Try inserting an ammeter at different points in the circuit, especially on both sides of the batteries. What were the results of your experiment?

You should have found that the amount of current measured at each point in the circuit is the same, regardless of where the ammeter is placed in this kind of circuit. This experiment indicates that, in a series circuit, each device receives the same amount of current and that the amount of current flowing back to the battery is the same as the amount flowing out.

When resistors are connected in series, all current travels through each resistor, one after the other. The electric current in the circuit passes through each lamp (resistance) in succession. The current through each resistance is the same. The current flowing in a series circuit is the same everywhere along the wire. To calculate the current in the circuit, the effective resistance of the circuit must be found. The effective resistance is the resistance of a single resistor that could replace all the resistors in the circuit. The single resistor would have the same current through it as the resistors it replaced. To find the effective resistance, Ohm's law is applied to the circuit as a whole and to its parts. The total voltage across the three resistors is equal to the potential difference across the power source. The total voltage across the three resistors is also equal to the sum of the voltage across the individual resistors. That is,

$$V = V_1 + V_2 + V_3$$

According to Ohm's law the voltage across R (all the resistors), is given by $V_1 = IR_1$ where I is the current through the circuit, Therefore,

$$V = IR_1 + IR_2 + IR_3$$

$$V = I(R_1 + R_2 + R_3)$$

If the three resistors were replaced by a single resistor with resistance R, the voltage across R could be found using Ohm's law: V=IR. Comparing this equation with the one above shows that in a series circuit

$$R = R_1 + R_2 + R_3$$

To summarize then, the effective resistance (R) of resistors in series is the sum of the resistances. Note that the resistance of R is larger than that of any one of the resistors.

In order to calculate the current of the series circuit with more than one resistor, we first calculate the effective resistance R, and then use Ohm's law in the form of I = V/R to calculate the current.

Example--Current in a Series Circuit

Four 15-ohm resistors are connected in series to a 30-V battery. What is the current in the circuit?

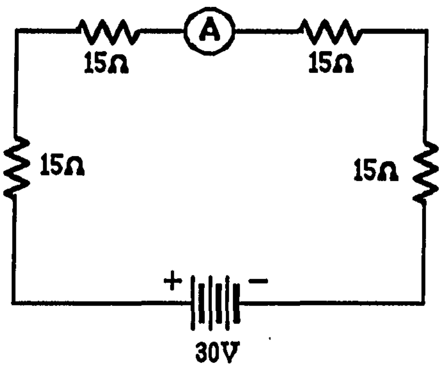


Figure 19

Using the computer simulation, build the circuit in Figure 19. Does the ammeter reading match the result of the calculations below? What happens if the ammeter is moved to a different part of the circuit? Does the reading change?

Write your answers below.

____

____

____

____

$$R = R_1 + R_2 + R_3 + R_4$$

$$= 15 + 15 + 15 + 15 = 60 \text{ ohms}$$

Then apply Ohm's law to the circuit.

$$I = \frac{V}{R} = \frac{30\text{ V}}{60\text{ ohms}} = 0.5\text{ A}$$

EXAMPLE--Voltage Drops in a Series Circuit

A 5.0 ohm resistor and a 10.0 ohm resistor are connected in series and placed across a 45.0-V potential difference.

a. What is the effective resistance of the circuit?
b. What is the current through the circuit?
c. What is the voltage across each resistor?
d. What is the total voltage across the circuit?

Given: $R_1 = 5.0$ ohm
$R_2 = 10.0$ ohm
$V = 45.0$ V

Unknowns: R, I, V_1, V_2,
Basic equation: $V = IR$

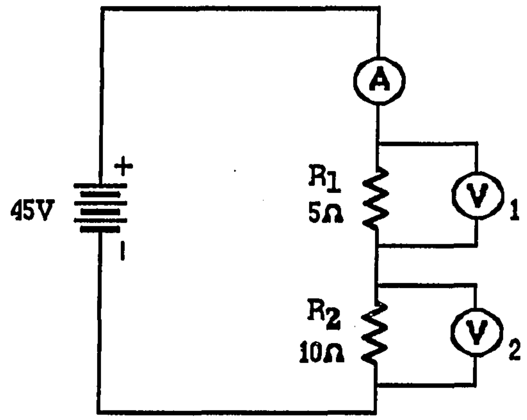


Figure 20

Using the computer simulation, build the circuit in Figure 20. You will have to take the voltmeter readings one at a time. Write the readings you observe in the space below. Do the readings of the meters match the result of the calculations? What reading do you get by putting a voltmeter connection across both resistors?

Write your answers below.

Solution:

a. $R = R_1 + R_2$

$= 5.0 + 10.0 = 15.0$ (ohm)

b. $I = \frac{V}{R} = \frac{45.0\ V}{15.0\ ohms} = 3.00\ A$

c. The voltage across R_1 is

$V_1 = IR_1 = (3.00\ A)\ (5.0\ ohms) = 15\ V$

The voltage across R_2 is

$V_2 = IR_2$

$= (3.00\ A)\ (10.0\ ohms) = 30.0\ V$

d. $V = V_1 + V_2$

$= 15\ V + 30.0\ V = 45\ V$

An important application of series resistors is the voltage divider. The voltage divider is designed to obtain a desired voltage from a battery that supplies a larger voltage. Consider the circuit in Figure 21. Two resistors, R_1 and R_2 are connected in series across a battery of voltage V. The effective resistance of the circuit is $R=R_1 + R_2$. The current, I, is given by $I = V/R=V/(R_1 +R_2)$. The desired voltage drop, V_2,is the voltage drop across resistor R_2. According to Ohm's law, V_2 equals IR_2. Replacing I by its equivalent calculated by the equation above gives

$$V_2 = IR_2 = \left(\frac{V}{R_1 + R_2}\right) X\ R_2 = \frac{VR_2}{R_1 + R_2}$$

EXAMPLE--Voltage Divider

A 9.0 V battery and two resistors, $R_1 = 400$ ohms and $R_2 = 500$ ohms, are connected as a voltage divider. What is the voltage across R_2?

Given: $V = 9.0$ V
$R_1 = 400$ ohms
$R_2 = 500$ ohms

Unknown: V_2

Basic equation: $V_2 = \frac{VR_2}{R_1 + R_2}$

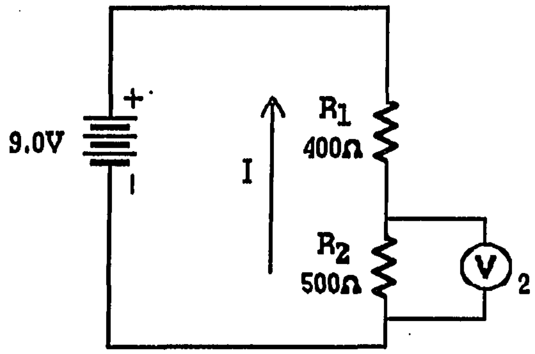


Figure 21

Using the computer simulation, build the circuit in Figure 21. Does the voltmeter reading match the result of the calculations? What reading do you get by putting the voltmeter connection across both resistors?

Write your answers below.

Solution:

$$V_2 = \frac{VR_2}{R_1 + R_2} = \frac{(9\ V)\ (500\ ohms)}{400\ ohms + 500\ ohms} = 5\ V$$

This is the end of the second section of the text. After you feel you have studied this booklet carefully, please return it to the proctor and you may leave. Remember to come to the proper room at the designated time tomorrow. Thank you.

APPENDIX G.

POSTTEST AND QUESTIONNAIRE

Instructions for Posttest

This is a test over the material on electricity that you have studied. Please answer the multiple-choice questions on the accompanying answer sheet. Completely fill in the circle for your desired answer. Use a number 2 or darker pencil.

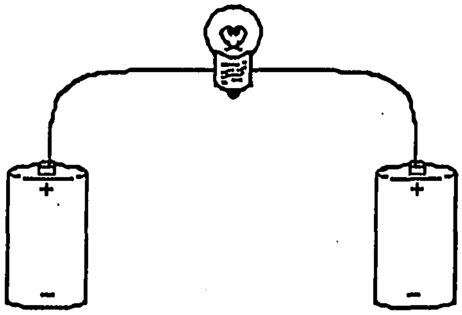
Do not put your name on the answer sheet. Instead, to maintain your confidentiality, put the name of your favorite rock or movie star (use the same name that you have used in the last two sessions), and your date of birth on the top of the answer sheet. Do not write your name or make any marks on the test booklet.

When you are done with the test, bring it to the proctor. The proctor will check to see if you have entered the information above and completed the test. Then the proctor will give you a credit card to fill out. Make sure you complete this card correctly, it is the only way you can receive your extra credit points for this experiment. When you have completed the card, place it in the location indicated by the proctor. Then you may leave.

NOTE: Conceptual serial questions have been marked with an asterisk (*).
Many off the conceptual serial questions have responses targeted at specific preconceptions. The responses so designated are printed in **bold** and have the preconception indicated in parenthesis after the response.

---

* 1. Will the bulb light in this diagram below?



a) **yes (Sink)**
b) no
c) can not tell

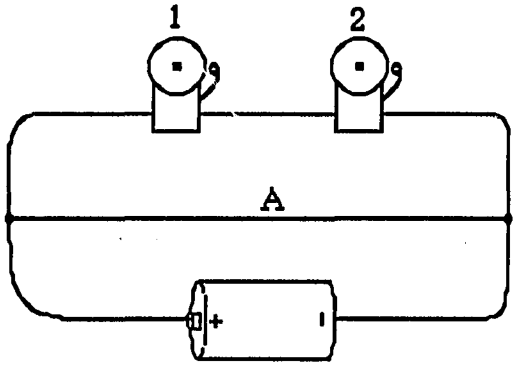
* 2. In the diagram above, the bulb will not light unless a wire is connected to point A and point B on the batteries.
a) agree
b) disagree
c) not sure

---

3. The advantage of a parallel circuit is
   a) The total resistance is equal to sum of the sub-resistances.
   b) There are different voltages for different resistances.
   c) There is the same amount of current for the entire circuit.
   d) There is the same voltage for the entire circuit.

---

* 4. Will both bells ring in this diagram below?

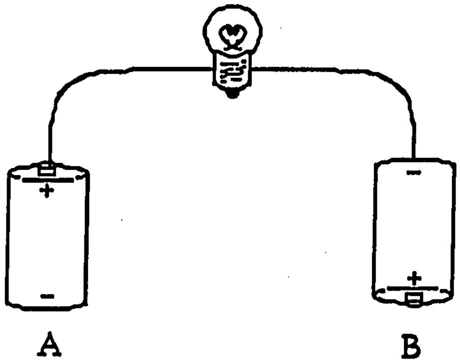


   a) yes (Short Circuit)
   b) no (Scientific--if A is also selected in question 5)
   c) can not tell

* 5. In the diagram above, if wire A were broken,
   a) both bells will ring (Scientific--if B is also selected in question 4)
   b) only one bell will ring
   c) neither will ring

---

* 6. Will the bulb light in this diagram below?



   a) yes (Sink)
   b) no
   c) can not tell

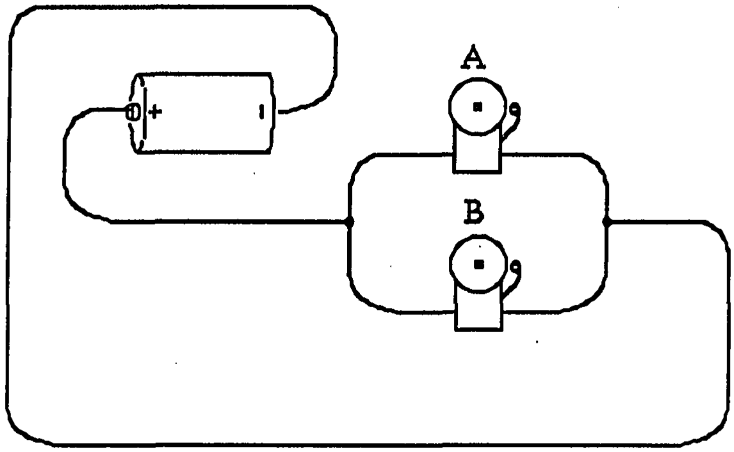
* 7. The bulb, in the diagram above, will not light unless a wire is connected between point A and point B in the batteries
a) agree
b) disagree
c) not sure

---

8. Potential difference is measured in
a) volts
b) ohms
c) amperes
d) joules

---

9. What will happen in this diagram below?



a) Both bells A and B will ring
b) Neither bell A nor B will ring.
c) Only A or B will ring, but not both.

10. In the diagram above, if both bells ring, how will their loudness compare?
a) A and B are the same loudness
b) A is louder than B
c) B is louder than A
d) cannot tell

---

11. Household appliances are connected in __________ circuits so that they can be used individually.
a) series
b) parallel
c) mixed
d) complete

---

12. As you plug more appliances to the same circuit in your house, the total resistance
    a) increases
    b) stays the same
    c) decreases
    d) none of the above

---

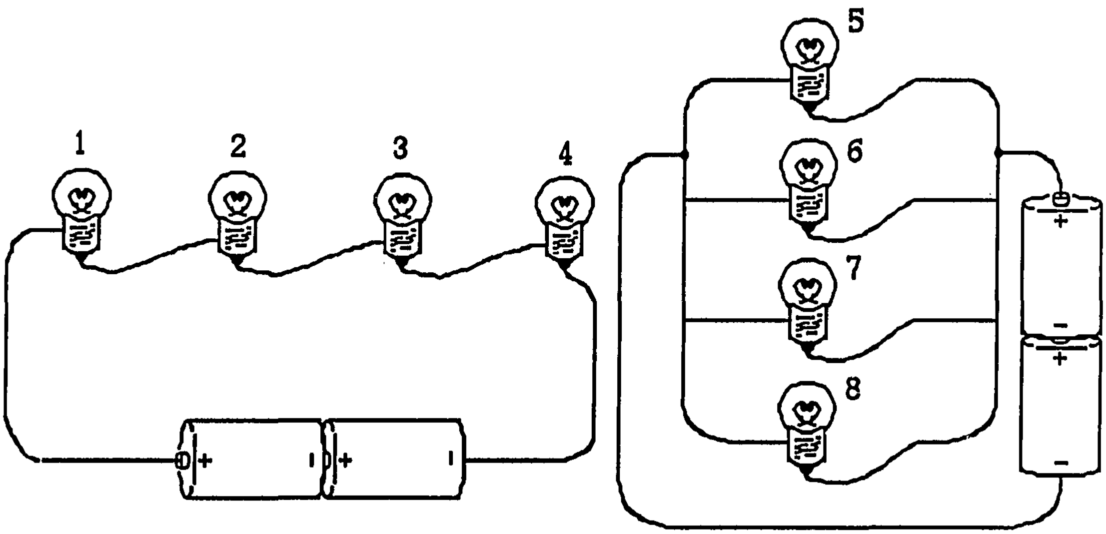
13. If three resistors are connected in series, the overall resistance will be
    a) the same as the largest single resistance.
    b) the sum of three resistances
    c) less than the largest single resistance
    d) less than the smallest single resistance.

---

14. A 30-V battery and two resistors, R_1, and R_2 are connected in series. The resistance of R_1 will be _______________ the resistance of R_2.
    a) greater than
    b) less than
    c) equal to
    d) can not tell

---

15. How do you think of the brightness of the bulb 3 will compare to bulb 8 in this diagram below?



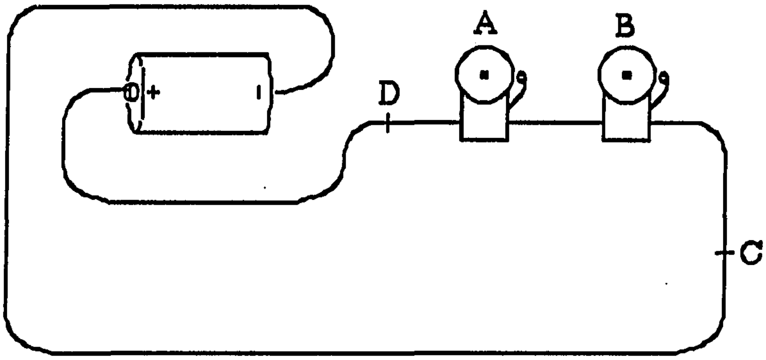
    a) bulb 3 will be brighter than bulb 8
    b) bulb 8 will be brighter than bulb 3
    c) bulb 3 will be equal to bulb 8 in brightness

---

16. Resistance is measured in
   a) volts
   b) amperes
   c) joules
   d) ohms

---

* 17. What will happen in this diagram below?

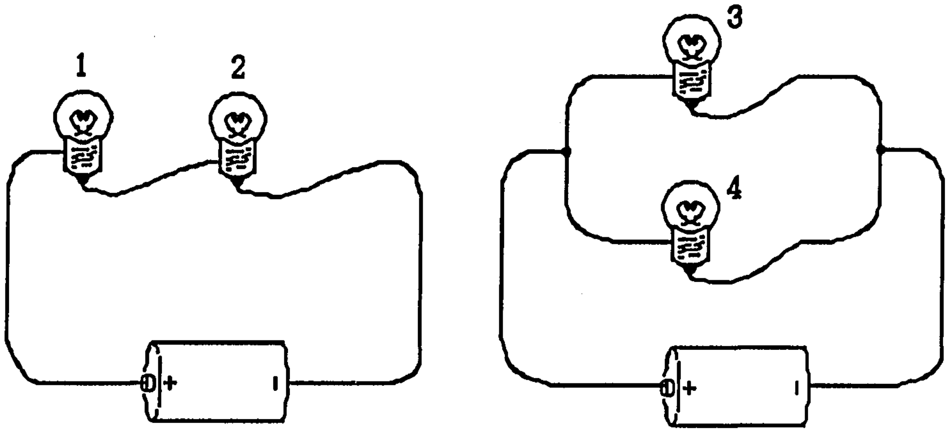


a) both bells will ring
b) neither bell will ring
c) only A or B will ring (Clashing Currents)

18. In the diagram above, how will the loudness of bell A compare to the loudness of bell B?
   a) A and B will be equally loud (Scientific)
   b) A will be louder than B (Unidirectional Without Conservation)
   c) B will be louder than A (Unidirectional Without Conservation)
   d) A and B will be equally loud, but the current will be weaker at point C than D. (Unidirectional With Sharing)

---

19. How do you think bulb 1 will compare to bulb 3 in brightness in the diagram below?



a) 1 will be brighter than 3
b) 3 will be brighter than 1
c) 1 will be equal to 3 in brightness

---

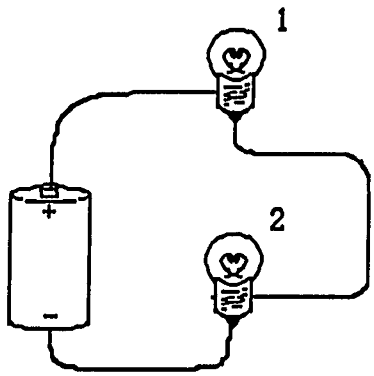
20. Ohm's law shows the relationship among
a) voltage, current, and power
b) power, resistance and current
c) voltage, current and resistance
d) voltage, current and circuit

---

21. If two resistors A and B are series connected into a circuit and the resistance R_A is greater than R_B, what is the total voltage for the circuit if the current is equal to 1 ampere?
a) $V=R_A+R_B$
b) $V=R_A=R_B$
c) $V=1/R_A+1/R_B$
d) $V=R_A-R_B$

---

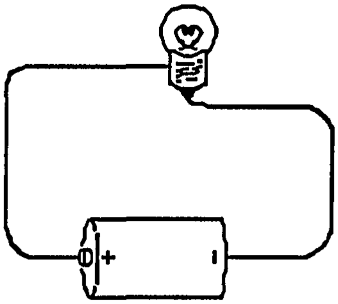
* 22. Which the following do you think will happen in this circuit below?



a) both bulbs will light
b) neither bulb will light
c) only bulb 1 will light (Clashing Currents)
d) only bulb 2 will light (Clashing Currents)

* 23. In the question above, why do you think so?
a) because the conflict of positive and negative electricities coming from both sides of the battery can cause the bulbs to light. (Clashing Currents)
b) because bulb 1 can get positive electricity and bulb 2 get negative electricity simultaneously. (Sink)
c) because electricity can pass through the bulbs and move from one side of the battery to the other.

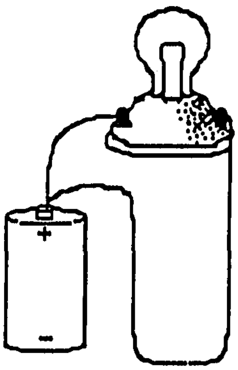
* 24. Will the bulb light in the circuit below?



a) yes
b) no
c) not sure

* 25. For the question above, why do you think so?
   a) **positive and negative electricities come from each side of the battery simultaneously and meet at the bulb. The conflict of the positive and negative electricities cause the bulb to light. (Clashing Currents)**
   b) electricity flows from one side of the battery to the other and when the electricity passes through the bulb, the bulb lights.
   c) There is no electricity in this circuit.

* 26. Will this bulb light in the circuit below?



a) **yes (Sink)**
b) no
c) can not tell

27. Which of the following provides the best explanation of your answer for the question above?

a) **because the battery and the bulb are hooked up , this causes electricity to flow. (Sink)**

b) **electricity flows along one of the wires to the bulb from the battery causing the bulb to light. (Sink)**

c) electricity can not flow because the positive and negative sides of the battery are not connected to the bulb.

---

28. What will happen to the voltage across resistor R_1 in a circuit if you add one more resistor to the series circuit?

a) the voltage across R_1 will stay the same

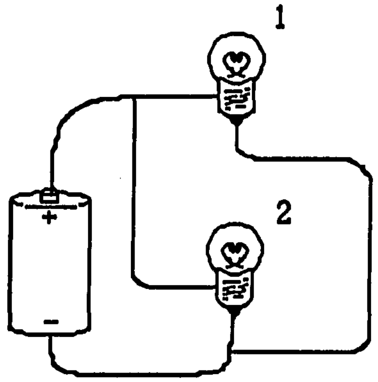
b) the voltage will increase

c) the voltage will decrease

d) none of above

---

29. What will happen in this diagram below?



a) both bulb 1 and 2 will light.

b) neither bulb 1 nor 2 will light.

c) only one of the bulbs will light.

30. In the diagram above, if both bulbs light, how will their brightness compare?

a) bulb 1 will be equal to bulb 2

b) bulb 1 will be brighter than bulb 2

c) bulb 2 will be brighter than bulb 1

d) cannot tell

---

31. All conditions which limit the flow of electrons in an electric circuit are labeled.

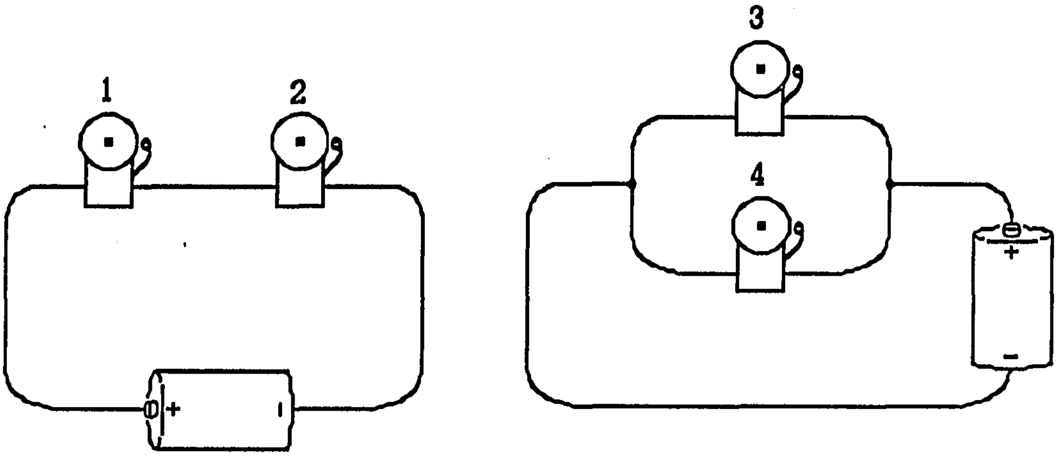
a) current

b) resistance

c) power

d) voltage

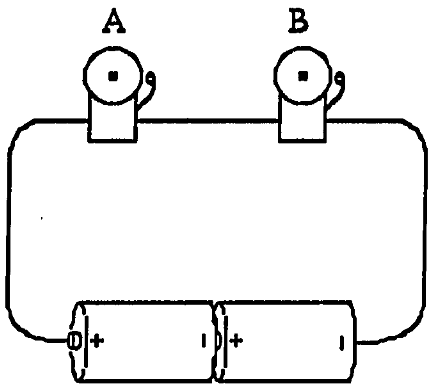
32. Which of the following statements is true for this diagram below?



a) bell 2 rings louder than bell 4.
b) bell 1 and 2 ring equally loudly, bells 3 and 4 ring equally loudly, but bell 1 and 2 are louder than bells 3 and 4.
c) bells 1 and 2 ring equally loudly, bells 3 and 4 ring equally loudly, but bells 3 and 4 ring louder than bells 1 and 2.

33. The total voltage across 3 resistors is
a) the same as the drop across each resistor
b) equal to the sum of the voltage across the individual resistors
c) less than the voltage across the smallest resistor
d) none of the above

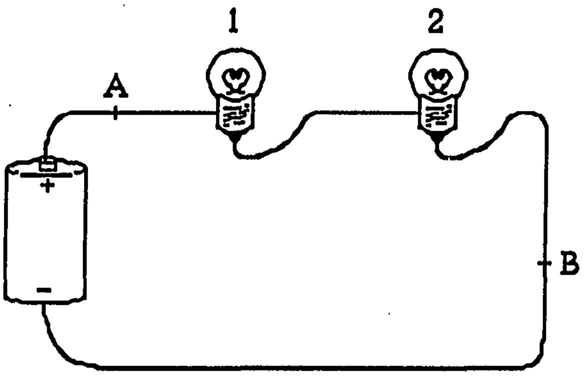
* 34. Which of the following best expresses what will happen in this diagram below?



a) both bells will ring.
b) neither bell will ring.
c) **only bell A will ring. (Clashing Currents)**
d) **only bell B will ring. (Clashing Currents)**

* 35. For the question above, why do you think so?
a) Electricity flows around the circuit and through the bells causing them to ring.
b) **Positive electricity flows from one side of the batteries and negative electricity from the other. The positive and negative electricities clash at the bells and cause them to ring. (Clashing Currents)**
c) **Positive electricity flows to one bell and causes it to ring. Negative electricity flows to the other bell and causes it to ring. (Sink)**
d) **Positive and negative electricities can only meet at one bell and cause it to ring. (Clashing Currents)**
e) **Positive and negative electricities can not meet at any bell and so neither can ring. (Clashing Currents)**

* 36. What will happen in this diagram below?



a) Both bulb 1 and bulb 2 will light.
b) Neither 1 nor 2 will light.
c) Either 1 or 2 will light, but not both.

* 37. In the diagram above, if the bulbs light, how would bulb 1 compare to bulb 2 in brightness?

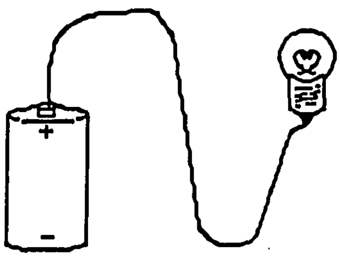
a) 1 would be equal to 2 (Scientific)
b) 1 would be brighter than 2 (Unidirectional Without Conservation)
c) 2 would be brighter than 1 (Unidirectional Without Conservation)
d) 1 would be equal to 2, but the current of electricity is weaker at point B than A. (Unidirectional With Sharing)

---

38. Using Ohm's Law, potential difference may be found by multiplying ____ times ____ a) current, resistance
b) current, voltage
c) voltage, resistance
d) current, watts

---

* 39. In the diagram below, will the bulb light?



a) yes (Sink)
b) no
c) can not tell

* 40. In the diagram above, how does the electricity cause this bulb to light, if it does?
  a) **Electricity can flow from battery to the bulb directly. (Sink)**
  b) Electricity can flow from bulb to the battery directly.
  c) There is no way for electricity to flow around in a circuit.

---

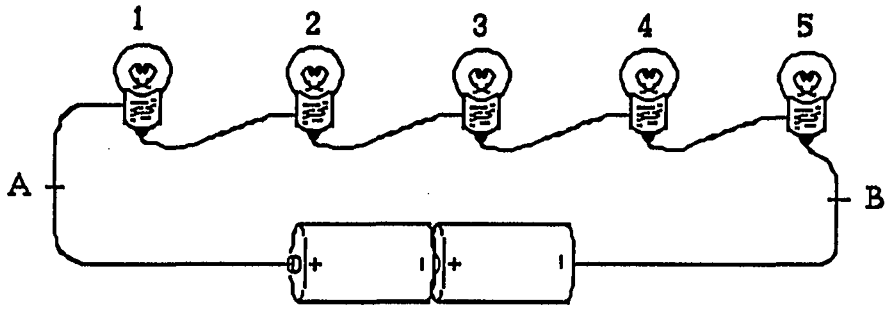
41. The total resistance of a _______ circuit is equal to the sum of individual resistances.
  a) series
  b) parallel
  c) mixture
  d) short

---

42. The unit of measurement of the force needed to move electrons is labelled
  a) ampere
  b) volt
  c) ohms
  d) watts

---

* 43. Will all bulbs light in this diagram below?

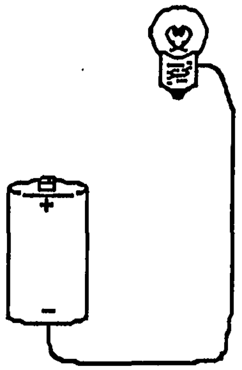


  a) yes
  b) no
  c) not sure

* 44. If all bulbs in the previous diagram light, which of the following describe the brightness of bulb 1 through bulb 5?
  a) **1 = 2 = 3 = 4 = 5 (Scientific)**
  b) **1 > 2 > 3 > 4 > 5 (Unidirectional Without Conservation)**
  c) **1 < 2 < 3 < 4 < 5 (Unidirectional Without Conservation)**
  d) **1 = 2 = 3 = 4 = 5, but the current of electricity is weaker at point A than point B. (Unidirectional With Sharing)**
  e) The bulbs do not light.

---

* 45. Will the bulb light in the diagram below?

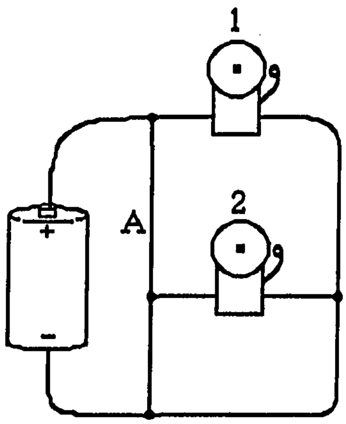


a) **yes (Sink)**
b) no
c) not sure

* 46. For the diagram above, why do you think so?
a) **Electricity flows from the battery to the bulb. (Sink)**
b) Because electricity can flow from the bulb to the battery directly.
c) No electricity can flow because there is no way for electricity to flow around the circuit.

---

* 47. Will the bells ring in this diagram?



a) **yes (Short Circuit)**
b) **no (Scientific--If B is also selected in question 48)**
c) can not tell

* 48. In the diagram above, if wire A were broken,
a) **both bells would ring (Short Circuit)**
b) **only one bell would ring (Scientific--If B is also selected in question 47)**
c) neither bell would ring

---

49. Three 30-ohm resistors are connected in series and placed across a difference in potential of 135 V. How much voltage is dropped across each resistance?
a) 45 V
b) 135 V
c) 90 V
d) 1.5 V

50. Three resistors of 3-ohm, 5-ohm, and 4-ohm are connected in series across a 12-V battery. What is the voltage drop across each resistor?
a) 5 V, 7 V, 6 V
b) 3 V, 5 V, 4 V
c) 0.1 V, 0.3 V, 0.2 V
d) 8 V, 10 V, 9.0 V

51. Ten Christmas tree bulbs connected in series have equal resistances. When connected to a 120-V outlet, the current through the bulbs is .5 A. What is the effective resistance of the circuit?
a) 200 ohms
b) 100 ohms
c) 50 ohms
d) 20 ohms

52. Three 20-ohm resistors are connected in series across a 12-V generator. What is the current in the circuit?
a) 0.5 A
b) 7200.0 A
c) 2.0 A
d) 180.0 A

53. A circuit with a 36-ohm resistance is connected to a 12-V battery. Find the current in the circuit.
a) 3.00 A c) 432 A
b) 0.33 A d) 48 A

54. A 20-ohm resistor and a 30-ohm resistor are connected in series and placed across a 110-V potential difference. What is the current in the circuit?
a) 0.45 A
b) 2.20 A
c) 5500 A
d) 160 A

55. A household iron has 11 amperes of current when connected to a 120-V electric outlet. Find the iron's resistance in ohms.
   a) 0.09 ohms
   b) 1320 ohms
   c) 11 ohms
   d) 131 ohms

56. A circuit with a current of 4 amperes has 35 ohms of resistance. What is the voltage of the electric source ?
   a) 140 V
   b) 8.750 V
   c) 0.114 V
   d) 39 V

57. A current of 15 amperes passes through an electric stove with a potential difference of 240 volts. What is the resistance of the stove?
   a) 16 ohms
   b) 0.0625 ohms
   c) 3600 ohms
   d) 255 ohms

58. A lamp having a resistance of 10 ohms is connected across a 15- V battery with 2 A current. What resistance must be connected in series with the lamp to reduce the current to .5 A?
   a) 40 ohms
   b) 20 ohms
   c) 10 ohms
   d) 80 ohms

59. What would be the voltage if a 25-ohm heater connected in a circuit with .24 amperes current?
   a) 104 V
   b) 6 V
   c) 0.0096 V
   d) 25.24 V

60. A light bulb with a resistance of 140 ohms is connected to a source having a potential difference of 120 volts. What current will flow?
   a) 0.860 A
   b) 1.167 A
   c) 260 A
   d) 16800 A

61. In a voltage divider with V= 9 V, R_1 = 500 ohms and R_2 is a photo resistor. What is the output voltage, V_2 across R_1 when a bright light strikes the photocell and R_2 = 400 ohms?
   a) 2 V
   b) 16 V
   c) 8 V
   d) 4 V

62. A 10-ohm resistor and a variable resistor are connected in series and placed across a 12-V source. The variable resistor is adjusted until the current in the circuit is .6 A. At what resistance is the variable resistor set?
a) 20 ohms
b) 0.5 ohms
c) 10 ohms
d) 90 ohms

63. A current of .15 amperes passes through a lamp with a resistance of 75 ohms. What is the voltage?
a) 0.002 V
b) 500 V
c) 11.25 V
d) 110 V

64. What is the current through a conductor having a resistance of 75 ohms connected to a 12-V battery?
a) 9000 A
b) 0.16 A
c) 0.625 A
d) 195 A

65. A 10-ohm resistor, a 15-ohm resistor, and a 5-ohm resistor are connected in series across a 90-V battery. What is the current in the circuit?
a) 0.33 A
b) 2700 A
c) 120 A
d) 3 A

66. A current of 5 A flows through a toaster connected to a 110-V source. What is the toaster's resistance?
a) 0.45 ohms
b) 550 ohms
c) 115 ohms
d) 22 ohms

67. Gender: A. Male B. Female

68. Class Year: A. Freshman B. Sophomore C. Junior D. Senior E. Other

69. Category of Major:
A. Engineering B. Physical Science C. Biological Science
D. Social Science E. None of these

70. Category of Major:
A. Art or Design B. Mathematics C. Education
D. Agriculture E. None of these

71. Category of Major:
A. Business B. Veterinary Medicine C. Family & Cons. Science
D. Humanities E. None of these

72. Age: A. 18 or under B. 19-21 C. 22-25 D. Over 25

73. Did you take physics in high school? A. Yes B. No

74. Did you ever build electronic or electrical toys as a child or adolescent?
A. Yes B. No

75. Have you had any formal educational experiences other than in high school or college that involved training in electricity (for example, mail order courses, community college courses, etc.)?
A. Yes B. No

76. Have you taken a physics course in college? A. Yes B. No

77. Have you taken an electrical or computer engineering course in college?
A. Yes B. No

78. Have you done any electrical repair work such as appliance repair, house wiring, or car wiring?
A. Yes B. No

79. Before participating in this experiment, what type of computer had you used the most?
A. Microcomputer B. Mainframe C. No computer at all

80. Before participating in this experiment, had you ever used a Macintosh?
A. Yes B. No

81. What type of computer programming courses have you taken in high school and college?
A. BASIC B. Pascal C. FORTRAN
D. Other E. I have never had a programming class

82. Prior to participating in this experiment, how did you feel about computers?
A. I hated them B. I disliked them a little C. I tolerated them
D. I liked them a little E. I really enjoyed them

83. How do you feel about computers now?
A. I hate them B. I dislike them a little C. I tolerate them
D. I like them a little E. I really enjoy them

APPENDIX H.

MEAN SCORES AND ANOVA TABLES

Mean Scores--Conceptual Serial Questions

Condition	n	M	SD
Text Type			
Traditional	46	18.67	4.32
CCDT	37	20.59	3.47
Simulation			
None	32	18.78	4.26
Before	27	20.22	3.22
During	24	19.75	4.58
Gender			
Male	36	20.92	3.22
Female	47	18.47	4.33
Traditional Text/			
No Simulation	15	17.60	4.42
Simulation Before	17	19.94	3.25
Simulation During	14	18.29	5.18
CCDT/			
No Simulation	17	19.82	3.96
Simulation Before	10	20.70	3.29
Simulation During	10	21.80	2.62

Analysis of Variance--Conceptual Serial Scores

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIGNIFICANCE
Covariates				
Electrical Experience	1	239.914	18.884	.000
Main Effects				
Text Type	1	72.848	5.734	.019
Simulation	2	31.306	2.464	.092
Gender	1	4.414	.347	.557
2-Way Interactions				
Text Type x Simulation	2	4.944	.389	.679
Text Type x Gender	1	4.080	.321	.573
Simulation x Gender	2	25.427	2.001	.143
3-Way Interactions				
Text Type x Simulation x Gender	2	11.667	.918	.404
Explained	12	38.112	3.000	.002
Residual	70	12.705		
Total	82	16.423		

Mean Scores--Sink Model Questions

Condition	n	M	SD
Text Type			
Traditional	46	.85	1.21
CCDT	37	.54	.87
Simulation			
None	32	.81	1.09
Before	27	.59	.84
During	24	.71	1.30
Gender			
Male	36	.39	.60
Female	47	.96	1.29
Traditional Text/			
No Simulation	15	.87	1.13
Simulation Before	17	.65	.93
Simulation During	14	1.07	1.59
CCDT/			
No Simulation	17	.77	1.09
Simulation Before	10	.50	.71
Simulation During	10	.20	.42

Analysis of Variance--Sink Model Scores

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIGNIFICANCE
Covariates				
Electrical Experience	1	7.791	6.939	.010
Main Effects				
Text Type	1	1.612	1.435	.235
Simulation	2	.924	.823	.443
Gender	1	1.282	1.142	.289
2-Way Interactions				
Text Type x Simulation	2	.524	.467	.629
Text Type x Gender	1	1.739	1.549	.217
Simulation x Gender	2	.398	.355	.703
3-Way Interactions				
Text Type x Simulation x Gender	2	.409	.364	.696
Explained	12	1.371	1.221	.287
Residual	70	1.123		
Total	82	1.159		

Mean Scores--Clashing Currents Model Questions

Condition	n	M	SD
Text Type			
Traditional	46	.91	1.19
CCDT	37	.68	.82
Simulation			
None	32	.94	1.10
Before	27	.63	.88
During	24	.83	1.13
Gender			
Male	36	.53	.88
Female	47	1.02	1.11
Traditional Text/			
No Simulation	15	1.20	1.32
Simulation Before	17	.47	.80
Simulation During	14	1.14	1.35
CCDT/			
No Simulation	17	.71	.85
Simulation Before	10	.90	.99
Simulation During	10	.40	.52

Analysis of Variance--Clashing Currents Model Scores

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIGNIFICANCE
Covariates				
Electrical Experience	1	8.125	8.131	.006
Main Effects				
Text Type	1	1.035	1.035	.312
Simulation	2	1.429	1.430	.246
Gender	1	.517	.517	.474
2-Way Interactions				
Text Type x Simulation	2	2.222	2.223	.116
Text Type x Gender	1	.003	.003	.958
Simulation x Gender	2	.545	.545	.582
3-Way Interactions				
Text Type x Simulation x Gender	2	.807	.807	.450
Explained	12	1.580	1.581	.117
Residual	70	.999		
Total	82	1.084		

Mean Scores--Unidirectional Without Conservation Model Questions

Condition	n	M	SD
Text Type			
Traditional	46	.98	1.15
CCDT	37	.51	.93
Simulation			
None	32	1.13	1.21
Before	27	.63	1.04
During	24	.46	.78
Gender			
Male	36	1.03	1.18
Female	47	.57	.95
Traditional Text/			
No Simulation	15	1.87	1.13
Simulation Before	17	.70	1.11
Simulation During	14	.36	.50
CCDT/			
No Simulation	17	.47	.87
Simulation Before	10	.50	.97
Simulation During	10	.60	1.08

Analysis of Variance--Unidirectional Without Conservation Model Scores

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIGNIFICANCE
Covariates				
Electrical Experience	1	1.266	1.364	.247
Main Effects				
Text Type	1	7.256	7.816	.007
Simulation	2	5.017	5.404	.007
Gender	1	4.478	4.823	.031
2-Way Interactions				
Text Type x Simulation	2	3.583	3.859	.026
Text Type x Gender	1	.611	.658	.420
Simulation x Gender	2	.405	.436	.648
3-Way Interactions				
Text Type x Simulation x Gender	2	.578	.622	.540
Explained	12	2.472	2.663	.005
Residual	70	.928		
Total	82	1.154		

Mean Scores--Unidirectional With Sharing Model Questions

Condition	n	M	SD
Text Type			
Traditional	46	.70	.87
CCDT	37	.32	.53
Simulation			
None	32	.22	.49
Before	27	.74	.90
During	24	.71	.75
Gender			
Male	36	.25	.44
Female	47	.74	.87
Traditional Text/			
No Simulation	15	.20	.56
Simulation Before	17	.88	.99
Simulation During	14	1.00	.78
CCDT/			
No Simulation	17	.24	.44
Simulation Before	10	.50	.71
Simulation During	10	.30	.48

Analysis of Variance--Unidirectional With Sharing Model Scores

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIGNIFICANCE
Covariates				
Electrical Experience	1	4.390	10.080	.002
Main Effects				
Text Type	1	1.351	3.102	.083
Simulation	2	2.448	5.621	.005
Gender	1	1.596	3.666	.060
2-Way Interactions				
Text Type x Simulation	2	.427	.980	.381
Text Type x Gender	1	.477	1.094	.299
Simulation x Gender	2	.242	.555	.576
3-Way Interactions				
Text Type x Simulation x Gender	2	.642	1.474	.236
Explained	12	1.349	3.098	.001
Residual	70	.436		
Total	82	.569		

Mean Scores--Scientific Model Questions

Condition	n	M	SD
Text Type			
Traditional	46	3.13	2.18
CCDT	37	4.68	2.12
Simulation			
None	32	3.06	2.24
Before	27	4.37	2.20
During	24	4.21	2.20
Gender			
Male	36	4.36	2.24
Female	47	3.40	2.23
Traditional Text/			
No Simulation	15	1.87	1.55
Simulation Before	17	3.59	2.29
Simulation During	14	3.93	2.13
CCDT/			
No Simulation	17	4.12	2.26
Simulation Before	10	5.70	1.25
Simulation During	10	4.60	2.37

Analysis of Variance--Scientific Model Scores

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIGNIFICANCE
Covariates				
Electrical Experience	1	35.386	9.645	.003
Main Effects				
Text Type	1	55.707	15.183	.000
Simulation	2	21.501	5.860	.004
Gender	1	.190	.052	.821
2-Way Interactions				
Text Type x Simulation	2	9.961	2.715	.073
Text Type x Gender	1	.208	.057	.812
Simulation x Gender	2	2.703	.737	.482
3-Way Interactions				
Text Type x Simulation x Gender	2	9.962	2.715	.073
Explained	12	13.955	3.804	.000
Residual	70	3.669		
Total	82	5.174		

Mean Scores--Short Circuit Preconception Questions

Condition	n	M	SD
Text Type			
Traditional	46	1.33	.97
CCDT	37	.68	.78
Simulation			
None	32	1.53	.78
Before	27	.59	.91
During	24	.88	.96
Gender			
Male	36	.69	.80
Female	47	1.30	.95
Traditional Text/			
No Simulation	15	1.53	.74
Simulation Before	17	.94	1.03
Simulation During	14	1.07	1.07
CCDT/			
No Simulation	17	1.12	.78
Simulation Before	10	.30	.48
Simulation During	10	.80	.79

Analysis of Variance--Short Circuit Preconception Scores

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIGNIFICANCE
Covariates				
Electrical Experience	1	7.397	5.571	.021
Main Effects				
Text Type	1	10.535	7.934	.006
Simulation	2	9.008	6.784	.002
Gender	1	1.403	1.057	.307
2-Way Interactions				
Text Type x Simulation	2	2.480	1.868	.162
Text Type x Gender	1	.027	.021	.886
Simulation x Gender	2	.575	.433	.650
3-Way Interactions				
Text Type x Simulation x Gender	2	.951	.716	.492
Explained	12	3.495	2.632	.006
Residual	70	1.328		
Total	82	1.645		

Mean Scores--Model Classifications

Condition	n	M	SD
Text Type			
Traditional	46	3.17	1.288
CCDT	37	3.65	1.549
Simulation			
None	32	2.78	1.453
Before	27	3.81	1.302
During	24	3.71	1.268
Gender			
Male	36	3.69	1.327
Female	47	3.15	1.459
Traditional Text/			
No Simulation	15	2.40	.828
Simulation Before	17	3.65	1.320
Simulation During	14	3.43	1.342
CCDT/			
No Simulation	17	3.12	1.799
Simulation Before	10	4.10	1.287
Simulation During	10	4.10	1.101

Analysis of Variance--Model Classification Scores

SOURCE OF VARIATION	DF	MEAN SQUARE	F	SIGNIFICANCE
Covariates				
Electrical Experience	1	11.678	6.873	.011
Main Effects				
Text Type	1	6.589	3.878	.053
Simulation	2	11.064	6.511	.003
Gender	1	.108	.063	.802
2-Way Interactions				
Text Type x Simulation	2	.601	.353	.704
Text Type x Gender	1	1.005	.591	.445
Simulation x Gender	2	2.319	1.365	.262
3-Way Interactions				
Text Type x Simulation x Gender	2	1.138	.670	.515
Explained	12	3.893	2.291	.016
Residual	70	1.699		
Total	82	2.020		

CHI-SQUARE FREQUENCY TABLE FOR TEXT TYPE BY MODEL CLASSIFICATION

Count Std. Res. Text Type	Model Classification Low	Medium	High	Row Total
Trad Text	14 .0	24 1.5	8 -1.7	46 55.4%
CCDT	11 .0	8 -1.7	18 1.9	37 44.6%
Column Total	25 30.1%	32 38.6%	26 31.3%	83 100.0%

Chi-square	D.F	Significance
11.364	2	0.003

CHI-SQUARE FREQUENCY TABLE FOR SIMULATION BY MODEL CLASSIFICATION

Count Std. Res. Simulation	Model Classification Low	 Medium	 High	 Row Total
None	14 1.4	11 -.4	7 -1.0	32 38.6%
Before	5 -1.1	11 .2	11 .9	27 32.5%
During	6 -.5	10 .2	8 .2	24 28.9%
Column Total	25 30.1%	32 38.6%	26 31.3%	83 100.0%

Chi-square	D.F	Significance
5.335	4	0.2546

APPENDIX I.

QUESTIONS AND RESPONSE KEYS USED IN POSTTEST ANALYSIS

Questions and Response Keys Used in Posttest Analysis

SECTION	QUESTION	RESPONSE
Conceptual Serial		
	1	B
	2	B
	4	B
	5	A
	6	B
	7	B
	17	A
	18	A
	22	A
	23	C
	24	A
	25	B
	26	B
	27	C
	34	A
	35	A
	36	A
	37	A
	39	B
	40	C
	43	A
	44	A
	45	B
	46	C
	47	B
	48	B
Sink Model		
	1	A
	6	A
	23	B
	26	A
	27	A or B
	35	C
	39	A
	40	A
	45	A
	46	A

Questions and Response Keys Used in Posttest Analysis

SECTION	QUESTION	RESPONSE
Clashing Currents Model		
	17	C
	22	C or D
	23	A
	25	A
	34	C or D
	35	B, D or E
Unidirectional Without Conservation Model		
	18	B or C
	37	B or C
	44	B or C
Unidirectional With Sharing Model		
	18	D
	37	D
	44	D
Scientific Model		
	4 and 5	B and A
	18	A
	37	A
	44	A
	47 and 48	B and B
Short Circuit Preconception		
	4	A
	47	A
	48	A