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Teaching Electricity To Freshman Physical Science Students
Through Constructivism

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TEACHING ELECTRICITY TO FRESHMEN PHYSICAL SCIENCE STUDENTS THROUGH CONSTRUCTIVISM

By

Jerry Van Horn

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

TEACHING ELECTRICITY TO FRESHMEN PHYSICAL SCIENCE STUDENTS THROUGH CONSTRUCTIVISM

By

Jerry Van Horn

The goal of this unit was to teach electricity to freshmen physical science students using a constructivist approach utilizing a series of laboratories and hands on activities. The activities were designed to reflect five postulates of constructivist theory: utilize student's previous knowledge, require sustained mental effort, create dissatisfaction with previous knowledge, contain a social component, and apply to the student's lives. The hypothesis of this research was that the investigative experiences and constructivist approach would enhance the students' conceptual understanding of electricity.

Prior to the unit, the students were given a pre-test that included fifteen short answer questions that covered information related to the unit. Of the fifty-seven participants involved in the study, the average score on the pre-test was thirteen point nine percent. Upon completion of the unit, students were given the same fifteen questions on a post-test. The average post-test score of the fifty-seven participants increased to eighty-four point three percent. The data indicate that the unit successfully reshaped the students' preexisting knowledge and misconceptions and provided them with a better conceptual understanding of electricity.

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Introduction

The Fowlerville science staff analyzed the science curriculum and made significant changes to the Physical Science curriculum during the 2002 – 2003 school year. Analysis of the High School Proficiency Test showed that Fowlerville students were scoring low in a number of physics related objectives. Up to this point, the semester long ninth grade physical science class was primarily chemistry based. Topics such as mechanics, heat, electricity, magnetism, and nuclear physics were not covered. The chemistry objectives taught, however, were reinforced in the students' chemistry class or a junior level integrated science class prior to the eleventh grade proficiency test. Since the students were not introduced to the required physics objectives, the staff decided that the physical science class would shift from a chemistry-based curriculum to a physics-based curriculum in the fall of 2003.

Since my research was being conducted during the summer of 2003, I needed to choose a topic that I had not taught before. I decided to work on a topic generally emphasized on proficiency tests as well as a topic in which I felt relatively weak: electricity. Since I did not take physics in high school, the extent of my electrical knowledge came from a ninth grade Physical Science class, a Physics II college class at Central Michigan University, and a Physics for Teachers lab course at Michigan State University. I remember little from my high school class and was thoroughly perplexed by my college class. The professor moved very rapidly and presented material from a theoretical perspective. Consequently, I memorized enough to get by, but had a very weak conceptual understanding. It was not until I had completed the Physics for Teachers laboratory course at Michigan State University that I had gained a strong foundation of electricity. There I completed a lab based electricity curriculum, called

CASTLE (capacitor aided system for teaching and learning electricity), that provided me with an excellent framework for thinking about electricity.

With this foundation, I set out to design a unit that could be presented to my students through a series of experiments, activities, and demonstrations that would make a difficult concept engaging, understandable, and relevant. In order to achieve this, I decided to design the unit around constructivist theory. Constructivism has become an integral part of current education reform and is supported by the National Science Education Standards and Project 2061 (Haney, Lumpe, Czerniak, 2003). My hypothesis for this research is that teaching the unit using a constructivist approach will successfully improve the students conceptual understanding of electricity.

Constructivists assume that knowledge is actively constructed in the mind of the learner. One constructivist theorist, Thomas W. Shiland, believes that constructivist theory can be explained through five basic postulates (1999). First, learning requires sustained mental effort. Learners do not incorporate ideas into a meaningful mental framework by having material simply presented to them (Driver, 1988). Rather, learners need to grapple with new information in order to gain a foundation that makes sense to the learner. As a result, constructivists feel that the behaviorist approach to learning is inadequate. Simply presenting material to students and asking them to memorize and recite that material back does not result in learning. In fact, numerous studies have shown that most college students hang on to grand misconceptions even after successfully passing a course (Lorsbach et al. 1995). Therefore, while it may be possible to memorize factual material and successfully relay that information back, it is apparent that without deeper thinking, naïve ideas remain firmly implanted in the mind of the learner.

A second basic postulate of constructivist theory is that students' prior knowledge is important and relevant to the learning process (Jofili, Geraldo, & Watts 1999). When students enter classrooms, they come to class with a host of explanations for how the world around them works. Therefore, when students are offered new insights into a topic, they can deal with it in one of four ways: delete their preexisting knowledge, modify their preexisting knowledge so that it meshes with the new information, modify the new information so that it fits with their preexisting knowledge, or reject the new information altogether (Sewell, 2002). Since little thought is required to simply ignore new information altogether, many students resort to it. Consequently, constructivists believe that it is the teacher's job to identify misconceptions that are widely held by the students and to address those misconceptions. Instead of dismissing the misconceptions as incorrect, the teacher should provide students with opportunities to explore other possibilities that allow students to determine the flaws in their initial framework while developing new ideas that are more intellectually sound (Windschitl, 1999). Once this has been accomplished, constructivists believe that a deeper level of understanding is attained while previous misconceptions are replaced.

Shiland's third postulate of constructivist theory is that meaningful learning occurs when learners are dissatisfied with their present knowledge. This means that if learners are able to correctly hypothesize how an unknown situation will turn out, a restructuring of information will not occur (Saunders, 1992). Therefore, a correct solution to a problem may deepen a learner's level of understanding about a topic, but the learner has not had to reshape his thinking. It is when an expected outcome does not occur that a learner needs to reevaluate his existing knowledge and restructure it so that it encompasses the new information. This allows the learner to dismiss previous misconceptions and provides him with a stronger foundation than he previously had.

A fourth postulate to constructivist theory is that learning has a social component. When discussing new information that has been assimilated, learners test the fit of that information into their new framework of understanding (Lorsbach & Tobin 1993). If they have truly learned something, they should be able to express that information to others in a clear and concise way, thus deepening their understanding. Likewise, individuals listening to someone else can learn meaningfully by constantly assessing and questioning the material being presented so that it fits with their preexisting knowledge (Lord, 1998).

Shiland's final postulate of constructivist theory is that learning needs application. In order to maximize learning, students need to be exposed to applications that demonstrate the value of the new concept. Therefore, to get learners to buy-in to the importance of a topic, they need to see how the topic relates to them personally. Relevance plays a critical role in learning. Without it, learners fail to see the importance of a topic. As a result, thought about the topic is minimized and meaningful learning is not attained. By relating concepts to students' lives, their interest level is raised and they are provided with a context for thinking about the new topic.

In addition to these five postulates, I believe that the constructivist teacher needs to provide students with opportunities to learn material in different ways. With the traditional behaviorist approach, students are presented with information from the teacher and the textbook and expected to learn the material. However, there are multiple ways that individuals learn. A traditional approach of teaching utilizes primarily analytical and verbal learning. According to Gardner, however, there are nine distinct categories of learners (Gardner, 2000). Therefore, to provide students with an optimal chance to learn, they must engage in activities and materials that suit them best. These activities include those that are suited not only to analytic and verbal learners, but also to visual, spatial, kinesthetic, and interpersonal learners as well.

Scientific Background

Around 600 B.C., a Greek philosopher named Thales of Miletus discovered that amber would attract bits of dust and small particles after it had been rubbed with fur. Unknowingly, he had discovered electrostatics. Electrostatics is the study of electrically charged objects. An object becomes electrically charged when it has an excess of either positive or negative charge.

The positive and negative charges responsible for Thale's discovery come from small particles called atoms. Atoms are the building block of all matter and consist of three smaller particles known as protons, neutrons, and electrons. Each atom contains a positively charged center called the nucleus. The nucleus contains both positively charged protons and uncharged neutrons, and it is held together very tightly. Surrounding the nucleus is the electron cloud which contains negatively charged electrons. The electrons are not held as tightly as the protons and neutrons are. Although protons are more massive than electrons, the two particles carry the same quantity of charge. Since the number of protons is typically the same as the number of electrons, atoms are generally neutral. Therefore, even though charges exist within atoms, they do not act as charged bodies because the amount of positive and negative charge offset one another.

When two bodies are brought together, however, charge can be transferred from one object to another. This occurs because objects have different affinities for electrons. Some objects, like amber, have strong affinities for electrons. This means that when an object like fur is rubbed against amber, some of the loose outer electrons in atoms making up the fur are "scraped" off onto the amber. Once this happens, the amber has more electrons than it does protons. As a result, the amber becomes negatively charged. Fur, on the other hand, loses negatively charged electrons. Therefore, there are more protons than there are electrons making the fur positively charged. It is important to note that electrons have not been created or destroyed during this process. Instead, electrons were simply transferred from the fur to the amber. The total amount of charge has been conserved throughout this process.

If the fur and the amber are brought near one another after they have been charged, the two objects will attract. This occurs because objects that have opposite electrical charges exert an attractive force on one another. If two objects with like charges are brought near one another, the two objects will repel because objects with like electrical charges exert a repulsive force on one another.

The size of the force that is exerted on two point charges depends on two factors: the quantity of charge on the two particles and distance the particles are separated. This relationship was discovered by Charles Coulomb and can be expressed as

$$F = k \frac{q_1 q_2}{d^2}$$

where k represents the proportionality constant, q_1 and q_2 represent the quantity of charge in coulombs on the particles, and d is the distance the particles are separated. The coulomb, abbreviated C, is the amount of charge contained in 6.25×10^{18} electrons or protons. This equation shows that if the distance between two particles remains constant, the force between them will increase if the charge on either of the particles increases. It also shows that if the charges on the particles remain constant, the force between them will increase if the particles are moved closer together.

Interestingly, a charged object can also exert a force on an uncharged object located nearby. For example, when the amber is rubbed with fur it becomes negatively charged. When the amber is placed near dust, the dust will accelerate from its stagnant position toward the amber until the two are sticking together. This occurs because the amber induces a charge in the neutral dust. The centers of positive charge within the dust are shifted so that they migrate toward the amber. While the dust is still neutral overall, the charges have been redistributed such that the amber and dust are attracted to one another.

Another type of electricity was discovered accidentally by Luigi Galvani in 1780 as he was dissecting a frog. During the dissection, Galvani was able to successfully move a charge through a frog's leg causing it to twitch. Unwittingly, Galvani developed a technique whereby a sustained flow of electric charge was possible. This accident led to the discovery of electrical current.

While electrostatics addresses objects that have a net charge, electrical current deals with the flow of charge. Oftentimes, this flow occurs in an uncharged object such as a copper wire. The flow of charge is known as electrical current and is defined as the rate at which charge flows through some substance. Electrical current is expressed in amperes, abbreviated A. One ampere is equal to one coulomb of charge moving through a substance in one second. This is roughly the amount of current that passes through a one hundred watt light bulb connected to a household circuit in the United States every second.

One thing that determines the amount of current that flows through a circuit is the voltage that is applied across the circuit. One can think of voltage as electrical pressure. Just like pressure is needed to get water to flow, pressure is needed to get electric charges to flow. The greater the amount of pressure, the greater the flow of charge will be. Therefore, in order to get current to flow through a circuit, a voltage difference must exist across the ends of the circuit. Without a difference in voltage, a pressure gradient does not exist and charge will not flow. The greater the pressure gradient is, however, the greater the current will be. Voltage, also known as potential difference, is measured in volts, abbreviated V.

A second factor that determines how much current will flow through a circuit is resistance. As current flows through a circuit, individual charge carriers encounter friction as they move. Since friction always acts in a direction that is opposite to the motion of an object, the friction the charge carriers encounter acts to slow them down. In an electric circuit, this friction is known as resistance. A number of factors affect the overall resistance in a circuit. These factors include the length of the resistor, the diameter of the resistor, the temperature of the resistor, and the material out of which the resistor is made. If a circuit contains a single resistor and the quantity of that resistor is increased while the voltage remains constant, the amount of current flowing through the circuit will decrease.

The relationship between current, voltage, and resistance was first described by Georg Ohm in the early 1800's. He determined that the current flowing through a circuit was directly proportional to the voltage applied across the circuit and inversely proportional to the resistance of the circuit. Ohm's Law, therefore, can be expressed as:

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

where I stands for current, V for voltage, and R for resistance. Consequently, to maximize current flow through a circuit with one resistor, the voltage applied across the circuit should be maximized while the overall amount of resistance within the circuit should be minimized.

Current is generally carried through circuits, pathways along which charge flows. In order to get a sustained current flow, the circuit must be free of gaps and allow charge to be carried. These types of circuits are called closed circuits. In order to stop current from flowing, the pathway must be broken. This type of circuit is an open circuit. Generally, switches are employed in a circuit and act to open and close the circuit as needed. Circuits can be connected together in one of two primary ways: series or parallel.

Ohm's law can be applied to series and parallel circuits to help one understand why these circuits function differently. A series circuit contains a single pathway for charge to flow through. Since there is only one pathway, the current at each spot in a series circuit has to be the same. To determine how much current there is in a series circuit one needs to determine the sum of the resistances in the circuit. The total current flowing though the circuit is determined by dividing the total voltage applied across the circuit by the sum of the individual resistors in the circuit. This has some interesting ramifications. If the circuit contains resistors that have different amounts of resistance, it follows that the voltage drops across the different resistors must be different. Therefore, a resistor with a large amount of resistance requires a large voltage drop across it. This makes sense if one realizes that the current needs to be the same at each location within the circuit. A greater electrical pressure is required to push a certain amount of current through a high resistance. If one were to look at the voltage drop across each individual resistor, the sum of those voltage drops would be equal to the voltage drop applied across the entire circuit.

A parallel circuit, on the other hand, contains multiple pathways through which current can travel. Since there are multiple pathways for current to travel through, the amount of current in one branch may be different from the amount of current in a different branch. Since each branch connects directly to the power source, the voltage drop across each branch is equal to the voltage supplied by the power source. Therefore, a branch that has less resistance will have a larger current passing through it. In order to determine the total amount of current running through a parallel circuit, one would need to calculate the current running through each branch of the circuit. The sum of these currents is equal to the total amount of current in the circuit. An interesting ramification of adding additional branches to a parallel circuit is that it serves to reduce the overall amount of resistance within the circuit. As the overall amount of resistance decreases, the amount of current flowing through the circuit increases. This can be problematic because larger currents mean more heat is produced. This raises the risk of an electrical fire. As a result, fuses and circuit breakers are typically wired into parallel circuits for safety purposes.

Demographics

This study was conducted with freshman enrolled in three Physical Science classes at Fowlerville Jr. High School. Fowlerville is a small, rural village located approximately thirty miles east of Lansing. Ethnically, it is a relatively non-diverse community of 15,757 individuals. Caucasians comprise over ninety-five percent of the population. Economically, on the other hand, the community is quite diverse. The median household income is $60,337 which exceeds the state average by $12,041. While the median household income is greater than the state average, the number of adults in the community who possess a bachelor's degree is nearly ten percent less than the state average. This data leads one to believe that there is an affluent group of well educated individuals within the district that raises the overall median household income. At the same time, there is a group that is not as well educated that make much less money. These numbers help explain the economic disparity I see between students on a daily basis.

Fowlerville Jr. High has approximately 830 students in grades seven, eight, and nine. At the beginning of this study, 277 of those students were in ninth grade, of which I taught eighty-seven. Fifty-seven of these students agreed to participate in the study. Of the fifty-seven students, twenty-nine were female; twenty-eight were male; fifty-six were Caucasian and one was Asian.

Physical Science is one of three credits needed in science to graduate from Fowlerville. Consequently, all incoming freshman are required to take the course unless they are able to successfully test out of the class. We do not offer an "advanced" physical science course; therefore, a wide range of ability levels are present in each class. For instance, some students in my science class also take a low-level algebra course while other students in my class are taking geometry and algebra-II courses. This wide disparity of intelligence and motivation has made teaching the course so that all students receive a meaningful education difficult.

Implementation

Constructivist theory states that students' prior knowledge is important and relevant to the learning process. Therefore, before I designed the unit, I set out to determine common misconceptions about electricity that are widely held. I know from personal experience that these misconceptions can be detrimental to the learning process. These misconceptions must be addressed so that students can maximize their learning potential. Below are some widely held misconceptions about electricity (Science Education Center, 2002), (Hewitt, Suchocki, and Hewitt 2003).

1. Static electricity is electricity that is static – not moving.
2. Static electricity is a build-up of electrons – it has nothing to do with protons.
3. Electrical charges occur in some materials but not in others.
4. Current electricity is the opposite of static electricity.
5. A current carrying wire is electrically charged.
6. Electric current flows out of a battery, not through it.
7. Electric current is the flow of electrons - nothing else.
8. Electric current moves at the speed of light.
9. Voltage and current are two words for the same thing.
10. Voltage flows through a circuit.
11. In series circuits, the amount of current varies in devices of different electrical resistance.
12. In a parallel circuit, the equivalent resistance of the circuit increases with the addition of more resistors.

I looked for labs and activities that addressed these misconceptions. It was my goal to provide students with opportunities to discover inadequacies in their own thinking so that they could restructure their thoughts. According to constructivist theory, this is much more powerful than simply telling students that their current thoughts are wrong and telling them how they should think. In addition to looking for labs that addressed misconceptions, I searched for activities that incorporated the five basic postulates of constructivist theory mentioned earlier. The labs and activities should require sustained mental activity, utilize and create dissatisfaction with previous knowledge, contain a social component, and be applicable to the students' lives.

A final item that I considered before designing my unit was the type of equipment to use. Oftentimes, teachers use the best laboratory equipment available when studying a topic. Unfortunately, students don't always make the necessary connections when they are using sophisticated equipment. Consequently, I decided to use common everyday materials to introduce my unit. More sophisticated equipment was introduced after students had a firm foundation with the basic concepts of electrostatics and current electricity.

Summary of Activities

The electricity unit was introduced during the twelfth week of the second semester and was completed over the course of five weeks. Prior to the start of the unit, students were given a *Pre-Test* (A-17) that contained fifteen questions based on the objectives of the unit. Upon completion of the pre-test, students were introduced to the electricity unit which was broken down into two basic categories: electrostatics and electrical current. Throughout the unit, students were engaged in numerous labs and activities that can be found in appendix A. The manner in which the labs were assessed can be found in appendix B – the teacher section of the unit.

The electrostatics portion of the unit was covered in the first week and a half. Four labs and a number of demonstrations involving a Van de Graaff generator were performed during this part of the unit as shown in Figure One on page fifteen. These activities addressed the three electrostatics' objectives:

Objective 1: Describe how electric charges are transferred and explain why electric discharges occur.

Objective 2: Analyze factors that affect the strength and direction of electric forces.

Objective 3: Determine the polarity of an unknown charge using an electroscope.

The labs and assignments found in appendix A are arranged in the same order that they were distributed to the students. The electrostatics portion of the unit began with an *electrostatics mini-lab activity* (A-1) and a *charged grains lab* (A-2). Both activities were designed to engage the students and draw them into the study of electrostatics by having them perform various "magical" tricks using common everyday materials. Many students were mesmerized by the fact that they could charge themselves and cause a pencil to move simply by moving their finger back and forth near the tip of a

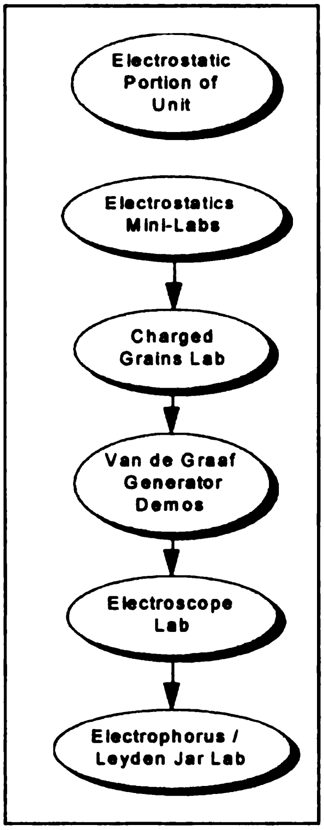

Figure 1: Flowchart for electrostatic portion of unit

pencil. After completing the two labs, students had been introduced to the idea that charge can be transferred to an object through friction, conduction, and induction. Furthermore, they determined that opposite electrical charges attract while like electrical charges repel. In addition, they concluded that the electrical force between two objects depends on the amount of charge on the objects and how far the objects are separated from one another.

After completing these labs, the students were introduced to the Van de Graaff generator. Since it was my first time teaching the unit, I was unsure of what to expect. I quickly learned that any interest I had elicited with the first two labs paled in comparison to the enthusiasm brought about by the generator. Students were very excited to take part in the demonstrations that reinforced the topics covered in the first two labs. The two demonstrations that brought about the most interest were the hair raising demonstrations and the large sparks created by the discharge of the generator.

Following the excitement of the Van de Graaff generator, students performed an *electroscope lab* (A-3). The students used hand-made electroscopes to explore electrostatic charges through both conduction and induction. Students also determined how to use the electroscope to identify the polarity of an unknown charge.

After completing the electroscope lab, I showed the students that a metal enclosure, known as a Faraday cage, located around an electroscope prevented the electroscope from becoming charged. The students saw that an electroscope placed inside a metal pot and covered with a metal strainer could not be charged. Even when a Van de Graaff generator was placed near the electroscope, it failed to become charged. They discovered that an electrostatic charge placed on a metal enclosure remains on the outside surface of the container. Many of the students found it interesting that this was the reason why it was safe to be inside a car during a thunderstorm. Many were under the false impression that a car was safe because of the of the car's insulated tires.

The final activity of the electrostatics portion of the unit was the *Electrophorus and Leyden Jar lab* (A-4). During this activity, students used an electrophorus capable of producing a large number of successive electrostatic charges. These charges were transferred to an aluminum pie pan and in turn transferred to a device called a Leyden Jar. The Leyden Jar stored large amounts of charge until the students were ready to discharge it. The Leyden Jar was a precursor to today's capacitor, a device used in electrical circuits.

The Leyden jar lab provided a nice transition from the subject of electrostatics to electrical current. We discussed the fact that large amounts of charge could be stored and discharged through objects, but that a sustained flow of charge was not possible with this device. With that, we shifted our focus from electrostatics to current electricity. This portion of the unit was completed in three and a half weeks. Ten labs and a project were performed during this part of the unit as shown in Figure Two on page eighteen. The activities were completed to address ten electrical current objectives:

Objective 1: Distinguish a conductor from an insulator.

Objective 2: Describe the conditions necessary for electric current to flow.

Objective 3: Describe the factors that affect resistance.

Objective 4: Relate the current in a circuit to the resistance of the circuit and the voltage across it using Ohm's Law.

Objective 5: Analyze the differences between cells connected in series and in parallel.

Objective 6: Construct and analyze circuits using circuit diagrams.

Objective 7: Analyze the differences between circuits connected in series and in parallel.

Objective 8: Describe devices and procedures for maintaining electrical safety.

Objective 9: Determine the cost required to run various electrical devices based on current electrical costs.

Objective 10: Connect a household circuit containing two outlets, a switch, and a light fixture.

The electrical current portion of the unit began with the *Water Analogy activity* (A-5). Two bottles were attached by a piece of tubing that connected the bottom of the bottles together. When the tubing was clamped and water was placed into one bottle, the water stayed in that bottle. As soon as the students removed the clamp, water began immediately pouring through the tube into the second bottle. The flow continued until

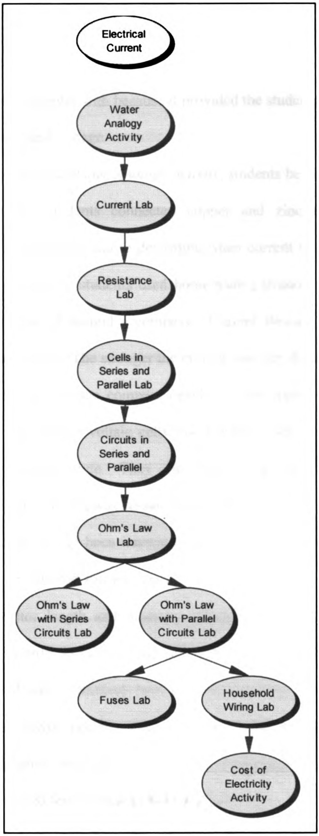

Figure 2: Flowchart for electrical current portion of unit

the water was at the same level in both bottles. After completing the activity, we discussed the similarities between the flow of water and the flow of electricity. This was an invaluable activity to begin with because it provided the students with a framework for thinking about current and voltage.

After completing the *Water Analogy activity*, students began the *Current Lab* (A-6). During this lab, students connected copper and zinc electrodes in various arrangements and in various media to determine when current would flow. In order to measure the flow of current, students used homemade galvanoscopes that consisted of many turns of wire placed around a compass. Current flowing through the compass causes the needle to deflect. The stronger the current was that flowed through the circuit, the greater the deflection of the compass needle. After completing the lab, students realized that they had created voltaic cells that worked when two different electrodes were separated by an electrolyte. They also realized that the amount of current was greater when more than one cell was connected together.

Once the students had been introduced to electrical current, they explored how that current could be affected by resistance. During the *resistance lab* (A-7), students looked at how resistor length and diameter affected the amount of current flowing through a circuit. In order to look at resistor length, students used a homemade rheostat made out of a shaved pencil. Students hooked a circuit up that included some batteries, a light bulb, and the shaved pencil. They determined that the shorter the pencil lead resistor was, the brighter the light bulb glowed. Consequently, they determined that shorter resistors provided less resistance than did longer ones.

Next, the students looked at resistor diameter and its effect on resistance. Since Play-doh conducts electricity, they made different diameter "wires" out of the Play-Doh and inserted these Play-doh cylinders into a circuit. Using multimeters, students measured the current running through the circuit and the voltage across the Play-doh resistor. They then calculated the amount of resistance to determine that as the diameter increased, the total amount of resistance decreased.

After exploring the basics of current, voltage, and resistance, the students began investigating circuits in more detail. In the *Cells in Series and Parallel lab* (A-8), students examined how connecting cells in series and parallel affected a circuit. During the lab, students used zinc and copper electrodes dipped in a salt water solution. They connected the cells together in both series and in parallel and measured the voltage across the cells. Once complete, the students realized that the voltage across cells in parallel was identical to the voltage across a single cell while the voltage across cells in series was equal to the sum of the voltages across each individual cell.

The next lab that the students encountered was the *Circuits in Series and Parallel lab* (A-9). While the information in this activity was primarily a review for the students, it was very important that they knew how to connect circuits together in series and parallel for some more complex labs that were forthcoming. In the lab, students explored both series and parallel circuits and were reminded about their differences.

Following this lab, the students completed three successive labs related to Ohm's Law. During the first lab, the *Ohm's Law lab* (A-10), students investigated the relationship between current, voltage, and resistance. At this point, they already knew that more voltage meant more current and more resistance meant less current. They did not, however, know exactly how these quantities related to one another. Consequently, the students completed a two part lab where either the voltage or the resistance of a simple circuit was held constant while the other value changed. After completing the lab and graphing the data, students realized that current was directly proportional to voltage and inversely proportional to resistance.

Next, students completed the *Ohm's Law with Series Circuits lab* (A-11) and the *Ohm's Law with Parallel Circuits lab* (A-12). During these two labs students investigated series circuits and parallel circuits and learned how Ohm's Law can be applied to each type of circuit. For instance, students learned that as more resistors are added in series, the total amount of resistance in the circuit increases. As more resistors are added in parallel, however, the total amount of resistance decreases. These ideas can be major stumbling blocks for students so we spent considerable time on these two labs.

Once the students had been introduced to parallel circuits and resistance, students recognized that adding additional resistors in parallel posed a real safety risk. A decrease in resistance means a corresponding increase in current. In turn, this means an increase in the amount of heat generated and a real possibility of an electrical fire. Consequently, we performed the *Fuses Lab* (A-13) to illustrate how circuit breakers and fuses are used in modern day electrical circuits. Students discovered that fuses and circuit breakers help protect circuits against overloads and short circuits.

After discussing fuses and circuit breakers and how they are incorporated into household circuits, we began our last lab: the *Home Wiring Lab* (A-14). In this lab, students were shown how outlets, switches, and light fixtures are connected with a PowerPoint presentation. They were required to take notes so that they would be able to connect two outlets, a switch, and a light fixture.

The final assignment in the electricity unit was the *Cost of Electricity activity* (A-15). After learning about how electricity works I wanted to make sure that the students had an understanding of how much it cost to use various electrical devices. Each student picked out three devices that he or she felt was important and calculated the amount of money required to use those devices for a month.

Upon completion of the unit, students were given the *Electricity Unit Study Guide* (A-16). After completing and reviewing the study guide, students took the fifteen question short answer *Post-Test* (A-17). This test was identical to the pre-test that students took at the beginning of the unit. In addition, the students were given a 50 question *Electricity Multiple Choice Test* (A-18).

Evaluation

Quantitative Data

At the beginning of the electricity unit, the students were given a 15 question short answer pre-test. The test, appendix A-17, was comprised of ten two point questions and five three point questions that covered the unit's objectives. The rubric that was used to grade these tests is found in appendix B-17. Upon completion of the unit, the students were given the same 15 question test. Average scores on the pre-test and post-test for my fourth, fifth, and sixth hours are shown in Table 1.

Fourth Hour		**Fifth Hour**		**Sixth Hour**	
Pre-Test	Post-Test	Pre-Test	Post-Test	Pre-Test	Post-Test
14.0%	80.7%	14.4%	85.1%	13.3%	87.1%

Table 1: Average Pre-Test and Post-Test Scores by Class Period

The results show a dramatic increase in correct responses from the pre-test to the post test. Fourth hour scores increased by 66.7%, fifth hour scores increased by 70.7%, and sixth hour scores increased by 73.8%. The dramatic increase in scores can be attributed to three factors. First, students knew that the pre-test was going to be used to provide baseline data for my thesis. They knew that it would not be counted as a grade, so some individuals may not have put forth their best effort. Second, the pre-test was given with approximately thirty minutes left in class on the first day of the unit. Therefore, students did not have the entire sixty minute class period to work on the test. Questions that were not finished in class were to be taken home and completed as homework. Consequently, some students did not complete all of the questions causing the average score to be less than it otherwise might have been. Third, and most importantly, students really did have a limited electrical knowledge and genuinely struggled with the pre-test.

After completing the unit, however, students apparently had gained a firm conceptual foundation and were able to answer most of the questions to a high degree of competency. The pre-test and post-test were broken down by question number and analyzed. Figures 3, 4, and 5 represent the average score students in different hours received on each of the three point test questions.

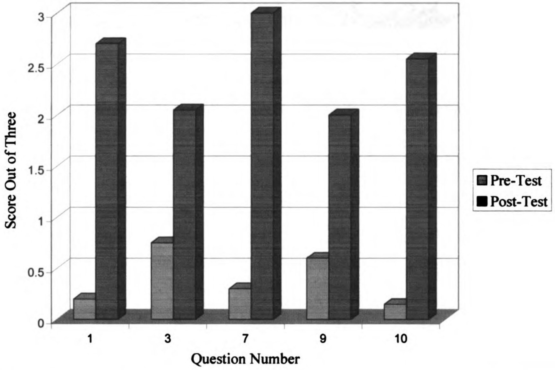

Figure 3: Fourth Hour Average Scores on the Three Point Test Questions (n = 20)

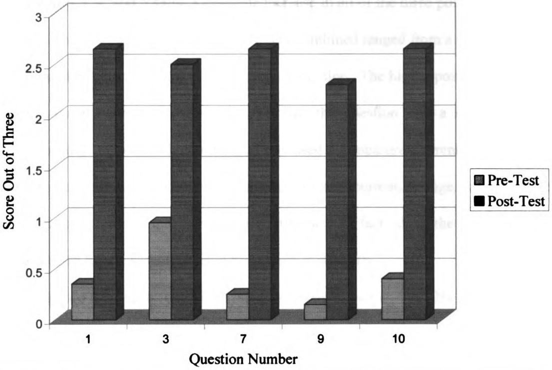

Figure 4: Fifth Hour Average Scores on the Three Point Test Questions (n = 20)

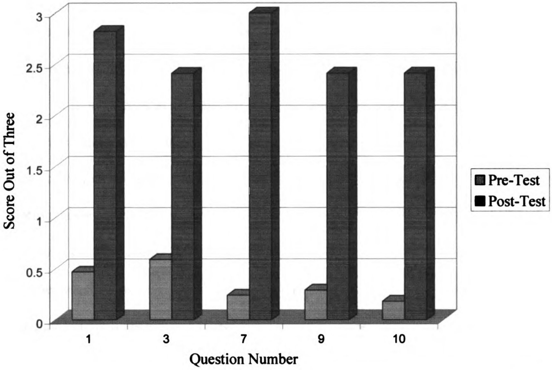

Figure 5: Sixth Hour Average Scores on the Three Point Test Questions (n = 17)

Figures 3, 4, and 5 show a dramatic increase in all of the three point short answer questions. The average score for the three hours combined ranged from a high of 96% on question number seven to a low of 74% on question nine. The higher post-test scores for question number seven are due to the fact that the question was a recall problem. Students needed to recall the units that are used to measure current, voltage, and resistance. Since we had worked extensively in labs with current, voltage, and resistance, this proved to be an easy question for most students. In fact, all of the students in my fourth and sixth hour classes answered this question correctly.

The two questions on which students scored below an 80% were question numbers three and nine. It was disturbing that the average score for question number three was a 77%. In each of the three hours, this question received the highest pre-test scores. However, on the post-test, it proved to be the second most difficult three point question. The question asked the students to differentiate an insulator from a conductor and to give an example of each. While we discussed this concept briefly in class, we did not perform a specific lab on conductors and insulators. I knew the students had been introduced to this concept in seventh grade. I felt that I could briefly review the subject assuming the students already knew the material. Unfortunately, only 25% of the students were able to answer the question on the pre-test correctly. Therefore, my assumption about their prior knowledge was incorrect. Furthermore, it shows that learning by discussing a topic is not as effective as a hands-on activity for most students.

The question which received the lowest marks on the post-test was question number nine. This question asked the students how voltage and resistance affected the current in a circuit. It went on to ask what would happen to the amount of current if the voltage was doubled and what would happen to the current if the resistance was doubled.

The reason why this question scored the lowest was because students did not specifically explain that the current would double if the voltage was doubled and that the current would be halved if the resistance was doubled. Since they were not specific, they did not earn the total number of points. This is unfortunate because most students understood the relationship based on my classroom observations.

Figures 6, 7, and 8 represent the average score students earned in different hours on each of the two point test questions. The average scores on the post-test for the three hours ranged from a high of 100% on question number eleven to a low of 64% on question number fourteen.

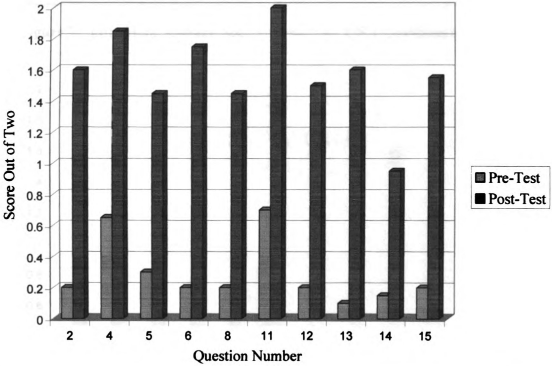

Figure 6: Fourth Hour Average Scores on the Two Point Questions (n = 20)

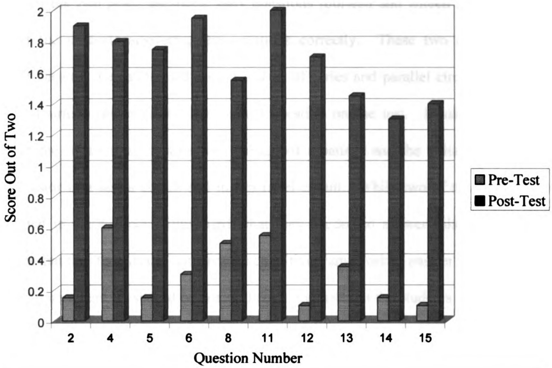

Figure 7: Fifth Hour Average Scores on the Two Point Questions (n = 20)

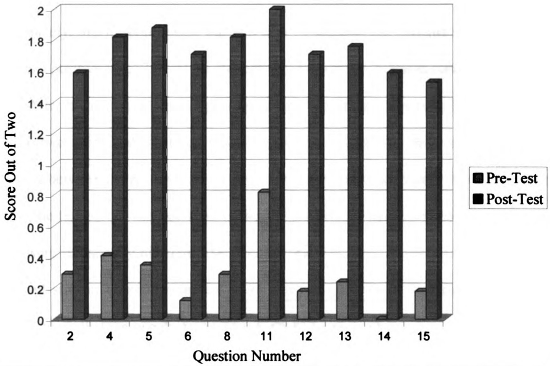

Figure 8: Sixth Hour Average Scores on the Two Point Questions (n=17)

Of the two point questions, only questions fourteen and fifteen had fewer than 80% of the students answering the questions correctly. These two questions were difficult because they addressed the intricacies of series and parallel circuits. Question number fourteen proved to be the hardest question on the test. It asked students to describe the relationship between the voltage of a battery and the voltage drop across each resistor in a series circuit and in a parallel circuit. While two of the labs that we completed in class directly illustrated what they needed to answer this question, it is apparent that the students did not have the cognitive framework to answer this question as well as some others. It should be noted, though, that 64% of the students in the study did answer this difficult question accurately. Question number fifteen was similar to number fourteen. Instead of asking about voltage, question fifteen dealt with the amount of current at different places in a series circuit, including the battery. One of the misconceptions mentioned earlier was that current flows out of a battery, not through it. Unfortunately, this misconception was still held by some of the students at the end of the unit. On a positive note, 75% of the students did answer this question correctly.

After breaking the pre and post-test down by number, a paired t-Test was run on both the two point and the three point questions to verify that there was a statistical difference between the pre-test and the post-test that could be attributed to the unit. After running the test on the two point questions, the probability that the pre-test and post-test results were statistically different from one another was greater than 99.99%. Likewise, the paired student t-Test run on the three point test questions showed a greater than 99.99% chance that the two data sets were statistically different.

Qualitative Data

Throughout the electricity unit I repeatedly heard students comment on how much they were enjoying it. I often heard comments on how the labs were more fun than either lectures or worksheets. Occasionally, I overheard students discussing the usefulness of the labs or saw eyes light up with wonder and excitement. I also noticed that many students who had previously not put forth much effort were actively involved with the labs. Sometimes, these students even took the lead and would tell others what to do. This gave me a sense of pride because I realized that I was reaching some students that I had previously not reached.

As the unit progressed, I realized that the students were really gaining an understanding of electricity. Before the unit began, the students were given a pre-test. At the end of the unit, the students were asked the same questions on a post-test. On the pre-test, one of the questions asked students to explain why a balloon that had been rubbed against your hair can stick to a wall and not fall off? One of my higher level students answered the pre-test question by saying, "When you rub a balloon against your hair it creates static electricity. That electricity, then, can cling to the wall because it is looking for a route towards the ground." After the unit was complete he answered the same question by saying, "When a balloon is rubbed against hair, it strips electrons from the hair making the balloon negatively charged. Then, when the balloon is brought near the wall, the wall becomes polarized. Since opposites attract, the balloon clings to the wall."

A student who generally did not perform as well as the above student answered the same question on the pre-test by saying, "The reason why a balloon can be rubbed against your head and not fall off when you put it on the wall is because of static electricity. It takes static energy from your hair/head and then goes onto the balloon where the balloon sticks. The same student answered this question on the post-test by saying, "A balloon that has been rubbed against your hair can stick to the wall because you have just charged the balloon negatively. Then when you take the negatively charged balloon near the neutral wall the charges in the wall are split up so that the positive charges are pushed toward the surface of the wall while the negative charges are pushed away from the surface. The opposite charges attract." Even though this student does not seem to understand it is only the positive and negative centers of charge that migrate, her post-test answer is much improved.

Another question asked the students to explain the difference between current and voltage. On the pre-test one of my lower level students said, "Current is when electricity is moving, voltage is when it is stored." After the unit had been completed, the same student answered the question by saying, "Current is the flow of charge. Current is like water while voltage is like the pressure that is necessary to get water to flow. So, it takes voltage, specifically a difference in voltage across a circuit, to get current to flow."

A higher level student answered the same question on the pre-test by saying, "Current is different then voltage because voltage is the amount of electricity (speed/power) in a circuit at a given time and current is ?" The same student answered the post-test question by saying, "The difference between current and voltage is that current is the flow of charge while voltage is the electrical pressure that is required to get charge to flow."

The hardest question on the test was question number fourteen. This question asked students to describe the relationship between the voltage of a battery and the voltage across each resistance in a series circuit and in a parallel circuit. One of my highest level students answered the question on the pre-test by saying, "I don't know."

He answered the same question on the post-test by saying, "The voltage drop across each resistance in a series circuit will add up to the voltage of the source. In a series circuit the voltages are divided up among the resistors, because each resistor is not hooked up to positive and negative terminal of the battery. In a parallel circuit, the voltage drop across each branch of the circuit is the same as the voltage of the source. This is because each branch of the parallel circuit is connected to both the positive and the negative terminal of the battery.

A lower level student answered the same question on the pre-test by also saying, "I don't know." His answer improved on the post-test when he stated, "The voltage across each branch in a parallel circuit is going to be the same as the voltage of the battery. The voltage across the resistors in a series circuit gets split up so that the voltages across the resistors is less than the voltage of the battery." Even though this student did not state that the voltage drops across each resistor in a series circuit added up to the voltage of the battery, his post-test answer illustrates an understanding of the basic concepts.

I saw answers similar to these again and again on the pre-test and post-test. I was amazed by the number of misconceptions that students came into the unit with and how they were able to reshape those erroneous thoughts into a correct conceptual framework.

Discussion and Conclusion

The goal of this unit was to improve the students' conceptual understanding of electricity by using a constructivist approach to its instruction. After reflecting on the results, I believe that the goal has been met. Student test scores improved an average of 70.4% from the time students took the pre-test to the time they took the post-test. The majority of the questions on the test required students to apply knowledge that they had gained during the unit. Therefore, the data indicate that students reshaped their preexisting knowledge and misconceptions to gain a better conceptual understanding of electricity.

I firmly believe that the most influential part of the unit was the labs and hands-on activities that the students performed. These activities required sustained mental activity from the students while often creating dissatisfaction with or a questioning of previous knowledge. This forced the students to reevaluate and modify their ideas about electricity. While some students do this with a more traditional approach, I believe that more of my students were actively involved in thinking about the labs and modifying their conceptual framework to incorporate the new information into it. In addition, the labs provided students with relevant applications in social contexts. Students were able to talk about their discoveries and help one another get past stumbling blocks. Without these activities, I believe the test scores would have been significantly lower.

While I felt the unit was a successful overall, the one major drawback was the length of time it took to cover the unit. I found that labs and activities often took longer for the students to work through than I had anticipated. In order to provide students with ample time to get through the lab and share their results and discoveries with the class, we often had to spend a day and a half or more to finish working with the material.

Therefore, where I may have given the students the formula for Ohm's law and discussed the relationships between current, voltage, and resistance in twenty minutes, we spent two days in class performing a lab on deriving Ohm's law. At the end of the lab, I am sure that students had a much better understanding of where the law came from and how the three variables related to one another. However, I did not teach all of the material that was dictated by the physical science curriculum for the semester. While most students gained a deep understanding of electricity, they did so to the detriment of learning about other topics.

Since I completed the unit in the spring of 2004 and did not write my thesis until the spring of 2005, I was able to modify some of the electricity unit to teach it in a timelier manner. I scaled back on the number of labs that the students did, performing many as demos in front of the class. Some of the labs, like the *Ohm's Law for Series Circuits and Parallel Circuits* were scrapped altogether because of their length. Consequently, I was able to introduce the entire physical science curriculum. Unfortunately, the average test score for this unit using the same post-test dropped from an 84.2% during 2004 to a 71.2% in 2005. Based on this comparison, it appears that decreasing the number of labs and hands-on activities caused the test score to drop thirteen percent. Some of this drop may be attributable to the students I had this year. As a whole, they were less motivated than the class I had in 2004. A quick perusal of my gradebooks shows more zeros for assignments in 2005 than 2004. More importantly, however, is the fact that I covered the same amount of material in less time. The students did not perform the same number of labs and as a result they were not forced to consider many of the topics in as much detail as the previously year. Consequently, this year's students, in my opinion, did not walk away with the same level of basic understanding of electricity as last year's students.

This poses a serious dilemma for me. On one hand, I know that it is important for my students to have a deep conceptual understanding of the topics in which we engage. On the other hand, I know that I need to make my way through a certain amount of material by the end of the year. In order to maintain a balance between teaching for understanding and getting through the entire curriculum, I plan on cutting out all activities that are not specifically addressed by the Michigan Curriculum Framework (MCF). As a result, next year I will have my students complete the labs on the electrical current portion of the unit. Since electrostatics is not stressed in the MCF, I will perform some demonstrations with the Van de Graaff generator to give them a basic understanding of electrostatics. All other labs dealing with electrostatics will be cut out of the unit.

APPENDICES

Appendices A: Electricity Unit Student Work

Physical Science
Electricity Unit
Electrostatics Mini-Labs

Name:______________________

Date:_________ Hour:_________

Purpose
To determine ways that objects can become charged and discharged.

Materials
Stocking, Polyethylene Bag, Plastic Box, Puffed Rice, Aluminum Foil, Fur, Burette, Funnel, Water, Ebonite Rod, Ping-Pong Ball, Comb, Newspaper, Aluminum Pie Pan, Balloon, Pre-Made Wire "Palm-Tree", Wool, Silk Thread, Chair, Sharpened Pencil

Discussion
All objects are made from atoms that contain electrical charges. Every atom consists of both positively charged protons and negatively charged electrons. Generally, objects contain the same number of protons and electrons and are, therefore, neutral. It is possible, however, to transfer electrons from one object to another. When this occurs, an imbalance of charge results. The object that has lost the negatively charged electrons becomes positively charged while the object that has gained electrons becomes negatively charged.

The term given to the study of charged particles is called electrostatics. During this activity, you will be looking at various ways objects can become charged and discharged.

Procedure
Fill The Stocking
Step 1. Hold the toe of the stocking and place the stocking against the wall.
Step 2. Rub the bag back and forth across the stocking 10 times.
Step 3. Pull the stocking away from the wall and hold it in the air.
Step 4. Record your observations.

What happens to the stocking when it is pulled away from the wall?

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Electrostatic Jumping Beans
Step 1. Rub the cover of the box vigorously with wool.
Step 2. Record your observations.

What happens to the objects in the box when the box top is rubbed?

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Magical Water

Step 1. Make sure the stopcock of the burette is closed. The "handle" should be parallel with the desktop.
Step 2. Use the funnel to fill the burette with water.
Step 3. Rub the ebonite rod vigorously with fur.
Step 4. Open the stopcock slowly until a thin stream of water emerges.
Step 5. Place the rod near the water but do not allow the two to touch.
Step 6. Record your observations (Try also turning the stopcock so that the water drips out drop by drop)

What happens to the water as the rod approaches it?

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The Obedient Ping Pong Ball
Step 1. Place the ping pong ball on the table top.
Step 2. Rub the comb briskly with wool.
Step 3. Bring the comb near the ball without touching it.
Step 4. Record your observations.

What happens to the ping pong ball as the comb is brought near it? Can you control the motion of the ball?

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The Dry Newspaper
Step 1. Rub the newspaper with the clear polyethylene bag vigorously for 30 seconds.
Step 2. Place the aluminum pie pan in the center of the newspaper.
Step 3. Pick the newspaper up by its edges.
Step 4. Have someone else quickly touch the metal top.
Step 5. Record your observations.

What happens as you move your finger toward the metal on top of the newspaper?

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The Palm Tree

Step 1. Rub the balloon briskly with wool.
Step 2. Hold the palm tree by the glass tube and bring it near the balloon.
Step 3. Touch the wire "trunk" of your tree to the balloon.
Step 4. Record your observations.
What happens as the balloon is brought near your palm tree?

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The Tricky Thread

Step 1. Rub the comb vigorously with wool.
Step 2. Move approximately 12 inches of silk thread near the comb until they touch.
Step 3. Draw the comb up and away from the thread slowly so that the thread and comb become separated.
Step 4. Continue to move the comb up slowly
Step 5. Record your observations.

Can you control your piece of thread? How?

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Magic Fingers

Step 1. Place a pencil on the back of a chair so that it is balanced.
Step 2. Rub your feet against the carpet.
Step 3. Draw your finger toward the graphite point of the pencil.
Step 4. Record your observations.

What happened to the pencil as you brought your finger toward it?

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Note: Portions of this lab were adapted from Graf, Rudolf F. Safe and Simple Electrical Experiments. Toronto: General Publishing Company Ltd., 1964.

Physical Science
Electricity Unit
Charged Grains Lab

Name:________________________

Date:__________ Hour:__________

Purpose
To observe some of the effects of static electricity

Materials
Wire clothes hanger, puffed rice coated with aluminum foil, silk thread, comb, wool, glass rod, silk, 2 rubber balloons, saran wrap

Discussion
All matter has a fraction of its electrons in a relatively loosely held state. When bodies touch each other or come into close contact by rubbing, the surface electrons from one body "get loose" and move to the other surface. The bodies are no longer neutral; the one which gains electrons becomes negatively charged and the other body that has lost electrons becomes positively charged.

Different materials have different affinities for gaining or losing electrons. Glass rods lose electrons when rubbed against silk leaving the glass with a positive charge. Combs gain electrons when rubbed against wool leaving the comb with a negative charge.

In generating electric charges, friction does not create more electrons. Electrons simply move between surfaces, keeping their total number the same. Electrons get redistributed and are not created or destroyed.

As with any electrostatic experiment, weather plays a critical role. Experiments work best when the weather is cool and dry. On damp summer days, electrons can "leak" off charged objects causing the experiments not to work properly.

Procedure

Step 1. Hang one of the aluminum foil coated grains out of the way.
Step 2. Rub a comb with a piece of wool.
Step 3. Touch the grain with the comb.
Step 4. After touching the grain, move the comb toward it once again.

1. After touching the grain initially can you touch it again?

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Step 5. Bring the wool that you rubbed the comb with near the grain.

2. What happens as the wool is brought near the grain?

Step 6. Touch the grain with your finger.
Step 7. Rub the glass rod with the piece of silk and touch the grain with the rod.
Step 8. After touching the grain, try to touch it again with the glass rod.

3. What happens to the grain?

Step 9. Bring the silk that you rubbed the rod with near the grain.

4. What happens as the silk is moved near the grain?

Step 10. Touch the grain with your finger.
Step 11. Charge the comb by rubbing it with wool and the glass rod by rubbing it with silk.
Step 12. Charge the grain by touching it with the comb.
Step 13. Bring the glass rod toward the grain.

5. What happens and what general conclusion can be drawn from this?

Step 14. Pull the second aluminum foil covered grain down so that both grains are hanging side by side.
Step 15. Charge the comb by rubbing it with wool.
Step 16. Touch one of the grains with the comb and then move the comb away.

6. What happens when you do this? Why?

Step 17. Touch one of the grains with your finger and remove your finger immediately.

7. What happens and why?

8. How do you think that the aluminum covered grains could be used to determine whether the charge on an object was positive or negative?

Step 18. Move one of the aluminum covered grains out of the way.
Step 19. Blow up the two balloons.
Step 20. Charge one of the balloons negatively by rubbing it with wool.
Step 21. Charge the other balloon positively by rubbing it with saran wrap.
Step 22. Hold a balloon in each hand and approach the single grain from both sides. Once the grain begins to move stop moving the balloons and observe.

9. What happens to the grain? Why?

Note: Portions of this lab were adapted from Graf, Rudolf F. Safe and Simple Electrical Experiments. Toronto: General Publishing Company Ltd., 1964. 21-23.

Physical Science
Electricity Unit
Electroscope Lab

Name:______________________

Date:_________ Hour:_________

Purpose
To determine how to use an electroscope. To charge the electroscope by contact and induction

Materials
Electroscope, rubber rod, wool, glass rod, silk

Discussion
An electroscope is a device that is used for determining the presence of electrostatic charges. It indicates the existence of charges on objects brought near it, and it can also indicate the type of charge on that object.

The electroscope consists of an aluminum foil ball that is attached to a stiff piece of wire. The wire passes through a cork attached to a flask. Light metal leaves rest on the bottom of the stiff wire. The flask is used to assure that air currents do not disturb the sensitive leaves.

As with any electrostatic experiment, weather plays a critical role. Experiments work best when the weather is cool and dry. On damp summer days, electrons can "leak" off charged objects causing the experiments not to work properly.

Procedure

<u>Part A.</u> Charging by contact

Step 1. Discharge the electroscope by touching the aluminum foil ball with your finger.
Step 2. Rub the rubber rod with wool. Touch the rod to the aluminum foil ball.

1. What happens to the leaves of the electroscope?

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2. What charge is on the leaves and <u>how</u> do you know this? (Think of previous labs)

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Step 3. Discharge the electroscope by touching the foil ball with your finger.
Step 4. Charge the rubber rod with wool.
Step 5. Bring the charged rod near the foil ball but do not touch it.

3. What happens when the charged rod is placed near the foil ball?

4. What happens when the charged rod is moved away from the foil ball?

5. How does this differ from when the charged rod touched the foil ball? Why do you think that this difference occurs?

Part B. Charging by Induction

Step 6. Devise a way to leave a charge on the electroscope using the charged rubber rod without touching the rod to the foil ball. This means that the leaves of the electroscope should remain partially separated once the rod is removed. Remember, you cannot touch the foil ball with the rod! (Call me over to show me how to do this when you have successfully accomplished this)

6. Explain how you charged the electroscope in step 6.

7. What charge is placed on the leaves of the electroscope in step 6? How do you know?

8. Now that the electroscope is charged, what would happen to the leaves if you brought a positively charged object near the foil ball? How about a negatively charged object?

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Note: Portions of this lab were adapted from Graf, Rudolf F. Safe and Simple Electrical Experiments. Toronto: General Publishing Company Ltd., 1964. 11-14.

Physical Science
Electricity Unit
Electrophorus and Leyden Jar Lab

Name:______________________

Date:_________ Hour:_________

Purpose
To use a device that can produce a large number of successive charges of static electricity. To create an object for storing electrical charge.

Materials
Electrophorus, wool, electroscope, rubber rod, neon circuit tester, plastic drinking glass, aluminum foil, plastic comb, paper clips.

Discussion
An electrophorus is a device that is capable of producing a large number of successive charges of static electricity. The electrophorus that we will be using is a phonograph record. An aluminum pie pan with an insulated handle will be placed against the electrophorus in order to acquire a charge. Whenever the aluminum pie pan is discharged, one can simply place the pie pan back onto the record to charge it once again.

The electrophorus is particularly useful because it can be used to charge a Leyden Jar. A Leyden jar is a device that can be used to store electrical charges. Prior to the development of the Leyden jar, many methods of producing electric charges had been discovered; however, there was not a method for storing these electric charges. In this experiment, you will build a Leyden jar similar to the first one built in 1745.

Procedure

Part A – Using the electrophorus

Step 1. Place the record on a flat surface and rub the surface with wool vigorously for at least 30 seconds
Step 2. Hold onto the handle of the pie pan and place it onto the electrophorus (record). Once the pie pan is on the record place a finger on the pie pan.
Step 3. Remove your finger.
Step 4. Lift the pie pan off the electrophorus.
Step 5. Touch the aluminum pie pan with your finger.

1. What happens when you bring your finger near the charged pie pan?

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Step 6. Charge the electroscope negatively by touching the foil ball with a rubber rod that has been rubbed with wool.
Step 7. Repeat steps 2 – 4 to recharge the electrophorus
Step 8. Bring the electrophorus near the electroscope without touching it.

2. What charge does the electrophorus have and how do you know?

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3. Explain how the pie pan becomes charged. (Careful – This takes some thought)

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Step 9. Repeat steps 2 – 4 to recharge the electrophorus.
Step 10. Hold onto one of the terminals of the neon circuit tester. Bring the other terminal near the electrophorus.

4. What happens when the electrophorus is brought near the neon circuit tester?

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<u>Part B</u> – Building and using the Leyden jar

Step 11. Tear off a square of aluminum foil big enough to wrap around the outside of the plastic drinking glass.
Step 12. Neatly wrap aluminum foil around the outside of the plastic drinking glass. The foil should cover the bottom of the cup and come three quarters of the way up.
Step 13. Remove the foil from the outside of the cup. Place the foil inside the cup.
Step 14. Repeat steps 11 – 12. This time leave the aluminum foil on the outside of the cup.
Step 15. Attach enough paper clips together so that they will make a chain that can reach from the top of the cup to the bottom of the cup.
Step 16. Attach the first paper clip to the comb such that the top of the paper clip sticks above the comb.
Step 17. Lay the comb across the top of the cup.
Step 18. Repeat steps 1 – 4 to recharge the pie pan.
Step 19. Touch the charged pie pan to the top paper clip of the Leyden jar.
Step 20. Repeat steps 2 – 4 to recharge the pie pan. Again touch the charged pie pan to the top paper clip.
Step 21. Repeat step 20 another six times
Step 22. Place one end of the copper wire against the foil on the outside of the cup. Bring the other end of the wire toward the top paper clip.

5. What happens when the wire touches both the outside of the cup and the paper clip?

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Step 23. Repeat steps 18 – 21 to recharge the Leyden jar.
Step 24. Hold one of the terminals of the neon circuit tester against the outer aluminum foil. Touch the other end to the top paper clip.

6. How does this flash of light compare to the flash of light produced by the electrophorus?

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7. What conclusion can you draw from this?

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Step 25. Experiment on your own. Here are a few things to try. First, recharge the electrophorus. If you touch the outer layer of foil and the paper clip you should receive quite a shock. How does this shock compare to touching the electrophorus after it has been charged. Another thing you can try is to hold onto the outer layer of foil as you charge the electrophorus. When discharged, you should notice an even bigger shock.

Note: Portions of this lab were adapted from Graf, Rudolf F. Safe and Simple Electrical Experiments. Toronto: General Publishing Company Ltd., 1964. 16 – 20.

Physical Science
Electricity Unit
Flowing Water Mini Lab

Name:________________________

Date:__________ Hour:__________

Purpose
To determine why and how water flows.

Materials
Bottles(3), rigid plastic tubing, flexible rubber tubing, clothespin(2), water, beaker

Procedure
Step 1. Connect the two similar sized bottles together with the flexible rubber tubing.
Step 2. Place one clothespin on the flexible tubing to pinch it off. Attach the second clothes pin to the first to form a tight seal.
Step 3. Fill the beaker with water.
Step 4. Transfer water from the beaker into one of the bottles.
Step 5. Remove the clothespin and observe.

1. When does the water stop flowing out of initial container of water?

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Step 7. Dump the water out of each container.
Step 8. Remove one of the containers and replace it with the container that is a different size.
Step 9. Repeat steps 3 – 6.

2. How does this trial compare with the one from above?

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3. Make a generalized statement about what is necessary for water to flow.

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Note: Portions of this lab were adapted from <u>700 Science Experiments For Everyone.</u> New York: Delacorte Press, 1958. 168.

Physical Science
Electricity Unit
Current Lab

Name:________________________

Date:__________ Hour:__________

Purpose
To determine how to create and detect an electrical current.

Materials
Galvanoscope, copper (2), zinc (2), wires (3), cups (2), distilled water, tap water, salt water, sugar water, felt, lemon,

Discussion
The earth's magnetic field aligns the magnetized needle of a compass in a North-South position and holds it there. The compass needle remains stationary as long as a current carrying wire is not placed near the compass. However, a compass placed over a current carrying wire will cause the needle of the compass to deflect. The current carrying wire creates another magnetic field, which, in addition to that of the earth's, affects the position of the compass needle.

Electric current is invisible, but it can be detected with a device known as a galvanoscope. A galvanoscope is a device that utilizes the fact that current flowing in a wire will deflect a compass needle. A galvanoscope amplifies this effect because many turns of wire are placed around a compass. Thus, the current in each wire is added to that of every other wire. As a result, a galvanoscope is capable of creating a magnetic field that is greater than that generated by a single current carrying wire. Consequently, one can detect very small currents with this device.

To use the galvanoscope, it should be placed so that the needle is aligned with the North and South poles. The two wire leads should then be connected to the object that is being tested. A deflected compass needle indicates that current is flowing in the circuit being tested. If there is not a deflection, then current is not flowing in that circuit.

Procedure
Step 1. Sand the copper and zinc metal. Each metal should be shiny before you start.
Step 2. Connect two wires to the wire leads of the galvanoscope.
Step 3. Orient the compass so that the needle is aligned with the North and South poles.
Step 4. Connect the zinc to one of the free ends of the wire with an alligator clip.
Step 5. While watching the galvanoscope, connect the copper to the other wire with an alligator clip. If the needle deflects, then current is flowing. If it does not deflect, there is no current. Record your observations in the table.
Step 6. Connect the two pieces of metal with a wire to form a complete loop. Record your observations.
Step 7. Disconnect the wire that you attached in step 6.
Step 8. Pour distilled water into one of your cups.
Step 9. Place the two metals into the cup of distilled water. Make sure that the metals do not touch one another. Record your observations.

Step 10. Pour the distilled water down the drain and replace it with tap water.
Step 11. Place the two metals into the cup of tap water and record your observations.
Step 12. Remove the metals from the tap water.
Step 13. Pour a fair amount of salt into the cup with the tap water.
Step 14. Place the two metals back into the cup making sure that they do not touch one another. Record your observations.
Step 15. Remove the zinc metal from the cup.
Step 16. Connect the remaining piece of copper and zinc together with a wire.
Step 17. Fill the second cup with tap water and add a fair amount of salt.
Step 18. Place the piece of copper and zinc that you just connected into the two cups of salt water. The zinc should go into the cup that already contains the piece of copper. The new copper piece should go into the fresh cup of salt water.
Step 19. Place the piece of zinc that you removed from the first cup in step 15 into the second cup of salt water. Record your observations.
Step 20. Remove all the metals from the cups.
Step 21. You may take the piece of zinc and copper that are not connected to the galvanoscope and set them to the side. You will no longer need them. You may also dump out <u>one</u> of the cups of salt water.
Step 16. Place the piece of felt into a cup with salt water and allow it to soak for a minute.
Step 17. Remove the felt and squeeze it so that the excess water is removed.
Step 18. Place the felt between the copper and zinc. Apply light pressure to the top metal. Record your observations.
Step19. Remove the felt and place it to the side.
Step20. Replace the zinc metal with the other piece of copper metal. You should now have two pieces of copper attached the galvanoscope.
Step21. Place the two pieces of copper into the salt water making certain that they do not touch. Record your observations.
Step 22. Remove both pieces of copper from the salt water.
Step23. Replace the pieces of copper with pieces of zinc. You should now have two pieces of zinc connected to the galvanoscope.
Step24. Place the two pieces of zinc into the salt water and record your observations.
Step25. Remove the two metals from the cup and pour the salt water down the drain.
Step26. Remove one of the pieces of zinc and replace it with copper. You should now have a piece of zinc and a piece of copper connected to the galvanoscope.
Step27. Rinse the cup out with distilled water. After rinsing, fill the cup with distilled water.
Step28. Pour a fair amount of sugar into the cup with distilled water.
Step29. Place the two metals into the cup and record your observations.
Step30. Remove the two metals from the cup. Pour the sugar water down the drain.
Step 31. Place the two pieces of metal into an apple. The pieces of metal should be close to one another, but should not touch. Record your observations.

Results

	Current Detected (yes or no)	**Amount of Needle Deflection (°)**
Zinc and copper		
Zinc and copper connected in a complete circuit		
Zinc and copper in distilled water		
Zinc and copper in tap water		
Zinc and copper in salt water		
Zinc to copper to zinc to copper in salt water		
Zinc and copper separated by salt water soaked felt		
Copper and copper in salt water		
Zinc and zinc in salt water		
Zinc and copper in sugar water		
Zinc and copper in apple		

Conclusion

What conclusions can you draw about electric current? (What seems to be necessary for current to flow? When did the most current flow? Why can current flow through some liquids but not others?, etc.)

Note: Portions of this lab were adapted from Graf, Rudolf F. Safe and Simple Electrical Experiments. Toronto: General Publishing Company Ltd., 1964. 75 – 7

Physical Science
Electricity Unit
Resistance Lab

Name:_______________________

Date:_________ Hour:_________

Purpose
To investigate resistance to current flow.

Materials
D-cell batter holder, D-cell battery (2), Pencil, wire (3), flashlight bulb, bulb holder, Play-Doh, multimeters (2), ruler or sheet of paper with a 10 cm mark

Discussion
When a flashlight bulb is connected to a battery, a current will flow through the bulb which will heat its filament and cause it to light up. If we can control this flow of current, we can then control the amount of light we will get from our bulb. If we have less current, we will get less light. In order to get less current, we must impede its flow by inserting some sort of resistance which will resist or impede the flow of current. Such a device is called a <u>rheostat</u>.
The rheostat helps control the current in radios to change the loudness of the sound we get from them, in motors to change their speed, in appliances to change their heat output, and in theatre lights to make them grow brighter or dimmer.

Procedure

<u>Part A</u> – Resistance with pencil lead

Step 1. Connect one end of a shaved pencil to the negative terminal of a battery using a wire. Connect one light bulb terminal to the positive side of the battery using a wire. Connect the other terminal of the light bulb with another wire. Move the free end of this wire along the length of the pencil lead.

1. What happens to the flashlight bulb as the two alligator clips move away from one another?

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<u>Part B</u> – Resistance with Play-Doh

Step 2. Roll Play-Doh into 4 different sized cylinders that range in diameter from 1.0 – 2.0 cm. Each cylinder should be at least 14 cm in length. The quality of the experimental results will depend strongly on the uniformity of the cylinders. Maintain the same diameter over the entire length and avoid cracks or voids in the Play-Doh.

Step 3. Connect the circuit so an alligator clip lead connects the positive terminal of the battery holder to the red lead of a multimeter. Another alligator clip lead should be connected to the black lead of the multimeter. The multimeter should be set to the current function. Another alligator clip lead should be connected to the negative terminal of the battery.

Step 4. Place one of the Play-Doh cylinders into the circuit. It should be pushed into the two alligator clip leads that are not connected to anything.

Step 5. Set the second multimeter to the voltage function.

Step 6. Place the two leads from the second multimeter into the Play-Doh 10 cm apart. The black lead should be inserted into the negative end while the red lead should be inserted into the positive end. If you do this correctly, the multimeter reading will be positive. If you reverse the leads, the value the multimeter gives you will be negative.

Step 7. Record the current and voltage readings simultaneously. The current is found on the multimeter that is attached to the circuit with alligator clips. The voltage is found on the multimeter whose probes are stuck into the Play-Doh.

Step 8. Remove the Play-Doh from the circuit.

Step 9. Repeat steps 4 – 8 with the remaining Play-Doh cylinders.

Step 10. Determine the resistance of each Play-Doh cylinder by dividing the voltage in volts across the Play-Doh by the current in amps running through the Play-Doh

Results

Play-Doh Diameter (cm)	Voltage (V)	Current (mA)	Current (A)	Resistance (Ω)

Make a graph of the resistance (y-axis) vs. the diameter of the play-doh (x-axis).

Conclusions

2. How does the length of a resistor affect the current of a circuit? Explain how you know this and explain why this occurs. (Reflect on Part A)

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3. What mathematical relationship between resistor diameter and resistance does the graph illustrate?

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4. **Briefly summarize the findings of this lab. Specifically, how does the resistor length and the resistor diameter affect the resistance and the current in a circuit.**

Note: Portions of this lab were adapted from Watson, George.
http://www.physics.udel.edu/~watson/scen103/colloq2000/problems/playdohexpt.html

Physical Science
Electricity Unit
Cells in Series and Parallel

Name:________________________

Date:__________ Hour:__________

Purpose
To determine the advantages and disadvantages of cells connected in series and in parallel.

Materials
Cups (3), salt water, multimeter, zinc and copper electrodes, wires

Discussion
Batteries can be connected together in one of two ways. A series connection occurs when the positive electrode of one cell is attached to the negative electrode of a second cell. A parallel connection occurs when the positive electrode of one cell is connected to the positive electrode of the other cell while the negative electrodes of the two cells are also connected.

When zinc and copper are the two electrodes, zinc is the negative electrode and copper is the positive electrode. The salt water acts as an electrolyte solution that allows charge to flow through the liquid.

Procedure

Part A – Cells in Series

Step 1. Sand all of your electrodes.
Step 2. Fill a glass with 150 mL of tap water and add 1 tbsp of salt.
Step 3. Place one copper and one zinc electrode into the salt water making sure they do not touch one another.
Step 4. Set the multimeter to measure voltage.
Step 5. Touch the black lead of the multimeter to the zinc electrode and the red lead from the multimeter to the copper electrode. Record the voltage in the data table.
Step 6. Repeat step 2 and add a second cell by filling another cup with salt water. Place a copper and a zinc electrode in this cup as well.
Step 7. Connect the zinc electrode from one cup with the copper electrode from the other cup.
Step 8. Place the black multimeter lead against the piece of zinc that is not attached to a wire. Place the red lead against the copper electrode without a wire. Record the voltage in the data table.
Step 9. Add a third cell by filling a third cup with salt water. Add your last copper and zinc electrodes to this cup.
Step 10. Connect the metal without a wire in the second cup to the opposite metal in the last cup.
Step 11. Repeat step 8 to determine the voltage of the three cells in series.

Part B – Cells in Parallel

Step 12. Remove the metal electrodes from two of the cups. Disconnect the wires from these electrodes.
Step 13. Measure the voltage of the two electrodes in the first cup. Once again, place the black lead against the zinc and the red lead against the copper. Record your voltage.
Step 14. Add a second cell by placing a zinc electrode and a copper electrode into a second cup of salt water.
Step 15. Connect the two pieces of zinc together with a wire and the two pieces of copper together with a wire.
Step 16. Measure the voltage by placing the red lead of the multimeter against a copper electrode and the black lead against the zinc electrode in the same cup. Record your voltage.
Step 17. Add a third cell by adding a third cup of salt water. Place the remaining zinc and copper electrodes into the solution. Connect the zinc electrode to the zinc electrode in the middle cup and the copper electrode to the copper electrode in the third cup.
Step 18. Repeat step 17 and record the voltage.

Results

Cells in Series		**Cells in Parallel**	
# of cells	**voltage (v)**	**# of cells**	**voltage (v)**
1		**1**	
2		**2**	
3		**3**	

- Make a graph of voltage vs. the number of cells connected in series using Excel. It should be an XY scatter-plot. Place the # of cells in the first column and the voltage in the second column. When complete, add a linear trendline.

- Make a graph of voltage vs. the number of cells connected in parallel using Excel. It should be an XY scatter-plot. Place the # of cells in the first column and the voltage in the second column. When complete, add a linear trendline

Conclusions

1. How does the number of cells connected in series affect the voltage of the system?

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2. How does the number of cells connected in parallel affect the voltage of the system?

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3. What is an advantage of adding cells in series?

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4. A remote control car requires 12 volts to operate. How many 1.5 volt batteries would be necessary to power the car? How must the batteries be arranged?

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5. How do you think the addition of cells in parallel affects the longevity of these cells? Will they last for a longer time or a shorter time? Why do you think this?

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Note: Portions of this lab were adapted from Cunnigham James and Norman Herr. Hands-On Physics Activities with Real-Life Applications. New York: The Center for Applied Research in Education, 1994

Physical Science
Electricity Unit
Circuits in Series and Parallel Lab

Name:________________________

Date:__________ Hour:__________

Purpose
To determine how various arrangements of flashlight bulbs affect bulb brightness.

Materials
D-Cell, D-Cell battery holder, connecting wire, 3 flashlight bulbs, 3 bulb holders,

Discussion
A dry cell, commonly called a battery, is a source of electrical energy. Many arrangements are possible to get this energy from dry cells to flashlight bulbs. Series circuits have a single pathway through which electrons can move while parallel circuits have multiple pathways for electrons to move through.

Procedure
Step 1. Arrange one bulb (without a holder), one battery, and up to two bare wires in as many ways as you can to make the bulb emit light. Sketch each of your successful arrangements below.

1. Describe the similarities among your successful trials.

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Step 2. Screw one of the bulbs into a bulb holder.

2. What two parts of the bulb does the holder make contact with?

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Step 3. Connect one bulb to two D-Cells. Note the apparent brightness of the bulb.
Step 4. Connect a second bulb in series to the circuit. Note the apparent brightness of the bulb.
Step 5. Connect a third bulb to the circuit in the same fashion. Note the apparent brightness of the bulb.

3. Do the bulbs light in each of the series circuits you have designed?

____

4. Which circuit contains the brightest bulb or bulbs? The dimmest bulb or bulbs? The first, second, or third?

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Step 6. In the circuit with 3 bulbs unscrew one of the bulbs. Screw this bulb back in and unscrew a different one.

5. What happens when a bulb that is connected in series is unscrewed from its base?

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Step 7. Remove the bulbs connected in series from the battery. Rearrange the bulbs such that two bulbs are connected in parallel. Note the apparent brightness of the bulbs.
Step 8. Add another bulb in parallel to the circuit. Note the apparent brightness of the bulbs.
Step 9. Unscrew one of the bulbs in the circuit and observe. Screw this bulb back in and unscrew a different bulb from the circuit.

6. Do the bulbs light in each of the parallel circuits you have designed?

____

7. Which parallel circuit contains the brightest bulb or bulbs? The dimmest bulb or bulbs?

____

8. What happens when a bulb that is connected in parallel is unscrewed from its base?

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9. Summarize the differences between series and parallel circuits.

Note: Portions of this lab were adapted from Conceptual Physics Laboratory Manual. USA: Addison-Wesley Publishing Company, Inc., 1987. 279 – 282.

Physical Science
Electricity Unit
Ohm's Law Lab

Name:________________________

Date:__________ Hour:__________

Purpose
To determine how voltage and resistance affect the current in a circuit.

Materials
2 Multimeters, 10 Resistors ranging from 33Ω - 1,000Ω, 4 D-Cell Batteries, D-Cell Batter Holder, Wires, Switch

Discussion
In the early 1800's, Georg Simon Ohm, a German physicist, developed the law that now bears his name. He determined that electrical current is controlled by two variables: voltage and resistance.
During this lab you will attempt to determine the relationship between current, voltage, and resistance. To accomplish this, you will begin by maintaining a constant voltage. You will then test different resistors and determine how they affect current. Later, you will maintain a constant resistance. You will then test how different voltages affect the current.

Procedure

<u>Part A</u> – Voltage vs. Current at constant Resistance

Step 1. Connect the circuit so that the negative battery terminal is connected to a switch. Attach a 100 Ω resistor to the other end of the switch. Attach the other end of the resistor to the black lead of a multimeter. Finally, attach the red lead of the multimeter to the positive terminal of the battery.
Step 2. Set the multimeter to the current function.
Step 3. Set the other multimeter to the voltage function.
Step 4. Close the switch.
Step 5. Place the leads of the 2nd multimeter against the ends of the resistor. If the leads are reversed, the voltage reading will be negative.
Step 6. Measure the current and voltage simultaneously. Record the measurements in the first data table.
Step 7. Repeat the above steps with a 2nd, 3rd, and 4th battery.

<u>Part B</u> – Current vs. Resistance at constant voltage.

Step 8. Turn the multimeter that you used to measure voltage to the resistance function.
Step 9. Measure the resistance of each resistor by touching the leads of the meter to either end of the resistor. Do this while the resistor is not connected to anything. Arrange the resistors in order of increasing resistance. Record the values in order in the second data table.

Step 10. Choose the lowest valued resistor. Set up a circuit that is identical to the circuit on the previous page. You will keep two D-Cells in the battery holder for the rest of the lab. Change the multimeter back to the voltage function.

Step 11. Close the switch and measure the current and voltage of the circuit simultaneously. Record the measurements in the second data table.

Step 12. Repeat steps 10 – 11 for each resistor.

Results

Data Table # 1

# of Batteries	Current (mA)	Current (A)	Voltage (V)
1			
2			
3			
4			

Data Table # 2

Resistance (Ω)	Voltage (V)	Current (mA)	Current (A)

- Using the first data table make a plot of voltage in volts vs. current in amps using Excel. It should be an XY scatter-plot. Place the current measurements in the first column and the voltage measurements in the second column. When complete, add a linear trendline and determine the slope of this line.
- Using the second data table make a plot of current in amps vs. resistance in ohms using Excel. It should be an XY scatter-plot. Place the resistance measurements in the first column and the current measurements in the second column. When complete, add a power trendline.
- Using the second data table make a plot of current in amps vs. $^1/_{resistance}$ in $^1/_{ohms}$ using Excel. It should be an XY scatter-plot. Place the $^1/_{resistance}$ values in the first column and the current measurements in the second column. When complete, add a linear trendline and determine the slope of the line.

Conclusions

1. What mathematical relationship between voltage and current does the graph illustrate?

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2. What mathematical relationship between resistance and current do the graphs illustrate?

____

____

3. What does the slope of the voltage vs. current graph represent? How closely does it agree with the actual value? (Calculate the % error)

____

____

____

4. If a fifth D-Cell battery was added to the circuit for part A, what would you expect the current to be for the circuit? Why?

____

____

____

5. What does the slope of the current vs. $^1/_{resistance}$ graph represent? How closely does it agree with the actual value? (Calculate the % error)

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6. Did the potential difference across the resistor in part B change when you changed the resistor in the circuit?

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Physical Science
Electricity Unit
Ohm's Law with Series Circuits Lab

Name:________________________

Date:__________ Hour:__________

Purpose
To determine the relationships among the voltages, currents, and resistances in a series circuit.

Materials
Multimeter (2), D-cell (2), D-cell battery holder, different resistors (3), switch, connecting wire

Discussion
In a series circuit, the devices and the wires connecting them form a single pathway for electron flow between the terminals of a battery. This means that resistors that are connected in a series circuit must be connected together end to end. Electrons that flow through this current leave the negative terminal of the battery, pass through each resistor, and then return to the positive terminal of the battery.

Procedure

Step 1. Connect the circuit as you did in the last lab. Begin with the resistor of lowest resistance. The multimeter should be set to the current function.
Step 2. Set the multimeter that is not being used in the circuit to the voltage function.
Step 3. Close the switch.
Step 4. Place the leads of the 2nd multimeter against the ends of the resistor. If the leads are reversed, the voltage reading will be negative.
Step 5. Measure the current and voltage simultaneously. Record your measurements. Calculate the resistance across R_1.

Current (I) = ____________ A Voltage (V) = ______ V

Calculated Resistance R_1 = _______Ω

1. How does the calculated value of the resistance compare to the manufacture's rated value? Calculate the % error.

____

____

Step 6. Modify the circuit to include a second resistor in series. Measure the current between the positive battery terminal and the first resistor, between the two resistors, and after the second resistor. Measure the voltages across the first resistor, the second resistor, and both resistors. To measure the current at the 3 different locations you will need to detach the multimeter and reconnect it in the correct spot. To measure the voltages you can simply touch the probes across the correct resistors.

Current at A_1 = _____ A   Current at A_2 = _____ A   Current at A_3 = _____ A

Voltage V_1 = _____ V   Voltage V_2 = _____ V   Voltage V_3 = _____V

4. How do the current readings compare?

____

____

5. How do the three voltage readings compare?

____

____

____

6. Calculate the values of R_1 and R_2. Show your work.

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7. Divide V_3 by the current. How does the result compare to the sum of the resistances you calculated in part 6?

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8. What is the relationship among the current in the circuit, the <u>sum</u> of the resistances, and the voltage across <u>all</u> the resistances?

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Step 7. Record the manufacturer's rating of each of the three resistors.

R_1 = _____ Ω R_2 = _____ Ω R_3 = _____ Ω

Step 8. Arrange all three resistors, the switch, and the batteries in series. Close the switch, measure and record the total voltage V4 across all three resistors.

V_4 = _____ V

9. According to the manufacturer's ratings, what is the total resistance in the circuit?

____

10. Predict what the readings will be for the multimeters measuring current at A_1, A_2, and A_3.

____

____

Step 9. Measure the current between the positive terminal and the first resistor, between the first and second resistor, and after the last resistor. Also measure the voltages across each individual resistor. Use the same technique as you did for step 6.

Current at A_1 = _____ A   Current at A_2 = _____ A   Current at A_3 = _____ A

Voltage V_1 = _____ V   Voltage V_2 = _____ V   Voltage V_3 = _____ V

11. How do your measured values of the currents through the multimeter compare to the value you predicted in step 4?

____

____

12. Calculate the values of the resistances of R_1, R_2, and R_3 from your current and voltage measurements. Show your work.

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13. Divide V4 by the current. How does the result compare to the sum of the resistances you calculated in part 12?

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Conclusions

14. How do the currents in different parts of a series circuit compare?

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15. Describe the relationship among the voltage of the source and the voltages across each resistance in a series circuit.

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16. Describe how current relates to the sum of the resistances and the sum of the voltages.

Note: Portions of this lab were adapted from Conceptual Physics Laboratory Manual. USA: Addison-Wesley Publishing Company, Inc., 1987. 285 – 288.

Physical Science
Electricity Unit
Ohm's Law with Parallel Circuits Lab

Name:______________________

Date:_________ Hour:_________

Purpose

In a parallel circuit, the devices and wires are connected to two common points. This means that resistors that are connected in a parallel circuit are connected such that the left side of each resistor is in contact with one point in the circuit while the right side of the resistor is in contact with a different point in the circuit. Electrons leaving the negative terminal of a battery can travel through any branch of the circuit. There are multiple pathways that an electron may follow. However, a particular electron will flow through one branch and then continue on to the positive terminal of the battery. A particular electron does not leave the negative battery terminal, flow through each branch, and then return to the positive terminal.

Materials

Multimeter (2), D-cell (2), D-cell battery holder, resistors of equal resistance (2) different resistor, switch, connecting wire

Procedure

Step 1. Connect the circuit as you did for the last lab. Begin with one of the resistors of equal resistance. The multimeter should be set to the current function.

Step 2. Set the multimeter that is not being used in the circuit to the voltage function.

Step 3. Close the switch.

Step 4. Place the leads of the 2nd multimeter against the ends of the resistor to measure the voltage drop across this resistor. If the leads are reversed, the voltage reading will be negative.

Step 5. Measure the current and voltage simultaneously. Record your measurements. Calculate the resistance across R_1.

Current (I) = _______ A

Voltage (V) = ______ V

Calculated Resistance R_1 = ________

Step 6. Place a second resistor of equal resistance in parallel with the first resistor.

1. Predict whether the current measured at A_3 will be greater than, less than, or the same as the current measured in step 1.

____

2. Predict whether the voltage V_1 across the first resistor will be greater than, less than, or the same as it was in step 1.

____

Step 7. Close the switch. Measure and record the current running through the 1st resistor, the second resistor, and through the battery. Also measure the voltage across each resistor and across the entire circuit.

Current at A_1 = _____ A Current at A_2 = _____ A Current at A_3 = _____ A

Voltage V_1 = _____ V Voltage V_2 = _____ V Voltage V_3 = _____ V

3. How do the three current readings compare?

____

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4. How do the three voltage readings compare?

____

____

5. Calculate the values of resistances R_1 and R_2 using Ohm's law. Show your work.

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6. Calculate the equivalent resistance of the circuit by dividing the voltage of the source, V_3, by the current through the source, A_3. Show your work.

____

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7. How does the equivalent resistance of the circuit compare with the two values you calculated for the individual resistances in number 5.

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Step 8. Change R_2 so that R_1 and R_2 now have <u>different</u> resistances. The setup should be identical to step 6 with the exception that you now have resistors of different resistance in your circuit

Step 9. Repeat step 7. Measure and record the current and voltage at each of the locations.

Current at A_1 = _____ A Current at A_2 = _____ A Current at A_3 = _____ A

Voltage V_1 = _____ V Voltage V_2 = _____ V Voltage V_3 = _____ V

8. How do the three current readings compare?

____

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9. How do the three voltage readings compare?

____

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10. Calculate the values of resistances R_1 and R_2 using Ohm's law. Show your work.

11. Calculate the equivalent resistance of the circuit by dividing the voltage of the source, V_3, by the current through the source, A_3. Show your work.

12. How does the equivalent resistance of the circuit compare with the two values you calculated for the individual resistances in number 5.

Conclusions

13. Describe the relationship among the currents in a parallel circuit.

14. Describe the relationship among the voltages in parallel branches of a circuit.

15. Describe the relationship among the equivalent resistance and the individual resistances in a parallel circuit.

Note: Portions of this lab were adapted from Conceptual Physics Laboratory Manual. USA: Addison-Wesley Publishing Company, Inc., 1987. 289 - 293.

Physical Science
Electricity Unit
Fuse Lab

Name:________________________

Date:_________ Hour:__________

Purpose
To determine how a fuse can protect a circuit.

Materials
3 D-Cell batteries, insulated wires, flashlight bulbs, bulb sockets, switch, steel wool, balloon, hook-up wire with stripped sections in the middle

Discussion
As electrical energy passes through a wire, some is converted into heat. The amount of electrical energy released as heat is directly proportional to the current. In fact, the amount of heat released is proportional to the square of the current. Therefore, if one were to triple the current in a wire, it would give off 9 times (3^2) the amount of heat it was originally giving off. Because the heating effect in wires increases as the square of the current passing through them, wires in high current circuits can overheat and start a fire.
Thomas Edison recognized the danger of excessive current and developed a device known as the fuse. A fuse consists of a thin, special wire enclosed in a nonconducting material. When current through a wire exceeds a certain amperage, the metal in the fuse will melt, thereby opening the circuit before any real damage can occur.

Excessive current in a circuit can result from two different events. One such event is called a short circuit. A short circuit results when wires on opposite sides of an appliance touch, creating a low resistance pathway that allows current to bypass the appliance. Current increases dramatically during a short circuit and can cause the wire in the fuse to melt.

Another event that can result with excessive current is an overloaded circuit. You learned in the last lab that as resistors are added to a parallel circuit the overall resistance of the circuit lowers. According to Ohm's law, as the resistance of a circuit decreases, the current of the circuit will increase. Consequently, as more appliances are connected together in parallel, current for that circuit will increase. If enough appliances are connected, the heat produced from the current can cause the wire in the fuse to melt and "blow" the fuse.

Procedure

Part A – The Fuse

Step 1. Pull a couple of strands off the steel wool pad and roll these strands together.
Step 2. Connect the steel wool, one battery, and a switch together in series.
Step 3. Close the switch and observe. (if nothing happens, you have too much steel wool)

1. What happens when the switch is closed?

____

____

<u>Part B</u> – Short Circuits

Step 4. Repeat step one to create another steel wool fuse.
Step 5. Connect a fuse, switch, light bulb, and 1 battery together in series. Make sure that each wire connected to the bulb holder has a bare section in the middle of the wire.
Step 6. Close the switch and observe.
Step 7. Hold the bare sections of wire connected to either side of the light bulb together.

2. What happens when the switch is closed initially?

____

____

3. What happens when the two bare sections of wire are touched together? Why does this happen?

____

____

____

____

<u>Part C</u> – Overloading the Circuit

Step 8. Repeat step one to create another steel wool fuse.
Step 9. Connect 3 D-Cells together in series
Step 10. Connect the fuse in series to the positive terminal of the battery.
Step 11. Connect 3 bulbs in parallel to this circuit.
Step 12. Continue adding bulbs in parallel one at a time to the circuit. Continue until the fuse "blows". You may need to share bulbs with other groups for this step depending on the size of your fuse.

4. How many bulbs were required to melt the fuse?

____

____

5. Why doesn't the fuse blow initially? Why do you have to add more bulbs to get the fuse to blow?

____

____

____

____

6. The fuse boxes of some older houses were not designed to carry the loads required by modern appliances. To avoid continuously replacing fuses, some people replaced fuses with copper pennies. Explain why this is extremely dangerous.

____

____

____

____

7. Why are fuses connected in series with the power supply while all the other appliances are connected in parallel?

____

____

____

____

<u>Extension Question</u>

8. The amperage rating for a fuse is stamped onto the fuse. The car fuse shown in the first picture is rated at 15 amps. This means that a current of 15 amps can pass through the fuse, but any additional current will cause the wire in the fuse to melt. Explain how you could determine the amperage rating for your steel wool strand and actually measure it if time permits.

____

____

____

Note: Portions of this lab were adapted from Cunnigham James and Norman Herr. <u>Hands-On Physics Activities with Real-Life Applications.</u> New York: The Center for Applied Research in Education, 1994. 578 – 580.

Physical Science
Electricity Unit
Household Wiring Lab

Name:________________________

Date:__________ Hour:__________

The following is text that accompanies the power point presentation.

Slide 1: How we will connect our circuit for class.
We will be wiring two receptacles, a switch, and a light. We want the receptacles to work all of the time and the light to only work when the switch is turned on. Therefore, we will wire a plug to one of the receptacles. We will then connect the next receptacle, the switch, and finally the light.

Slide 2: Wiring a Receptacle
Receptacles can be wired in a number of ways. The way shown in the picture is similar to the way we will do it. Notice that two large wires enter the electrical box: one from above and one from below. Each of these large wires has three wires inside.

Slide 3: Wiring a Receptacle - # 2
Notice that each large wire contains a white wire, a black wire, and a bare copper wire. The black wire is the "hot" wire (120 V), the white wire is the "neutral" wire (0 V), and the bare copper wire is the "grounding" wire.

Slide 4: Wiring a Receptacle - # 3
If you are connecting the wires to the screw terminals, always connect the Black wire to the Brass screw and the white wire to the silver screw. Pigtail the bare copper wires together using a third, small piece of copper wire. Connect the ends of the copper wires together in a wire nut and attach the free end of the pigtail to the green grounding screw.

Slide 5: Wiring a Receptacle - # 4
When using the push-in fittings in the back of the receptacle, always push the Black wires into the side of the receptacle with the Brass screws. Push the white wires into the side of the receptacle with the silver screws.

Slide 6: Wiring a Receptacle - # 5
We will use the push-in fittings on the back of the receptacle. To remove a wire from a push-in fitting, place a screwdriver firmly in the release opening while simultaneously pulling the wire out.

Slide 7: Wiring a Single Pole Switch
Single pole switches are used to control a light from a single switch. As you can see from the picture, they have two brass screws. The ones we will be using also have a third green screw for grounding.

Slide 8: Wiring a Single Pole Switch - # 2
A single pole switch is used to turn an object, like a light, on or off. Unlike a receptacle that has 4 screw terminals, a switch has two. Since our switch is in the middle of the circuit, it will have two cables entering the box.

Slide 9: Wiring a Single Pole Switch - # 3
To wire our switch, you will need to connect the two black wires to the push-in fittings in the back of the switch. Since the switch just opens or closes the circuit, you do not hook the white neutral wires to it.

Slide 10: Wiring a Single Pole Switch - # 4
After connecting the black wires, we need to connect the white wires. To do this, the white insulation needs to be removed from the end of each wire. The wires then need to be screwed into a wire nut together.

Slide 11: Wiring a Light Fixture
Our light fixture is at the end of the circuit. Therefore, we will only have one wire entering the box.

Slide 12: Wiring a Light Fixture - # 2
Attach the black wire to the brass screw and the white wire to the silver screw. Attach the bare copper wire to the green screw that is located inside the electrical box.

Physical Science
Electricity Unit
Cost of Electricity Activity

Name:________________________

Date:__________ Hour:__________

Purpose:
To determine how much it costs to use some of your favorite electrical devices over a period of 30 days.

Discussion:
The power company sends your family a bill every month for the electrical energy that your family uses. The total cost of the bill is equal to the number of kilowatt-hours of electricity you have consumed multiplied by the rate that the power company charges per kilowatt-hour.

Procedure:
Step 1. Determine the electrical rate the power company charges your family per kilowatt-hour of electricity consumed.

1. ____

Step 2. Pick three electrical devices which are important to you. List those devices in the table below.
Step 3. Determine the power rating of each of these devices in kilowatts. Record that value in the table as well.
Step 4. Estimate the amount of time you use each device over the course of a day. Multiply this value by thirty and record this value in the table.
Step 5. Multiply the power rating of the device in kilowatts by the amount of time the device is used during the month. Record this value as the amount of energy used in the data table.
Step 6. Multiply the energy consumed during the month in kilowatt hours by the rate the power company charges you per kilowatt hour. Record the amount it costs to use that electrical device in the table.

Electrical Device	Power Rating (kW)	Time Used Per Month (h)	Energy Consumed (kWh)	Cost to use Device for the Month ($)

Physical Science
Electricity Unit
Electricity Unit Study Guide

Name:________________________

Date:__________ Hour:__________

1. What is the unit of charge?____
2. The electrical force between two charged particles depends on two things. What are these two things?____

   ____
3. How does the electrical force change as charged particles are brought closer together? Drawn further apart? ____

   ____
4. What is the charge of an electron? A proton? What happens when these particles are brought near one another? ____

   ____
5. What are three methods by which an object can become charged?

   ____
6. Through which method is charge transferred when a comb is rubbed through your hair? The comb becomes charged how (+ or -)? Your hair becomes charged how?

   ____
7. Explain what is meant by electrical polarization. (This is the same thing as charging by induction)

   ____

   ____
8. If you charge a balloon negatively, it can be stuck on a wall and it will remain in place. Can the same thing be done with a positively charged balloon? Explain.

   ____

   ____
9. Two charges exert a certain force on one another. How is the force affected if the magnitude of each charge triples?____
10. How is the force between two charged particles affected when the distance between the two charged particles is halved?______________________________________

11. Two charges separated by one meter exert a 1 Newton force on one another. If the charges are pushed to 0.5 m of separation, what will be the force that the particles exert on each other now?____________________

12. When do electrons flow in a wire?____________________

____

13. What is the unit of electrical current?____________________

14. What is the unit of electrical voltage?____________________

15. What is the unit of electrical resistance?____________________

16. What is the unit of electrical power?____________________

17. Does current or voltage flow through a wire? ____________________

18. Does current or voltage get applied across a wire?____________________

19. The current through a 2 ohm resistor connected to a 12-V power supply is what?

____

20. A 5 ohm resistor has a 2 A current in it. What is the voltage across the resistor?

____

21. When a 9-V battery is connected to a resistor, 1 A of current flows in the resistor. What is the resistor's value?____________________

22. What is the electric power of a lamp that carries 3 A at 120 V?

____

23. A 60-W light bulb and a 100-W light bulb are each rated at 120-V. Which light bulb has the larger resistance?____________________

24. What happens to the brightness of the bulbs as more lights are arranged in series? Why?____________________

____

____

25. What happens to the current moving through the power source as more bulbs are added to a circuit in series?____________________

26. Does current flow through and then out a battery or does current simply flow out of the battery?____________________

27. How are the circuits in your car and house arranged: series or parallel? How do you know?____________________

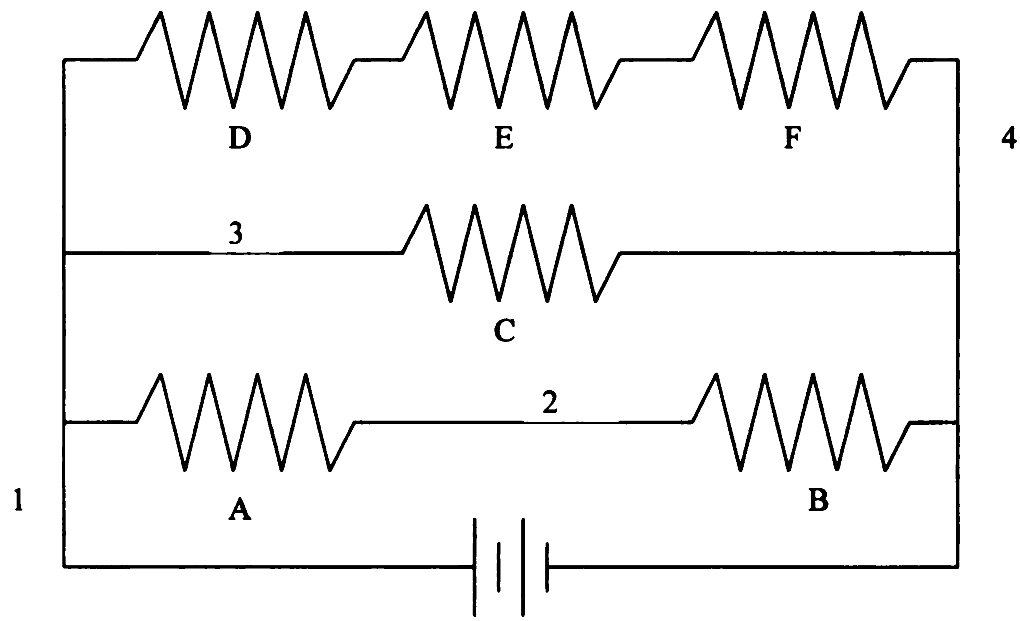
____

28. Two lamps, one with a thick filament and one with a thin filament are connected in series. The current is greater in which lamp?______________________________

29. Two lamps, one with a thick filament and one with a thin filament are connected in parallel to a battery. The voltage is greatest across which lamp?__________________

30. Two lamps, one with a thick filament and one with a thin filament are connected in parallel to a battery. The current is largest in which lamp?____________________

Use the figure below to answer the following questions 31 - 36.



31. If each cell has a voltage of 1.5-V, what is the total voltage of the circuit?__________

32. How does the brightness of bulb C compare to Bulb E?_________________________

33. Bulbs A and B are connected in series or parallel?______________________________

34. Which group of bulbs draws the least current?__________________________________

35. Which bulbs remain lit if bulb E is unscrewed?_________________________________

36. At which numerical location would a fuse be located for this circuit?______________

37. When are batteries arranged in series?____

38. When are batteries arranged in parallel?______________________________________

39. What happens to the voltage as batteries are connected in series? In parallel?_______

40. How does wire diameter relate to electrical resistance?________________________

____

41. If the resistance of a circuit is doubled, what happens to the current in the circuit?

____

42. If the voltage of a circuit is reduced to a quarter of its original value, what happens to the current in the circuit?____

43. What is meant when it is said that electric charge is conserved?__________________

____

44. Two resistors connected in series have a certain resistance. The same two resistors connected in parallel have a certain resistance. When connected in parallel, do the resistors have more resistance, less resistance, or the same resistance? ____________

____

45. How does wire length relate to electrical resistance?__________________________

____

46. How does temperature relate to electrical resistance?_________________________

____

47. How does the current in one location of a series circuit compare to the current in another location of the series circuit?____________________________________

____

48. How do you determine the total amount of resistance in a series circuit?___________

____

____

49. How does the sum of the voltage drops across each resistor in a series circuit relate to the voltage of the source?____

____

____

50. How does the current in one location of a parallel circuit compare to the current in another location of the parallel circuit?__________________________________

____

51. How does the voltage drop across one pathway of a parallel circuit compare with the voltage drop across a different pathway of the parallel circuit?________________

52. How does one determine the total amount of current in a parallel circuit?__________

53. What happens to the resistance of a parallel circuit as more branches are added to the circuit?________________

54. Fuses blow and circuit breakers trip when there is a short circuit or when a circuit becomes overloaded. Explain what happens in each circumstance.________________

55. Explain how to wire a household outlet.________________

56. Explain how to wire a household switch.________________

Physical Science
Electricity Unit
Electricity Pre and Post-Test

Name:________________________

Date:__________ Hour:__________

Directions: Answer the following questions on a separate sheet of lined paper. Answer each question fully in complete sentences.

1. Explain why a balloon that has been rubbed against your hair can stick to a wall and not fall off. Be specific.

2. Two electrically charged objects brought near one another exert a force on each other. Explain what two things affect the strength of this force.

3. What is the difference between an insulator and a conductor of electricity? Give examples of each.

4. A ping-pong ball covered in aluminum foil is tied to a silk thread. A plastic comb is rubbed with wool. When this happens, the comb becomes negatively charged. The comb is then brought near the ping-pong ball until the two touch. The plastic comb is then moved away from the ball and is rubbed with wool again. What will happen to the ping-pong ball when the comb is brought near it? Explain why.

5. What conditions are necessary in order to get electric charge to flow in a circuit?

6. Explain the difference between current and voltage.

7. What is the name of the units that are used to measure current, voltage, and resistance?

8. Electrical resistance depends on many things. Explain how the amount of resistance in a circuit depends on the length of the resistor and also how it depends on the diameter of the resistor.

9. How do voltage and resistance affect the current in a circuit? For instance, what happens if you double the voltage? Double the resistance?

10. Explain three differences between series and parallel circuits.

11. A student sets up two different circuits. The first circuit is powered by two batteries and has three light bulbs wired in series. The second circuit is powered by two batteries and has three light bulbs wired in parallel. What happens to both circuits if the middle light bulb is unscrewed?

12. A student sets up two different circuits. The first circuit is powered by two batteries and has three light bulbs wired in series. The second circuit is powered by two batteries and has three light bulbs wired in parallel. Are the bulbs in the series circuit brighter, just as bright, or dimmer than the bulbs in the parallel circuit? Explain why.

13. Are the fuses/circuit breakers in your house wired in series or in parallel? Explain why this is the case.

14. Describe the relationship between the voltage of a battery and the voltage drop across each resistance in a series circuit. Do the same thing for the resistors in a parallel circuit. (Assume there is only one resistor in each branch of the parallel circuit)

15. Explain how current flows through a series circuit that is powered by a battery. Specifically, explain whether current flows out of the battery and through the circuit or through the battery and through the circuit. Also, explain whether the current is the same at all places within the series circuit or if the current can vary at different places along the circuit.

Physical Science
Electricity Unit
Electricity Multiple Choice Test

Name:________________________

Date:__________ Hour:__________

Directions: Do not write on the test. X out the correct answer on your answer sheet.

1. The unit of electric charge, the coulomb, is the charge on __.
   a. one electron
   b. a specific large number of electrons

2. The electric force between charges is strongest when the charges are __.
   a. close together
   b. far apart
   c. the electric force is constant everywhere

3. The electrical forces between charges depends on the __.
   a. magnitude of electrical charges
   b. separation distance between electric charges
   c. both of these
   d. none of these

4. Rub electrons from your hair with a comb and the comb becomes __.
   a. negatively charged
   b. positively charged

5. An electron and a proton __.
   a. attract each other
   b. repel each other

6. To say that an object is electrically polarized is to say __.
   a. it is electrically charged
   b. its charges have been rearranged
   c. it is only partly conducting
   d. it is to some degree magnetic

7. A balloon will stick to a wall if the balloon is charged __.
   a. negatively
   b. positively
   c. either
   d. neither

8. Two charges exert a 1-N force on each other. If the magnitude of each charge doubles, the force will __.
   a. be the same
   b. double
   c. quadruple
   d. be eight times greater
   e. none of these

9. When the distance between two charges is halved, the electrical force between the charges __.
   a. quadruples
   b. doubles
   c. halves
   d. is reduced to one quarter its original value
   e. none of these

10. Two charges separated by one meter exert a 1-N force on each other. If the charges are pushed to 0.25 m separation, the force on each charge will be __.
   a. 1 N
   b. 2 N
   c. 4 N
   d. 8 N
   e. 16 N

11. A positive charge and a negative charge held near each other are released. As they move, the force on each particle __.
    a. increases b. decreases c. stays the same

12. An uncharged rice krispie grain is suspended by a silk thread from a coat hanger. When a negatively charged ebonite rod is brought nearby, without touching it, the grain __.
    a. becomes charged b. becomes polarized c. is repelled by the rod

13. Electrons are made to flow in a wire when there is __.
    a. an imbalance of charges in the wire
    b. a difference in the resistance between its ends
    c. a voltage difference across its ends

14. An ampere is a unit of electrical __.
    a. pressure b. current c. resistance d. power

15. Which statement is correct?
    a. Current flows through a circuit b. Voltage flows through a circuit
    c. Resistance is established across a circuit d. Current causes voltage

16. The current through a 10 ohm resistor connected to a 120-V power supply is __.
    a. 1 A b. 10 A c. 12 A d. 120 A e. none of these

17. A 10 ohm resistor has 5 A of current in it. What is the voltage across the resistor?
    a. 5 V b. 10 V c. 15 V d. 20 V e. 50 V

18. When a 10-V battery is connected to a resistor, 2 A of current flow in the resistor. What is the resistor's value?
    a. 2 Ω b. 5 Ω c. 10 Ω d. 20 Ω e. more than 20 Ω

19. The electric power of a lamp that carries 2 A at 120 V is __.
    a. 1/6 W b. 2 W c. 60 W d. 120 W e. 240 W

20. In an electric circuit, the safety fuse is connected to the circuit in __.
    a. series b. parallel

21. As more lamps are put into a series circuit, the overall current __.
    a. increases b. decreases c. stays the same

22. A circuit is powered by a battery. Current flows __.
    a. out the battery and into the circuit
    b. from the negative battery terminal to the positive terminal
    c. after a couple seconds pass
    d. through both the battery and the rest of the circuit

23. The headlights, radio, and defroster fan in an automobile are connected in __.
    a. series   b. parallel

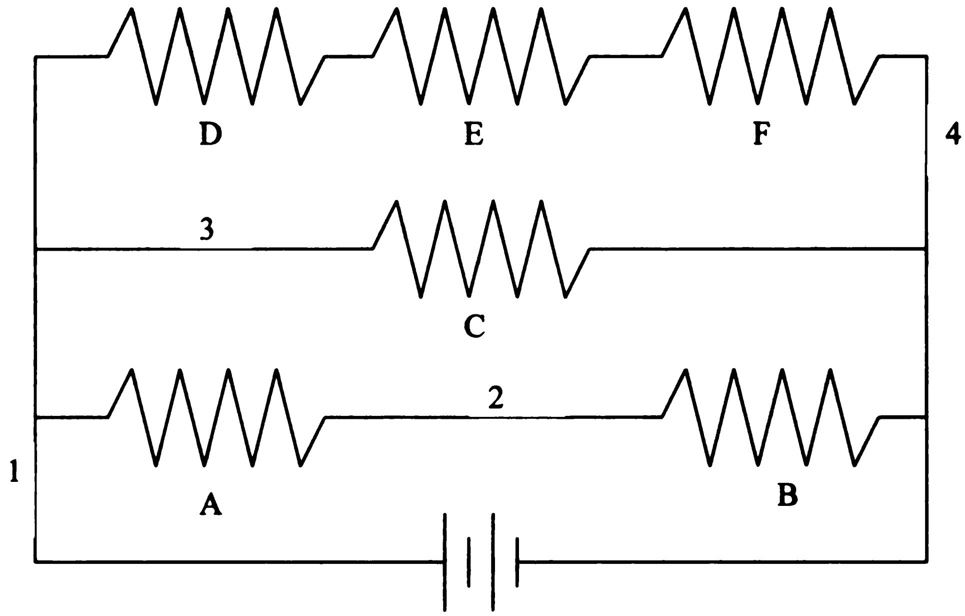
24. Two lamps, one with a thick filament and the other with a thin filament, are connected in series. The current is greater in the lamp with the __.
    a. thick filament   b. thin filament   c. the same in each lamp

25. Two lamps, one with a thick filament and the other with a thin filament, are connected in parallel to a battery. The voltage drop is greater across the lamp with the __.
    a. thick filament   b. thin filament   c. both voltages are the same

26. 24. Two lamps, one with a thick filament and the other with a thin filament, are connected in parallel to a battery. The current is largest in the lamp with the __.
    a. thick filament   b. thin filament   c. current is the same in both

27. A 60W light bulb and a 100W light bulb are each rated at 120 V. Which bulb has a larger resistance?
    a. the 60 W bulb   b. the 100 W bulb   c. both have the same resistance

Use the figure below to answer questions 28 – 33.



28. If each cell in the figure has a voltage of 1.5 volts, the total voltage of the circuit is __.
    a. 1.5 V   b. 3.0 V   c. 4.5 V   d. 6.0 V   e. none of these

29. How does the brightness of bulb A compare with the brightness of bulb D?
    a. Bulb A is brighter
    b. Bulb D is brighter
    c. The brightness of each bulb is the same

30. Bulbs A and B are connected in __.
    a. parallel   b. series

31. Which bulb or group of bulbs draws the least amount of current?
    a. Bulbs A & B   b. Bulb C   c. Bulb D, E, & F

32. Which bulb or group of bulbs will remain lit if bulb A is unscrewed?
    a. B, C, D, E, and F   b. C, D, E, and F   c. D, E, and F
    d. C, E, & F   e. C

33. At which location would a fuse be located for this circuit?
    a. 1   b. 2   c. 3   d. 4   e. 5

34. An ohm is a measure of electrical __.
    a. current   b. power   c. voltage   d. resistance

35. Batteries are arranged in series when __.
    a. a positive terminal from one battery is connected to the positive terminal of another battery.
    b. a positive terminal from one battery is connected to the negative terminal of another battery.
    c. a negative terminal from one battery is connected to the negative terminal of another battery.

36. How do wire diameter and resistance relate to one another?
    a. The larger the diameter of the wire, the larger the resistance will be.
    b. The smaller the diameter of the wire, the larger the resistance will be
    c. Wire diameter and resistance do not relate to one another.

37. When four D-cell batteries are connected together in parallel, the total voltage of the batteries is __. (Each D-cell is 1.5 V)
    a. 1.5 V   b. 3.0 V   c. 4.5 V   d. 6.0 V   e. none of these

38. In a parallel circuit, __.
    a. there is only one pathway for the voltage to move through.
    b. there are multiple pathways for the voltage to move through.
    c. there is only one pathway for the current to move through.
    d. there are multiple pathways for the current to move through.

39. If the resistance of a circuit is quadrupled, the current in the circuit will __.
    a. quadruple
    b. be eight times greater than the original value
    c. be sixteen times greater than the original value
    d. be one fourth the original value
    e. be one sixteenth the original value

40. Through which of the following methods can charge be transferred from one object to another?
    a. friction b. conduction c. polarization d. all of these

41. As more bulbs are placed into a series circuit, they become dimmer and dimmer. Why is this?
    a. Since there are multiple pathways for the current to flow through, more bulbs means more pathways. Each time an additional pathway is created, some of the current is taken away from the other pathways. This makes the bulbs less bright.
    b. Each time a bulb is placed in series, the amount of voltage across the circuit increases. The increase in voltage results in a decrease in current. This decrease in current causes the bulbs to be less bright.
    c. Each time a bulb is placed in series, the amount of resistance in the circuit increases. As the amount of resistance increases, the amount of current flowing through the circuit decreases. Less current means the bulbs will get dimmer.
    d. This does not happen. As more bulbs are placed into a series circuit, the brightness of the bulbs remains unchanged.

42. If a negatively charged ebonite rod touches a rice krispie grain, the grain also becomes negatively charged. If a different negatively charged rod is brought near the grain, what happens?
    a. nothing happens
    b. the grain is attracted to the rod
    c. the grain is repelled away from the rod

43. When the leaves of an electroscope are charged positively, they separate from one another. What happens if a negatively charged rod is brought near the electroscope?
    a. Since it does not touch the electroscope, nothing happens. The leaves stay the same distance apart.
    b. The closer the rod gets to the electroscope, the further the leaves separate from one another.
    c. The closer the rod gets to the electroscope, the closer the leave get to one another.

44. When a charged comb is brought near a ping-pong ball, the ball is attracted to the comb. By which method has the ping-pong ball been charged?
    a. friction b. conduction c. polarization d. all of these

45. The opposition to the flow of current through a circuit is __.
    a. voltage b. current c. resistance d. power

46. For electricity to flow through a circuit, the circuit must be __.
    a. in series b. in parallel c. open d. closed

47. To say that electric charge is conserved is to say that electric charge __.
    a. may occur in an infinite variety of quantities
    b. is a whole-number multiple of the charge of one electron
    c. will interact with neighboring charges.
    d. can neither be created nor destroyed

48. A conductor differs from an insulator in that a conductor __.
    a. has more electrons than protons
    b. has more protons than electrons
    c. has a higher resistance
    d. has a lower resistance

49. If you plug a toaster rated at 110 V into a 220 V outlet, current in the toaster will be about __.
    a. half what it should be
    b. the same as if it were plugged into 110 V
    c. more than twice what it should be
    d. twice what it should be

50. Compared to the equivalent resistance of two resistors connected in series, the equivalent resistance of the same two resistors connected in parallel is __.
    a. more b. less c. identical

APPENDICIES

Appendices B: Electricity Unit Teacher Resources

Electricity Unit
Teacher's Guide for the Electrostatics Mini-Labs
8 total points - 1 point per question

Fill the Stocking
When the stocking is rubbed with the bag, the stocking becomes charged. Since the entire stocking has become charged, and since like charges repel, the stocking "fills" up magically as if a person's leg was in it.

Electrostatic Jumping Beans
When the cover is rubbed, it acquires a negative charge. This induces a charge in the puffed rice and causes them to jump up to the cover. Once in contact, the puffed rice also becomes negatively charged and is repelled away from the cover. Once they fall onto the tin foil, they discharge and are ready to start the process over again.

Magical Water
After the ebonite rod has been rubbed, it becomes negatively charged. When placed near the water, it causes the polar water molecules to align themselves in the presence of the rod's electric field. The molecules align such that their positive side is facing the rod. Since opposites attract, the water is pulled toward the rod. The same thing would happen if the rod was positively charged.

The Obedient Ping-Pong Ball
When the negatively charged comb is brought near the ping-pong ball, it induces a charge in the ping-pong ball. As long as the two don't touch, you can get the ping-pong ball to follow the comb.

The Dry Newspaper
After the newspaper has been rubbed, it acquires a charge. When the metal pie pan is placed on the newspaper it acquires the same charge through contact. When the paper is lifted off the table and a finger at a much different voltage is placed near the pie pan they receive a shock.

The Palm Tree
Once the charged balloon touches the wire hanger, charge is transferred up the conducting wire to the tissue. Since the tissue is now charged with like charges, the individual strips now repel one another.

The Tricky Thread
After the comb has been rubbed, it becomes charged. As the rod is drawn up and away from the thread, a charge is induced in it and the thread will stand up when the comb is in close proximity.

Magic Fingers
After you've acquired a charge, you can induce a charge in the pencil causing it to follow your finger.

Electricity Unit
Teacher's Guide for the Charged Grains Lab
9 points – 1 point per question

1. After touching the grain initially, you can not touch it again. The rod and the foil covered grain have the same charge, making them repel from one another.

2. As the wool is brought near the grain, the two objects attract. They attract because they have opposite charges.

3. After touching the grain initially, you can not touch it again. The rod and the foil covered grain have the same charge, making them repel from one another.

4. As the silk is brought near the grain, the two objects attract. They attract because they have opposite charges.

5. The two attract. The general conclusion that can be formed from this is that oppositely charged objects are attracted to one another.

6. The two grains are repelled away from one another. They have each gained the same charge and objects with a like charge repel.

7. After touching one of the grains briefly, charge is removed from that grain. The other grain, however, is still charged. Consequently, the two grains still repel, but now they are closer to each other than they previously were. Obviously, the amount of charge on the grains plays a role in the amount of force between them.

8. If a known charge is placed on the grain, an unknown charge can be determined when it is brought near the grain. A like charge will cause the grain to repel while the opposite charge will cause the grain to attract.

9. The grain bounces back and forth between the balloons. Once it touches one balloon, it acquires that charge and is repelled. It moves toward the other balloon which has the opposite charge because opposites attract. Once it touches that balloon, it acquires that charge and is repelled. The process continues in this fashion causing the grain to bounce back and forth between the balloons.

Electricity Unit
Teacher's Guide for Electroscope Lab
8 points – 1 point per question

1. The leaves separate from one another because they have gained like charges.

2. The leaves have become negatively charged. We know that the rod is negatively charged and when it touches the foil ball some of this charge is transferred to the leaves of the electroscope.

3. The leaves separate because a charge has been induced in them.

4. As the charged rod moves away, the leaves collapse back down.

5. This differs from the previous example because in the previous example the leaves stayed separated. This difference exists because in the second trial The leaves did not acquire a permanent charge.

6. A charged rod needs to be placed near the foil ball of the electroscope without touching it. A finger from the opposite hand then needs to touch the foil ball. The finger gets removed, then finally the charged rod. A permanent charge has been left on the electroscope without ever touching it with the rod.

7. The leaves have acquired a positive charge. One knows this because the negatively charged rod will cause the leaves to collapse.

8. A positively charged object would cause the leaves to separate further, a negatively charged object would cause the leaves to collapse.

Electricity Unit
Teacher's Guide for Electrophorus and Leyden Jar Lab
7 points – 1 point per question

1. You receive a pretty good shock.

2. The pie pan has a large positive charge. This is apparent because when it is brought near the negatively charged electroscope, the leaves collapse.

3. It would seem that the pie pan would be negatively charged because the electrophorus was negatively charged. This is not the case, however. Instead, the pie pan becomes positively charged because the pan sits on top of ridges in the record. Since it is not in contact with the majority of the record, the electrophorus induces a charge in the pie pan. The positive charges shift toward the bottom of the pan while the negative charges shift toward the top of the pan. When the pie pan is touched, the some of the negative charge is drained away by the finger, leaving the pan positively charged.

4. When the pie pan is brought near the circuit tester, it flashes with light indicating that there was a difference in voltage between the two terminals of the tester.

5. A large spark forms.

6. This flash of light is brighter than before.

7. The conclusion that can be drawn from this is that the Leyden Jar stores electric charge. Therefore, there is a greater voltage difference between the two terminals of the tester causing the flash of light to be brighter.

Electricity Unit
Teacher's Guide for Flowing Water Mini-Lab
3 points (1 point per question)

1. The water stops flowing when the height of the water is the same in the two containers.

2. The exact same thing happens. Even though the containers have a different diameter, water flows out of one container and into the other until the height of the water is the same in each.

3. In order to get water to flow, there needs to be a pressure difference. This means that the water level at one location must be higher than the water level at a different location. As long as this difference exists, water flows. Once the water levels even out, water stops flowing.

Electricity Unit
Teachers Guide for the Current Lab
9 points (1/2 point for each row in the table, 4 points for the conclusion)

	Current Detected (yes or no)	**Amount of Needle Deflection (°)**
Zinc and copper	No	
Zinc and copper connected in a complete circuit	No	
Zinc and copper in distilled water	No	
Zinc and copper in tap water	Yes	*
Zinc and copper in salt water	Yes	***
Zinc to copper to zinc to copper in salt water	Yes	*****
Zinc and copper separated by salt water soaked felt	Yes	**
Copper and copper in salt water	No	
Zinc and zinc in salt water	No	
Zinc and copper in sugar water	No	
Zinc and copper in apple	Yes	**

Conclusion
Electric current is created when there is a potential difference between two electrodes that are separated by an electrolyte. A potential difference exists between copper and zinc but not between copper and copper or zinc and zinc.

A current can be drawn when zinc and copper electrodes are placed into any solution that is an electrolyte.

More current is drawn when zinc and copper cells are connected in series. Enough cells can run small electrical devices like a wall clock.

Electricity Unit
Teachers Guide for Resistance Lab
13 points (1 point each for the questions, 5 points for the table, 4 points for the graph)

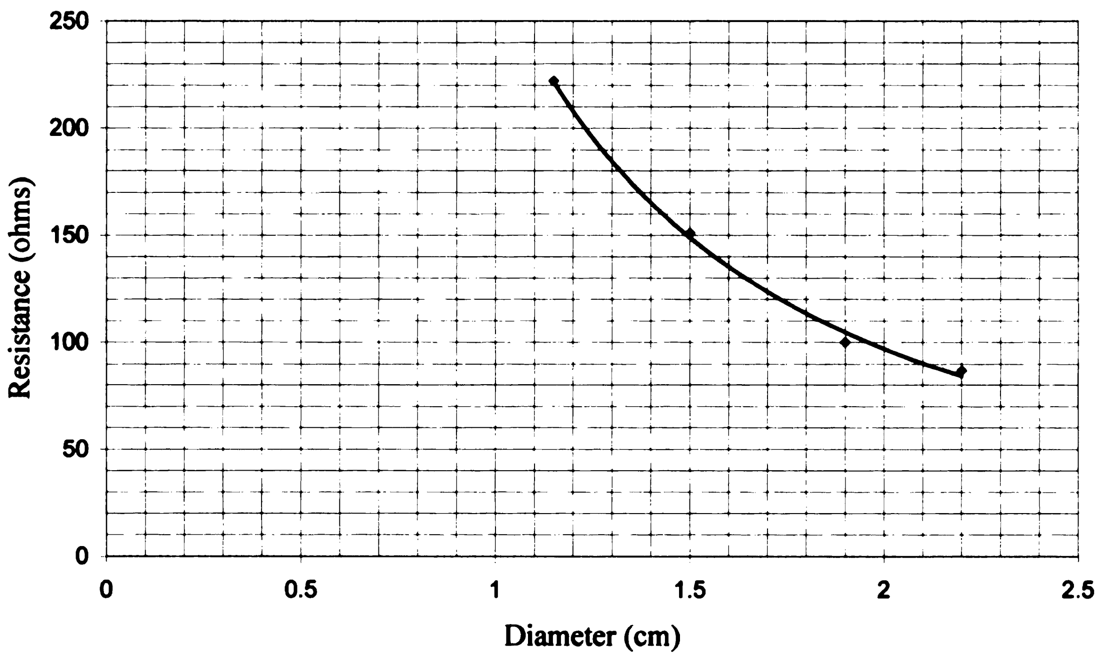
1. What happens to the flashlight bulb as the two alligator clips move away from one another?

As the alligator clips move away from one another, the light bulb grows dimmer.

Sample Data

Play-Doh Diameter (cm)	Voltage (V)	Current (mA)	Current (A)	Resistance (Ω)
1.15	1.33	6	.006	222
1.5	1.36	9	.009	151
1.9	1.20	12	.012	100
2.2	1.30	15	.015	86.7

Resistance vs. Diameter of Play-Doh "Wires" at a Constant Voltage



2. How does the length of a resistor affect the current of a circuit? Explain how you know this and explain why this occurs. (Reflect on Part A)

As the length of a resistor increases, the amount of current present in a circuit decreases. This is evident because as the alligator clip was slid down the pencil lead, the light bulb grew dimmer. The bulb is dimmer because of the increased resistance. Hence, fewer charges move by the filament every second causing the bulb intensity to decrease.

3. What mathematical relationship between resistor diameter and resistance does the graph illustrate?

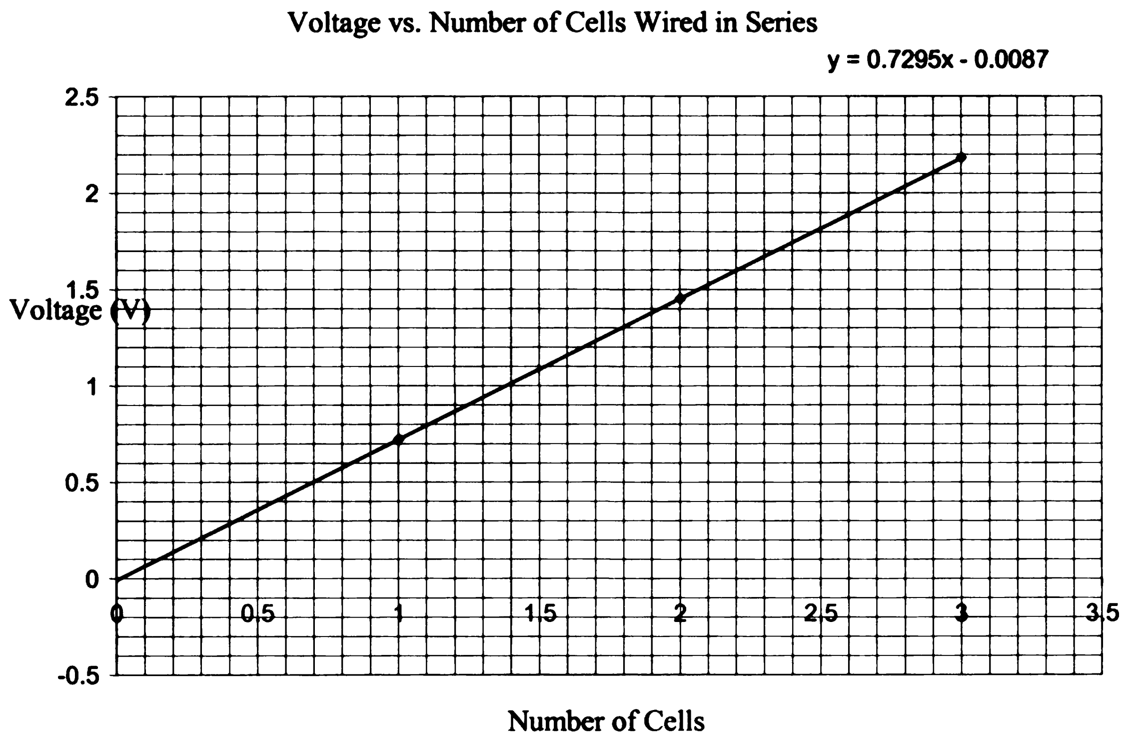
It is evident that as the diameter of the resistor increases, the resistance of that resistor decreases. In fact, the two are inversely proportional.

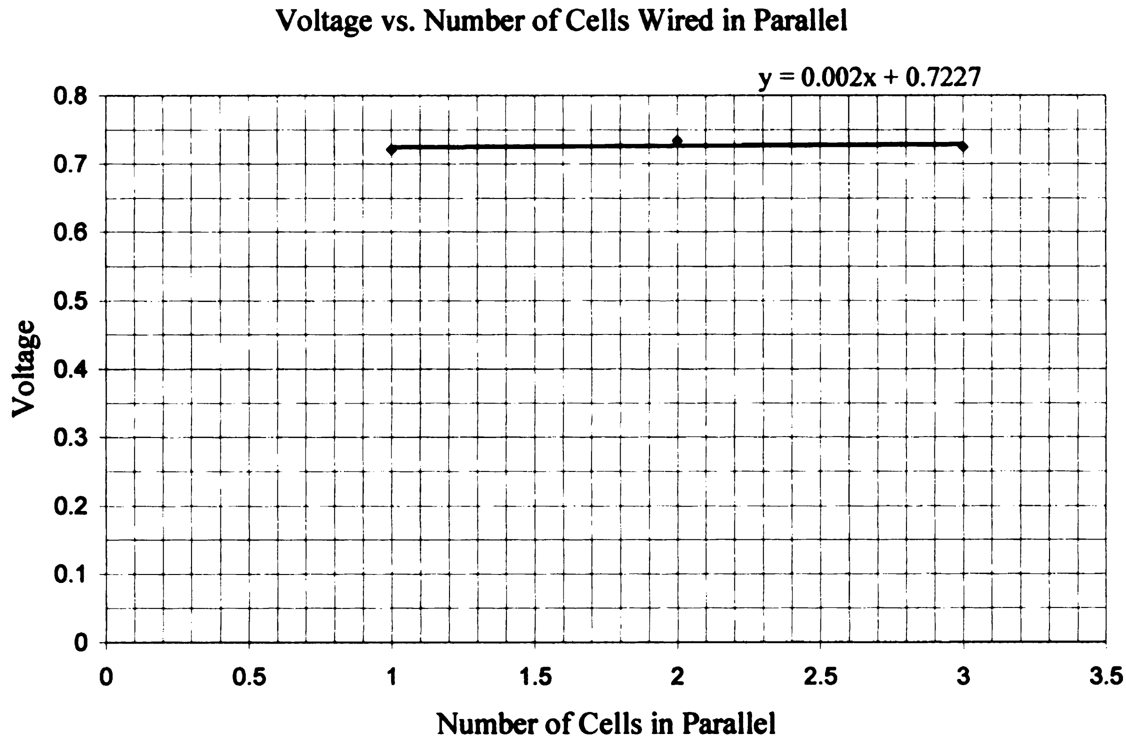
4. Briefly summarize the findings of this lab. Specifically, how does the resistor length and the resistor diameter affect the resistance and the current in a circuit.

This lab has shown that as the length and resistance are directly proportional while diameter and resistance are inversely proportional. Therefore, the length of a resistor is inversely proportional to current while the diameter of a resistor is directly proportional to current. Therefore, if one wants the maximum amount of current from a resistor, he should make the resistor's diameter large while making its length short.

Electricity Unit
Teacher's Guide for the Cells in Series and Parallel Lab
15 points (1 point per question, 8 points for the two graphs)

Cells in Series		Cells in Parallel	
# of cells	**voltage (v)**	**# of cells**	**voltage (v)**
1	.721	**1**	.721
2	1.45	**2**	.734
3	2.18	**3**	.725





1. How does the number of cells connected in series affect the voltage of the system?

The more cells there are, the higher the voltage is. When the cells are 1.5 V, each additional cell will add an additional 1.5 V to the circuit.

2. How does the number of cells connected in parallel affect the voltage of the system?

No matter how many cells are connected in parallel, the voltage of the circuit is always the same.

3. What is an advantage of adding cells in series?

The advantage of adding cells in series is that the voltage of the circuit is increased. While we haven't studied this yet, it will later become apparent that voltage and current are directly proportional. Therefore, the greater the voltage of a circuit, the greater the current of that circuit.

4. A remote control car requires 12 volts to operate. How many 1.5 volt batteries would be necessary to power the car? How must the batteries be arranged?

One would need to arrange 8 batteries in series to obtain the 12 volts required.

5. How do you think the addition of cells in parallel affects the longevity of these cells? Will they last for a longer time or a shorter time? Why do you think this?

Adding cells in parallel does not affect the voltage of the circuit. Therefore a circuit running off of 1 battery or 5 batteries in parallel will have the same voltage and hence the same amount of current. If they each have the same current, than the circuit with 5 batteries should last for much longer because only part of the current is passing through each battery. Therefore, fewer electrons are passing through each battery per unit time, thus extending the life of the battery.

Electricity Unit
Teacher's Guide for Circuits in Series and Parallel Lab
(10 Points – 1 point per question)

All diagrams must show the tip of the light bulb and the side of the light bulb connected in some way to the positive and negative terminal of the battery to receive credit for the drawings.

1. Describe the similarities among your successful trials.

All successful trials must have a complete circuit. The side of the metallic base and bottom of the metallic base must be connected to the positive and negative terminals of the battery. If these conditions are not met, the bulb will not light.

2. What two parts of the bulb does the holder make contact with?

The side of the metallic base and the bottom of the metallic base.

3. Do the bulbs light in each of the series circuits you have designed?

If connected properly, yes.

4. Which circuit contains the brightest bulb or bulbs? The dimmest bulb or bulbs? The first, second, or third?

Brightest = 1 bulb which was the first circuit. Dimmest = 3 bulbs in series which was the third circuit.

5. What happens when a bulb that is connected in series is unscrewed from its base?

All the bulbs in the circuit go out. Current has only one pathway to follow and when that pathway is broken, electrons can no longer move.

6. Do the bulbs light in each of the parallel circuits you have designed?

If connected properly, yes.

7. Which parallel circuit contains the brightest bulb or bulbs? The dimmest bulb or bulbs?

All circuits are, apparently, the same brightness.

8. What happens when a bulb that is connected in parallel is unscrewed from its base?

That bulb will go out; however, the other bulbs in the circuit remain lit.

9. Summarize the differences between series and parallel circuits.

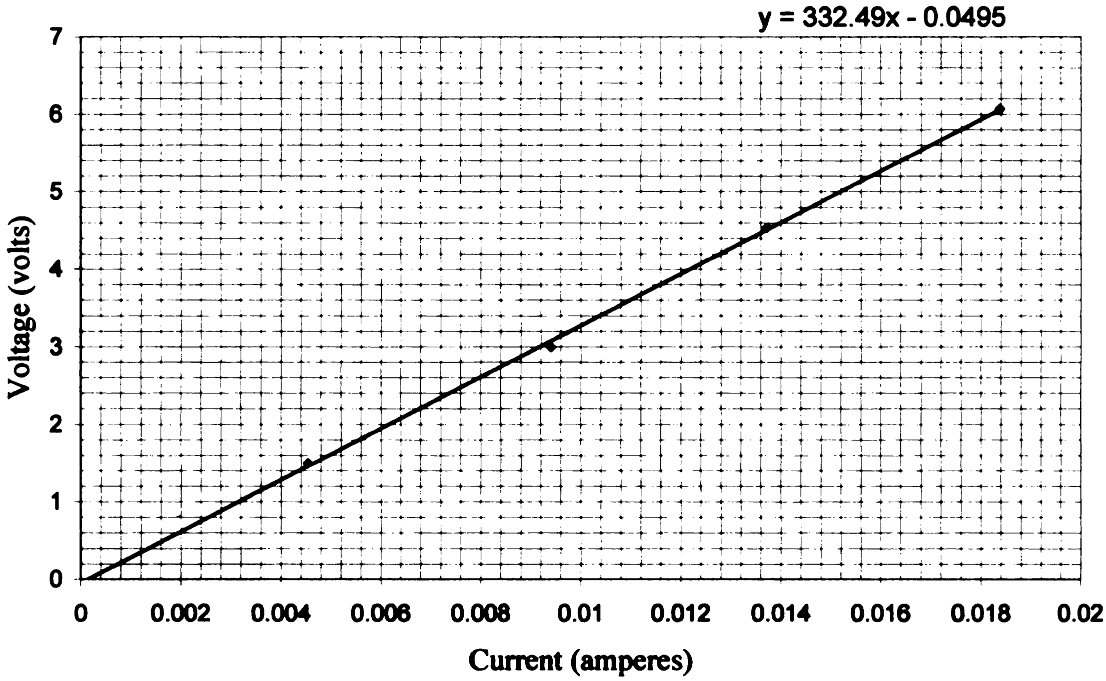
In a series circuit, there is only one pathway for electron flow. Therefore, as more resistances are added to the circuit, current decreases. Also, if the pathway is broken at any point, all devices stop working. In a parallel circuit, there are multiple pathways for electrons to follow. Each resistance is connected to the positive and negative terminal of the battery; therefore, the voltage across each resistance is identical. Consequently, the current for each resistance will be the same (assuming the resistors all have the same resistance). Since there are multiple branches connected to the battery terminals, if one device is removed, the others will still work.

Electricity Unit
Teacher's Guide to Ohm's Law Lab
25 points (Tables – 5 points, Graphs -14 points, Questions 1 point each)

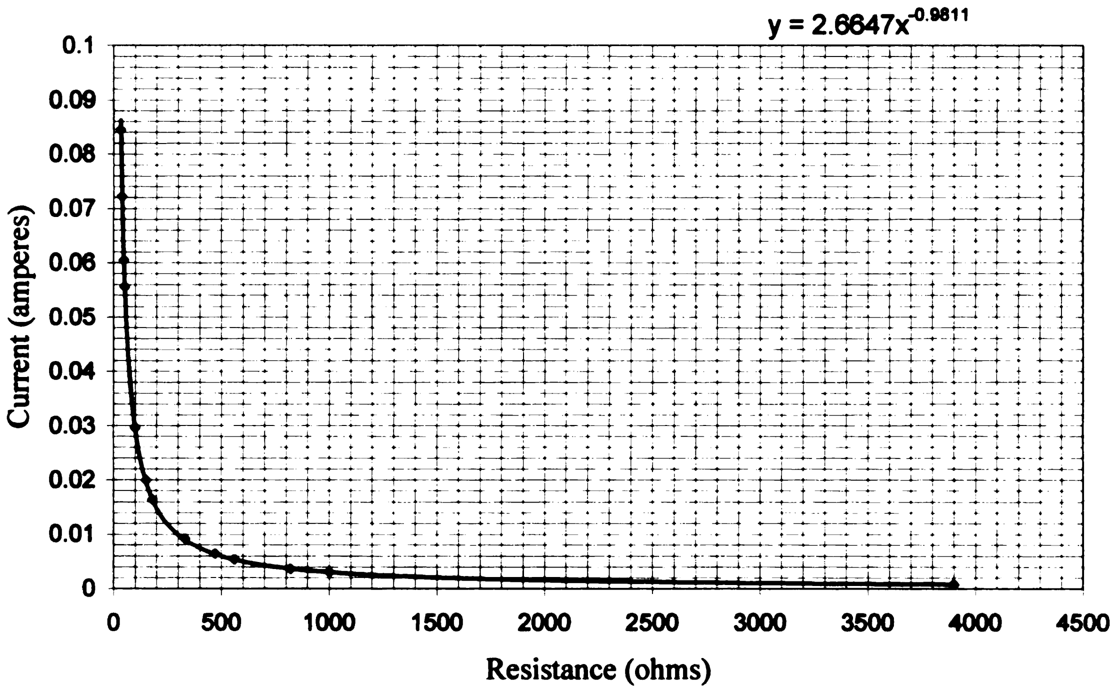
# of Batteries	Current (mA)	Current (A)	Voltage (V)
1	4.54	.00454	1.50
2	9.4	.0094	3
3	13.72	.01372	4.54
4	18.38	.01838	6.07

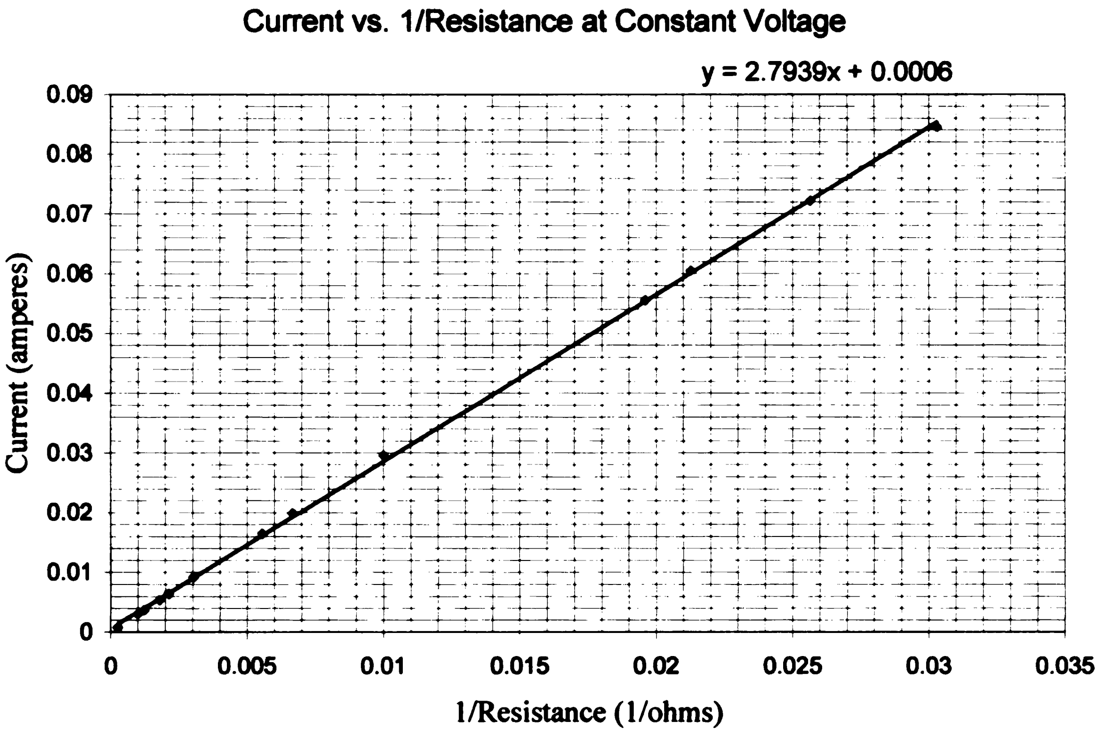
Resistance (Ω)	Voltage (V)	Current (mA)	Current (A)
33	All	84.5	.0845
39	Around	72.2	.0722
47	3.0	60.5	.0605
51		55.6	.0556
100		29.58	.02958
150		19.93	.01993
180		16.45	.01645
330		9.19	.00919
470		6.44	.00644
560		5.4	.0054
820		3.69	.00369
1000		3.06	.00306
3900		.77	.00077

Voltage vs. Current at Constant Resistance



Current vs. Resistance at Constant Voltage





1. What mathematical relationship between voltage and current does the graph illustrate?

Voltage and Current are directly proportional.

2. What mathematical relationship between resistance and current do the graphs illustrate?

Resistance and current are inversely proportional.

3. What does the slope of the voltage vs. current graph represent? How closely does it agree with the actual value? (Calculate the % error)

It represents the resistance of the resistor that was used during part A. The slope of the line I obtained was 333 Ω. The actual value of the resistor was 330Ω. The percent difference is 0.91%.

4. If a fifth D-Cell battery was added to the circuit for part A, what would you expect the current to be for the circuit? Why?

I would expect the current to be roughly .0229 A.

5. What does the slope of the current vs. $^1/_{resistance}$ graph represent? How closely does it agree with the actual value? (Calculate the % error)

It represents the voltage that was used during Part B. The slope of the line I obtained was 2.80 V. The actual measured voltage was 3.01 V. The percent difference is 6.98%.

6. Did the potential difference across the resistor in part B change when you changed the resistor in the circuit?

The potential difference did not change. The resistors were always connected across the same two D-Cells. Therefore, the voltage didn't change.

Electricity Unit
Teacher's Guide for the Ohm's Law with Series Circuits Lab
16 points (1 point per question)

Current (I) = .02958 A Voltage (V) = 2.922 V Calculated Resistance R_1 = 98.78 Ω

1. How does the calculated value of the resistance compare to the manufacture's rated value? Calculate the % error.

Calculated Value is 98.78Ω. Actual Value is 100Ω. % difference is 1.22%.

Current at A_1 = .01082 A Current at A_2 = .01082 A Current at A_3 = .01082 A

Voltage V_1 = 1.071 V Voltage V_2 = 1.921 V Voltage V_3 = 2.990 V

4. How do the current readings compare?

The current readings are identical.

5. How do the three voltage readings compare?

The voltages across the two resistors vary. The voltage across the smaller resistor is smaller than the voltage across the larger resistor. The sum of the voltages is equal to the voltage of the source.

6. Calculate the values of R_1 and R_2. Show your work.

R_1 = 98.98Ω R_2 = 177.54 Ω

7. Divide V_3 by the current. How does the result compare to the sum of the resistances you calculated in part 6?

276.34 Ω. This is very close to the sum of the resistances from part 6 – 276.52Ω.

8. What is the relationship among the current in the circuit, the sum of the resistances, and the voltage across all the resistances?

$I = V_3/R_{eq}$ = 2.990/276.52 = .010813 A

This means that the total current for a series circuit is equal to the sum of the voltages across each resistance divided by the sum of the resistors in the circuit.

R_1 = 100 Ω R_2 = 180 Ω R_3 = 270 Ω

V_4 = 3.02 V

9. According to the manufacturer's ratings, what is the total resistance in the circuit?

The total resistance is 550 Ω.

10. Predict what the readings will be for the multimeters measuring current at A_1, A_2, and A_3.

$I = V_4/R_{eq} = 3.02/550 = .00549$ A.

Current at A_1 = .00555 A   Current at A_2 = .00555 A   Current at A_3 = .00555 A

Voltage V_1 = .550 V   Voltage V_2 = .986 V   Voltage V_3 = 1.477 V

11. How do your measured values of the currents through the multimeter compare to the value you predicted in step 4?

They are very close (1.08 % off)

12. Calculate the values of the resistances of R_1, R_2, and R_3 from your current and voltage measurements. Show your work.

R1 = 99.1 Ω   R2 = 177.66Ω   R3 = 266.13Ω

13. Divide V4 by the current. How does the result compare to the sum of the resistances you calculated in part 12?

544.14Ω. This is very close to the sum of the calculated resistances from above (542.89Ω).

14. How do the currents in different parts of a series circuit compare?

The current in all parts of a series circuit are identical.

15. Describe the relationship among the voltage of the source and the voltages across each resistance in a series circuit.

The sum of the voltages across all resistors in a series circuit is equal to the voltage across the source. Moreover, the voltages across large resistors are higher than the voltages across small resistors.

16. Describe how current relates to the sum of the resistances and the sum of the voltages.

Current = The sum of the voltages divided by the sum of the resistances in a series circuit.

Electricity Unit
Teachers Guide for Ohm's Law with Parallel Circuits
15 points (1 point for each question)

Current (I) = .0293 A Voltage (V) = 2.95 V Calculated Resistance R_1 = 100.68 Ω

1. Predict whether the current measured at A_3 will be greater than, less than, or the same as the current measured in step 1.

It should be greater. There are multiple pathways each receiving the voltage of the source. Consequently, current should be greater.

2. Predict whether the voltage V_1 across the first resistor will be greater than, less than, or the same as it was in step 1.

The voltage should be the same as it was in step 1. All branches of the circuit should have the same voltage.

Current at A_1 = _____ A Current at A_2 = _____ A Current at A_3 = _____ A

Voltage V_1 = _____ V Voltage V_2 = _____ V Voltage V_3 = _____ V

3. How do the three current readings compare?

I do not have this information, but the current should be the same for A_1 and A_2. It should be the same because the voltage is the same and the resistors are of equal value. However, A_3 should be the sum of $A_1 + A_2$. The current through the circuit will be the sum of the current through each pathway.

4. How do the three voltage readings compare?

They should be identical to one another. Each pathway is connected to the positive and negative battery terminal; therefore, they should all have the same voltage.

5. Calculate the values of resistances R_1 and R_2 using Ohm's law. Show your work.

I do not do have this information, but R_1 and R_2 should come out to be the same.

6. Calculate the equivalent resistance of the circuit by dividing the voltage of the source, V_3, by the current through the source, A_3. Show your work.

I did not do this, but the equivalent resistance should be less than either resistor. The reason for this is the voltage across each resistor is identical. Therefore, the more pathways there are, the higher the current is going to be. Ohm's law states that current and resistance are inversely proportional. So, as the current increases through the circuit, the resistance of the circuit has to lower.

7. How does the equivalent resistance of the circuit compare with the two values you calculated for the individual resistances in number 5.

See answer for #6.

Current at A_1 = .0293 A Current at A_2 = .01648 A Current at A_3 = .0450 A

Voltage V_1 = 2.95 V Voltage V_2 = 2.95 V Voltage V_3 = 3.00 V

8. How do the three current readings compare?

The current differs through the two branches because the value of the resistor varies. The sum of the two currents, though, is the total current of the circuit. $A_1 + A_2 = A_3$.

9. How do the three voltage readings compare?

The voltages are close to identical.

10. Calculate the values of resistances R_1 and R_2 using Ohm's law. Show your work.

$R_1 = 100.68\ \Omega$ $R_2 = 179.00\Omega$.

11. Calculate the equivalent resistance of the circuit by dividing the voltage of the source, V_3, by the current through the source, A_3. Show your work.

$R_{eq} = 66.6\ \Omega$

12. How does the equivalent resistance of the circuit compare with the two values you calculated for the individual resistances in number 5.

The equivalent resistance is less than either of the resistors in part 5.

13. Describe the relationship among the currents in a parallel circuit.

The sum of the currents through each branch is equal to the total current of the circuit.

14. Describe the relationship among the voltages in parallel branches of a circuit.

All the voltages in the circuit are identical.

15. Describe the relationship among the equivalent resistance and the individual resistances in a parallel circuit.

The equivalent resistance is less than the smallest resistance in the circuit. For an explanation why this is, see number 6.

Electricity Unit
Teacher's Guide for the Fuses Lab
7 points (1 point per question)

1. What happens when the switch is closed?

The steel wool melts, thus opening the circuit.

2. What happens when the switch is closed initially?

The bulb lights and remains lit.

3. What happens when the two bare sections of wire are touched together? Why does this happen?

The steel wool melts. When the bare sections are touched together, a low resistance pathway is created that allows current to bypass the light. Since current increases dramatically, the fuse melts, the circuit opens, and the light bulb is no longer lit.

4. How many bulbs were required to melt the fuse?

Answers will vary depending on the size of the steel wool fuse.

5. Why doesn't the fuse blow initially? Why do you have to add more bulbs to get the fuse to blow?

The fuse does not blow initially because there is not enough heat to melt the steel wool. As more bulbs are added in parallel, the equivalent resistance of the circuit decreases causing the current of the circuit to increase. Eventually it increases enough to melt the steel wool.

6. The fuse boxes of some older houses were not designed to carry the loads required by modern appliances. To avoid continuously replacing fuses, some people replaced fuses with copper pennies. Explain why this is extremely dangerous.

This defeats the purpose of having a fuse. If a circuit is shorted or overloaded, wires can become overheated and potentially start a fire. The problem with the penny is that it is not going to melt in time to prevent a fire. It would take way too much amperage to melt the penny.

7. Why are fuses connected in series with the power supply while all the other appliances are connected in parallel?

Fuses are connected in series because everything in a series circuit stops working when the circuit is opened. Consequently, when the fuse melts, the circuit is broken and all appliances stop working. If it was connected in parallel, the other appliances would still work, even after the fuse blows. This would defeat the purpose of the fuse.

8. The amperage rating for a fuse is stamped onto the fuse. The car fuse shown in the first picture is rated at 15 amps. This means that a current of 15 amps can pass through the fuse, but any additional current will cause the wire in the fuse to melt. Explain how you could determine the amperage rating for your steel wool strand and actually measure it if time permits.

One could hook a multimeter up in series with the fuse. She could then add additional lamps noting the current running through the circuit. She would continue adding lamps until the fuse blew. The current reading on the multimeter prior to the fuse blowing would give her the amperage rating (roughly) of the steel wool fuse.

Electricity Unit
Teacher's Guide for Household Wiring Lab
(20 Points – all or nothing for hooking up the circuit correctly)

Students must hook the circuit up as follows:

<u>2 outlets</u>
Black wires to brass side push-in fittings
White wires to silver side push-in fittings
Bare copper wires pig tailed and attached to the green grounding screw

<u>Switch</u>
Black wires to push in fittings in the back
White wires wire nutted together
Bare copper wires pig tailed and attached to the green grounding screw

<u>Light Fixture</u>
Black wire attached to brass screw on fixture
White wire attached to silver screw on fixture
Bare copper wire attached to green grounding screw in electrical box

Outlets tested with a receptacle tester. If the two yellow lights come on, the outlet is wired correctly.

Fixture is tested by turning on the switch. If the outlets are properly wired and the light comes on, students get the full 20 points. If not, students must find their mistake and fix it.

Electricity Unit
Teacher's Guide for the Cost of Electricity Activity
10 points (1 point for rate charged, 1 point each for power rating, energy consumed, and cost to use device for the month)

1 point for rate charged – should be between 5 – 10 ¢ per kWh.

1 point for each of the three power ratings – checked against power rating tables obtained from the internet to make sure they are in the correct range.

1 point for each of the three energy consumed calculations (power rating times time used per month)

1 point for each of the three cost to use device for the month calculations (energy consumed times rate power company charges)

Electricity Unit
Teacher's Guide for the Electricity Study Guide
(No Points – Students get answer sheet if the complete study guide)

1. The unit of charge is the Coulomb. It represents the charge of billions and billions of electrons.
2. The magnitude of the two charges and the distance the two charges are separated.
3. The closer they are to on another, the greater the force is between them. The further they are moved apart, the weaker the force is between them.
4. electron = negative, proton = positive, As the particles are brought near one another, they are attracted to each other. Opposite charges attract.
5. friction, conduction, induction or polarization
6. friction, comb becomes negatively charged and hair becomes positively charged (hair strips electrons off the balloon)
7. Electrical polarization means the charges in an object have been rearranged giving one side of the object a slight positive charge and the other side of the object a slight negative charge. The object, overall, is still neutral.
8. Yes, a positively charged balloon will induce a charge on the wall and allow it to stick just like a negatively charged balloon would.
9. Use your formula → $3 \cdot 3/1^2 = 9$. This means the force will be nine times greater.
10. $1 \cdot 1/(^1/_2)^2 = {}^1/_{1/4} = 4$. This means the force will be four times greater.
11. This question uses information from number 11. You need to see that the distance of the particle separation goes from 1 meter to half a meter. Since the distance is halved, the force quadruples. The original force was 1 N so the final force will be <u>4 Newtons</u>.
12. They flow when there is a voltage difference across the ends of the wire.
13. The ampere
14. The volt
15. The ohm
16. The watt
17. Current flows through a wire.
18. Voltage is applied across a wire.
19. I = V/R = 12 V/2 ohms = 6 amps
20. V = I · R = 2 A · 5 ohms = 10 volts
21. R = V/I = 9 V/1A = 9 ohms
22. P = I · V = 3 A · 120 V = 360 Watts
23. The 60 Watt light bulb has a larger resistance because it is drawing a smaller current. If the current is less, that means there must be more resistance preventing the current from being higher.
24. The bulbs grow dimmer and dimmer. Each time a bulb gets added the voltage gets divided up more. Since there is less voltage per light bulb, the current decreases causing the light bulbs to dim.
25. The more bulbs there are, the less bright the bulbs are. The dimmer bulbs prove that the current in the circuit has decreased. Since the current has to be the same through all parts of the circuit, the current through the power source must decrease as well.
26. Current flows through the battery and the rest of the circuit.

27. Circuits in your home and car are arranged in parallel. If they were not, as soon as one appliance was turned off, all the others would shut off as well.
28. The current in every portion of a series circuit must be identical. Therefore, the current through each light is the same. The reason why the current must be the same for all portions of a series circuit is because there is only one pathway through which the current can move.
29. The voltage is the same across both lamps. Lamps connected in parallel are connected so that all lamps are connected to the same two battery terminals. Since they are connected to the same terminals, they have the same voltage.
30. Since there are multiple pathways through which current can flow in a parallel circuit, there can be different currents in different pathways. The two bulbs are connected so that they have the same voltage. Therefore, the current will be greater through the light bulb that has less resistance. Thick wires have less resistance than thin wires; therefore, the current will be larger through the bulb with the thick filament.
31. 3.0-V because there are two 1.5-V batteries.
32. Bulb C is dimmer than bulb G. (More bulbs in series = less current. Less current = dimmer bulbs)
33. Series
34. B, C, D, and E because they are the dimmest. Dimmer bulbs mean less current.
35. A, F, and G remain lit.
36. At location 1. If it was located anywhere else, it would not be effective. When it blows at location 1, every other light bulb would go off. If it was located anywhere else, it would only shut off a portion of the lights.
37. Batteries are in series when the positive terminal of one battery is connected to the negative terminal of another battery.
38. Batteries are in parallel when the positive terminal of one battery is connected to the positive terminal of another battery.
39. In series, voltages get added together. In parallel, voltages do not add together.
40. As wire diameter increases, resistance decreases.
41. Current is cut in 1/2.
42. The current is reduced to 1/4 its original value.
43. Charge can neither be created nor destroyed, simply transferred from one location to another.
44. In parallel, the resistors have less resistance. Think of bulbs in series and parallel. Two bulbs in series are dimmer than two bulbs in parallel. Therefore, the bulbs in parallel must have a larger current. That means the resistance must be lower.
45. As the length of a wire increases, resistance increases.
46. As the temperature of a conductor increases, resistance increases.
47. The current at all locations of a series circuit is the same.
48. Add each individual resistor up. If you have a 20 Ω, 80 Ω, and 100 Ω resistor, the total amount of resistance in the circuit is 200 Ω.
49. The sum of the voltage drops across the resistors in a series circuit is equal to the voltage of the source. Therefore, if you have a 9.0 V source, the voltage drops across the various resistors in the circuit need to add up to 9.0 V. If you have two resistors and the voltage drop across one resistor is 4 V, the voltage drop across the other resistor would need to be 5 V.
50. The current running through different branches of a parallel circuit can be different.

51. The voltage drop across each pathway of a parallel circuit is the same. If you have a 9.0 V source, then the voltage drop across each pathway will be 9.0 V. The voltage drop will be the same as the source's voltage because each pathway is connected to the positive and negative terminal of the battery.
52. The total current in a parallel circuit is equal to the sum of the currents in the branches.
53. As more branches are added, the amount of resistance in the circuit decreases. Just like if more checkout lines are opened at a supermarket, the amount of "congestion" in the supermarket decreases.
54. During a short circuit, wires on opposite sides of an appliance touch. This creates a low resistance pathway that allows current to bypass the appliance. Current increases dramatically during a short circuit and can cause a fuse to "blow" or a circuit breaker to "trip". As additional branches are added to a parallel circuit, the overall resistance of the circuit decreases. A decrease in resistance creates an increase in current. The higher current causes the wires to heat up and can cause a fuse to "blow" or a circuit breaker to "trip". This situation occurs when the circuit becomes overloaded.
55. To wire a household outlet, connect the black wires to the brass screws, the white wires to the silver screws, and connect the ground wires together and to the green grounding screw.
56. To wire a household switch, connect the black wires to the brass screws, connect the white wires together in a wire nut, and connect the ground wires together and to the green grounding screw.

Electricity Unit
Teacher's Guide for Short Answer Electricity Test
105 Points (Test worth 35 points – multiplied by 3)

The following items needed to be included in the answer to receive points

1. 3 points
   - Balloon becomes negatively charged because it takes electrons off your hair
   - Balloon placed near a wall induces a charge in the wall such that the positive centers of charge have shifted toward the surface of the wall
   - Opposites attract causing the balloon to move toward the wall and stick to it

2. 2 points
   - The force is directly proportional the product of the two charges
   - The force is inversely proportional to the square of the separation distance

3. 3 points
   - Insulators are materials that do not contain movable electric charges and have high electrical resistances. A conductor is a material that contains movable electric charges and has low electrical resistances.
   - Conductors are typically made out of metals, like copper, silver, and gold
   - Insulators are typically nonmetals, like air, wood, and rubber

4. 2 points
   - The ping-pong ball will be repelled as the negatively charged comb is brought near it.
   - The two will repel because each is negatively charged. Like charges exert a repulsive force on one another.

5. 2 points
   - One condition necessary to get electric charge to flow in a circuit is a complete circuit without any breaks or gaps.
   - A second condition necessary to get electric charge to flow is a voltage difference across the circuit. One obtains a voltage difference from a power source such as batteries, an electrical outlet, or a generator.

6. 2 points
   - Current is the flow of electric charge through a circuit and is defined as the amount of charge that passes through some portion of a circuit in a given amount of time.
   - Voltage is the electrical pressure that is applied across a circuit and is necessary to get a current to flow. Voltage is defined as potential energy per unit charge.

7. 3 points
   - Current is measured in amps
   - Voltage is measured in volts
   - Resistance is measured in ohms

8. 2 points
   - As the length of a resistor increases, the amount of resistance in the circuit also increases. The two are directly related.
   - As the diameter of a resistor increases, the amount of resistance in the circuit decreases. The two are inversely related.

9. 3 points
   - Voltage and current are directly proportional. Therefore, as voltage increases so does current. Resistance and current are inversely proportional. Therefore, as resistance increases, current decreases.
   - If the voltage across a circuit is doubled, the amount of current flowing through the circuit will also double.
   - If the resistance across a circuit is doubled, the amount of current flowing through the circuit will be cut in half.

10. 3 Points
    - A series circuit contains a single pathway for current to move through, a parallel circuit contains multiple pathways.
    - The current flowing through a series circuit is the same at each location in the circuit. A parallel circuit may have different amounts of current flowing through different branches.
    - The sum of the voltage drops across the resistors in a series circuit is equal to the voltage of the power source. The voltage drops across the branches of a parallel circuit is equal to the voltage of the power source.
    - Other answers could also be accepted here.

11. 2 Points
    - If the middle bulb of a series circuit goes out, all of the bulbs in the circuit will go out. Since there is only one pathway for electric charges to flow through, a break anywhere in the circuit causes current to stop flowing.
    - If the middle bulb of a parallel circuit goes out, all of the other lights will remain on. Since there are multiple pathways for current to flow through, only the pathway that has been opened will stop working.

12. 2 Points
    - The bulbs in the series circuit are dimmer.
    - The equivalent resistance of a series circuit can be determined by adding together the resistors. The more resistors in a circuit, the greater the amount of resistance in a circuit. Since resistance and current are inversely proportional, more resistance means less current. Consequently, the lights are dimmer. The equivalent resistance of a parallel circuit is less than the individual resistors because more pathways decrease the total amount of resistance.

Electricity Unit
Teacher's Guide for the Multiple Choice Electricity Test
100 points (Test worth 50 points – Multiplied by 2)

Answers

1. B
2. A
3. C
4. A
5. A
6. B
7. C
8. C
9. A
10. E
11. A
12. B
13. C
14. B
15. A
16. C
17. E
18. B
19. E
20. A
21. B
22. D
23. B
24. C
25. C
26. A
27. A
28. B
29. A
30. B
31. C
32. B
33. A
34. D
35. B
36. B
37. A
38. D
39. D
40. D
41. C
42. C
43. C
44. C
45. E
46. D
47. D
48. D
49. D
50. B

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