CURRENT ELECTRICITY

PROBLEM PRESENTATION / EXPLORATION

A. Homemade Batteries
  1. Lemon/coin battery
    a. Obtain a lemon and roll it a few times on the counter.
    b. Make two parallel slits very close together in the lemon
    c. Insert a copper penny (minted before 1982) in one slit and a nickel in the other slit. the coins can be very close but must not touch each other.
    d. Touch both coins with your tongue at the same time. What happens? [They will feel a small electric shock.] The lemon juice kills the bacteria on the coins. (I still think that it would be a good idea to clean the coins with soap and water and a brush before performing this activity.)
    e. A larger version of the lemon battery can be made by using larger strips of zinc and copper stuck into a lemon. About 1 volt can be produced with this type of battery. Because only a small amount of current is flowing, only a very small bulb may be made to light up. If you change the zinc to magnesium a small clock that runs on batteries can be operated. Just remove the alkaline battery and attach the magnesium strip to one side of the clamp that holds the battery. Attach the copper strip to the other side of the clamp. Allow the two metals to hang in a glass of orange juice. The clock will keep excellent time for quite a few hours. There is a commercial product called the Two Potato Clock® which is composed of zinc and copper electrodes that will run a digital clock for weeks. The electrodes can be stuck into potatoes, oranges, apples, Coke®, and many other substances. This clock will accurately provide time for months before the potatoes must be replaced. They can be ordered from Arbor Scientific Co. as well as from various toy stores.
  2. An 11¢ battery
    a. Clean a number of pennies (minted before 1982) and a number of dimes with soap and water and a brush.
    b. Soak pieces of filter paper (paper towel will do) in salt water.
    c. Arrange pennies and dimes in alternating layers separated by a piece of filter paper that has been soaked in salt water. Start on the bottom with a penny.
    d. Attach to the bottom penny with an alligator clip a wire hooked to one side of a galvanometer. Attach to the top dime with an alligator clip a wire hooked to the other side of the galvanometer. Note the reading. How large was the deflection? In which direction was the deflection. (If you don't have alligator clips you may hold the wires to the coins with your fingers. The magnitude of the current is so small that it will not harm you.)
    e. Reverse the leads from the coin battery to the galvanometer. Note the magnitude of the meter. Note the direction of the deflection. Were there any differences this time? [The magnitude remained the same. The deflection was in the opposite direction.]
    f. Based on your observations from which end of your coin battery did the electrons come out and go into the galvanometer? [Came out of the penny which is the negative end.]
    g. Change the number of dimes and pennies used to make the battery. Note the magnitude of the deflection as these changes are made. [No change in direction but the magnitude is larger when more coins are used. Each of the cells is in series with the other cells.]
  3. Wet cell battery (the Gerber Cell)

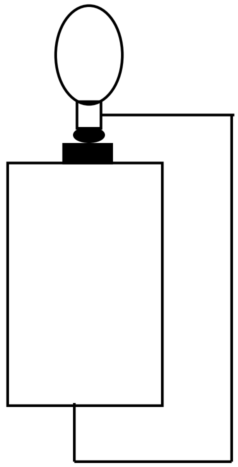
- a. Obtain strips of two different metals. Copper and magnesium make good ones.
- b. Sand the strips of metal with a fine coarse sandpaper. (The copper metal could be cleaned by dipping it in a dilute nitric acid solution for a few seconds. The magnesium strip could be cleaned by dipping it quickly into a 1 M hydrochloric acid solution.)
- c. Fill a Gerber® baby food jar with sodium sulfate solution. Place the magnesium strip in the jar.
- d. Cut a 15 cm strip of dialysis tubing and hold it under water until it becomes flexible. Tie a knot in one end to make a bag. Put the copper strip in the bag and fill the bag with copper sulfate solution. Place the bag with its contents into the Gerber® jar.
- e. Insert a rubber stopper so that the magnesium strip and the copper strip in the bag are held in place above the jar.
- f. Attach a volt meter to the two strips. Note the voltage produced in this "wet cell" battery.
- g. Attach two wires to a flash cube or a flash bulb. When these wires are touched to the magnesium and copper strips in the Gerber cell the flash bulb should be set off.

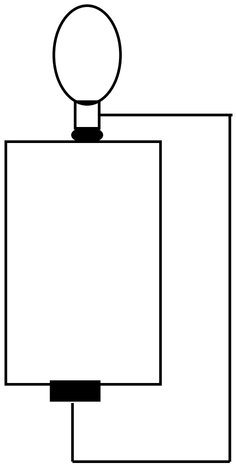
B. Batteries and Bulbs

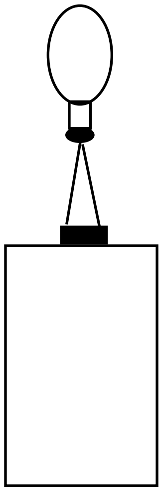
1. Although students can define a circuit after studying a textbook, they need concrete experiences with a battery, bulb, and wire to really understand the concept of a circuit.
2. Challenge: How many ways can you get a bulb to light using a battery, a bulb, and one wire?
3. Eventually one or two students will get the bulb to light. (You will be surprised how many students will have trouble doing this.) The other students will copy the arrangement to get their bulbs to light. Ask the class what special places on the battery and bulb must be touched to get the bulb to light.
    - a. Note that the dry cell battery has two special places. The top of the battery is the positive terminal, and the bottom of the battery is the negative terminal. Electrons flow from the negative pole to the positive pole of the battery through an external circuit.
    - b. The bulb has two special places that must be connected to the dry cell to light the bulb. The silver tip on the bottom of the bulb and the gold threads on the side of the bulb are the two special places that must be connected by a conductor to the two poles of the battery.
4. Urge the students to find other ways to light the bulb. Only after a variety of ways has been discovered should you give them the prediction sheet and ask them to predict which of the drawings represent a hookup where the bulb would light up. Let them build it and check their prediction.

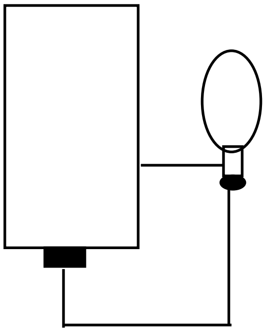
Batteries and Bulbs Prediction Sheet

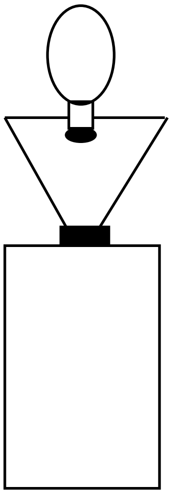
Draw a circle around each of the following that would light the bulb as depicted. Build any of those that you are not sure of and see if they do light the bulb.

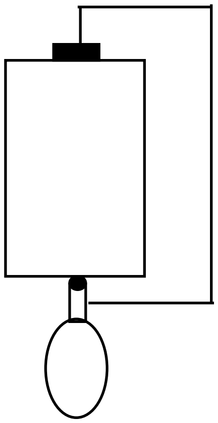












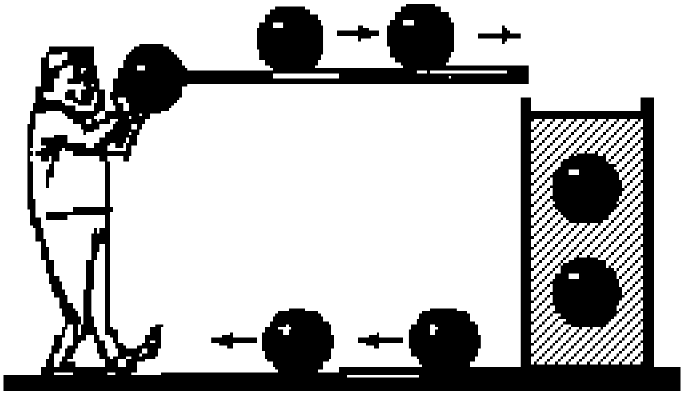
CLASS RESPONSE / CONCEPT INVENTION

A. Teacher Background

From the lessons on static electricity we have seen that electrons can be build up on a substance by physically rubbing two substances together in a way so that electrons are rubbed off (work done) one substance and transferred to the other. Work was required to separate the negative from the positive charge to create the static charge. Furthermore, we saw that a charged object (the electroscope) could be discharged. This was demonstrated by the sensation of being shocked as well as lighting up the dead fluorescent bulb. This movement of charges is called electric current. Normally we only call it current if it continues to move for more than a fraction of a second. If a path can be provided so that charge can continually move we have an electric circuit. The most important component of the circuit is the device capable of continually separating negative from positive charge. In doing this it imparts to the electrons stored energy that can be used to continue the flow of charge. This component is normally thought of as a battery. Traditionally the energy supplied to separate the charge is chemical energy due to the chemical reactions going on in the battery. Electric current always results at the expense of some other energy required to separate the negative from positive charges. Two other forms of energy that can be tapped are heat which produces a thermocouple and a solar cell which depends on energy supplied directly from the sun. In the next lesson (Electromagnetism) we will see that charge separation between terminals can be maintained by the application of mechanical energy to an electric generator.

The electric current in a circuit is due to the regular motion of the electrons past a given point. Current is defined as the rate of movement of charge past a definite cross section. In other words current equals the charge passing a certain cross section divided by the time taken for the charge to pass that point. The charge on 6.26×10^{18} electrons comprise a negative charge known as one **coulomb**. When one coulomb of charge passes a given point in one second the electric current is said to be one **ampere**.

The motion of electrons in a circuit can be described by comparing an electric circuit to an imaginary bowling ball circuit. Here a man lifts the balls from the floor to a shelf. The balls roll along the shelf into a cylinder of heavy oil. They fall through the oil at constant speed and are removed from the bottom by a trapdoor mechanism. The balls roll along the floor to be picked up by the man to repeat the process. As the man raises each ball from the floor to the shelf he transfers to the ball a certain amount of energy. On the shelf the ball has more gravitational potential energy than it had on the floor. If the ball fell off the shelf through the air its potential energy would be transformed to kinetic energy. But in falling at constant speed through the oil the potential energy lost by the ball is transferred to the molecules of the oil, raising its temperature. The bowling balls are agents by which the work the man does is transferred to heat in the oil. The process can continue as long as the man has enough energy to lift the bowling balls.

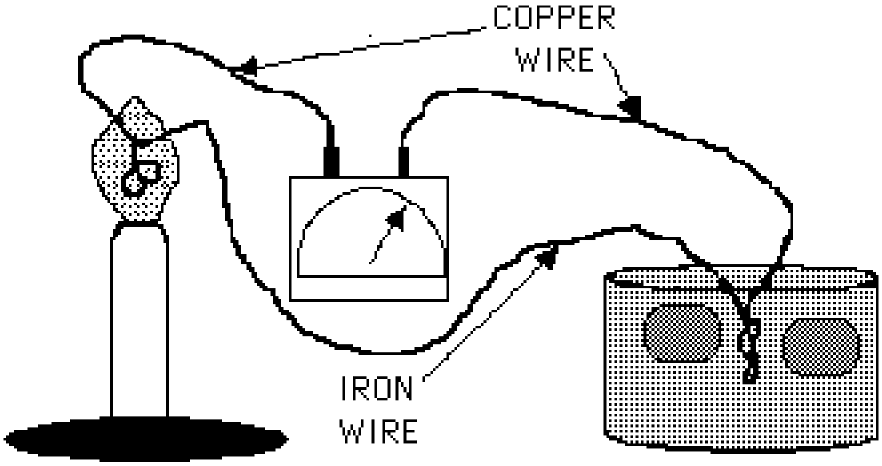


Similar terms can be used to describe the motion of electrons in the electrical circuit. The dry cell transforms its chemical potential energy to the potential energy of electrons as it "raises" them from the positive terminal of the battery to the negative terminal (chemical reaction provides the energy). The electrons drift through the circuit to a lamp. As the electrons "fall" through the lamp filament their potential energy is transferred to the ions of the filament, raising its temperature. The chemical energy of the cell is transformed to electrical potential energy which is transformed to heat in the lamp filament.

In the same way that the man supplies each bowling ball with gravitational potential energy, the dry cell supplies each electron with electrical potential energy. Thus there is an electrical potential energy difference per electron between the positive and negative terminals. The quantity of energy per charge is called **electrical potential**. If an amount of energy is supplied to an amount of charge as it moves between the terminals, there is an electrical potential difference between the two points. If a battery supplies 1.0 joules of potential energy for each coulomb of charge, there is an electrical potential difference of one **volt**. Often the term voltage is used in place of electrical potential. If the oil provided more resistance to the movement of the bowling balls, fewer of them would travel through the oil in a given amount of time. Thus, for the same amount of voltage a smaller amount of current would flow when there is greater resistance.

B. Thermocouple

1. Obtain three lengths of wire, two copper wires and one iron wire.
2. Join the iron wire and one of the copper wires together by twisting them to make a junction. Twist the other end of the iron wire to the other copper wire to make a second junction. Attach the remaining ends of the two copper wires to an ammeter.



3. Place the first junction in a beaker with ice and water (cold junction). Place the other junction in a candle flame (hot junction). Note what the ammeter is indicating.
4. Heat energy is being used to liberate the electrons which then can flow through the ammeter on their way to the cold junction.
5. Replace the candle with a Bunsen burner flame. What change is indicated? [The greater the temperature between the junctions, the greater the current.]
6. The current reading could be used to measure how great a temperature difference there is between the two junctions.

C. Conductivity tester

1. Connect one side of a bulb holder to one end of a dry cell battery. Connect a copper wire to the other side of the bulb holder. Attach an alligator clip to the free end of this wire.
2. Connect another copper wire to the other end of the dry cell battery. To this free end also attach an alligator clip.

3. Place a small bulb in the bulb holder and touch the two alligator clips together to see if the bulb will light. If it does the circuit is complete and ready to be used as a conductivity tester.
4. Test a number of objects by touching the two alligator clips to them. If the light bulb lights up they are conductors, if it doesn't they are non conductors.
5. From the selection of objects which cause the bulb to be brightest? Which allowed it to only barely light up?
6. Obtain a long pencil. Cut the wood of the pencil away to expose the graphite center. Scrape the wood off so that at least a 10 cm portion of the graphite is exposed.

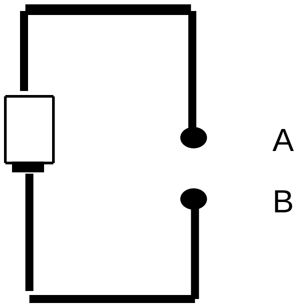
7. Attach one of the alligator clips from the conductivity tester to the pencil point at the end of the pencil. Touch the second alligator clip to the graphite exposed closest to the pencil point. Note the bulb.
8. Slide this second alligator clip along the graphite toward the eraser end. What happened to the brightness of the light in the bulb?
9. What could account for the smaller amount of current passing through the bulb as the alligator clip was moved from contact at about 4 cm from the other clip to about 10 cm from the other clip? [There was greater resistance due to the longer length of graphite the electrons had to travel. With the same pushing power provided by the battery, more friction and collisions with the carbon atoms in the graphite caused less charge per second to pass through the circuit. Consequently, the bulb didn't have as much current passing through it and it didn't light up as much.
10. Repeat step nine with only one change. Get one of those big fat pencils that first graders use or a carpenter's pencil that has big thick lead. Compare the brightness at the 4 cm mark and the 10 cm again. But also compare the brightness at the 4 cm mark for an ordinary pencil and the 4 cm mark for the fat lead pencil. In which case did there seem to be less current flowing (as deduced by the brightness of the bulb) ? In which case was there the most resistance to the flow of the current?
11. This leads us to the important relationship that as resistance increases, the amount of current decreases. More specifically it says that **if the voltage is held constant, current flow is inversely proportional to resistance**.
12. Use the first stripped pencil for the following investigation. Attach the first alligator clip at the pencil point. Attach the second one at the 4 cm point. Now replace the dry cell battery, first using a 1.5 volt, then a 6 volt, and finally a nine volt battery. Compare the brightness of the bulb under each new voltage.
13. **With the resistance being held constant the voltage is directly proportional to the current flow**. (The more voltage, the more current flowed which made the bulb brighter.)
14. For the third investigation we will need both of the scrapped pencil setups. The first one will feature the regular pencil with the 1.5 volt dry cell. The alligator clips will be attached at the pencil point and at the 4 cm mark. The second set up will use the fat pencil and the 6 volt dry cell. One alligator clip will be at the pencil point. Move the second alligator clip so that the brightness of the bulb will be the same as in the first set up.
15. We know that the thick lead offers more resistance that the thin lead. So if we start by putting the second alligator clip at the 4 cm mark in the fat pencil we know that there is more resistance being experienced than in the first set up. Because we have to move the clip toward the eraser end before the brightness is similar to the first set up, we know that for the same amount of current to be flowing (same brightness) there must be more resistance for more voltage. In other words, **with the current remaining constant, the voltage is directly proportional to the resistance**.

16. These three investigations have all been combined to give us what is commonly referred to as **Ohm's Law**. Using the following symbols, **I** for current, **V** for voltage, and **R** for resistance, Ohm's Law is expressed as:

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

D. "DRAW" a Circuit

1. With a very soft "lead" (graphite) pencil draw a simple circuit such as the following containing a battery and some "wires." The circuit is open because of the gap at A and B.

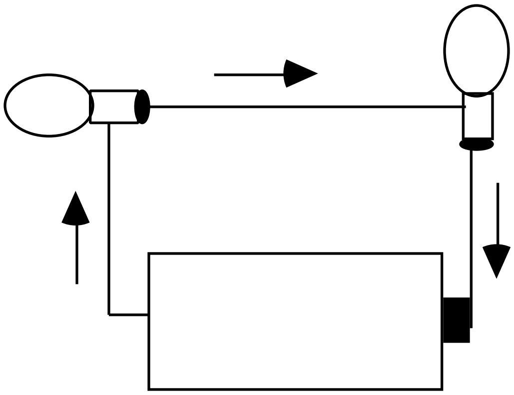


2. Place the leads of a VTVM (Vacuum Tube Voltmeter) on the dots at A and B. If the graphite lines are thick and no gaps occur, the meter should indicate that a current is actually flowing through the lines drawn. A tight connection must be made from the battery. Copper wires coming from the + and - ends of the battery should be taped securely to the graphite lines where the battery is indicated in the circuit.
3. Erase part of one line showing that without a complete circuit the current will cease to flow. Redraw the line and the current should start to flow again.
4. Lengthen the lines of the circuit to see if the meter changes.

CONCEPT EXTENSION

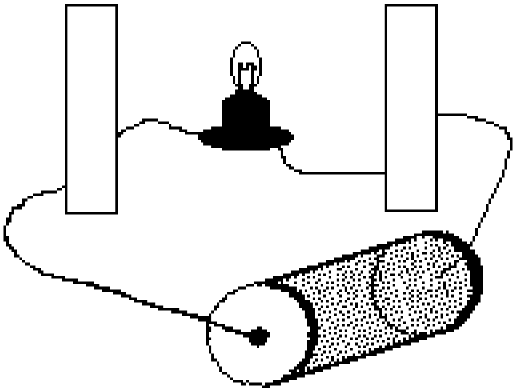
A. Challenge: How can you make two bulbs, a battery, and two wires light both bulbs?

1. As before, give the supplies to the students so they can explore rather than you telling them how to do it. If they have grasped the concept of a complete circuit and that the special places that must be attached on both the battery and the bulbs, they should figure this out in a short period of time.
2. The biggest problem they will probably have is keeping all the connections together. Provide some tape so that they don't get frustrated with the connections coming loose and lose sight of the idea of the light bulbs being hooked together in series.
3. Point out that in all of their successful circuits that **there is only one path that the electrons can take when they leave the negative end of the battery and follow before returning to the other end of the battery**. This is called a **series circuit**.

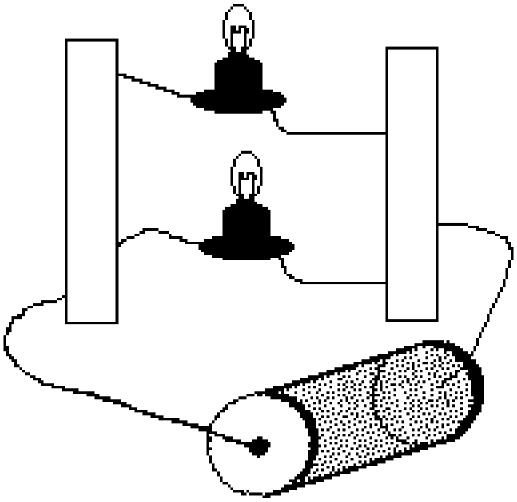


B. Parallel Circuits

1. Obtain two strips of aluminum foil about 15 cm long and 1 cm wide. Place them on the table parallel to each other with about 10 cm between them. Prepare two copper wires each with an alligator clip on one end. The other end of each should be securely attached to the poles of the dry cell battery. Screw in a bulb to a bulb holder and attach a copper wire to each post. Each of these wires should also have an alligator clip on one end.
2. Now, attach one of the alligator clips from one end of the battery to one of the alligator clips coming form the bulb holder. Before hooking the alligator clip from the wire attached to the other end of the battery to the second wire coming from the bulb holder, ask the class what will happen, if anything, when the connection is made. If they are following what you have done, they will see that this is nothing more than a simple complete circuit. When all the connections are made the bulb comes on.



3. Obtain a second bulb and bulb holder equipped with two wires having alligator clips on one end that are hooked to the holder exactly like the first one. Before proceeding, disconnect the clip coming from the battery to the second aluminum strip. Leave the first bulb hooked up as in #2 above.
4. Ask students what would happen if the second bulb and bulb holder were also connected to the two aluminum foil strips in the same fashion as the first one. In other words, the two aluminum strips are like two legs of a ladder and the first bulb/holder forms the first rung while the second bulb/holder forms a second rung. See diagram below.



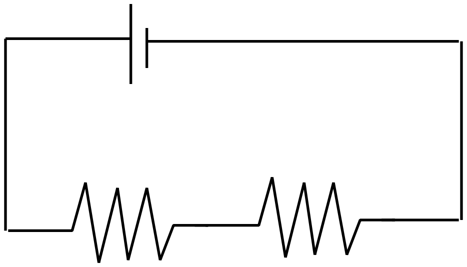
5. Hook the second bulb in but don't complete the circuit until some discussion has transpired. Have the students try and trace the path the electrons would

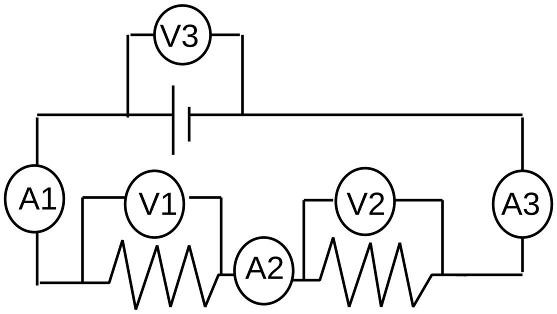
follow to get from one end of the battery back to the other end. Hopefully it will be seen that there is now **more than one path for the electrons to follow**. When the connection is completed, some electrons will travel one path while some will travel the other path. Consequently, both bulbs will light up? We call this type of circuit a **parallel circuit**.

6. Now give each student one battery, two bulbs, and four wires. Ask them to make a parallel circuit that will light up both bulbs.
7. After some experimentation time direct the students attention back to the aluminum strips and the two bulbs hooked together in parallel. Ask them what would happen if you unscrewed the top bulb so that it is not making connection. [Obviously the lower bulb should not go out because of the way we put the system together in steps. Indicate to them that this is the neat thing about parallel circuits, that if one bulb goes out the other can still stay lit.]
8. Find someone in the class that has the two bulbs wired in parallel and someone else who has them wired in series. Start first with the parallel one and say to the class, "What would happen if we unhook one of the bulbs, would the other one stay lit?" [When you do it, it stays lit.]
9. Repeat the question for the series circuit. [When one of the bulbs here is removed there is no longer any complete path for the electrons to follow and the other bulb goes out.]
10. Let them work some more with trying to set up parallel circuits.

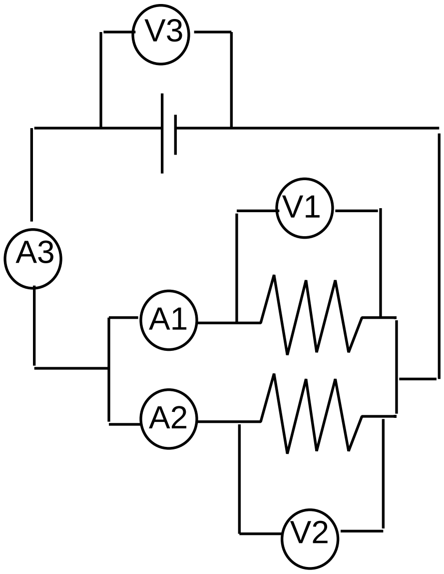
C. How Bright is the Light?

1. Four identical bulbs and two identical batteries are needed for this exercise.
2. First hook up a single bulb to a battery and note its brightness. Then hook another one in series. How does the brightness compare in the two cases. [Even though they were exposed to the same total voltage the amount of current flowing in the first case caused a brighter light. When the resistance was doubled in the second case the brightness was less. [As the resistance went up, the current went down; Ohm's Law.]
3. Unscrew one of the bulbs. What happens? [Since there is only one path for the electrons to follow, breaking the path prevents either bulb from staying lit.
4. Now hook two of the bulbs in parallel to an identical battery. Compare the brightness of the bulbs hooked up in series and those hooked up in parallel. [The bulbs in series will be dim while the bulbs in parallel will be brighter.]
5. Unscrew one of the bulbs. What happens? [The second bulb continues to burn. Since there are two paths for the electrons to follow on their way back to the other terminal of the battery, the second bulb continues to burn.]
6. Compare the brightness of the two bulbs in parallel with each other. What happens to the brightness when one of the bulbs is unscrewed? [The brightness is the same in each bulb. The brightness does not change with one bulb is unscrewed.]
7. If you have access to ammeters and volt meters, you might want to investigate quantitatively what they have qualitatively seen. The schematic below is that of two resistors (light bulbs) hooked to a battery in series. Below that is the schematic with the meters attached.





8. Meters A1, A2, and A3 will all read the same. The sum of V1 and V2 should equal V3. From this it appears that the current is the same throughout the whole circuit (only true for series circuits). It also appears that the sum of the voltage drops across the two bulbs equals the total voltage (also only true for series circuits).
9. Make the same measurements with the parallel circuit.



10. Meters V1, V2, and V3 will all read the same (only true for parallel circuits). The sum of A1 and A2 will equal A3 (also true only for parallel circuits). From this it seems that the voltage remains constant throughout the entire circuit. It also appears that the sum of the individual branch currents equals the total current in the cell.