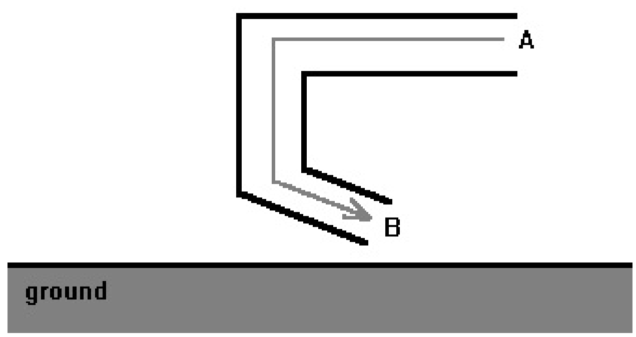
Chapter 26: Electronics

Electrical Circuits and Voltage

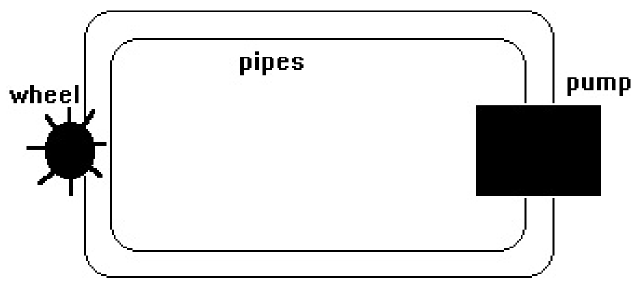
Although all of the concepts we have been discussing previously may seem very abstract and theoretical, they have very direct applications and ramifications in our everyday life. We live in a world that is essentially powered by electricity. We have learned to harness the electrical force and use it to light our homes, power our machines and give life to our communications. The study of the behavior of electrons in an electrical circuit, with an aim towards using that circuit for a practical purpose, is called electronics.

An electrical circuit is a set up which generally includes a source of electrical power, a conducting path and some other device which somehow uses the energy in the circuit. It is important to understand just how a circuit works in relation to the concepts learned previously. The power source provides an electric field and the conducting path (usually metal wires) "guides" and modifies this field. The purpose of the wires is to get the field restricted and cause it to go a certain way. Imagine that we were able to do such a thing with gravity. It would look like the diagram below:



Imagine that we had the ability to restrict gravity on the surface of the earth so that it existed only within the container outline in solid black lines, and furthermore, it was shaped to fit the container. If we dropped a mass from point A, it would "fall" to point B and have gained kinetic energy. At point B we could extract this energy in some fashion and then return the mass to point A (in this example, that would require no work, since there is no gravity outside of the tube, but in the case of electricity, it would). An electrical circuit is very similar. A field is created from one side of the power source to the other, using wires to shape and guide the field. Electrons are allowed to "fall" down the field from the negative to the positive side. They are then moved back "up" to the beginning. Moving them back "up" requires energy. Thus is the job of the power source not only to create the field the electrons move in, but also to bring them back to the beginning. It is the job of the wire to guide the electrons (so they go where we want them to) and also to supply the electrons in the first place. The particles that move in an electrical circuit are the free electrons in the wire. The path provides the particles. The device in the circuit is something that "gets in the way" of the particle's travels and thus uses some of their energy. This could be something like a resistor (which heats up due to the collisions of particles) or an electric motor which used the Lorentz force created by the moving particles to turn a motor (which provides resistance by Lenz's Law and thus takes energy away from the electrons).

Another common example presented in many textbooks is the water analogy. Imagine a circle of water pipes, with a pump and a water wheel enclosed in them (see diagram). The pump pushes the water around the pipes, and the water turns the water wheel..



The pump would be giving the water energy to flow around the pipes and turn the wheel. The wheel would be taking energy away from the water as it imparted rotational kinetic energy to the wheel. Comparing this to electricity, the pump would be the battery, the pipes would be the wires, the water would be the electrons, and the wheel would be whatever device is being powered (light bulb, heating element, etc.). There is a good deal of understanding that can be gained from this example. The student might want to consider the following:

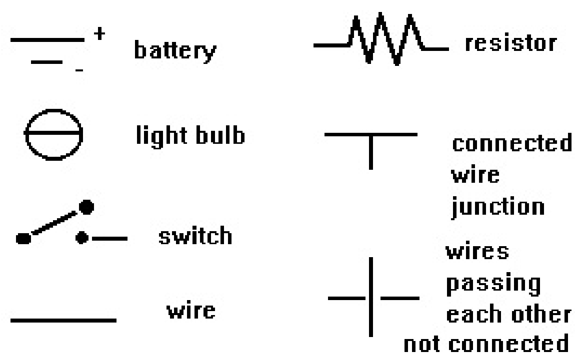
- What effect would changing the size of the pipes have on the energy of the water wheel?
- What would happen if you put in a more or less powerful pump?
- What if you put in two water wheels?
- What if you increased the resistance from friction of the water wheel or installed a larger one?

- What if you added extra pipes and expanded the set up to accommodate another water wheel (there are two ways to do this).
- What if you increased the lengths of the pipes?

We will refer back to this analogy time and time again in this section.

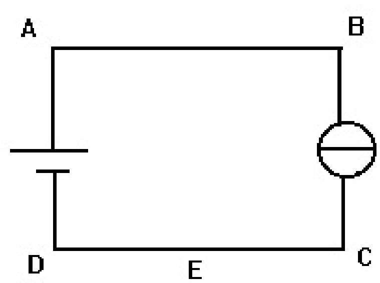
There is much more to be discussed about how a circuit operates on a conceptual level, but in the actual use of circuits there are many utilitarian ideas that simplify things. It is time to turn our attention to those ideas.

Before we begin to understand exactly how circuits work, it is helpful to lay down a few essential concepts and some terminology and diagramming conventions. In electrical diagrams, it is standard to use the symbols shown below:



It should also be noted that the wire we will use in discussing electrical circuits are to be considered "ideal wires". Ideal wires offer no resistance to the passage of electrons; in short they are frictionless.

Let us begin with a very simple circuit:



The points are labeled for future reference.

The first electrical concept we need to discuss is the voltage in the circuit. Voltage, we have learned, is a measure of the potential energy per charge that exists in a field. When dealing with electronics, it is helpful to remember that voltage is connected to energy in the circuit. It is not the same as energy, but the two are related. Imagine a positive charge moving in the circuit above (we use a positive charge for a slightly strange reason explained later). If we wished to discuss the energy changes that occur to the charge, we would have to specify the change from where to where. Voltage, you may recall, is a change. It is more properly written as ΔV instead of just V. However, in electronics, it is customary to drop the delta and just write it as V, assuming that everyone understands that it is actually a change.

This is important: voltage in a circuit is always a change in voltage from one point to another. It makes no sense to ask what is the voltage at one point. You must ask what is the voltage from one point to another, or what is the voltage change (or voltage drop) from one point to another.

In our water analogy, the strength of the pump is a measure of the voltage. A stronger pump would mean being able to move a bigger wheel.

With this in mind, what happens when a + charge goes from D to A in our circuit? The battery gives it more energy and thus we say that the voltage from D to A (written as V_{DA} and spoken as either "the voltage from D to A" or the "potential change from D to A") is positive because a positive charge will gain in energy going from D to A.

What about V_{BC}? In this case, some of the energy of the charge would be lost in the light bulb, thus the voltage is a drop or a negative.

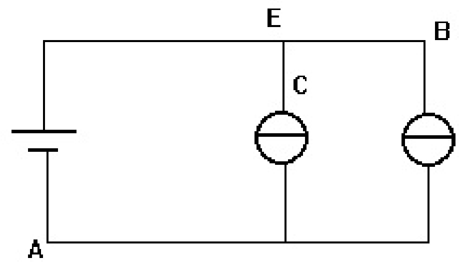
What about the voltage from C to D? In this case, the voltage change would be zero (in an ideal wire). No energy is either lost or gained.

What about the voltage from C to B? If a charge moved between them, it would lose energy. This poses a problem and for the moment we will not address this situation.

The voltage from A to D is obviously a negative and thus $V_{AD}=-V_{DA}$.

The last one to consider is V_{EA}. A bit of thinking will convince you that V_{EA} is the same as V_{DA}.

Now let us consider another circuit:



In this circuit, you should notice that:

$V_{AB}=V_{AC}$

because

$V_{AB}=V_{AE}+V_{EB}$ and $V_{EB}=0$

and

$V_{AC}=V_{AE}+V_{EC}$ and $V_{EC}=0$

From these example, you should be able to draw a number of conclusions about voltage. They are:

<u>Conclusions Regarding Voltage</u>

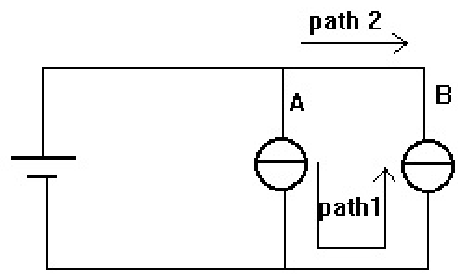
1.) Voltage must involve two points in the circuit.

2.) Voltage from point 1 to point 2 is opposite in sign to voltage from 2 to 1. i.e. $V_{AB}=-V_{BA}$ (but there is a problem with resistors...)

3.) If there is nothing in between the two points to give or take energy (battery, light, resistor) then $\Delta V=0$ in ideal wires.

4.) Voltage does not change when the wire splits into branches (as in the last example).

5.) Voltage is path independent, thus the most convenient path should be used to find the voltage. Consider the diagram below. The voltage from A to B can be found by evaluating the energy along either path 1 or path 2. Path 2 is easier and thus the voltage is zero.



Electric Current

During our discussion of electromagnetism, we introduced the idea of electrical current. We do so again here, to remind the student of these concepts and to relate current to electrical circuits. Please pardon the repetition.

In the previous circuits, we have been discussing how an electron will move around the circuit and gain energy. This happens because a voltage is applied (typically from a battery) which causes the electrons to move. This flow of electrons around the circuit is called a current. The electrical current is the rate at which charges flow, or, more precisely, the number of charges that flow past a point in a unit of time. Thus current is measured in charges/time or C/sec. A Coulomb per second is a special unit called an Ampere.

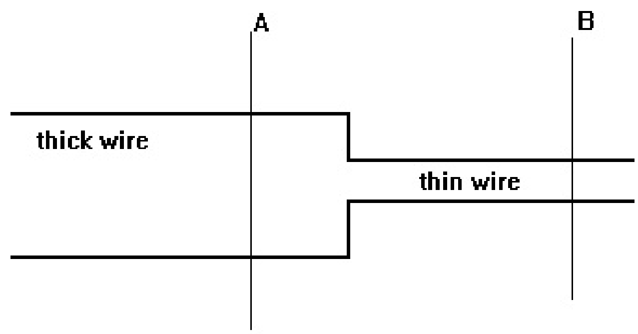
1 Amp = 1 C/1 second.

Current is not really a vector, it is often called a pseudo-vector. It does not have a direction, but for descriptive power we often say the current travels in the direction of the positive flow of charge. Notice how that would mean that in an electrical circuit, we would say that the current is actually opposite in direction to the flow of electrons. We abbreviate current with either a capital or a lower case "i".

It is very important for the student to understand exactly what current is and what it is not. Current is a measure of the number of charges that pass a given point in a given amount of time. Do not confuse current with the velocity of the electrons. Electrons in a wire will normally travel only on the order of cm per second. However, there are so many electrons in the wire that the current can be very high, even at such a slow speed. There are two ways to get a high current: either move many electrons slowly or a few electrons quickly.

The electrons in the metal are always jumping around, colliding and changing directions. In a circuit, the electrons continue to do just this, but the electric field that is produced by the battery will cause them to slowly move in one direction. In other words, a current is not a neat, orderly flow of electrons in a straight line, it is a mess of bouncing electrons that slowly moves to one side.

It should also be noted that currents do not change when the encounter a new wire. Consider a thick wire that is connected to a thin wire as shown.

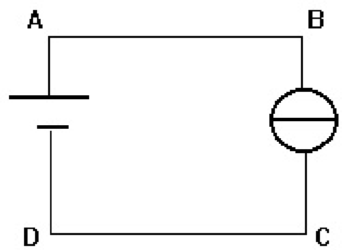


If we imagine electrons flowing through the wire, we can determine the current by counting the electrons that pass through plane A in a given time. Notice that the same amount of electrons must pass through plane B in the same amount of time, otherwise we have a problem (what would that be?). Thus the electrons must move faster in the thin wire, or at least they must be more crowded together.

Back to our water analogy, the current is the number of gallons per second that move through the pipes. A little bit of thinking will show you that the current in that example is the same if measured at any point (i.e. at the mouth of the pump, in the middle of the slide, at the intake of the pump, etc.)

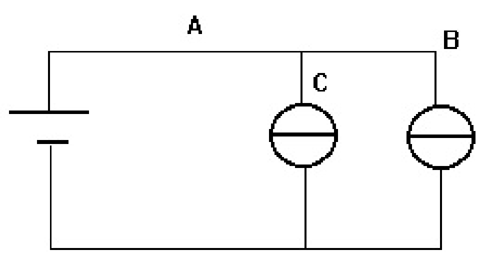
One final comment about current. The current is not the rate at which the electrical energy travels. Electrical energy travels much more quickly, at almost the speed of light. Halliday and Resnick give a good example in their third edition, saying that when a water hose is turned on, water power comes out before the water drops have traveled the length of the hose.

EX D.) By examining the currents at the points A, B, C, and D in the diagram below, draw a conclusion about the behavior of currents in a circuit.



We should have seen from that example two things about current. The first is that unlike voltage, current is only measured at one point in the circuit. Also, current is unaffected by obstacles that cause the electrons to lose energy. The current at all four points should have been the same.

EX F.) By looking at the currents at points A, B, and C, determine another property of current behavior.



From the last two examples we see that obstacles do not affect current but branches do. Notice how this is exactly the opposite of our conclusions about voltage.

Conclusions Regarding Current

1.) Current is measured at only one point in the circuit.

2.) Current does not change when electrons pass through an obstacle.

3.) Currents change when electrons hit a branch in the circuit.

4.) Current has a direction given by the apparent motion of positive charges.

Resistance and Ohm's Law

As electrons flow around a circuit, they often encounter resistance in their path. Resistance is not a property of the electricity flowing around the path, it is instead a property of the path itself. Resistance is a measure of an objects ability to resist the flow of electrons, or to let fewer pass through each second. It is measured in a unit called an Ohm (Ω) where

$$1\ \Omega = 1\ V/A.$$

Notice how the resistance is defined for an object, not a material. A little thought should tell you that the following factors will affect the resistance of an object:

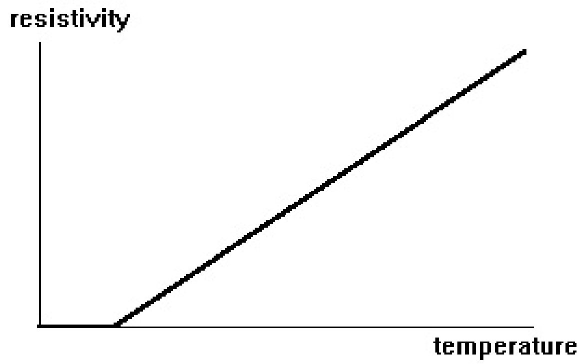
1.) Material
2.) Cross Sectional Area (A)
3.) Temperature (T)
4.) Length (L)

The material affects the resistance of the object in an obvious way; some materials are better conductors than others. When discussing materials, it is convenient to discuss their resistivity (ρ) which is a materials resistance to flow of electrons in Ohm-meters (Ωm). This concept will relate the other factors and give us a simple equation for the resistance of a wire:

$$R = \rho L/A.$$

Notice how the resistance of the wire is directly dependent on the length (twice as long means twice the resistance) and inversely related to the cross sectional area (twice the area, half the resistance). How does the resistance relate to the radius of the wire?

The next question is how does temperature affect resistivity? It turns out that resistance is <u>almost</u> linearly dependent on temperature (why does this make sense?). The relationship looks like the graph below:



Notice something interesting here, the resistivity hits zero before the temperature does. That means that at some temperature, a material offers no resistance to the passage of electrons. It is essentially frictionless to electrons trying to get through. This is a unique and important concept called superconductivity. If a material is at superconducting temperatures, it is a perfect conductor. The only problem with this is that it is difficult and expensive to keep conductors that cold. However, in recent years we have found materials that will superconduct at higher and higher temperatures. The "pot of gold" would be to find a material that superconducts at room temperatures. The benefits of superconductivity are many. Imagine a wire with no resistance. If we had electrons moving, they would stay moving forever. An incredible amount of power that is generated at the power plant is lost due to resistance in the wires as it travels to your home. If those wires were superconducting, electrical generation would be more efficient and cheaper.

This might be a good time to further elaborate on our comments regarding "ideal wires". When discussing voltage, we stated that there is no voltage (no potential difference) between two points that do not have an obstacle between them. This statement is only true if we are considering the wires to have no internal resistance. Such a wire is called an "ideal wire". Although this statement is inherently false (unless the wires are superconducting), we can use it as a fairly accurate approximation of reality, provided the resistance in the wires is negligibly small compared to the resistances in the devices in the circuit (An astute student should be able to determine exactly how this would affect our comments on currents in the circuit).

If one considers the three electrical properties discussed so far, voltage, current and resistance, one can come to the conclusion that they must somehow be related to one another. The amount of electrons that pass through a device in one second should be related to the energy pushing them and the resistance of the path they are traveling. This relationship is:

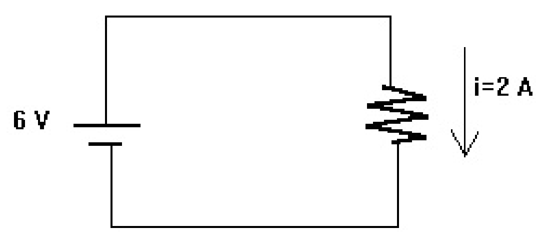
$$V=iR$$

Where V is the voltage from one end of the device to the other, i is the current flowing through it and R is the resistance of the device. The above equation is actually the definition of resistance. The resistance of a device is found by:

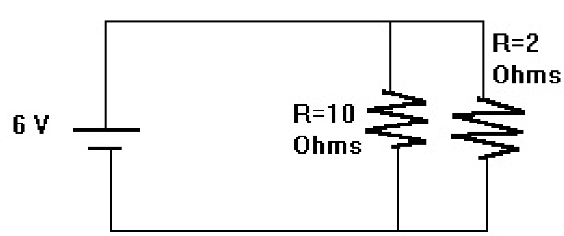
$$R=V/i.$$

<u>The above statement is always true, and the student should commit it to memory. It will be used over and over again in just about every problem involving electrical circuits.</u>

EX K.) What is the resistance of the resistor below?



EX U.) What is the current flowing through each of the two resistors below?



What we have just been discussing, V=iR, is often mistakenly called "Ohm's Law". In fact, many basic text books refer to it as such. In reality, it is not Ohm's Law, although it is related to it. Since it is often called as such, I will refer to it as the Pseudo-Ohm's Law.

The real Ohm's Law has to do with the actual resistance of a device. It says:

> "A device is Ohmic (meaning it obeys Ohm's Law) if its resistance is independent of the voltage across it or the current running through it (in both magnitude and direction)."

In other words, a device is Ohmic if its resistance is constant. For such a case, the graph of V vs i for the device would be a straight line. There are times, however, when a device is not Ohmic. Some devices, like a light bulb, have more resistance when more voltage is applied. The more power you give, the more resistance the device gives to the passage of electrons. Other devices will have different resistances when the voltage switches directions. It might be easy for electrons to pass through in one way, and difficult in the reverse direction.

It is important to note that regardless of whether or not the device is Ohmic, the Pseudo-Ohm's Law still applies. At any given voltage, the resistance of the device will be given by V/i. Mathematically, an Ohmic resistor will follow the equation:

$$V=iR$$

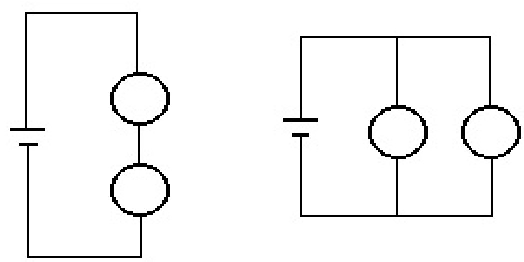
where R is a constant. While a non-Ohmic will follow:

$$V=iR(V)$$

where R is a function of V.

Series Versus Parallel Circuits

Imagine that you had a battery, some wires and two light bulbs and you wanted to put them into a circuit. There are two possible ways of accomplishing this:



The set up on the left is called wiring the light bulbs in series and the set up on the right is called wiring them in parallel. Using your knowledge of circuits, you should be able to reach the following conclusions:

Conclusions Regarding Series and Parallel

1.) In a series circuit, the light bulbs will have the same current, while in a parallel circuit they are not guaranteed to have the same current (true, if the bulbs are identical, they will, but that is a special case).

2.) In a series circuit, the light bulbs are not guaranteed to have the same voltage, but in a parallel circuit, they will always have the same potential difference across them.

If you think about this some more, you will realize that the parallel bulbs will burn brighter than the series bulbs, but will use up more power from the source. Also, on the series set, if one bulb burns out, the other will not glow (remember all those annoying holiday lights?). In the parallel circuit, if one bulb burns out, the other will remain lit. Most of the wiring in your home is done in parallel, while some is in series. For example, a circuit breaker (a switch that protects against over loads) is always wired in series. On the other hand, all of your outlets are wired in parallel, so that they have the same voltage. Besides that, they are wired in parallel so that if one device (a light bulb) burns out, the other circuits (for the refrigerator) still operate.

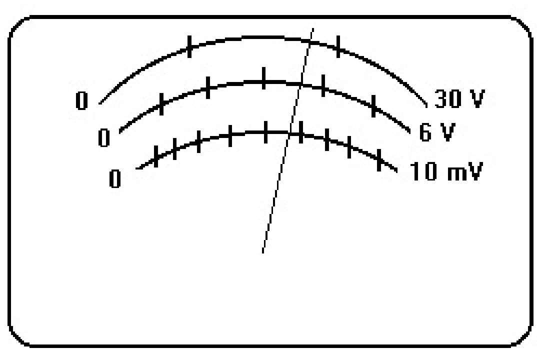
The terms parallel and series are also used in a general manner, meaning that any two things wired in line are called in series and two things wired next to each other are in parallel.

Electrical Meters

Before we proceed into the realm of analyzing electrical circuits, we should take a few minutes to go over the basics for using electrical meters. The devices are used in labs and in homes and factories to make electrical measurements. The three most common meters are the voltmeter, the ammeter and the ohmmeter.

Something that many meters have in common is that they often contain multiple scales and multiple inputs. To properly use a meter, you need two wires called leads. The black lead is always hooked up to the input labeled "ground" and the red lead should be connected to the input that will determine your scale. For example, if the voltmeter has inputs labeled: "10 mV", "1 V", and "100 V", you would need to determine in what range your measurement might fall. If you circuit had a 6 V battery, for instance, they you might expect to use the range from 0 to 10 V. The red lead would be hooked up to the appropriate input. If you are unsure of the voltages in your circuit, you would start with the greatest range and if the needle only moved slightly, you would go down one range. Never start on the most sensitive range, since overloading a meter could damage it.

Using the multiple scales is relatively easy as well. Since a meter may have many inputs, but only one needle, it is necessary to have different scales for each input. Consider the meter shown below:



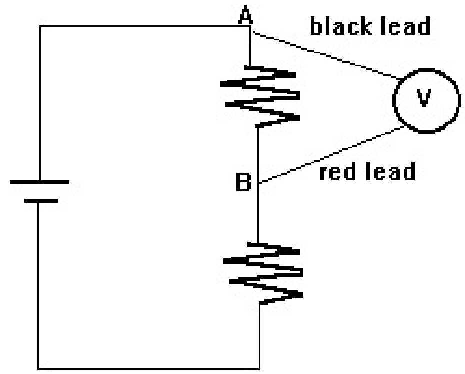
In this case, if your red lead were hooked to the 10 mV scale, the meter would read about 5.8 mV. If you were using the 6 V scale, the reading would be about 3.5 V and using the 30 V scale, the meter would read about 18 V.

Some meters are called multimeters and they contain scales and inputs for many different ranges and measurements. For example, a multimeter might be able to read voltages, currents and ohms, all in one device. Sometimes these meters are called "Simpson meters" since the Simpson company was one of the first to build a quality multimeter that was used in many labs and schools. On these meters there are often multiple inputs as well as a dial that is used to select the scale and the measurement to preform.

Before we look at each type of meter, we should mention one other practical aspect of using meters. Occasionally when using a meter, the needle will flip backwards instead of forwards. In this case, you need to simply switch positions of the red and black lead in the circuit (not on the inputs). If you had the device hooked up properly in the first place, this means that your reading is negative (the voltage is negative or the current is actually in the other direction). Because of this, it is always good not to hook the meter up permanent at first. Simply touch the leads to their proper locations at first to note the direction the needle moves. If it moves backwards switch the leads and note your answer as negative. If the meter is hooked up backwards and tries to read a negative answer, it may damage the meter.

Each of the three meters needs to be used properly to give accurate measurements. Probably the biggest mistake I see students make in an electrical lab is that they are trying to use an ammeter like a voltmeter or visa versa.

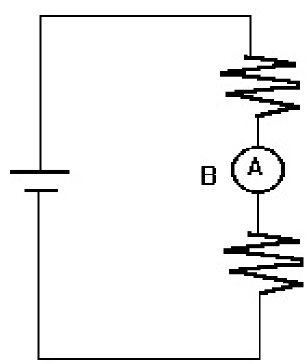
The voltmeter is used to measure voltage across a device. Since voltage is a measure of the difference between two points, the voltmeter must be hooked up touching two points in the circuit. If you wish to measure the voltage from point A to point B, you would simply touch the meter's black lead to point A and red lead to point B. Notice that the instructions were to touch the meters leads, not to interrupt the circuit. When using a voltmeter, it is not necessary to ever disassemble the circuit. You simply touch the leads one some exposed wires in the proper locations. The voltmeter should be used as shown below. In the diagram, the voltmeter (shown as a circle with a V in it) is measuring the voltage from A to B in the circuit.



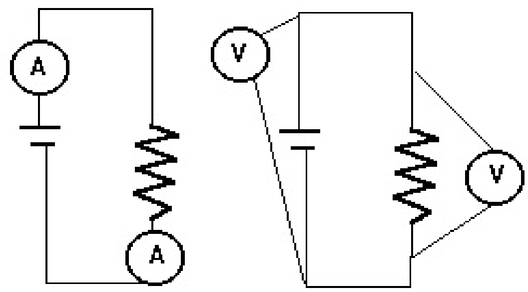
Notice how the voltmeter is connected "outside" the circuit. This meter is measuring the voltage from A to B and this is often called the voltage across the resistor. The voltage across the battery would require you to hook the meter up on each side of the battery.

The key to using a voltmeter correctly is to remember that it is always wired in parallel to the voltage being measured.

The ammeter is used in exactly the opposite manner from the voltmeter, just like our conclusions about obstacles and branches were reversed for the two quantities. Since current is measured at one point in the circuit, we need to hook up the meter at one location. This is done by breaking the circuit, inserting the ammeter and reconnecting the circuit so that it flows through the meter itself. The following drawing shows the proper way to hook up an ammeter so that it measures the current at point B in the drawing. Notice that there are no leads, instead the wires in the circuit are the leads for the ammeter. In short, the ammeter is always wired in series at the point where the current is to be measured.



A few comments should be made regarding the positioning of the meter leads in the circuit. Consider the diagram below.



If you were asked to measure the current passing through and the voltage across the resistor in the circuit, which of the two possible locations would you choose for the meters? The diagram on the left shows two choices for the ammeter, both of which are appropriate and both of which would yield the same result. The reason for this is obvious, since the current is the same all around the circuit. Now consider the two locations for the voltmeter on the right. Again, both locations yield the same result (consider the properties of voltage discussed previously in order to understand why). The reason this is discussed is that in real life circuits, sometimes the most obvious position for a meter is simply not convenient. Perhaps the wires are covered and down the line is an opening. If you know the properties of current and voltage, you can determine the most convenient position to place the meter and still get the desired result. In short, there is some latitude in positioning meters, but the user must know the properties of electrical quantities in order to take advantage of this latitude.

Also, for an ammeter to work properly, it must have a very very low internal resistance (it is after all an obstacle for the electrons and thus has some resistance of its own). Why is this so? A voltmeter, on the other hand, must have a very, very high internal resistance or it will not function properly. The reason for this is a bit complicated, so I will postpone asking the student for an answer until they have mastered analyzing electrical circuits.

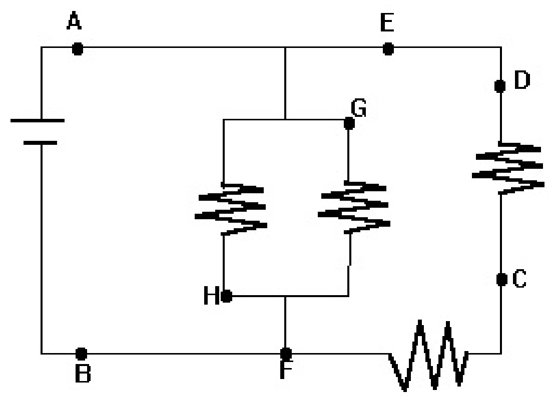
EX E.) What would a voltmeter do if hooked up like an ammeter? What would an ammeter do if hooked up like a voltmeter?

The last meter to mention is an Ohmeter. This device is not used with circuits, it is used with single objects. If you wished to determine the resistance of a piece of wire, you would simply connect the leads to either end of the wire and read the scale. The Ohmeter has its own internal power source which sends a current through the material and by knowing the voltage and current it determines the resistance. On such a meter, the scale is usually backwards. On the left is infinite resistance (no electrons can flow through) and on the right is zero resistance, meaning there is no impediment to the flow of electrons.

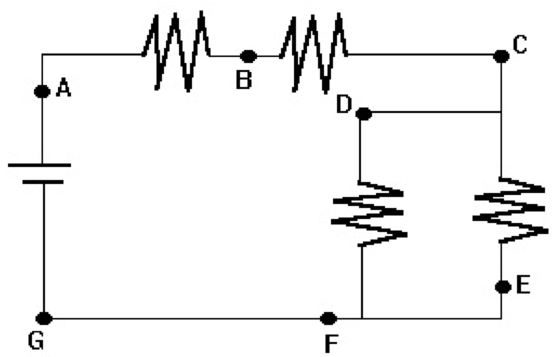
To sum up this section, remember that an ammeter is wired in series and a voltmeter in parallel.

Assignment #26

1.) In the following circuit, find four pairs of points that have the same voltage as V_{AB}.



2.) In the following circuit, find four points that have the same current as point A.



3.) Which has a greater resistance: a.) a copper wire with a cross sectional area of 0.00007 m^2 and a length of 35 m, or b.) one with a length of 6 m and an area of 2.3×10^{-5} m^2 ? (ELE12)

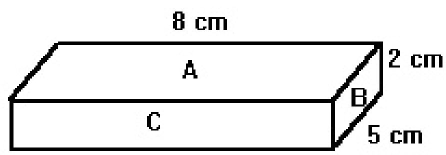
4.) A circuit consists only of a non-ideal wire and a battery. If the battery is 9 V and you want a current of 300 A to flow through the wire, what length of wire should you use if it has a cross sectional area of 0.35 cm^2 (0.000035 m^2) and a resitivity of 2.0×10^{-8} ohm.meters ? (ELE6)

5.) Suppose you wished to hang a wire between two poles 100 m apart. You have your choice of two materials (listed below) but your brackets can only hold a mass of 15 kg. For the lowest possible resistance, which material should you use ?

Material	Resistivity	Density
1	1.3×10^{-8}	8.6
2	2.0×10^{-8}	7.4
Units:	Ohm-meters	g/cm^3

(ELE8)

6.) Consider the block of material below. If you wished to splice this into a circuit, would you get less resistance by splicing it according to diagram 1 or diagram 2? (the sides are labeled with letters to illustrate the intended setup.) Support your answer with formulas.



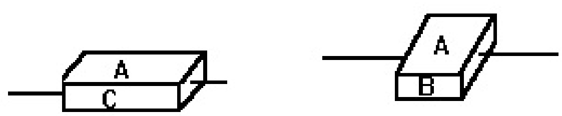


diagram 1 diagram 2

7.) Determine which resistor below is ohmic and find its resistance (the values were determined by an experiment and thus may not be exact).

Resist #1		Resist #2	
V (Volts)	i (Amps)	V (Volts)	i (Amps)
2	0.5	2	7.5
3	0.75	3	12.8
4	1	4	17.0
5	1.4	5	22.0
6	1.9	6	25.8

8.) An object is placed in a circuit and the following information is gathered. Find R(V) and determine the resistance of the device at 35 V.

V (Volts)	i (Amps)
3	0.083
6	0.042
12	0.021
15	0.017
20	0.012
22	0.011
28	0.009
30	0.008

8.) Decipher: "All articles that coruscate with resplendence are not truly auriferous." (DNCTHWG)

Lab #20 - Ohm's Law

Although not completely necessary, it is suggested that the activity #25 should be done before this lab.

In this lab you will attempt to verify Ohm's Law (as opposed to the Pseudo-Ohm's Law we have discussed in class). You will also learn to distinguish between Ohmic and non-Ohmic resistors. You will use a set resistor, a light bulb, and a motor and vary the voltage in the circuit as you measure the current. After recording the current through the device at varying voltages, you will graph the data and interpret the outcome. Ohm's Law states that for most resistors (materials) the current is directly proportional to the applied voltage. The constant of proportionality is called the resistance of the device. If a devices resistance is constant for varying voltages, the device is said to be Ohmic.

In order to vary the voltage, you will use a device called a rheostat or voltage divider. A voltage divider is basically a long coli of wire that you can tap into at any point. If a simple circuit is constructed with just a rheostat and a battery (figure 1), then the voltage will drop across the rheostat. The total voltage drop will of course be equal to the voltage of the battery. If the voltage drops equally through the rheostat, then if you tapped into the coil at the half way point and put another resistor in parallel you would have half the voltage across the new resistor. Since the rheostat is adjustable, you can get any voltage you require (up to the full voltage of the battery).

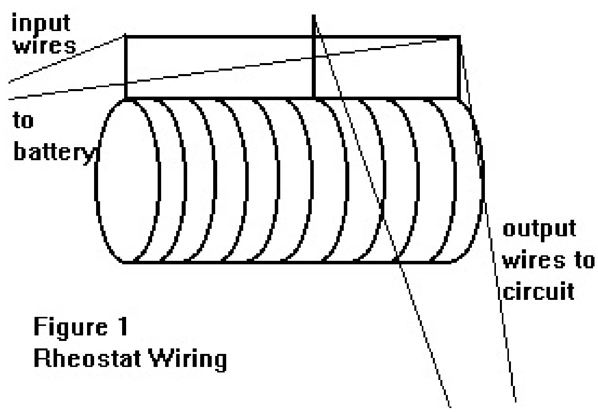


Figure 1
Rheostat Wiring

<u>Procedure:</u>

1.) Set up the circuit as shown in figure 2.

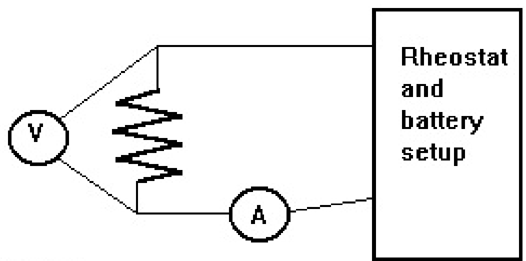


Figure 2
The testing circuit

2.) Adjust the rheostat for maximum voltage, record the voltage and the current.

3.) Readjust the rheostat so that the voltage is slightly lower and record the voltage and the current.

4.) Repeat step 3 so that you have a minimum of 8 different voltages and so that your readings cover the full range from 0 volts to the voltage of the battery.

5.) Construct a graph of V vs. I for the resistor and determine whether or not it is Ohmic.

6.) Repeat the entire procedure, substituting a first a light bulb and then an electric motor for the resistor.

Activity #25 - Electrical Meters

The main purpose of this lab is to give you some practice using electrical meters and constructing circuits. For each of the three circuits below you are to fill in all the possible quantities on the data chart by using the meters. Remember: A voltmeter requires you to touch the leads to two points, a ammeter requires you to break the circuit at the point in question. After you have taken the readings, analyze the data and look for trends and generalizations that you can make regarding circuits, voltage and current. Also: please take note of special instructions regarding the sign of the voltage.

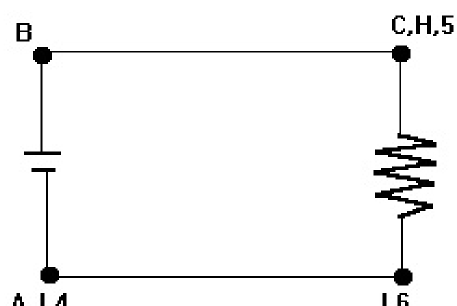
Procedure:

1.) Construct the circuit shown below. The actual values of the resistors is not important, as long as they are not too far apart in value (i.e. 5 Ω and 10 Ω are OK, 5 Ω and 50 Ω is too much of a difference.

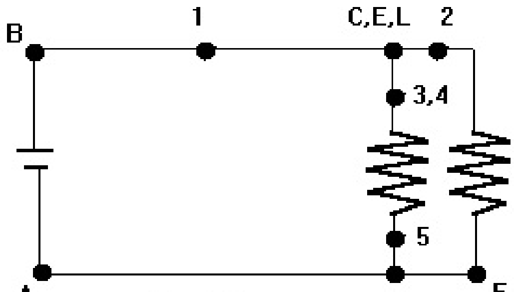
2.) Take all appropriate voltage readings using the voltmeter. When you are asked to find V_{AB}, place the black lead on A and the red lead on B. If the meter goes backwards, reverse the leads and record the voltage as negative. If the space on the chart is filled in, that means that that measurement is not necessary for that particular circuit. Also, note that some positions have more than one label (for example, the top right corner of the first circuit is called C, H and 5.

3.) Take all appropriate current readings by breaking the circuit and using an ammeter.

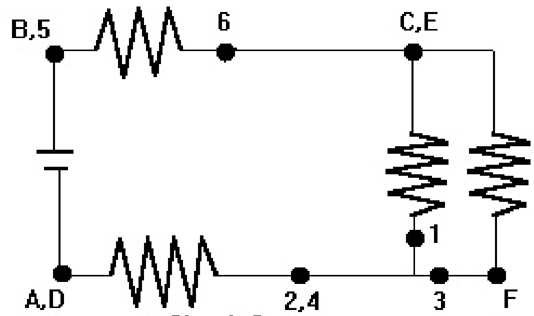
4.) Repeat the procedure for the circuits in figures 2 and 3.



Circuit 1



Circuit 2



Circuit 3

	CIRCUIT 1	CIRCUIT 2	CIRCUIT 3
V_{AB}			
V_{BC}			
V_{CA}			
V_{DE}			
V_{EF}			
V_{FD}			
i_1			
i_2			
i_3			
V_{12}			
V_{23}			
V_{13}			
i_4			
i_5			
i_6			

<u>Conclusions:</u> Besides teaching you to use the meters, this lab was designed to help you recognize some patterns regarding voltage and

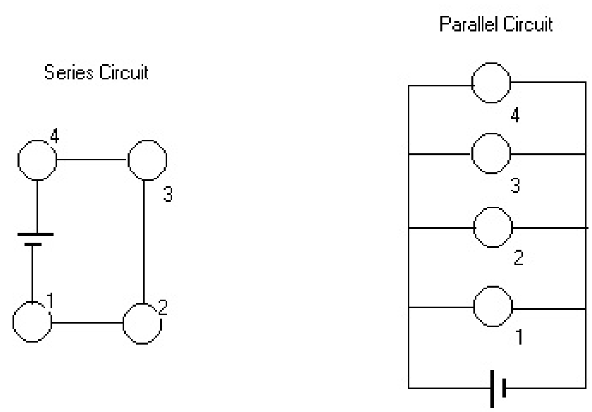
current. Review the data and make your own conclusions. Hint #1: Each of the sections in the data table should lead you to at least one conclusion. Hint #2: Obstacles ? Loops ? Junctions ?

Activity #25b - Series and Parallel

The purpose of this activity is to determine the differences between series and parallel circuits, both qualitatively and quantitatively. Although this is a very simple activity, it is one that all good students should be acquainted with.

Procedure:

1.) Construct both circuits below (simultaneously if possible)using identical batteries and light bulbs.



2.) Measure the current though and the voltage across each light bulb and record this information in the data table below.

3.) Remove one light bulb from each circuit and record your observations.

4.) Observe the brightness of the light bulbs and record your observations.

Light Bulb #	Series Current	Series Voltage	Parallel Current	Parallel Voltage
1				
2				
3				
4				

Conclusions:

In your conclusions, you should discuss the following (at a minimum): What patterns arise in the voltage and current measurements? How do these make sense according to what you have learned about electrical quantities? How do your observations regarding removing one light bulb make sense? How can you explain the brightness of the light bulbs according to the current and voltage measurements in each circuit? Note: brightness is related to power which is voltage times current. How are series and parallel circuits used in the wiring in your home?