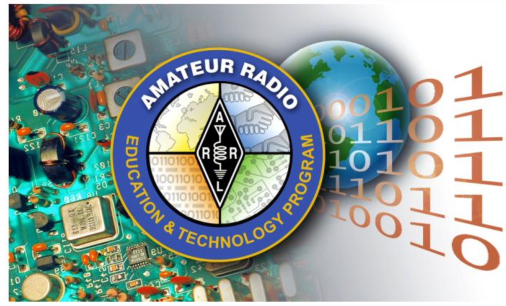
This is not a polished document and has not gone through a formal review process. It is intended to be a starting point user can adapt to the particular situation. You should change and edit the presentation to make it your own.

Basic Electronics



Basic Electronics Course Standard Parts List

Quantity	Part Description	Part Number	Jamco Number		Cost (2004)
1	Mastech Mulitmeter	M830B	220855CR		$9.95
1	Solderless Breadboard	JE24	20757CR		$9.95
1	Jumper Wires*	JE27	77825CR		$12.95
1	9V Battery Holder	BH-9V-A	216426CR		$0.79
1	1.5V Battery Holder	BH-311-2A	216071CR		$0.69
1	100 ohm **	29946CR			
1	200 ohm	59424CR			
1	330 ohm	30867CR			
2	1000 ohm	29663CR			
1	2.2K ohm	30314CR			
2	4.7k ohm	31026CR			
1	10K ohm	29911CR			
1	100K ohm	29997CR			
1	100uF Electrolytic Cap		94431CR		$0.09
1	Diode	1N914	179207CR		$0.05
1	Zener Diode		1N4732A	36089CR	$0.06
1	Transistor	2N3604	178597CR	$0.09	
1	LED	LH2040	94529CR	$0.19	

* More jumpers than needed for one student, can be shared to reduce costs

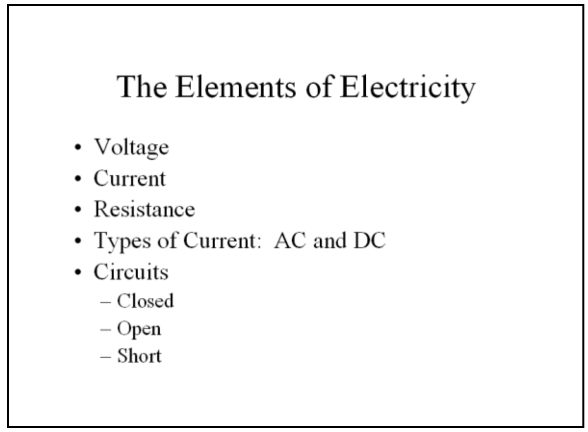
** Individual components are often sold is quantity, quantity purchase can be shared between students to reduce costs.

This course is intended for those interested in learning the basics of electronics. The topics discussed during the course are listed here in a brief outline. The topics up to and including Ohm's law are considered the most basic. The remaining topics cover additional fundamental components of basic electronics, however, they will only receive brief coverage.

The course will be presented in platform discussion, guided practice, and open question format, as the material dictates. The course uses a standard volt-ohm-meter (VOM) for illustration. If the participant has a different VOM the range settings and or readouts may be slightly different. The readings for the sample activities given in this presentation are based on the readings found while using the specified components they are provided for illustration purposes only. Your readings may be different.

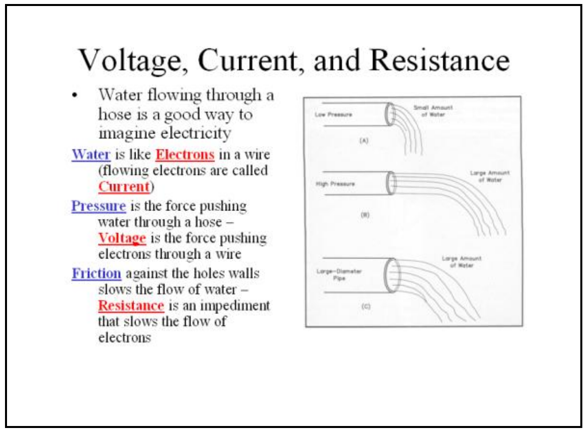
Basic Electronics for the New Ham
(Outline)

- The Elements of Electricity
- Volt-Ohm-Meter Basics (Measuring Electricity)
- Circuit Diagrams Basics (Electronic Roadmaps)
- The Resistor
- Ohm's Law
- The Capacitor
- The Inductor
- The Diode
- The Transistor (Electronic Valve)



We will begin by discussing the three fundamental parameters that define electricity. Extensive time will then be spent on how to measure the three components of electricity. During this section two of the three components (voltage and current) will be explored. This section will cover VOM measurement basics and allow you to become familiar with the most important piece of basic test equipment. The next section on circuit diagrams will show how electronic components are symbolized on an electronic road map called a schematic or circuit diagram. Many of the symbols presented will represent new concepts for many of you and these concepts will not be fully developed before the section is covered. Some will not be developed at all during the course. The intention here is to establish the fundamentals of interpreting circuit diagrams so that these illustrations of the arrangement of electronic components can be used to help with the remainder of the course. The final of the three components, resistors, will be covered next. How the three components are related mathematically is Ohm's law and this fundamental law will be covered in detail. These sections make up the very basic material of electronics.

Four additional components common to virtually all electronic circuits are the capacitor, inductor, diode, and transistor. These topics will be covered with a level of detail that will familiarize the students with the function of these components and the basics of how they work and react in difference situations.
ARRL's *Understanding Basic Electronics* is an excellent supplementary reference for this course.



Use the water analogy to explain the components of electricity. Have the audience visualize water flowing through a garden hose and then ask them to think what happens when:

1. They increase the pressure forcing the water through the hose by opening up the spigot – the water flows faster and squirts farther. The opposite happens when they reduce the pressure, the water flows slower, right down to a trickle. With electricity, the force pushing electrons through the wire, current, is voltage. If the voltage is increased, more current flow, if the voltage is decreased, less current will flow.

2. Now image keeping the pressure constant and visualize what happens when they change the amount of water available to flow through the hose. If there is lots of water, the water will flow out at full force, if there is limited water, no matter how hard you push, the water will only flow out at a small trickle. In electricity, if there is ample current available, it will flow through the wire at full capacity, if you limit the amount of current somehow, then the current will flow at a reduced rate.

3. Finally, imagine what would happen if you kept the pressure and the amount of water available constant, but restricted the diameter of the hose (like putting your finger over the end). The restriction prevents the all the water from coming out, but the water that does come out comes out with greater force (it will squirt further). Also the water behind the restriction actually slows way down to wait its turn to go out of the restricted hole. The same thing would happen if the interior wall of the hose was made very, very rough. The water molecules would run into the rough surface and slow down, this is very much like friction. In electricity, the current does not flow through a wire without running into something along the way, there is always some friction, but in electricity that friction is called resistance. When resistance goes up, the amount of current flow goes down, when resistance goes down, the amount of current flow goes up.

Ask the audience to do two things to reinforce the concept of resistance. First, ask them to rub their hands rapidly together and observe the sensation … heat. The friction between their hands, the resistance to the movement of their hands across each other, creates heat. The same is true in electricity as well as water flowing in a hose (though they might not feel the heat generated in the hose). Second, ask them to do an experiment at home, rapidly pump a bicycle air pump and feel the air hose, the hose can get quite hot. That is a demonstration of resistance (friction) in action.
Conclude by pointing out that during the water hose discussion, the three components of water flowing through the hose were interrelated, you really can't change one without affecting one of the other two components. The same is true in electricity and we will be discussing that relationship later.

Emphasize that the type of current is based on how the current flows in a wire. If it flows only in one direction, the current is called Direct Current (DC), if the current alternates from flowing in one direction one moment and then reversing to the other direction the next moment, the current is called Alternating Current (AC). Also emphasize that current magnitude (amplitude) is not a determinant of current type. DC does not have to be constant, as is normally the case of current flowing from a battery; DC only flows in one direction even if the amplitude varies.

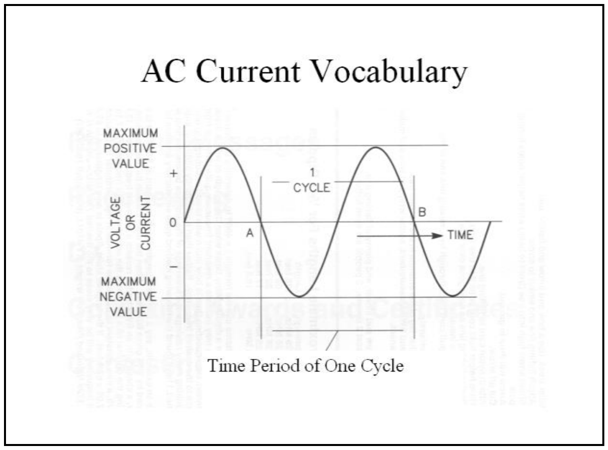
Forms of Current

- There are 2 types of current
  - The form is determined by the directions the current flows through a conductor
- **Direct Current (DC)**
  - Flows in only one direction from negative toward positive pole of source
- **Alternating Current (AC)**
  - Flows back and forth because the poles of the source alternate between positive and negative

Discuss the sources of DC and AC. Make note that both types of current are used in electronic devices. DC is generally used as a source of power for circuits. AC is generally used as signal sources to transfer energy or intelligence (information such as voice, media such as radio waves).

Point out that there are dedicated circuits within an electronic device that converts AC to DC and DC to AC, and from one type of AC current to another.

Discuss with the students what is being represented by the waveform. Make note that this represents an AC wave because the current lines above the zero line represent currents traveling in one direction in the wire (positive direction, positive voltage, positive current by conventions), and the current lines below the zero line travel in the opposite direction.



In talking about AC, the student needs to be able to use the right vocabulary to identify portions of the AC waveform.
The highest part of the wave, the maximum voltage or current, is called the peak of the wave.

The lowest part of the wave, the minimum voltage or current, is called the trough of the wave.

The time difference between identical parts of the wave, peak-to-peak, trough to trough, positive zero crossing point to positive zero crossing point, is the period.
The number of times the waveform repeats itself in one second is called the frequency. Frequency is measured in Hertz, which is one completed cycle per second.
The amount of magnitude or distance the peak (or trough) is away from the zero line is the amplitude. This represents the relative strength of the wave, large amplitude, strong wave, small amplitude, weak wave.

The peak to trough distance (vertical) is called the peak to peak.
For the most advanced students, you may want to bring up the concept of Root Mean Square (RMS) voltage. That is the DC equivalent voltage of an AC wave that produces the same amount of work. RMS voltage of a sine wave is .707 times the peak voltage.

Emphasize that when measuring voltage, the VOM is used to sample the voltage **across** the source, which is different than when measuring current where the current in the circuit must flow **through** the VOM to be measured. This makes it far easier to measure voltage in a circuit because the operator can simply place the probes across the component as it is wired in the circuit. In measuring current, the operator must physically interrupt the circuit (i.e., un-solder and connection) an insert the VOM into the circuit.

Measuring voltage

- Voltage type – DC and AC
  - When measuring voltage, the meter probes are placed **across** the voltage source.
  - The VOM uses two separate functions and ranges to measure DC and AC.
  - Because AC is a constantly changing wave form, measuring AC voltages is not a simple matter.
  - This VOM measures pseudo-RMS voltages

Point out on the VOM the two voltage measurement ranges, one for DC and the other for AC. During this program the audience will be using only the DC range.

Recall with the student that AC voltages have peaks and troughs on the waveform; this makes it difficult to measure a specific voltage because the voltage is constantly changing.

One approach is the measure the peak-to-peak voltage.

The preferred approach is to determine a voltage value for an AC wave will do an equivalent amount of work to a DC voltage. Measuring AC voltages in this way allows the user to compare voltages using a known standard, and more importantly, use the voltage readings in Ohm's law to calculate circuit performance. Ohm's law of course will be covered in future units. The preferred means to measure AC voltage is to measure the Root Mean Square (RMS) voltage. RMS is a weighted average voltage that compensates for the plus and minus nature of an AC wave. Without using RMS, the average voltage would be zero and the equivalent DC voltage would be too high for the amount of actual work that could be accomplished with the voltage. A detailed look at RMS would come in a more advanced study of basic electronics. This particular VOM measures pseudo-RMS which is a gross approximation. More expensive meters would read True-RMS.

Circuit is a word to describe a pathway for the flow of electrons. A good analogy is a racetrack for motor vehicle races. The vehicles run on the track. If there is a blockage or cut in the track, the race stops. If there is a shortcut, some of the vehicles will take that shortcut and get to the finish line by cheating. The path concept will become more important in future units to understand parallel and series circuits.

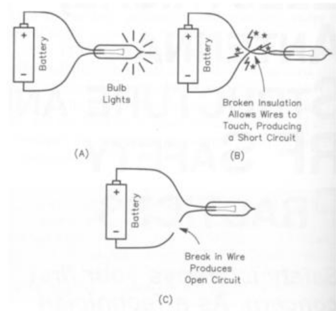
In electronics, there are three types of circuits. Open, Closed, and Short.

In an open circuit, the pathway (the conductor) is broken by some means and there is no complete pathway for the electrons to flow, and so they do not flow. A good example of an open circuit is an on/off switch. When the switch is in the off position, a portion of the switch mechanism that connects the electronic components to the power source is disconnected creating an open circuit.

Alternatively, if the on/off switch is closed, the switch mechanism connects the electronic components to the power source and the circuit is completed or closed. The electrons are free to flow through the circuit.

The short circuit is usually a bad thing. In this case, a failure in the path that results in a more direct circuit path being formed that goes around the electronic components that are intended to be energized. The short circuit path can cause dangerous current through areas (like your body) where the flow is not intended. Special safety components called circuit breakers or fuses are placed in the pathway to sense when a short circuit occurs and then open the circuit to stop the flow of current. Provide the audience with examples of circuits and safety devices in the classroom.

Circuits



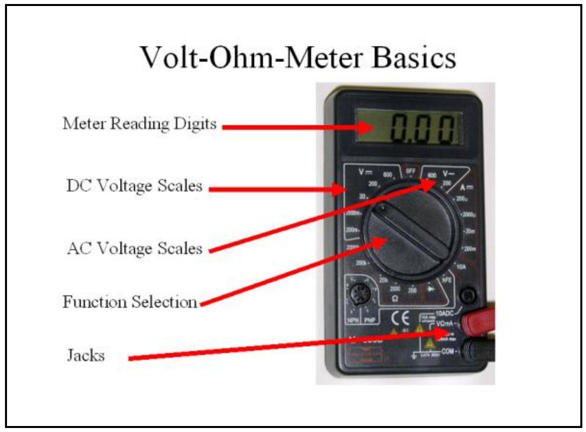
Reading assignment: Instruction manual for the VOM
Discuss with the students the various functions of the Volt-Ohm-Meter and the ones that you will be covering in the class (measuring voltage, current, and resistance).

Volt-Ohm-Meter (VOM) Basics

(Measuring Electricity)

- Common Functions
  - Voltage
    - AC/DC
    - Ranges
  - Current
    - AC/DC
    - Ranges
  - Resistance (DC only)
    - Ranges
    - Continuity
  - Semi-conductor Performance
    - Transistors
    - Diodes
  - Capacitance

Have the audience take a close look at their VOM as you take a tour of the basic meter and the meter functions.

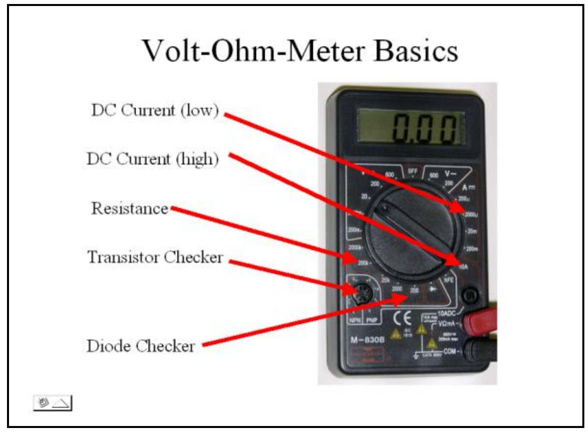


At the top of the meter is the reading display screen. The big round knob in the middle of the meter is the function selection knob. Ask the audience to turn the pointer on the function selection know to the left from the OFF position one click to the 600 DC volt scale. Notice that there are 3 zeros displayed and no decimal point. The meter can now read up to 600 volts DC. Ask the students to continue to rotate the function selection knob one click left through the other DC voltage ranges and note the change in the decimal point location. Ask the student to return the meter to the OFF position to turn off the power to the meter (and conserve battery power).

Point out to the audience the location of the two voltage ranges, DC and AC. Note that the AC ranges are fewer and cover only 200 and 600 volts AC. The wavy line indicates AC voltage, the solid/dashed line indicates DC voltage and current ranges.
Finally point out the location of the probe jacks. There are three jacks. The bottom most jack is the common or grounding jack. By convention the audience should insert the black probe lead in the common jack.
The middle jack is for accessing the voltage, resistance and low current ranges and is the most commonly used jack. Ask the students to insert the red probe lead in the middle jack. The meter is now ready to read most of the voltages, currents, and resistances the audience will encounter.

The upper jack is for high current levels from about 200 milliamps up to a maximum of 10 amps. If the user is not sure what the current level is that they will be measuring, it is prudent to start with the red probe lead in this jack and get an approximate current reading. If the current is less than 200 milliamps, then the user can return the probe lead to the center jack to get a more accurate reading.
Explain to the audience the purpose of the high current jack and the fuse protection that is internal to the meter to provide some over-current protection. Also inform the audience that the meter is powered by a replaceable 9-volt battery. The batteries will last a long time with wise use of the VOM (I.e., don't forget to turn it off when not in use).

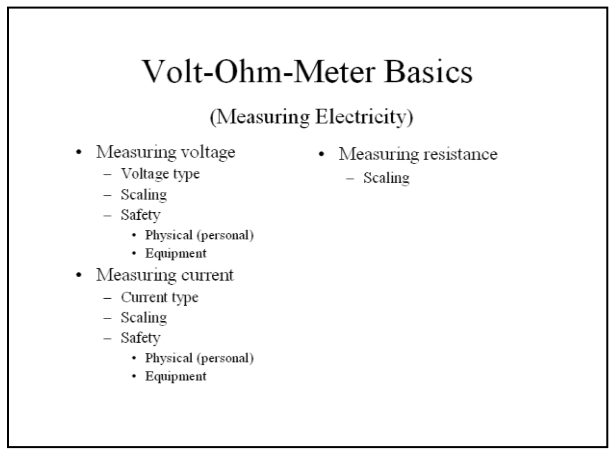
Use this slide to highlight the two current ranges. Also discuss the fuse protection that is internal to the VOM to prevent damage in the event of trying to measure too much current with the probe setting. The low current (up to 200 milliamps) can be measured with the center jack position, and up to 10 amps for high current with the upper jack position.

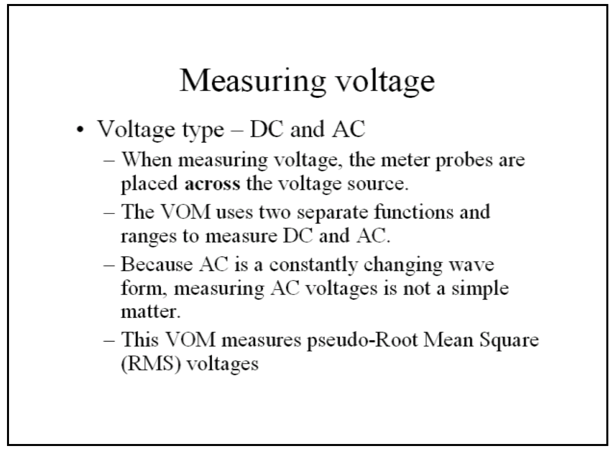


During this program, the audience will not be using the transistor checker function of the VOM, which is a more advanced function.

Point out that other VOMs have additional functions such as measuring AC current, measuring capacitance, and some have frequency counters for measuring low (up to the high audio range) frequencies.

Now on to actually using the meter. These are the three functions that will be covered in detail.





Emphasize that when measuring voltage, the VOM is used to sample the voltage **across** the source, which is different than when measuring current where the current in the circuit must flow **through** the VOM to be measured. This makes it far easier to measure voltage in a circuit because the operator can simply place the probes across the component as it is wired in the circuit. In measuring current, the operator must physically interrupt the circuit (i.e., un-solder a connection) and insert the VOM into the circuit.

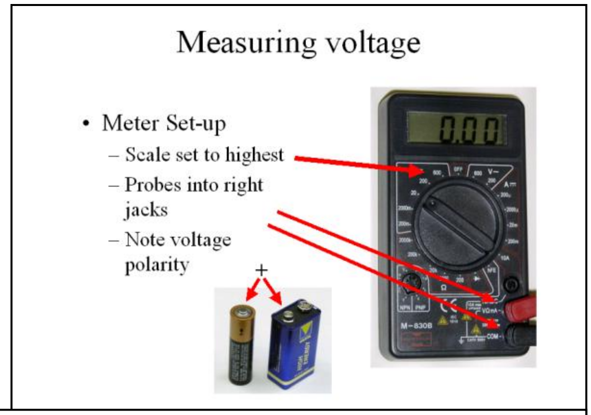
Point out on the VOM the two voltage measurement ranges, one for DC and the other for AC. During this program the audience will be using only the DC range.

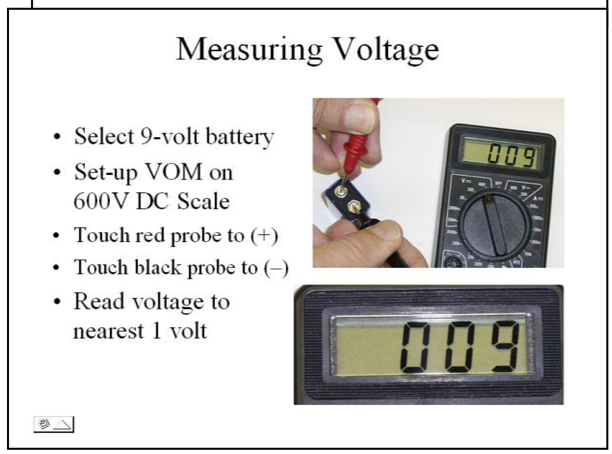
Recall with the student that AC voltages have peaks and troughs on the waveform; this makes it difficult to measure a specific voltage because the voltage is constantly changing.

One approach is the measure the peak-to-peak voltage.

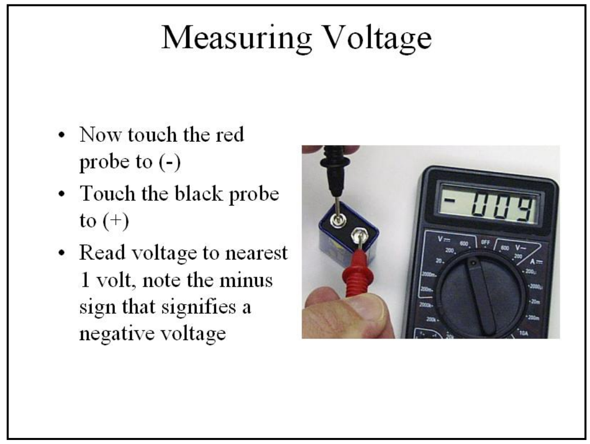
The preferred approach is to determine a voltage value for an AC wave that will do an equivalent amount of work to a DC voltage. Measuring AC voltages in this way allows the user to compare voltages using a known standard, and more importantly, use the voltage readings in Ohm’s law to calculate circuit performance. Ohm’s law, of course, will be covered in future units. The preferred measurement of AC voltage is to measure the Root Mean Square (RMS) voltage. RMS is a weighted average voltage that compensates for the plus and minus nature of an AC wave. Without using RMS, the average voltage would be zero and the equivalent DC voltage would be too high for the amount of actual work that could be accomplished with the voltage. A detailed look at RMS will come in a more advanced study of basic electronics. This particular VOM measures pseudo-RMS, which is an approximation. More expensive meters are able to read True-RMS voltage.

You will now take the audience through the process of measuring a voltage.
Point out that they need to ensure that the probes are in the middle and lower jacks.
By convention the black lead is the common or ground lead.
Initially set the voltage scale to the highest scale of 600 volts
Use a 9-volt battery for the voltage source, note that the male clip is the positive pole of the battery.
Go through with the audience how to set up the VOM to make a voltage measurement.
One technique to use if you are going to measure an unknown voltage is to use the highest scale, in this case the 600-volt DC scale. (Emphasize the difference between using the DC and the AC scale while measuring DC voltages)
While using the 600-volt scale, the resolution of the VOM is one volt.

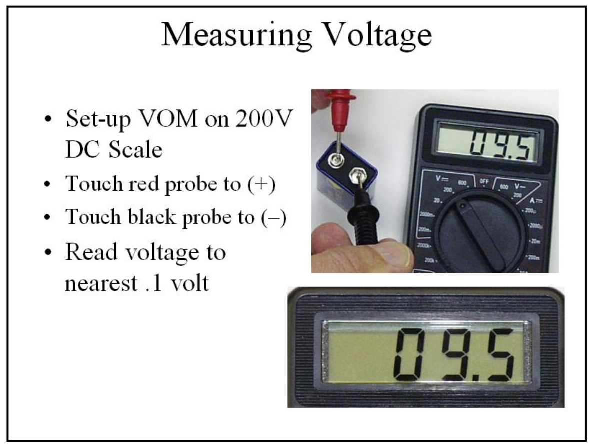




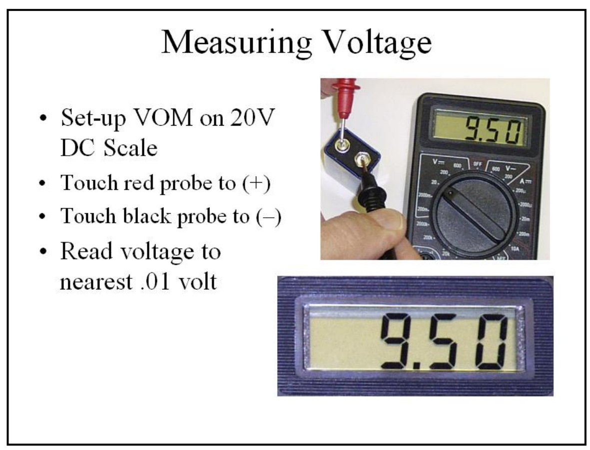
The purpose of this exercise is to show that the VOM can tell the difference between negative and positive voltages. Point out to the audience that some VOMs, particularly analogue types will not be as forgiving, that putting the probes on reverse voltages can damage the meters.



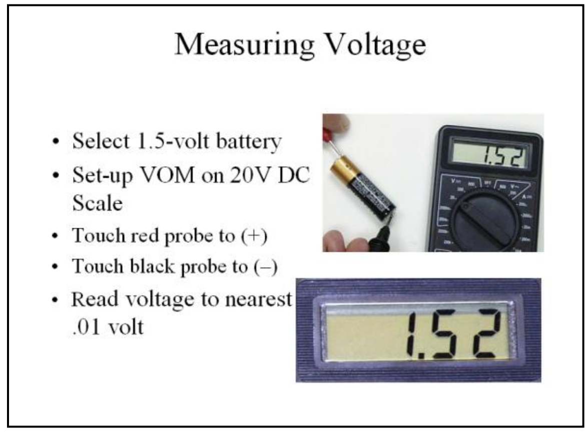
Using a voltage scale that is closer to the actual voltage shows an improvement in resolution, in this case the voltage value is to one decimal place or 1/10th of a volt.



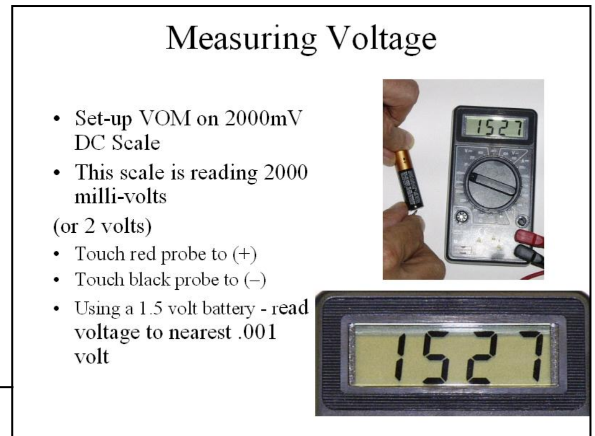
Again, using a scale a little closer to the actual voltage results in additional resolution, this time to 1/100th of a volt.



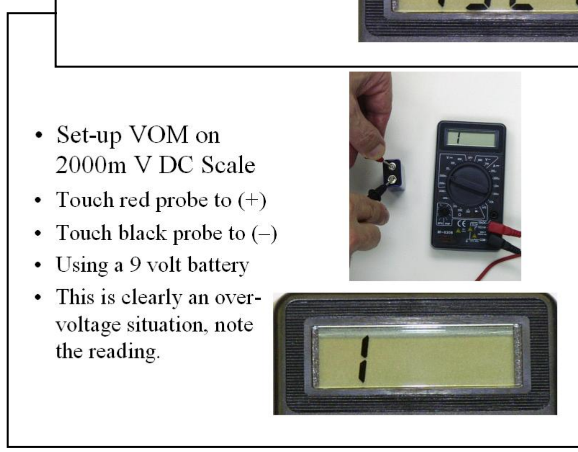
Repeat the same exercise using the 1.5-volt battery.



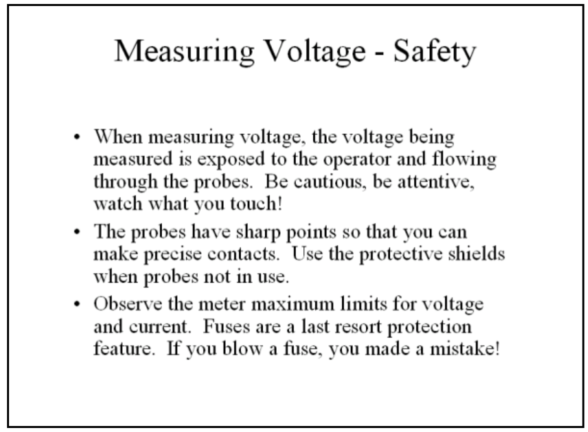
Emphasize to the audience that when they are using the 2000-millivolt scale, they actually are using the 2-volt scale because 2000 millivolts is the same as 2 volts. But because the display is in millivolts, there is no decimal point in this case. A reading of 1527 millivolts is the same as 1.527 volts. Note: The 200-millivolt scale is actually the 0.2-volt scale.



So what happens if you use a scale that is too low for the voltage being measured? As long as you do not exceed the maximum voltage value for the meter, in this case 600 volts, there will be no physical damage to the meter. The meter indicates an over voltage situation by displaying a single digit "1" at the far left. This "overage" indication is consistent with the other functions to be looked at later



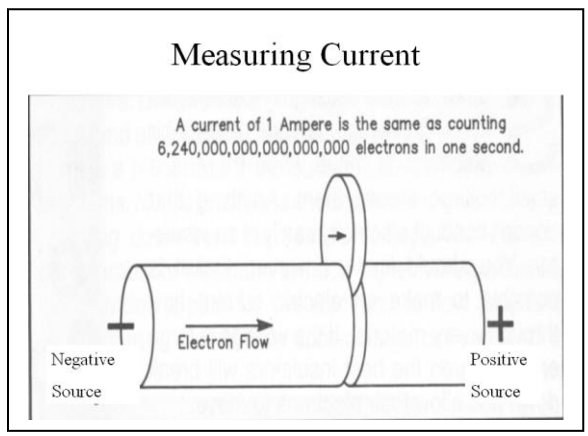
Spend some time with the audience discussing safety considerations particularly when working around high voltages and high currents. The operators of the voltmeter could be exposed to lethal voltage and current levels. Also when probing a live circuit, careless cross contacts and the resulting short circuits could route equipment damaging levels of voltage and current to the circuit under test. Personal experiences will help illustrate the point.



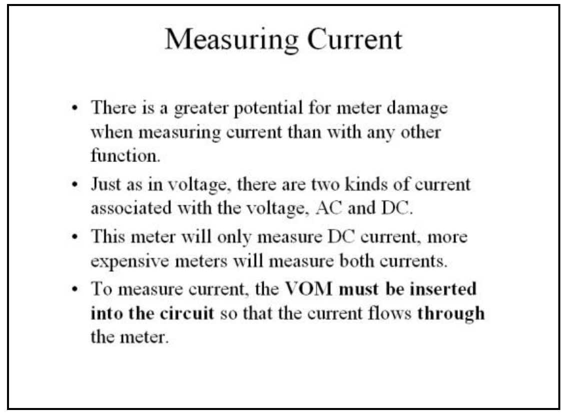
A good technique is the do a “dry run” of probe placement with power turned off. During the dry run, the operator can see if the probe placement is correct and not short-circuiting to damaging voltages and currents. Practice probe placements, and once confidant, turn on the power source to make the measurement.

Another good technique is to start all measurements at the highest range and then adjust the range downward to the appropriate level. There are usually automatic protection features in VOMs, but it is best not to consistently depend on them doing their intended jobs.

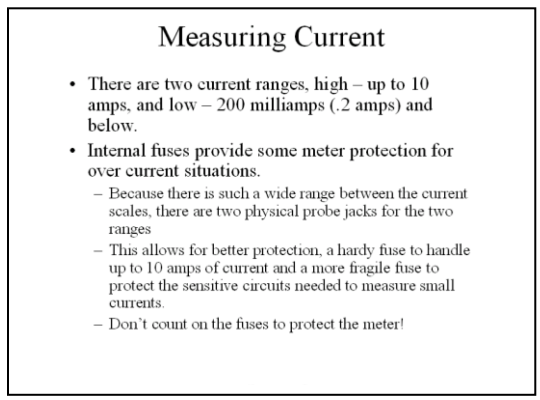
What is current? Current is the flow of electrons through a conductor, the water analogy is that current is like the water flowing through a hose. Current is measured in amperes, and as shown in this illustration, 1 ampere is the current is a large number of electrons flowing past a spot in the conductor in 1 second. Current in typical electronics can be in the range of hundredths of amps to millionths of an amp (microA) to billionths of an amp (nanoA). You will generally work with 10s of amps down to micro amps in typical electronic devices.



Continue your discussion of safety, particularly equipment safety, when measuring current. Re-emphasize the difference between AC and DC voltages and currents.

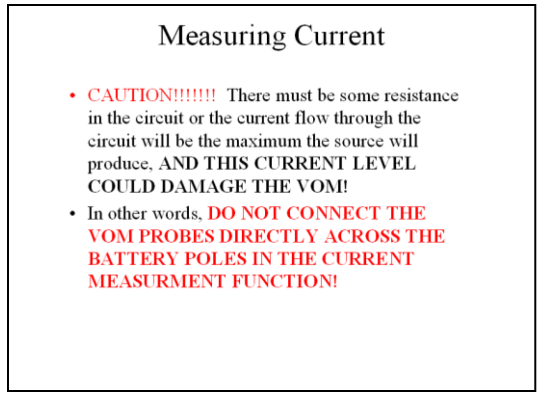


Finally, spend some time to amplify the final bullet. To measure current, the current must flow through the meter as opposed to measuring voltage when it was only necessary to sample the voltage surrounding the source (or component of interest). Generally, to have the current flow through the VOM, an existing circuit must be broken (i.e., un-soldered) and the meter probes connected to either side of the "break." The VOM then becomes part of the path through which the current must flow.

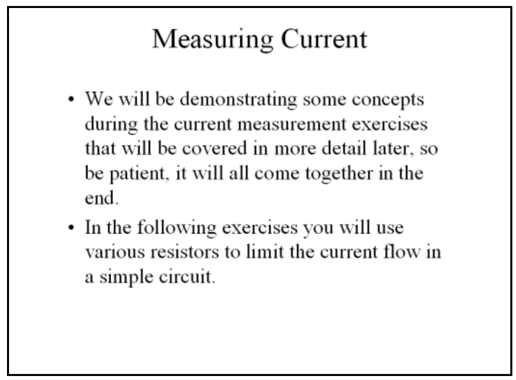


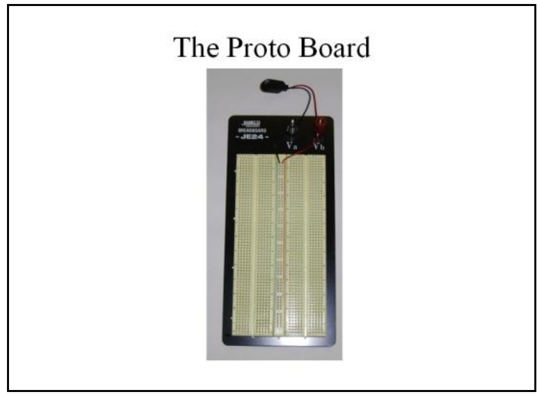
While the audience is looking at the VOM, point out the two current scales and the associate probe jacks. In most situations the user will use the center jack and the low current scale. There may be rare occasions when higher than 200 milliamps will be measured. This will require switching the probe jack along with selecting the high current range on the meter.
In the event of an over current situation, the internal fuse will blow. To return the VOM to operation, the fuse must be replaced, with the same size fuse, by opening the VOM case and replacing the fuse. If the user is going to be making frequent current measurements, particularly in high current situations, it is advisable to have spare fuses handy at the workbench.
This might be a good time to talk about how fuses operate and the cautions surrounding replacing fuses (use the same current rated fuse as the one blown). Demonstrate replacing one in the meter.

With no resistance in the circuit, the voltage source will provide the full current available to the circuit. There is essentially no resistance in the VOM probe lines, therefore if the probes are connected directly across the battery poles, the full current in the battery will flow through the VOM, and probably blow the fuses.
Emphasize to the audience, that during the following current measurement exercises, they must be careful to ensure that the suggested resistance is in the circuit and that the VOM probes are placed as will be illustrated. The previous suggestion on meter safety applies and this might be a good place to practice … do a dry run on probe placement.



Resistors will be covered in detail in a later section. The audience will need help in identifying different resistance values from the color codes that are used in the exercises. The audience will want to learn more about resistors and the color codes at this point, try to keep the audience focused on the lesson at hand and that is to learn how to use the VOM to measure current. They need to be patient and wait until later for the more detailed discussion on resistors.

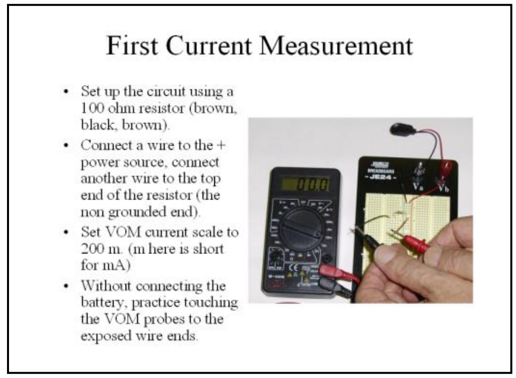




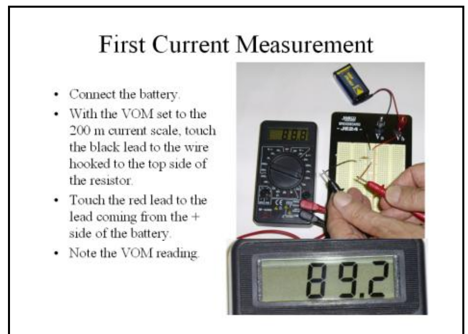
Proto stands for proto-typing. Go over with your audience the orientation of the different interconnected holes in the board. The vertical rows in the center that have red and blue lines next to them are connected together, the holes in the red row are connected together, the holes in the blue row are connected together. The boards as shown are configured to have these rows as power sources, red for positive, and blue for ground (normally black represents the ground in DC circuits when red is associated with the positive pole).
There are 4 banks of horizontal holes. The holes in each horizontal bank are connected together. The horizontal rows are where the components will be interconnected, and the vertical center rows will be connected to the circuits to provide power.

Point out to the audience that the current flow path goes from the negative pole of the battery, through the resistor (which restricts the amount of current flow), then through the VOM, and finally returns to the battery positive pole. The VOM is part of the circuit. Contrast this arrangement to what would be used to measure the voltage across the resistor where the resistor would be connected directly to the battery poles and the current path include only the battery and resistor. The VOM would be connected across the resistor (and likewise the battery) and the voltage would be sampled or sensed by the meter.

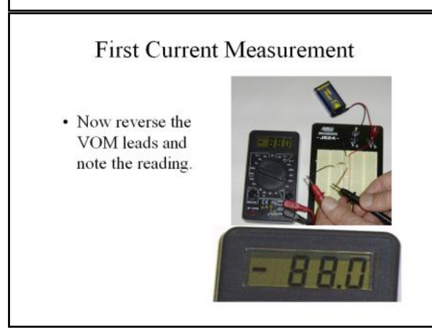
Take some time and help the audience wire up the first circuit. Dry run them with meter lead placement, etc.



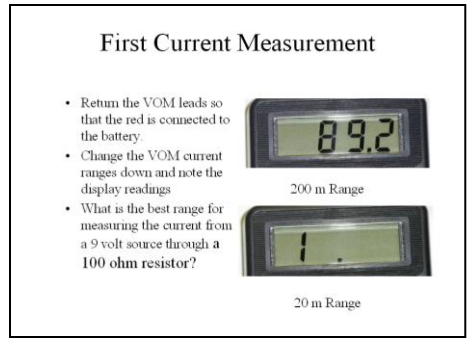
Now connect up the battery and measure the current. Your readings will likely vary from the ones in this presentation.
This is a good time to talk with the audience about the current being measured. In the 200m range, the readings will be a maximum of 200 milliamps, or 0.2 amps. Here the reading is 89.2 milliamps or 0.0892 amps.



While the power is still connected to the circuit, ask the students to reverse the VOM probe leads. They should note that the meter reading is about the same except that there is a negative sign on the meter.

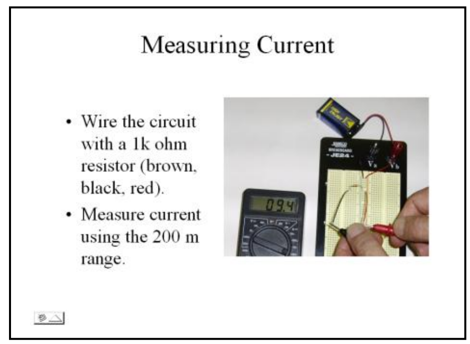


Ask the audience to return the VOM probe leads back the way they were to get a positive reading. Next ask them to change the range to the 20m range. On this range, the meter will display a maximum of 20 milli amps. Their display should read a single 1 digit, displaced to the left, which indicates an over current situation. Remember the current flowing through the resistor was 89.2 milli amps, well above the maximum range of the meter setting. The lesson here is that an over current reading is indicated by a single 1 digit, if this occurs you need to switch the meter to a higher range.



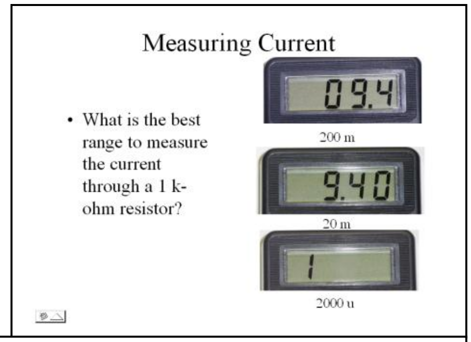
Tell the audience your personal technique for dealing with setting ranges on the VOM.

Task the audience with replacing the 100-ohm resistor with a 1k-ohm resistor. Point out to the audience that the letter k here means kilo or 1000. The 1k resistor is 1000 ohms. 10k is 10,000 ohms, and 100k is 100,000 ohms. Ask them what they think will happen to the current flow through this higher resistance component. Their answer should be less current will flow. Ask them if the 200m range that is appropriate for this situation. If they suggest that a lower current range is appropriate, return with the suggestion that that may be true, but it doesn't hurt to start with the range too high and adjust later, particularly when they are dealing with unknown values of resistance.

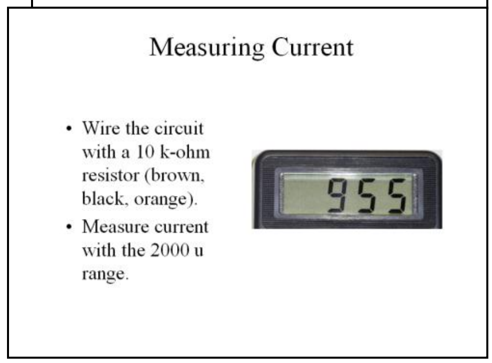


The reading on the 200m range should be approximately 9.4. Again, go over with your audience what the reading means, in this case 9.4 milliamps. With this current in mind, have the audience predict what the reading will be on the 20m, 2000u, and 200u ranges. This would be a good time to introduce the scale of the 2000u and 200u ranges. The u in this case stands for microamps, or millionths of an amp. The 2000u range will display up to .002 amps or 2 milliamps. The 200u range will display up to .0002 amps or 0.2 milliamps.

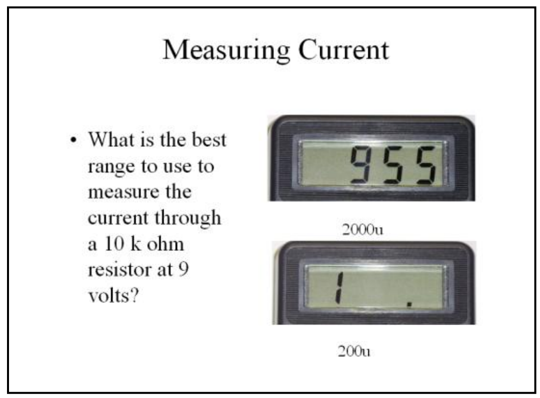
Have the audience confirm their predicted readings. In this case, the current is 9.4 milliamps. The 2000uA range will read up to .002 amps or 2 milliamps, therefore you get the over current reading. In the 200mA range, the reading is 9.4 milliamps and only to one decimal point. The best resolution is obtained by using the 20mA range.



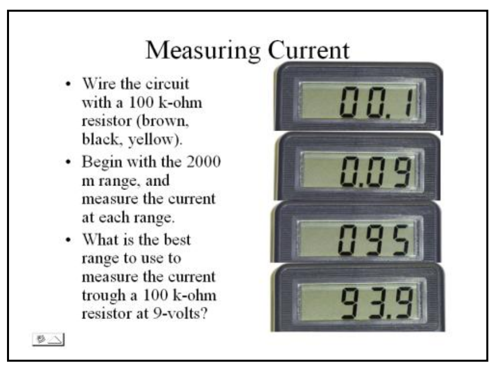
Replace the resistor with a 10k ohm resistor read the current using the 2000u scale. The audience should be able to interpret the reading. On the 2000uA scale, the reading is 955uA or 955 microamps. To convert to milliamps, move the decimal to the left 3 places or .955 milliamps. To convert to amps, move the decimal to the left 6 places or .000955 amps.



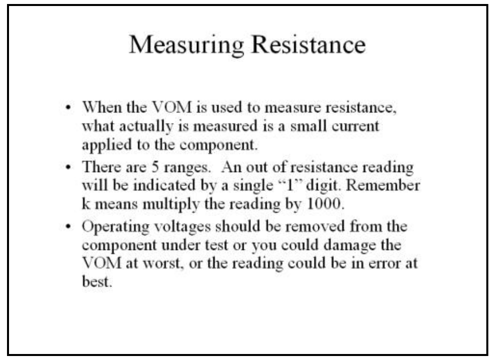
955 micro amps is greater than the 200 micro amps that can be displayed using the 200u range, therefore there will be an over current reading. The 2000u range gives the best reading.



In this exercise, using a 100k-ohm resistor, ask the audience to start at the 200m scale and read the current using each of the four ranges and record their results. This will be a good opportunity to again go over converting currents from amps to milli amps to micro amps and also illustrate how to determine the best range for the current being measured.

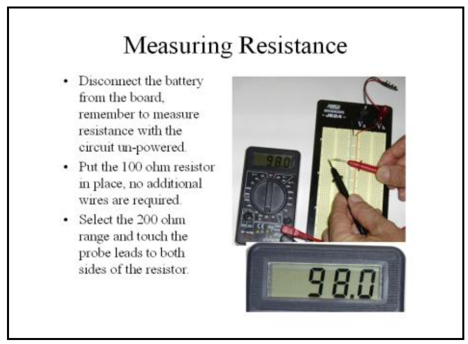


When measuring resistance, there is a small voltage supplied by the meter to energize the component, the red probe lead has the positive voltage. The VOM then measures the current flowing through the component and the resistance is calculated using Ohm's Law (which will be covered later in detail).



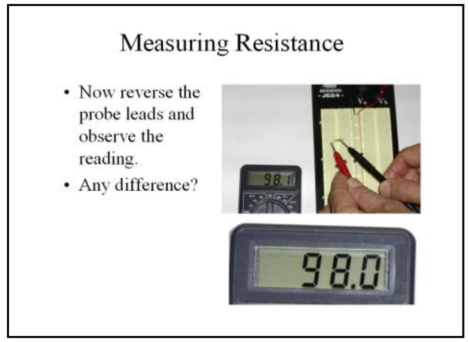
Go through the 5 ranges.
200 will read up to 200 ohms
2000 will read up to 2000 ohms
20K will read up to 20,000 ohms
200k will read up to 200,000 ohms
2000k will read up to 2,000,000 ohms or 2 meg ohms (meg means 1,000,000)
If the power is removed from the circuit, there is little danger that the VOM could be damaged (although some components can be damaged).

Re-emphasize that the power should be removed from the circuit before resistance measurements are made. The resistor is put into the proto board only to hold the component. Caution the audience that they should attempt to hold the probes by the plastic handles, not necessarily just for safety, but also because their body parts have some resistance value that could corrupt the readings.

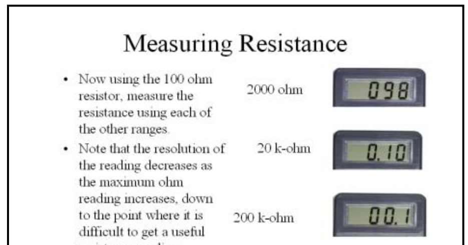


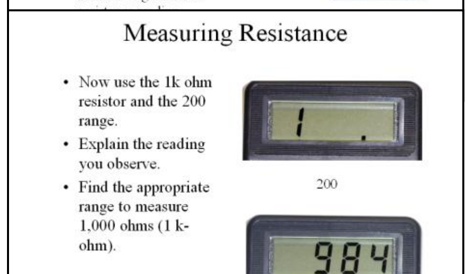
Also emphasize, that when measuring resistors, it does not matter which way the meter probes are placed on the resistor, the readings should be identical. This is not necessarily the case in more advanced resistance measuring techniques, particularly when using the VOM to determine the integrity and polarity of diodes. This will be covered in detail later. Right now though, the probe placement does not matter.

There should be no difference in the readings.

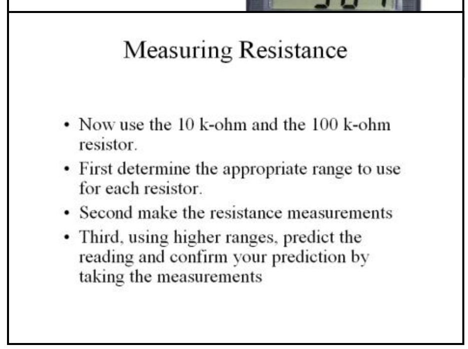


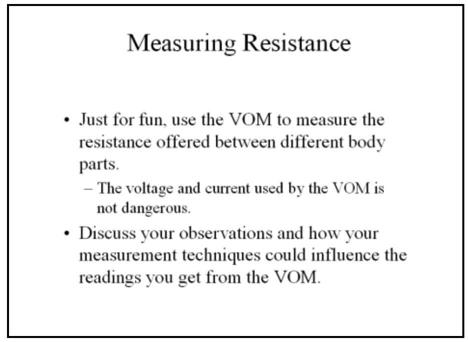
Point out to the audience, that by going to higher ranges, the decimal point of the reading moves to the left, and eventually goes so far to the left that resistance is not displayed. The resistance is still 100 ohms; it is just below the threshold of the display. Using the 200 range will result in an over resistance indication, a single digit 1. Point out to the audience that over anything on this meter is indicated by a single digit 1.
The most appropriate range to measure 1000 ohms is the 2000 range. The other higher ranges work, but the resolution decreases as the decimal point is moved to the left.



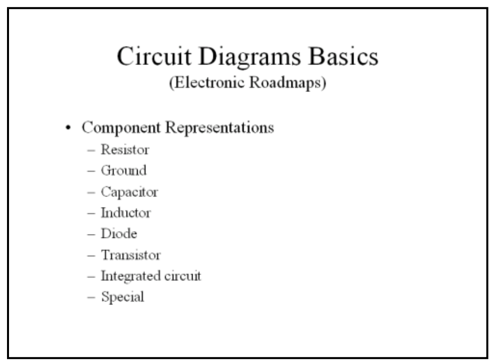


The audience by now should have a pretty good idea of how to measure resistances. Use this as an opportunity to fine-tune their skill.



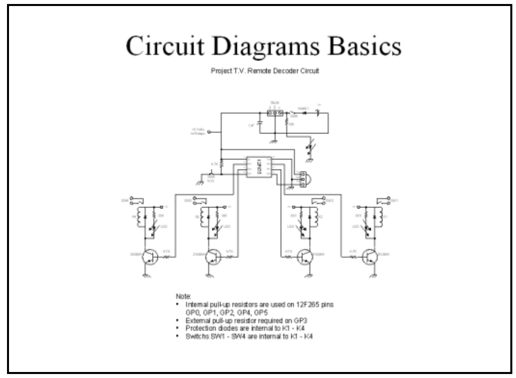


This can be a fun activity. Suggest some measurements the audience might make, but leave the majority of the measurement techniques up to them.
Some suggestions:
Probes across individual fingers. 1.8 meg
Probes held between thumb and finger, one in each hand. 1.4 meg
Probes from the skin on the ankle and skin on hand. Off scale
Dry skin versus moist skin. Dry 1 meg, moist 96k
Lightly touching ht probes compared to a firmer grasp on the probes. Light 1 meg, firm 300k
The point here is that body contact with the probes during measurements can influence the ohmmeter reading and should be avoided, particularly when measuring high values of resistance. You can bring this up again later when you are covering parallel and series resistance.



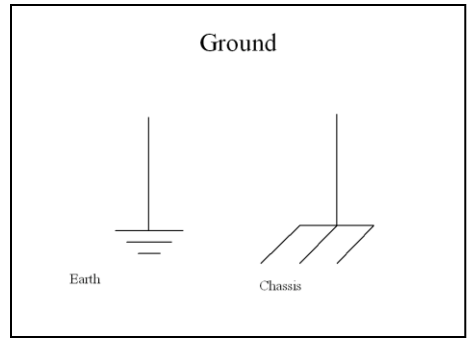
The audience probably has observed that trying to build up a circuit using a picture or words can be difficult and confusing … and they have only been dealing with at most one component, one current/voltage source, and one meter. A better way to communicate how a circuit is put together is to use circuit diagrams.
There are many, many diagram symbols used to symbolize the various electronic components. There are minor variations in the individual symbols to represent variations within a component class. The following discussion is only an introduction intended to give the audience a basic working knowledge of circuit diagrams.
Circuit diagrams are road maps that show the pathways that current can take from the current/voltage source, through the individual components of the circuit to accomplish some task, and return to the current/voltage source to complete the circuit.
The diagram symbols that will be covered are listed in the slide. The audience may not know what each of the component does yet, but their individual functions will be covered later in the course.

This is a simple example of a circuit diagram. In this case, the circuit decodes the signals sent by a TV remote control and turns on and off electrical relay switches in response to the keys pressed on the TV remote.
Point out to the audience that the diagrams they will be working with are very simple.



The symbol on the left is for a fixed value of resistance. The symbol on the right shows a pointer that can be moved across the resistor to vary the resistance. Point out to the audience that they use variable resistors all the time … volume controls on audio equipment.
Generally, a symbol with a pointed arrow associated with it represent variable (or changeable) components.

Grounding though at first appearances is a simple topic; it really does have some subtle differences as represented by these two symbols for ground. A ground is a common return path to the current in a circuit to the voltage/current source. By convention, the ground connection is hooked to the negative pole of the power source. Usually in reality, the ground is the originating source of electrons. This seems to be backwards, but that is the standard convention. In the early days of automobiles, the positive side of the battery and other voltage/current sources were connected to ground, that is not true today.



The term grounding probably comes from the safety term related to connecting an electronic device to a metal rod driven into the earth to provide a safety path for stray current to flow into the earth and not through the operator's body. For instance, many high structures have lightening rods that are hooked to grounding rods driven into the earth so that in the event of a lightening strike, the dangerous currents from the lightening strike flow harmlessly into the earth and not through humans in the vicinity.

There are two basic types of grounds as represented by the two symbols. The symbol on the left, that looks like a shovel, represents a ground connection to an earth ground. Usually there is only one connection between an electrical device and an earth ground, and that connection is primarily for safety (this could be argued that the earth ground is also important for proper RF performance, but that discussion can be done in more advanced courses).

The symbol on the right, that looks like a rake or pitchfork, represents a chassis ground. A chassis is the metal box or foundation that the electronic device is contained in. The symbol actually represents multiple connections between components and the chassis. The chassis ground is used to provide the common path for current to flow back to the power source to complete the circuit.

These are symbols that represent fixed and variable capacitors. The function and operation of capacitors will be covered in some detail a little later, but ask the audience to describe what the internals of a capacitor might look like based on the symbol. They probably will say two metal plates separated by a space. If they don't say that you should. That is basically what a capacitor is, two conductors separated by a non-conductive space.

To give just a brief description of a capacitor, mention that capacitors can be thought of tiny and very temporary storage batteries. Capacitors store electrical energy in an electro static field between the plates. Anyone who has combed their hair or have taken clothing out of a dryer knows what static electricity is, allow the audience to make that connection.

These are the symbols of inductors. Point out that if there were an arrow, the inductor would be variable. Again, based on the symbol, ask the audience to describe what is inside the component. They will probably need a little coaxing to come up with a coil of wire, or a coil of wire with something inside the coil.

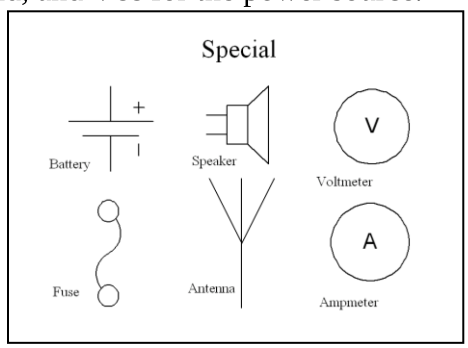
As a brief introduction to inductors, tell the audience that inductors store electrical energy in a magnetic field that is formed around the coil when current passes through it. Most of the audience will be familiar with the earth's magnetic field. One theory is that the earth's magnetic field is formed because electrons are moving within the molten metal that makes up the earth's core. The same thing happens at a very tiny scale in inductors in a circuit.

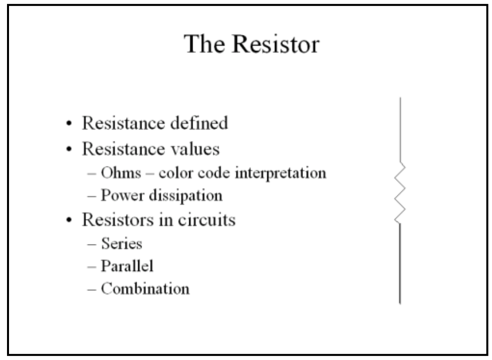
There are numerous types of diodes for various purposes. Describe to the audience what each symbol represents. The regular diode, the zener diode, and light emitting diode.

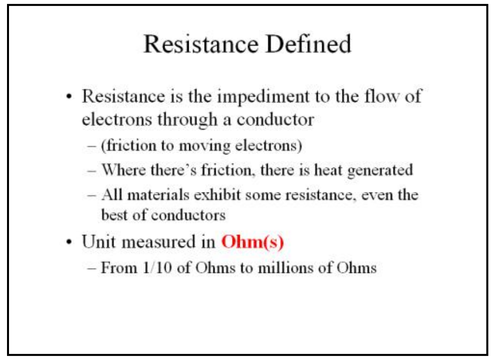
A trick to help the audience to identify the types of bipolar transistors is to look at the direction of the arrow. If the arrow is pointing out, it is Not Pointing iN, that is an NPN transistor. If the arrow is pointing in, it is Pointing iN Proudly, that is a PNP transistor. On the FET, the direction of the arrow identifies the material of the junction, in the illustration the arrow is not pointing in; therefore this represents a P junction FET.

By their very nature, integrated circuits are a collection of components that together perform a function. It is not necessary to know what goes on inside the IC, just how the IC interfaces with the rest of the circuit. Therefore the symbol provides only information on which pin of the IC is connected to the surrounding components. Sometimes there is a descriptive label on a pin, for instance GND for ground, and Vcc for the power source.

These are the symbols for a battery, speaker, voltmeter, fuse, antenna, and amp meter.







Begin by having your audience rub the palms of their hands together and noting what they observe. Point out that their hands do not move freely across the surface of the other palm. In the process of rubbing their hands back and forth, heat is generated. This heat comes from the friction between the palm surfaces, which resists the movement of the hands … in the process of resisting, the energy of movement (kinetic energy) is converted into heat.

The same thing happens as electrons try to move through a conductor or other material. The electrons run into things as they move, and each collusion causes the electron's movement to be impeded in some way. The resulting lost of kinetic energy is converted into heat. In the majority of the cases in electronics, this heat is imperceptible. In other cases, the heat is desirable as is the case with a stovetop. In still other cases, the generated heat must be moved away from the electronic device to prevent damage (fans on a computer).

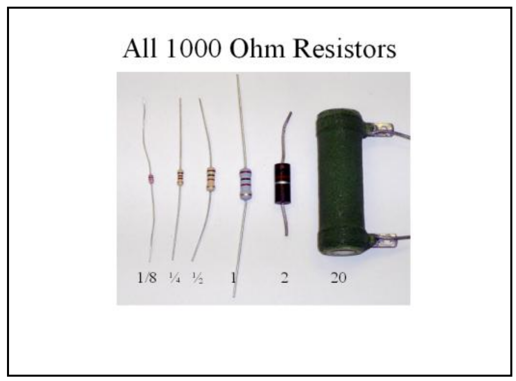
In summary, resistance is friction toward moving electrons. All materials provide some level of resistance. The unit of resistance is the Ohm. Resistance measurements can range from incredibly small to incredibly large.

Discuss with the audience the various types of resistors and the application of each type. Stress the concepts and the differences between the resistance value and the power rating value. Resistors with power rating values of 1/8th watt up to 10s of watts can all have the same resistance value. In this case, physical size doesn't matter as far as resistance is concerned.

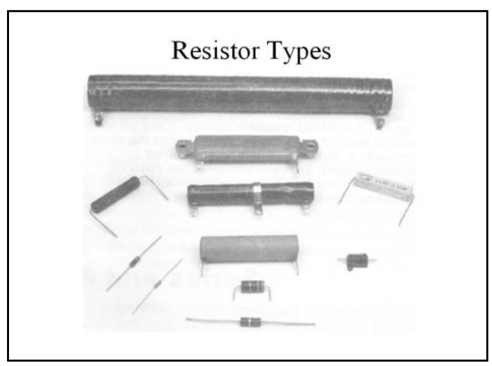
Resistor Types

- Fixed Value
- Variable value
- Composite resistive material
- Wire-wound
- Two parameters associated with resistors
  - Resistance value in Ohms
  - Power handling capabilities in watts

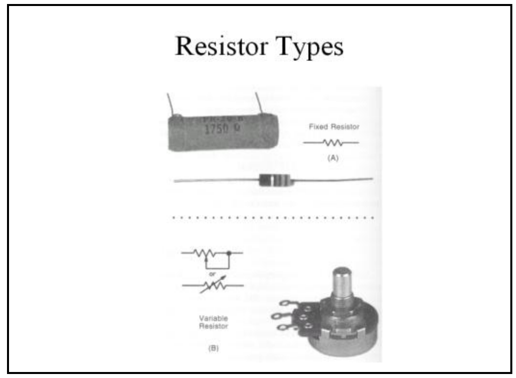
Also point out the composite resistors are generally used when close tolerance and wide ranging values are required. Wire wound resistors are used generally where low resistance but high power handling capabilities are required. As a side note point out that because wire wound resistors are actually large and long coils of wire, the wire wound resistor can and does act like an inductor under AC conditions and therefore care and caution should be exercised when using wire wound resistors in AC applications (for instance, do not use a wire wound 52 ohm resistor as a radio dummy load).



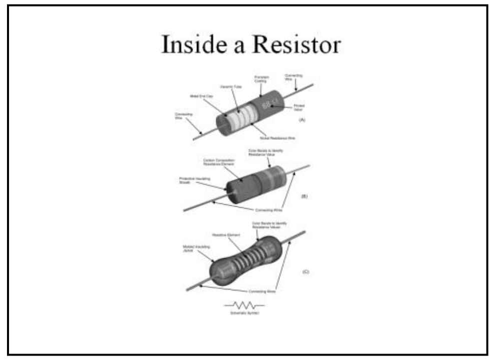
Point out the relative size differences between composite and wire wound resistors. All of these resistors could have the same resistance value even though their relative sizes vary widely.



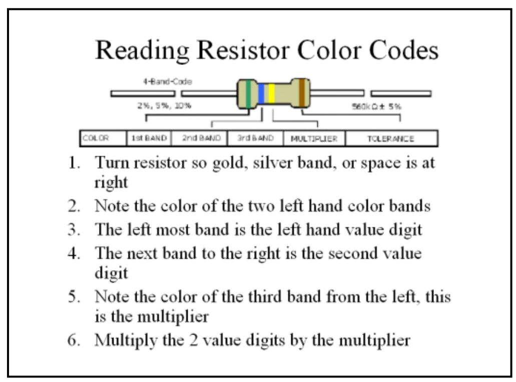
Here is illustrated the differences between variable (adjustable) resistors and fixed resistors. Point out the difference in circuit diagram symbols that was covered earlier.



Discuss with your audience the basic physical makeup of the typical resistor.



Model how to read a resistor color code with the audience. Use a 1K resistor (brown, black, red, and tolerance band). Have the audience follow along with their own 1K resistors.



1.Orient the resistor with the tolerance band to the right (the gold or silver band). If there is no band (20% tolerance resistor), orient the resistor so the bands are toward the left.
2.Take note that the 2 significant digits of the resistor value are going to be represented by the two left most color bands.
3.Note that the left most band is brown, which translates to a value of 1.
4.Moving left to right, note that the next band is black, which translates to a value of 0.
5.Continue moving left to right, note the multiplier band is red, which translates to a multiplier of 100.
6.Multiply the 10 times 100 = 1000 or 1K ohm.
7.

Reading Resistor Color Codes

Color	1st Digit	2nd Digit	Multiplier	Tolerance
black	0	0	1	
brown	1	1	10	
red	2	2	100	
orange	3	3	1,000	
yellow	4	4	10,000	
green	5	5	100,000	
blue	6	6	1,000,000	
violet	7	7	10,000,000	
gray	8	8	100,000.000	
white	9	9	1,000,000,000	
gold				5%
silver				10%
no color				20%

1.3.3K or 3300
2.47K
3.100
4.1 meg
5.2.2K or 2200
6.68K
7.39K

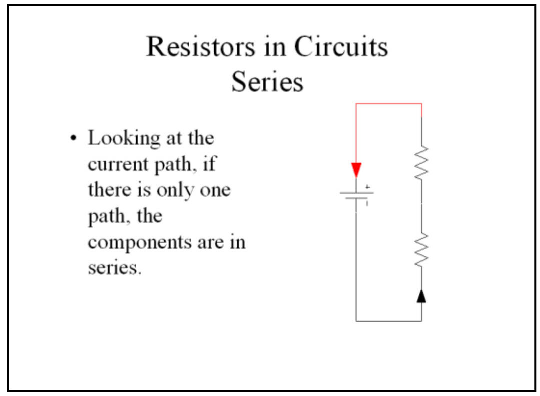
Reading Resistor Color Codes (Practice Problems)

1. Orange, orange, red?
2. Yellow, violet, orange?
3. Brown, black, brown?
4. Brown, black, green?
5. Red, red, red?
6. Blue, gray, orange?
7. Orange, white, orange?

Power dissipation

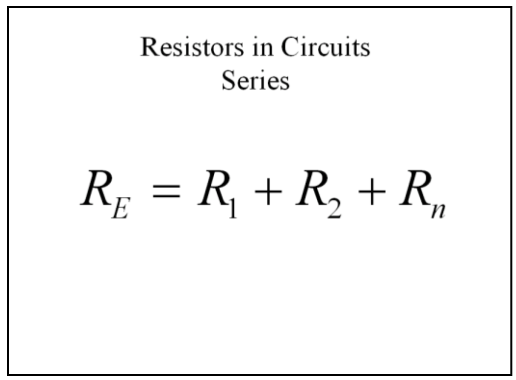
- Resistance generates heat and the component must be able to dissipate this heat to prevent damage.
- Physical size (the surface area available to dissipate heat) is a good indicator of how much heat (power) a resistor can handle
- Measured in watts
- Common values ¼, ½, 1, 5, 10 etc.

The main distinction between series and parallel circuits is how many paths the current has available to complete the course from the negative pole of the power source to the positive pole. In this diagram, all the current from the battery must pass through both resistors. Therefore this circuit is a series circuit.



At this point you need to develop the concept of equivalent resistance. Equivalent resistance is what the total resistance would be if you substituted a single resistor for the resistors that make up the circuit. In this case, if the two resistors were to be combined and replaced with a single resistor that had the same resistance, that single resistor would be the equivalent resistor.

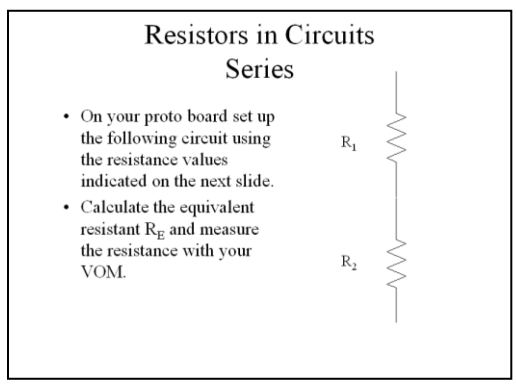
It is easy to calculate the equivalent resistance of resistors in series. It is the simple sum of all the resistances. The subscripts above refer to the first, second, and all subsequent resistors n. All resistance valued are added together.



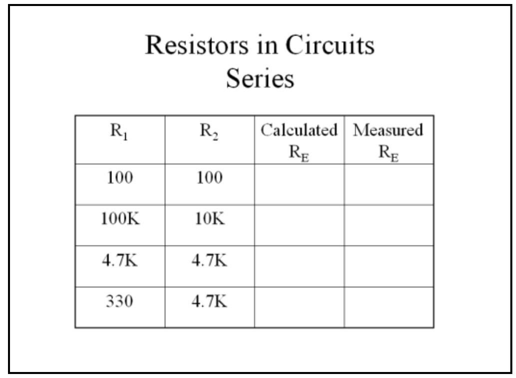
For example, if R1 is 100 ohms and R2 is 200 ohms, then the equivalent resistance would be 300 ohms.

Another example, if R1 is 50 ohms, R2 is 10k ohms (remember 10,000 ohms), and R3 is 500 ohms, the equivalent resistance would be 10,550 ohms.

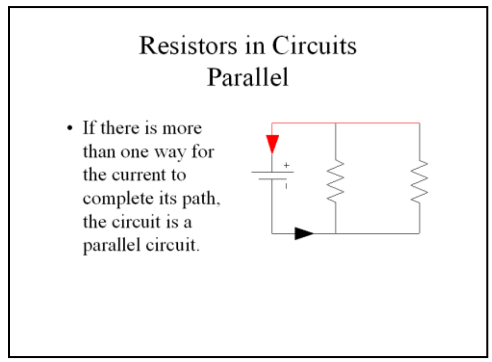
Work with the audience on the first few circuits and then let them experiment and provide help as needed.



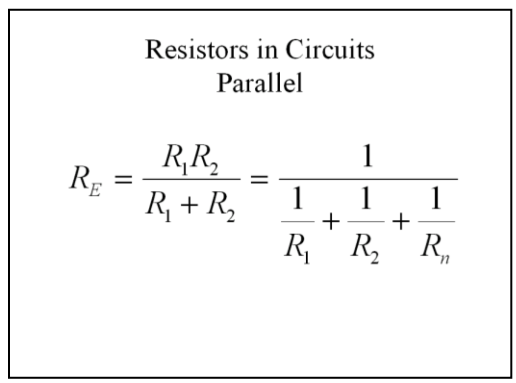
100 + 100 = 200
100K + 10K = 110K or 100,000 + 10,000= 110,000
4.7K + 4.7K = 9.4K or 4,700 + 4,700 = 9,400
330 + 4.7K = 5.03K or 330 + 4,700 = 5,030
The measured resistances should be close to the calculated values. Depending on the quality of the resistors, the actual value of the resistor can be different with a specified tolerance. Common tolerances are +/-20%, +/-10%, +/- 5%, and +/-1%.



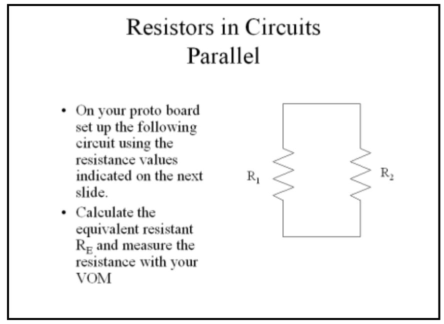
In this case, there are two possible paths. The electron flow divides and some pass through the left and some pass through the right hand resistor. Since there is more than one path option, this is a parallel circuit.



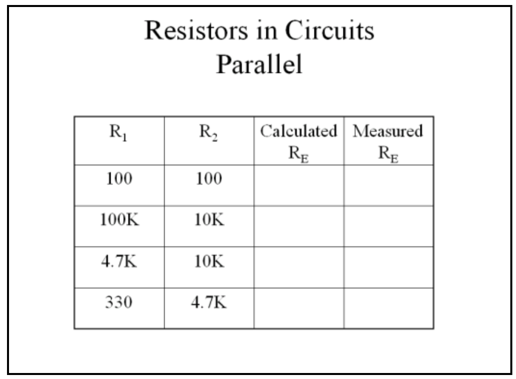
The left hand formula is really just the same as the right hand formula except it is for two resistors in parallel only, and the algebra has been done on the right hand formula to make it a little simpler.
Point out to the audience, that by the very nature of a parallel circuit, the equivalent resistance will be less than any of the single resistors that make up the circuit. Sensitize the audience to this fact so that as they go through the exercises, they will see this as being true.



This property makes sense if you think about it. Referring back to the water analogy. If there is more than one hose for the water to flow through, each path has a relatively narrow hose (resistance). Then what the water sees as it approached the hose openings is not the narrow opening of just one hose, the sum total of all the openings, which would make it appear that there is one large opening to go through … one large opening is like seeing one lower resistance path than the individual hose openings.

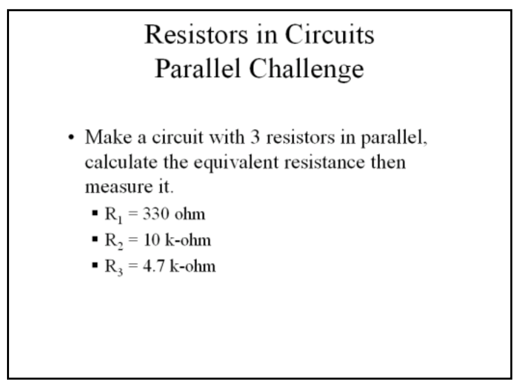


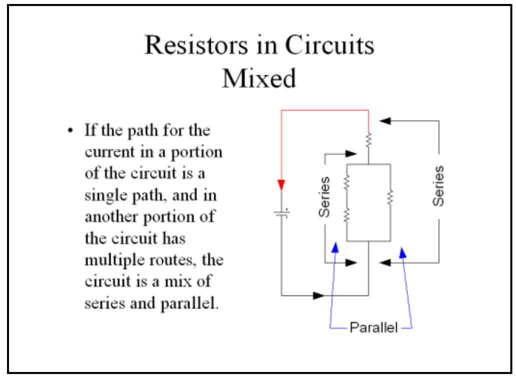
100 and 100 = 50
100K and 10K = 9090
4.7K and 10K = 3197
330 and 4.7K = 308
Emphasize to the audience that the equivalent resistance is always less that the lowest value of the single resistors.
The measured values should be close to the calculated values. Task the audience to build the circuit and measure the resistance. On the test bed the resistance was:
49.5 ohms
8920 ohms
3150 ohms
312 ohms



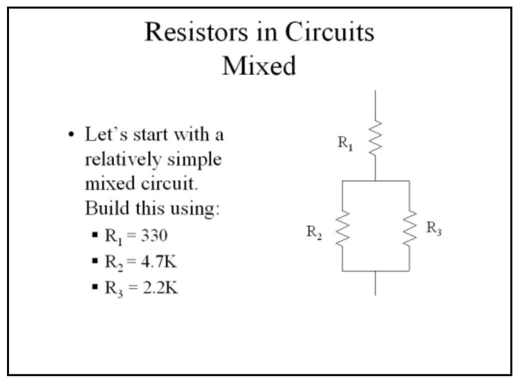
R_1	R_2	Calculated R_E	Measured R_E
100	100		
100K	10K		
4.7K	10K		
330	4.7K		

330 and 10K and 4.7K in parallel = 299.
Task the audience to build the circuit and measure the resistance. On the test bed the resistance was 302 ohms.



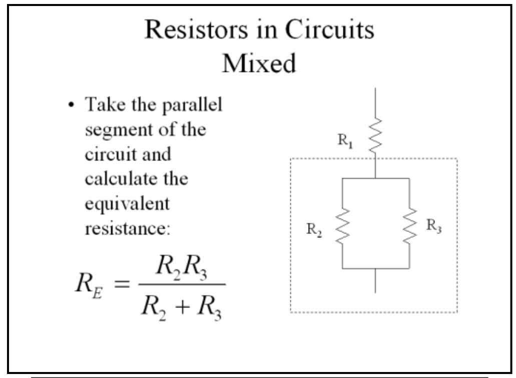


Circuits are usually not just series or parallel, most practice circuits are a combination of the two. In order to analyze these mixed circuits, you need to be able to divide sections of the circuit and look at the smaller section individually. Then once each segment is analyzed, the segments can be put back together to make the whole circuit.
In this circuit, if you look at the two resistors in the lower left of the circuit, these resistors are in series. The equivalent of these two resistors in series is the simple sum of the two resistance values.
Next, this equivalent combined resistor is connected in parallel with the bottom right resistor because there are two paths for electrons going into this portion of the circuit. The equivalent of these two resistors is: (R1*R2)/(R1+R2).
Finally, the resistor at the top is in series with the equivalent resistor at the bottom because the current has only one path.

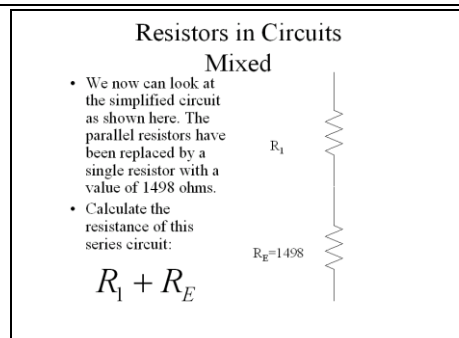


Your audience will probably need some assistance in building this circuit and locating the points to make the resistance measurements.

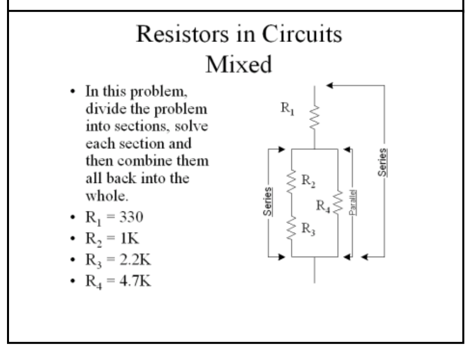
The equivalent resistance is 1498 ohms.
Ask the audience to confirm their calculations by measuring the resistance of the parallel portion of the circuit. Do this by putting one probe on the junction of R1, R2, and R3, and the other probe of the bottom junction of R2 and R3.



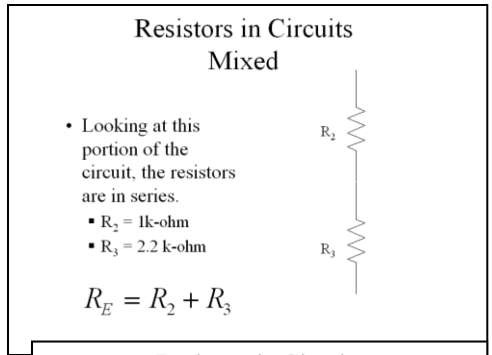
Task the audience to build this portion of the circuit and measure the resistance. It should compare with the calculated value. On the test bed for the course, the equivalent resistance was measured to be 1486 ohms.330 = 1498 = 1828 ohms
Ask the audience to measure the total resistance and confirm their calculations. One the test bed the resistance was 1820 ohms.



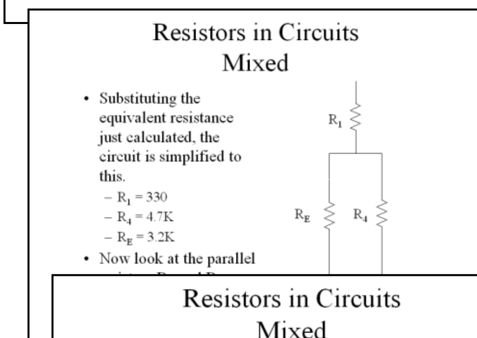
This mixed circuit looks intimidating, but if you model for your audience how to break it down into smaller chunks to simplify the circuit. Point out that R2 and R3 are in series and therefore the equivalent resistance of R2 and R3 can be found by using the series formula. Next, that equivalent resistance for R2 and R3 is then in parallel with R4 and the parallel formula can be used to find the next equivalent resistance. Finally, R1 and the equivalent resistance are in series and the series formula applies. The following slides take the audience through each step.

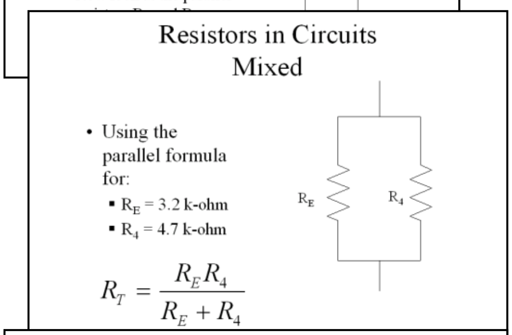


The equivalent resistance of these two resistors in series is the sum of the resistances. R_E = 3.2K = 3,200 ohms
The measured resistance on the test bed was 3,170 ohms.

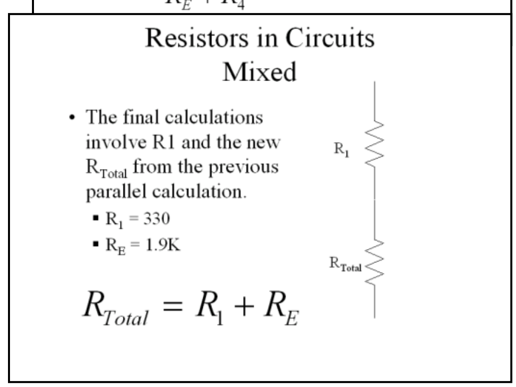


It is helpful if the audience redraws the circuit on a scrap piece of paper so they can keep track of the substitutions. Now that the equivalent resistance has been found for the series pair R_2 and R_3, the equivalent resistance is placed in the circuit. The next step is to simplify the parallel resistor R_E and R_4.
Solving this parallel portion of the circuit R_E = 1.9K.
The measured resistance on the test bed was 1,880 ohms.

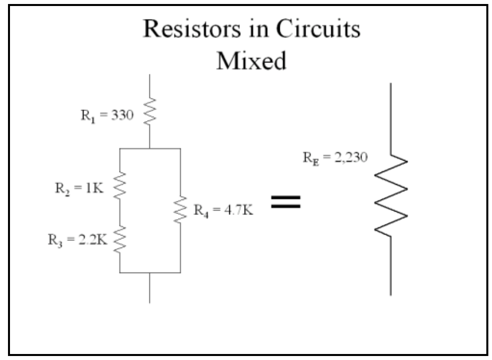


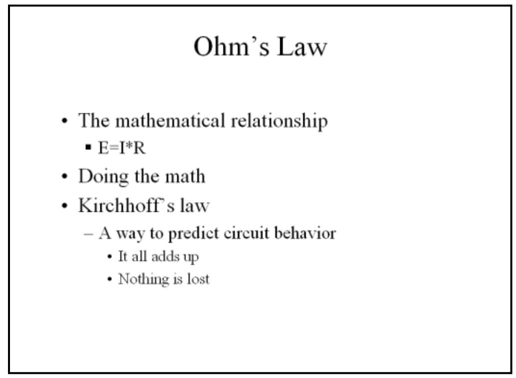


The circuit can now be further simplified by substituting the equivalent resistance just calculated in for the parallel portion of the circuit. The final calculation involves now only two resistors in series, R_1 and R_E.
The final resistance is 2,230 ohms.
The measured resistance on the test bed was 2,220 ohms.

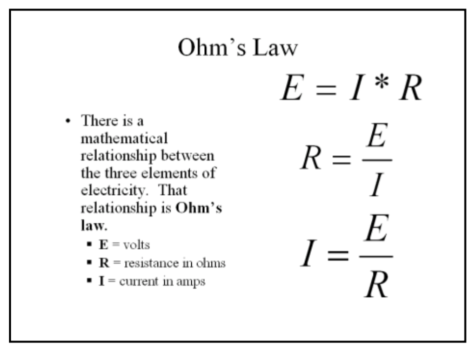


The end result is that the circuit on the left has been simplified to the single equivalent resistance on the right.
Task the audience to now build the circuit on their proto boards and measure the overall resistance to verify their calculations.
330 is orange, orange, brown
1K is brown, black, red
2.2K is red, red, red
4.7K is yellow, violet, red

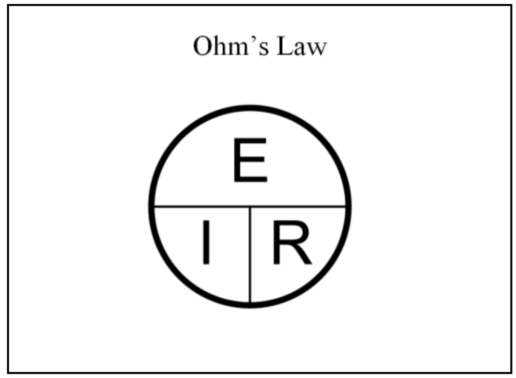




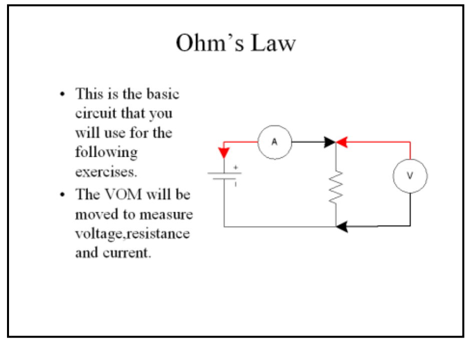
Discuss with the audience the Ohm's law formula. Take some time to develop the formulas from the basic formula E=I*R.
The letter E comes from the scientific term for voltage which is electromotive force. The letter I from the French word *intensite'*.
In the following sequence of slide, the audience will be doing an exercise in which they will set up a circuit using resistors and a voltage source (9 volt battery), predict current using Ohm's law, and verify their calculations by taking voltage, current and resistance measurements with the VOM.



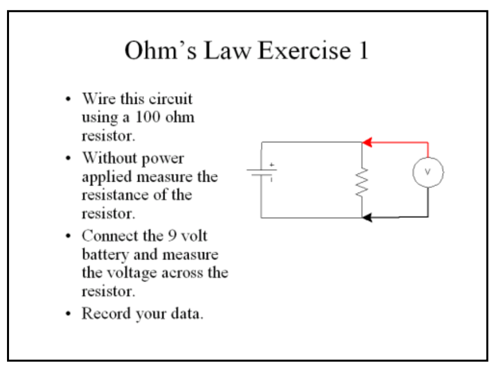
Some in the audience might find this representation of Ohm's Law more memorable. Take some time to explain how to use this kind of chart.



Ensure the audience is interpreting this circuit diagram correctly. The selected resistor will be mounted on the proto board. The 9-volt battery will be connected to the power source. The VOM will be used across the resistor when no power is applied to measure the resistance. A wire will be inserted where the amp meter is shown to provide current to the resistor, and the VOM will be placed across the resistor to measure the voltage. Finally, the VOM in the amp meter mode will be inserted into the circuit between the battery and the resistor to measure the current. The exercises will take a few steps and the audience should record their data in a systematic way so that they can easily see the relationships, and therefore see the relationships expressed in Ohm's law.

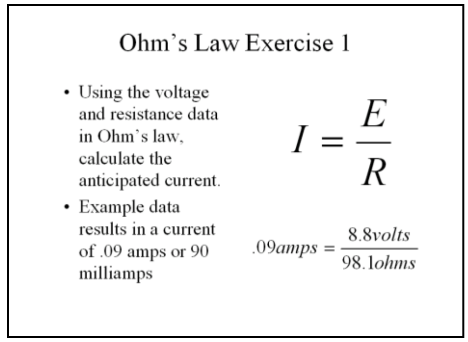


Mention to the audience that with this arrangement, they are simply measuring the resistance of the resistor and the voltage across the battery. Even though they are using a 100-ohm resistor, the resistor is not going to be exact. And even though they are using a 9-volt battery, depending on the load on the battery and the condition of the battery, the actual voltage and current supplied by the battery can vary quite a bit. Therefore besides take the readings for practice; the readings will give more accurate results in their exploration of Ohm's law instead of relying on the predicted values.

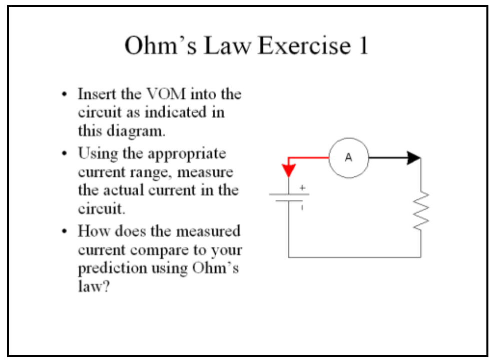


In the circuit used by the author, R = 98.1 ohms, V = 8.8 volts

The audience will have different data and different results, but it should all be within the ballpark of these figures.

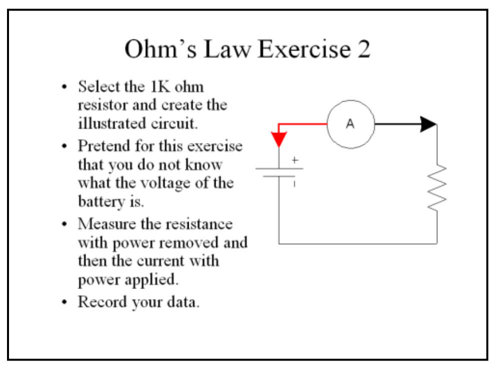


The audience will have to add some connecting wires to the circuit so that the VOM probe leads can be touched to the battery + pole and the resistor lead. Some may have the probe leads reversed and end up with a negative reading. Just reinforce that the negative reading is usable, they just have to be cognizant of the sign and the direction of current flow (and drop the negative sign when making comparisons to the calculations).

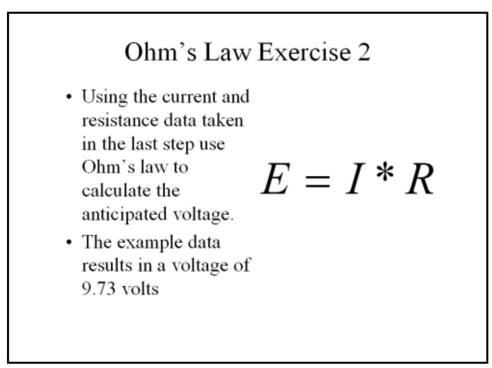


The current measurement in the example was 88.4 milli-amps or .0884 amps. Comparing this to the calculated value of .09 amps, there is good correlation between the predicted current and actual current.

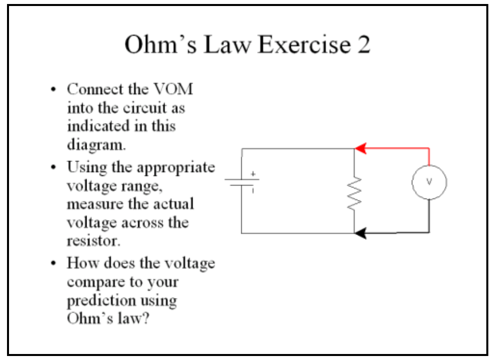
In this example R = 983 ohms, I = 9.39 milli-amps or .00939 amps.



The audience will have different data and different results, but it should all be within the ballpark of these figures.



The actual voltage measured during course development was 9.32 volts. There is good correlation between the predicted voltage of 9.7 and actual voltage of 9.32.



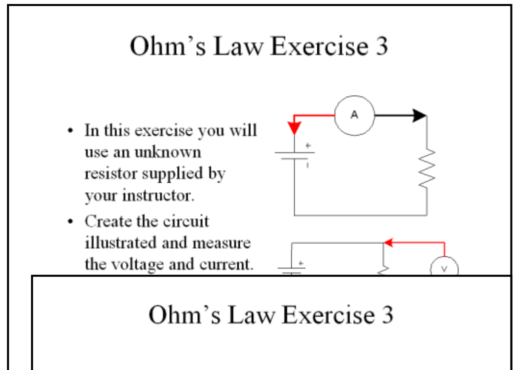
Before the class, take some resistors and disguise the values by covering the resistor body with tape. Provide these resistors to the audience for this exercise.

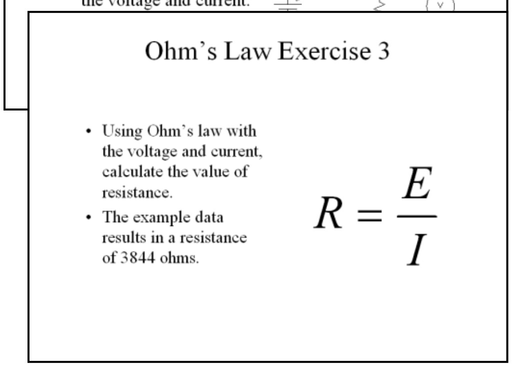
In the example used to build this exercise, a 3.8K resistor was used. Use some odd value.

V = 9.38

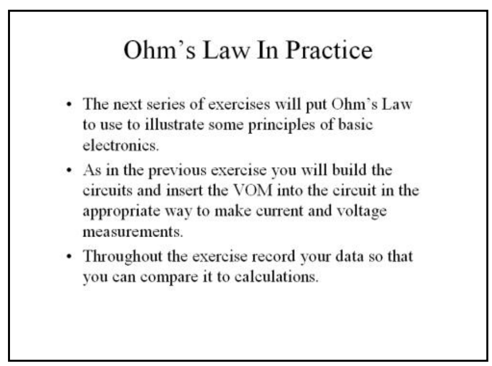
I = .00244 amps or 2.44 milliamps

The actual resistance measured during course development was 3.82K ohms. There is good correlation between the predicted resistance of 3844 and actual resistance of 3.82K.

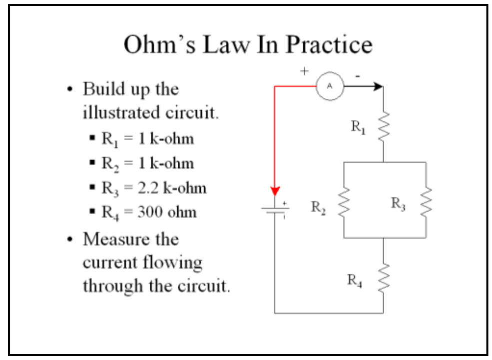




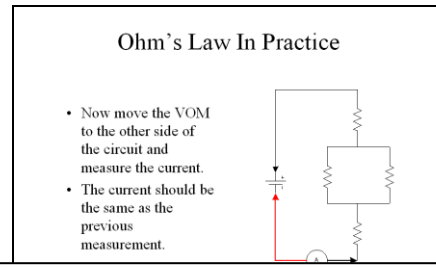
During the next sequences of exercises the audience will be taken through incremental steps to develop Kirchhoff's Law. Avoid talking about Kirchhoff's law, depending on your audience, the term may sound to mysterious and difficult. Better to have them experience Kirchhoff's Law first and then learn what it is called later.



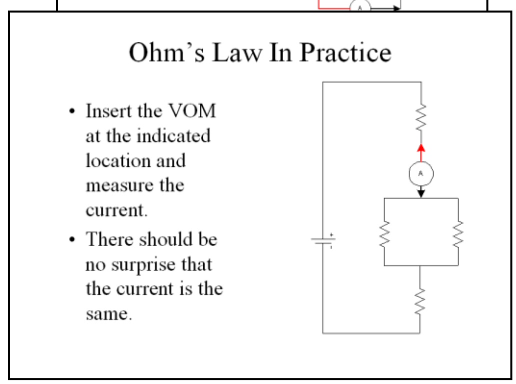
The audience will be inserting the VOM into this circuit at various locations to measure current and voltage.
On the test bed the current was 4.65 milliamps.



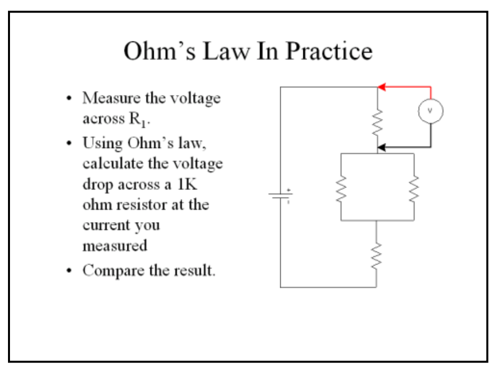
On the test bed the current reading was 4.65 milli-amps.
The point to emphasize here is that the same level of current flows into and out of the circuit.



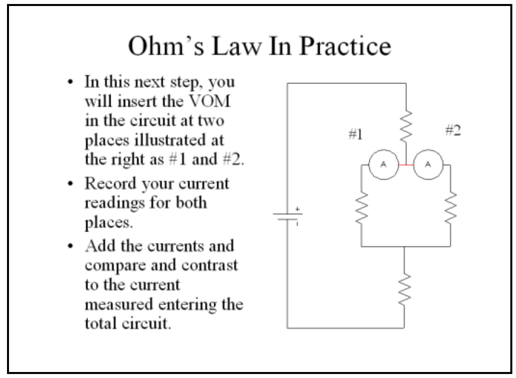
The result is in fact the same, 4.65 milli-amps.



On the test bed, the voltage was 4.6 volts.
Using Ohm's Law E=I*R; E=.00465*1000; E=4.65 volts

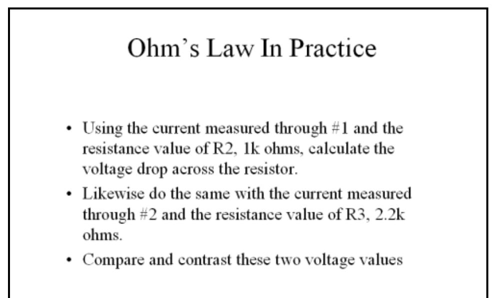


The audience may need some help wiring up this circuit.
This is an importand part of this learning activity. The two currents should add up to be equal to the total current entering the circuit. The point here is that the total current is split between the two paths available. The more observant participants will see that the higher current amount goes through the leg that has the least resistance. Ask a participant to explain why this happens.

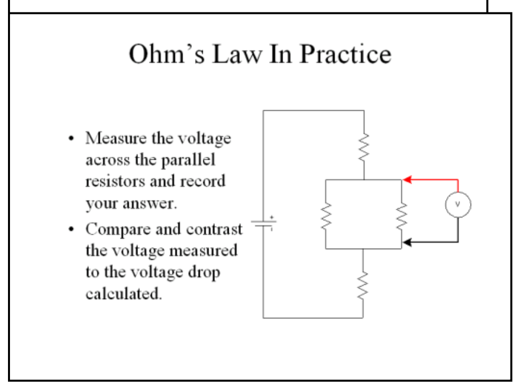


The current through R2, the 1K-ohm resistor was 3.21 milli-amps.
The current through R3, the 2.2K-ohm resistor was 1.44 milli-amps.
The total was 4.65 milli-amps compared to the total 4.65 milli-amps. Also note that the current through the 1K-ohm resistor was greater than through the 2.2K-ohm resistor, lower resistance, high current.

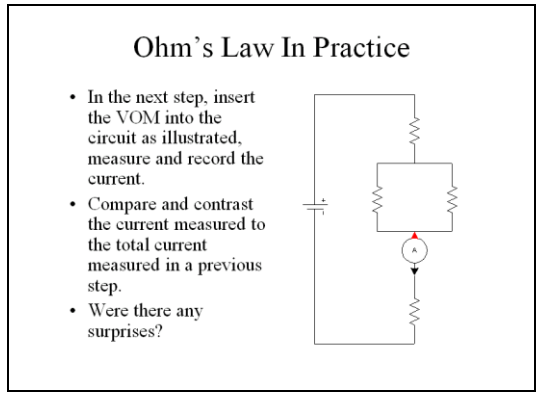
Using the currents from the test bed.
I #1 = .00321 amps; .00321*1,000 = 3.21 volts
I #2 = .00144 amps; .00144*2,200 = 3.168 volts
The values are essentially the same, and they should be.



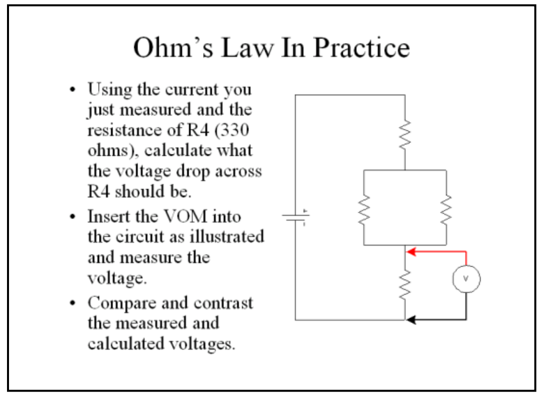
The voltages should be the same. On the test bed the voltage was 3.17 volts.
Ask the audience to keep track of this voltage and the voltage drop measured across R1. These values will be used a little later to make a point.



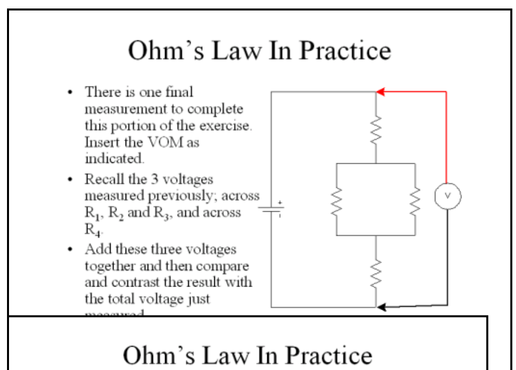
The current reading here should be the total current through the circuit. On the test bed the current was 4.62 milliamps.



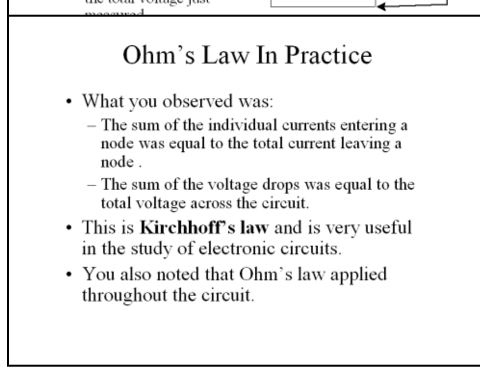
Using the current from the test bed I = .00462 amps and 330 ohms, .00463*330 = 1.52 volts. Measuring the voltage on the test bed the voltage was 1.56 volts.

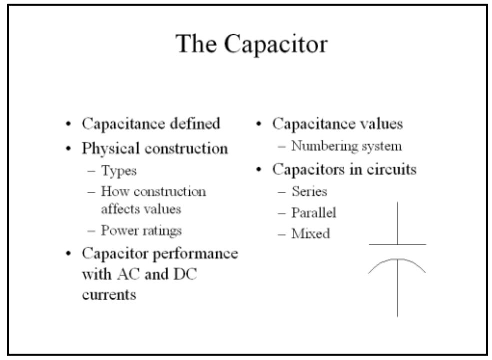


On the test bed this final voltage was 9.33 volts.
The voltage across R1 was 4.6 volts
The voltage across R2 and R3 was 3.17 volts
The voltage across R4 was 1.56 volts
The total of measured voltages was 9.33 volts.



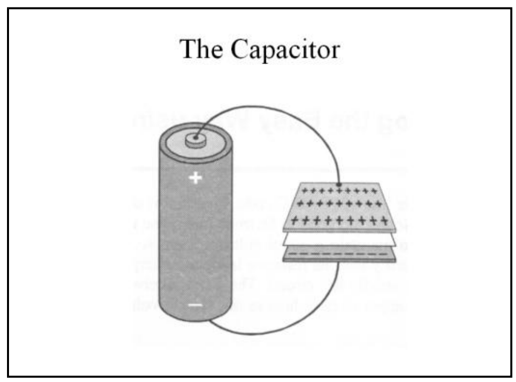
Take some time to hit this point home; the audience essentially derived Kirchhoff's Law through their experiment and measurements. The combination of Kirchhoff's Law and Ohm's Law make a powerful combination for the study and understanding of electronic circuits. Using a strategy of dividing a circuit into simple parts and applying these two laws, virtually all the secrets and mystery of electronic circuits can be explained and understood.



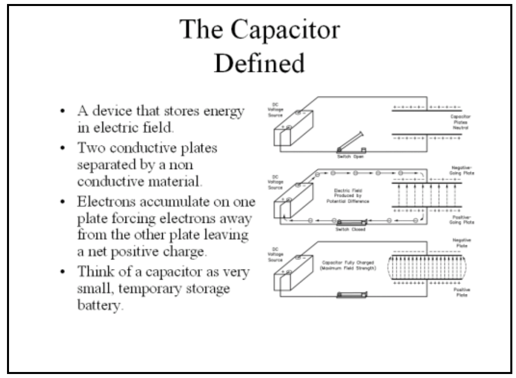


Emphasize with the audience that you will not be going into as much detail as you discuss the remaining basic electronic components. The purpose of this course is to give a very basic overview of electronics and a just a basic understanding of what these components do in a circuit is part of that understanding. If more information is desired, additional study materials and in-depth reading is available on the subject.

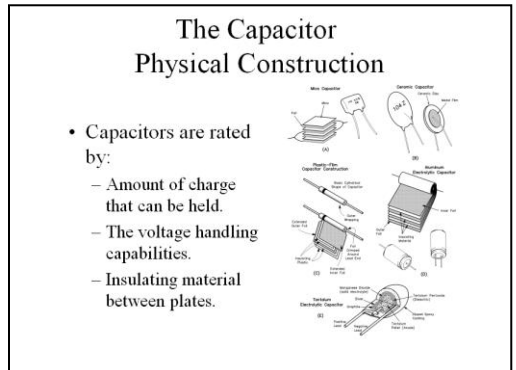
In this next section you will cover what a capacitor is, what it does, the physical characteristics that influence the amount of capacitance, and how capacitors react differently in series and parallel circuits from resistors.



Bring to the audience the analogy of static electricity when they comb their hair or take clothing out of a dryer. Apposing charges build up on the comb and hair. When the comb is brought into proximity to the hair, the hair is attached to the comb and stands on end. Everyone has experienced static discharge with an unexpected spark. The phenomenon is basically how a capacitor works, by storing that change.



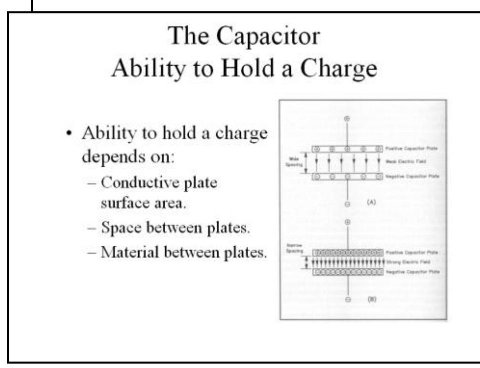
The basic unit of capacitance is the farad. A single farad in reality can hold a very large amount of charge and in electronic circuits, and the amount of capacitance is usually in the millionths and billionths of a farad (micro-farad, pico-farad, nano-farad).



Capacitors are identified by the type of insulating materials between the conductive plates, i.e., air, mica, tantalum, ceramic, polystyrene, etc.

The value of the capacitor is determined by 3 physical factors:

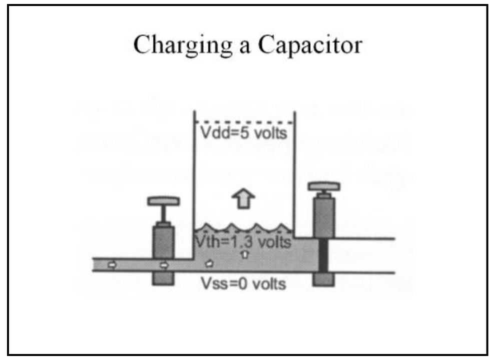
1.The amount of surface area of the conductive plates. The larger the surface area, the more charge, and therefore the higher capacitance value.



2.The distance between the plates. The closer the conductive plates are to each other, the stronger the electrostatic field that is developed. When the plates are close together, the attraction between the opposing poles is stronger. The closer the plates are together the higher the capacitance.

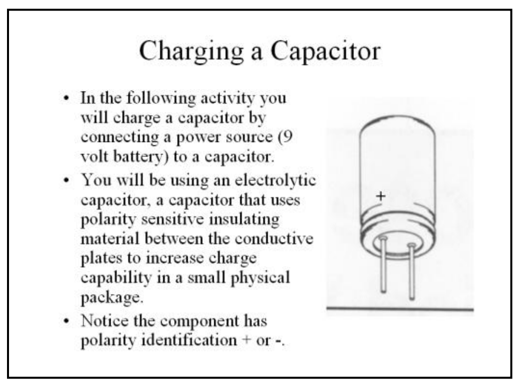
3.The insulating material between the plates. Certain materials are more conducive to separating the poles than others; this allows capacitors to handle higher voltages or to hold a charge longer. Certain materials are very thermally stable and will not expand or contract as much with temperature changes therefore making the capacitance value more stable over wide operating temperatures.

Spend some time talking about how a capacitor is charged. Go back and use the water analogy to help explain how a capacitor works. In this illustration water (electrons) is entering the tank (capacitor) from the right. The rate that the water (electrons) enters the tank (capacitor) depends on how much pressure (voltage) pushing on the water. The outlet valve on the right is closed so water (electrons) cannot escape. When there is no water (electrons) in the tank (capacitor), the reverse pressure (voltage) from the water (electrons) in the tank (capacitor) would be zero and the water (electrons) would rush into the tank (capacitor) un-impeded. When the tank (capacitor) has all the water (electrons) it can hold, the reverse pressure (voltage) of the water (electrons) would equal the pressure (voltage) pushing the water (electrons) in to the tank (capacitor) and the flow of water (electrons) would stop and remain constant. The tank (capacitor) is in a charged state with the pressure (voltage) inside the tank (capacitor) equal to the pressure (voltage) of the water (electron) supply.

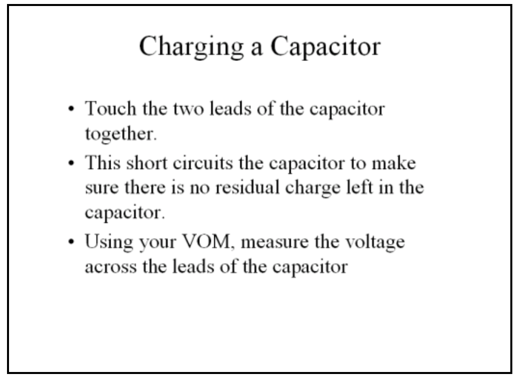


In the beginning the water (electrons) rush in at a rapid rate because there is no opposing pressure (voltage) built up. As the opposing pressure (voltage) builds as more water (electrons) enters the tank (capacitor), the rate of water (electron) flow slows until it virtually stops when the tank (capacitor) is full.

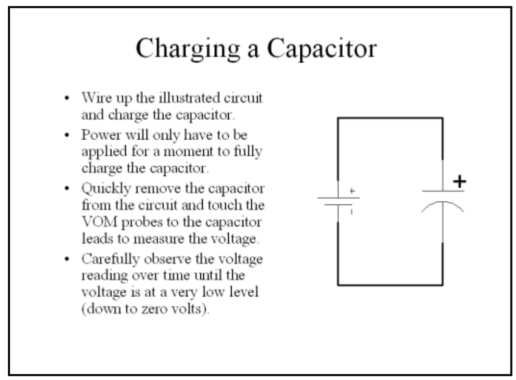
Describe to the audience the physical arrangement of the conductive plates within their electrolytic capacitor. There are two sheets of conductive material separated by a chemically active past dielectric (insulating) material. The two sheets are connected to the leads that come out the bottom of the capacitor. The sheets are rolled up, much like a sleeping bag, and put into the container they are holding.



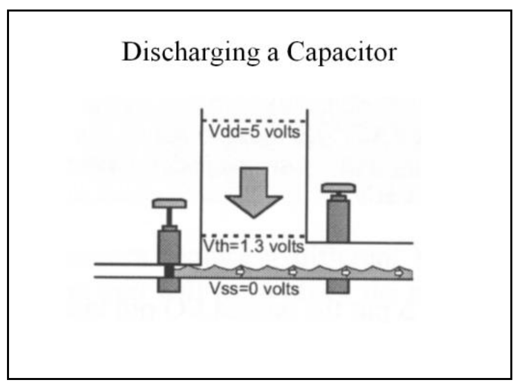
Ensure with your audience that the voltage and current levels of the capacitor they are using are very, very low and safe. This may not always be the case. Capacitors are main components in power supplies in consumer electronic devices. In some cases, power supply capacitors can be charged with high voltages and supply high currents that could be harmful. So caution is generally advised when working with capacitors that are installed in power supply circuits.
The voltages measured should be virtually zero.



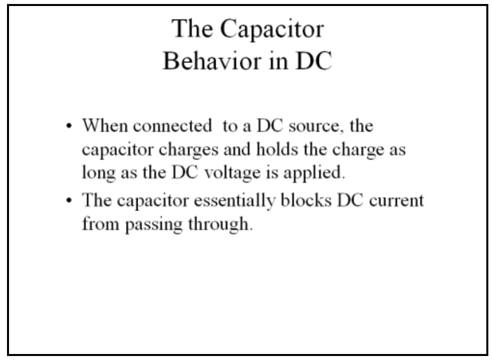
Emphasize with the audience to take note of the polarity of the capacitor and attach the + or – side of the capacitor to the appropriate pole of the battery. There is little danger that reversing the polarity will damage the capacitor in this case, but they should get into the habit of watching polarities.
The audience will have to experiment to find the appropriate range on the VOM, the capacitor will be charged to approximately 9-volts, therefore the 20 volt range would be appropriate. The audience should observe that the voltage quickly bleeds off and they can continue to monitor the lower voltages by switching to lower VOM ranges.



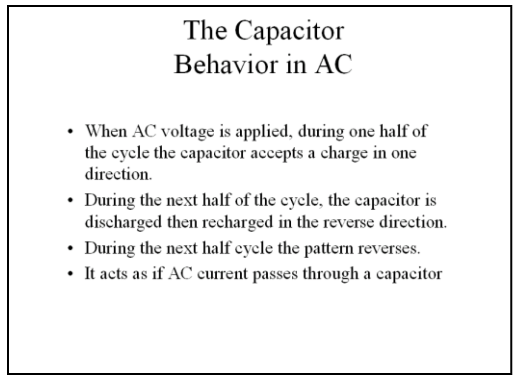
This illustration returns to the water tank analogy to help show what happens after the capacitor is charged and allowed to discharge. The intake valve on the left is closed, and the outlet valve on the right is opened. In the previous activity, when the VOM was connected to the capacitor, a path was opened for the electrons to flow from the capacitor (the VOM does take a little bit of the current to make the readings). Initially when the capacitor was fully charged, there was approximately 9 volts of pressure pushing the electrons down the conductor. As the voltage drops in step with the reduced charge, the pressure pushing the electrons also decreases causing a decrease in electron flow. How this showed up on the VOM was an initial, rapid voltage drop that slowed down to a crawl. In reality, a capacitor loses its charge only after a prolonged period of time; the voltage drop is asymptotic to zero (never reaches zero).



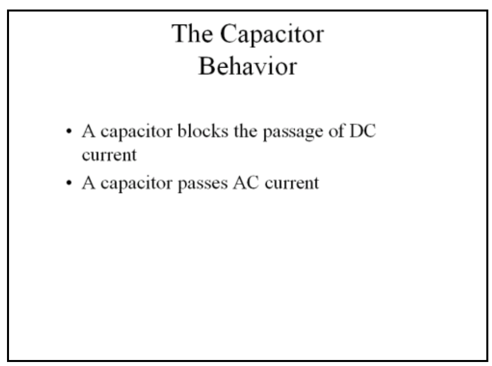
Point out to the audience that they used DC to charge the capacitor. Once the capacitor reaches full charge (the forward voltage equals the reverse pressure), the current ceases to flow, it stops, and it is essentially blocked.



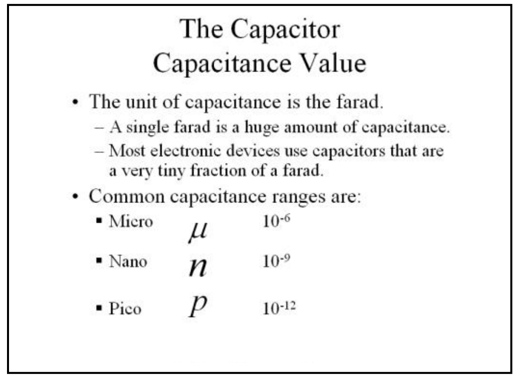
This is going to take a little more explaining. Talk the audience thorough the process after you review what AC is.
During the positive portion of the cycle, electrons are drawn from plate 1 and added to plate 2, the capacitor is charged with plate 2 being negative and plate 1 being positive.
After the peak of the positive cycle, the capacitor begins to discharge. When the cycle begins to go negative, electrons are added to plate 1 and drawn away from plate 2. The capacitor is charged with plate 1 being negative and plate 2 being positive.
If the audience looks at just one plate, the plate goes from positive to negative and back again … just as if the plate were a source of AC!



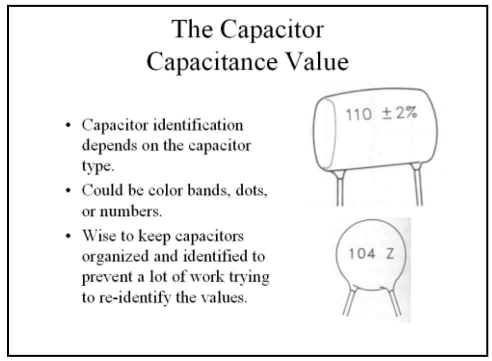
In summary, cover that the capacitor blocks the passage of DC and passes AC. You can add an additional tidbit that depending on the value of capacitance, a capacitor more readily passes certain frequencies, this concept is called the capacitive reactance.



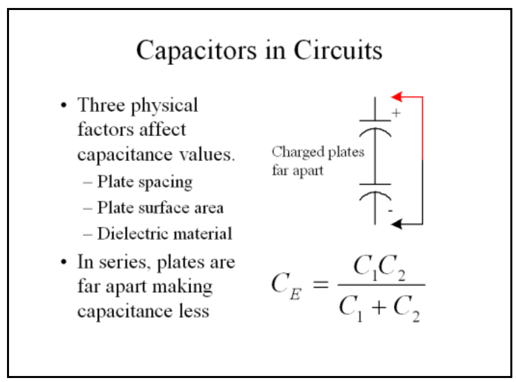
Point out to the audience the wide range of capacitance values. The most common values are micro and pico farad though sometimes you will see values listed as nano farad.

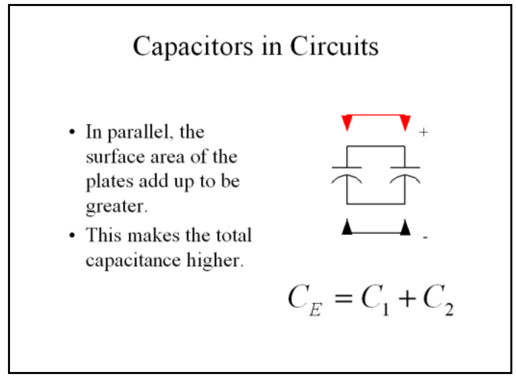


Capacitor identification can be a little tricky and complicated. These two illustrations show the typical numbering system. Here are some common examples:
1uf = 105
.1uf = 104
.01us =103
1000pf = 1nf = 102
.047uf = 473
.022uf = 223

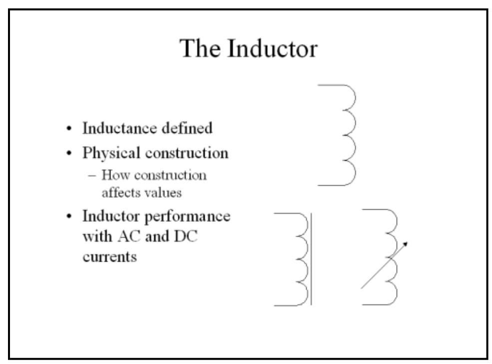


The audience should already be familiar with parallel, series, and mixed circuits from the previous discussion. There is a little twist that is important when dealing with capacitors in circuits, the mathematics is the opposite of what they use with resistance, i.e., parallel capacitances are a simple sum, and series capacitance is the reciprocal sum.
It is fairly easy to see why there is a difference if the audience goes back to what physical factors affect the amount of capacitance, or the amount of charge the device can hold. There are two physical factors, the surface area of the conductive plates and the distance between the conductive plates.



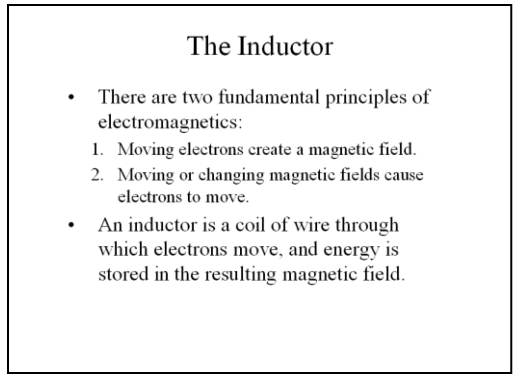


The surface area of the conductive plates in parallel capacitors add together. The electrons on the plates connected to the negative pole of the source spread out across both capacitor's plate, the positive change (absence of electrons) on the plates attached to the positive pole of the source also spread out, the plates are still only separated by the same distance as if there was just a single capacitor. So more electrons are exposed over a greater surface but at the same distance, therefore the capacitance will be more. The simple sum.
The two formulas should look familiar. Emphasize with the students that even though the formulas look the same as the ones used for series and parallel resistances, the mechanism that these formulas represent are different between resistors and capacitors. The important thing to remember, that the formulas are applied in the opposite direction between resistors and capacitors.

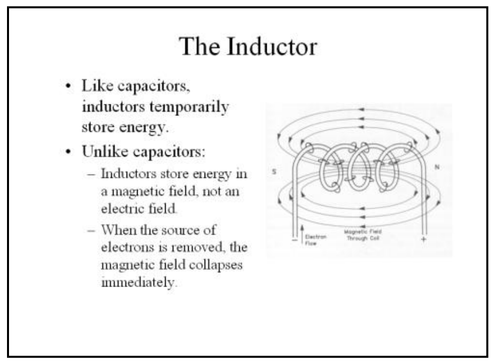


Now turning to inductors. Inductors are essentially coils of wire that are used to store energy temporarily in a magnetic field. Inductors combined with capacitors are used in many different kinds of electronic circuits because of their property to oscillate or "ring". Energy in one component feeds the other, back and forth in an oscillating or "ringing" manner at a specific frequency. This phenomenon is called resonance. Additionally, paired inductors in close proximity, with overlapping magnetic fields, allow energy to flow from one inductor to the other, by "inducing" a current in the other inductor. This is basically how a transformer works. These concepts are beyond the scope of this basic course, however, the audience should be aware of the basic function of the inductor.

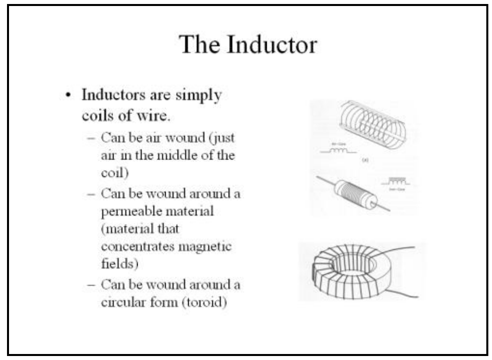
A very good demonstration of the two fundamental principles is to drop a strong magnet through a conductive pipe (such as copper or aluminum and a non conductive pipe such as PVC). The magnet falls right through the non-conductive pipe as expected, but drops slowly though the aluminum pipe, and even more slowly through the copper pipe. What is happening is that the moving magnetic field tries to cause the electrons in the conductor to move, those electrons in turn create and opposing magnetic field that slows the magnet's decent. The magnet falls through copper more slowly because copper is a better conductor than aluminum.
A good source of magnets for this demonstration is at: http://www.gaussboys.com/product_info.php?products_id=31.



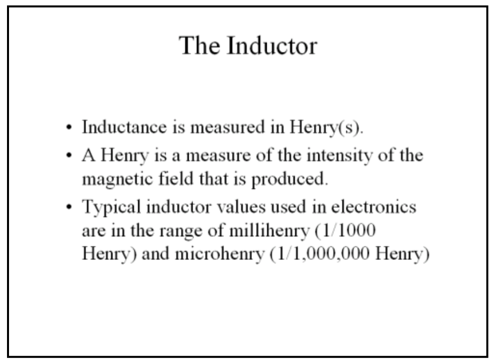
Discuss with the audience the concept of magnetic fields related to the two fundamental principles of electronics. Give some examples that they may be familiar with, like the coil in a car or the electro-magnets they made in school or played with as children.
Emphasize that like capacitors, inductors temporarily store energy, but unlike capacitors the energy is stored in a different form, a magnetic field.



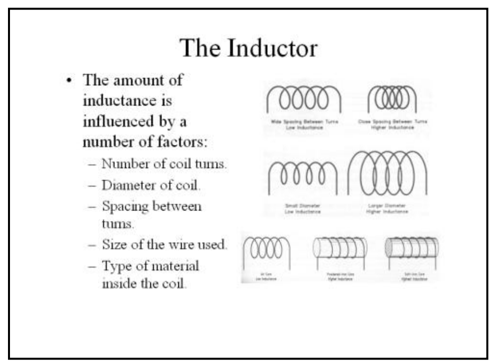
Discuss with the audience the physical makeup of the typical inductor … a coil of wire. The permeable material (meaning it accepts and concentrates magnetic fields) helps to generate a larger magnetic field in the inductor without adding wire. The permeable materials are metallic mixtures that usually include iron. The magnetic field created by an inductor surrounds the inductor. The toroid, or doughnut form, helps to keep the magnetic field contained within the immediate vicinity of the inductor. This is sometimes desirable so that inductors near each other will not interact.



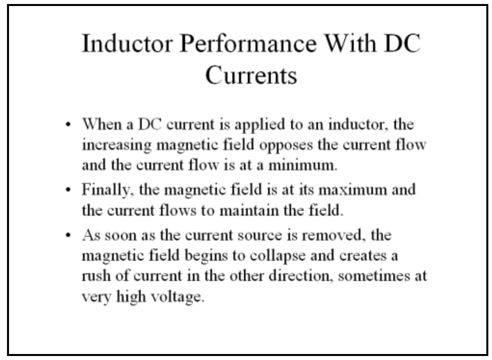
As in capacitance and the Farad, a single Henry is a huge amount of inductance and would require a very large component. In electronics, the values of inductance are generally in the milli and micro ranges.



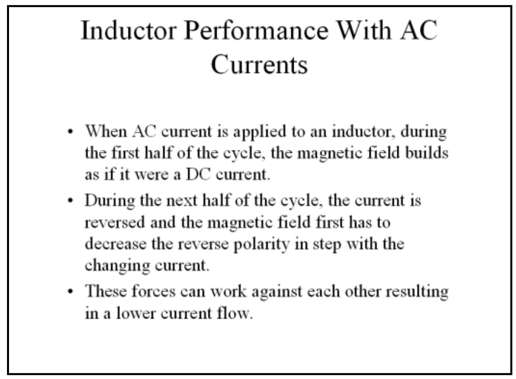
All of these factors contribute to the value of inductance. All of these factors are mathematically related and an inductor's value can be predicted pretty well if these dimensions are known. The math and the formulas are beyond the scope of this course, but they are by no means too difficult for those in the audience who are interested.



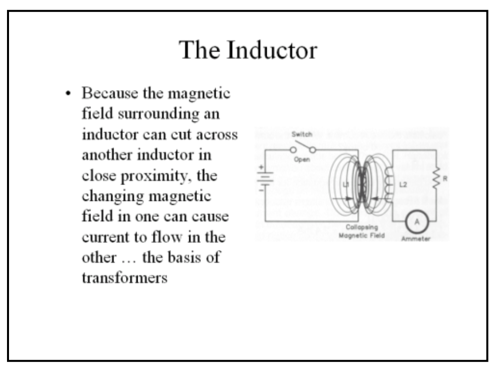
Take some time to talk your audience through the process as a DC current flows through the inductor. During the building of the magnetic field, that process actually impedes the growth of the field, but the current flow will prevail to build up the field to the maximum. But when the current is suddenly taken away, the field immediately begins to collapse with a resulting high voltage across the inductor. This is how the high voltages are generated in a car to cause the ignition spark.

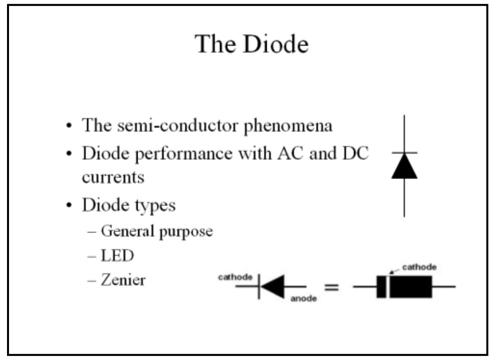


With AC current, the current and the magnetic field are constantly reversing. The inductor causes a “delaying action” for the reacting current. These properties actually act against each other. The result is that collapsing magnetic field and the reverse generated current all combine to act like resistance to the current flow, this type of resistance is called reactance. As the frequency of the AC current increases, the apparent resistance (reactance) increases. This makes sense, a straight wire, one with no coiled turns, would only exhibit pure resistance to the flow of electrons through the wire. But once you start to coil the wire and focus the induced magnetic field, the inductor properties and the changing magnetic field will add additional resistance (reactance) to the flow of electrons.

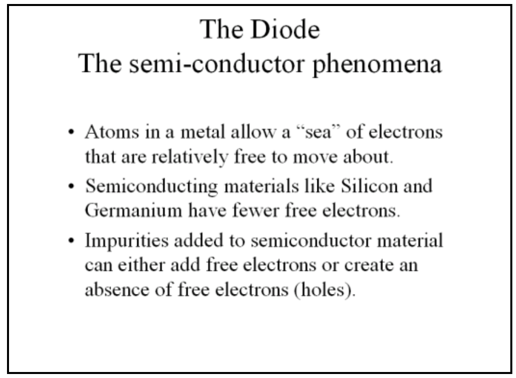


Pairs of inductors in close proximity is another important use of inductors in electronics. The household transformer that converts 120V AC wall current into current that will run a 12V DC radio probably uses a transformer and other circuits to do the conversion. It is important to go back to the two fundamental principles stated earlier in this unit (moving electrons create magnetic fields, changing magnetic fields cause electrons to move). This would be a good opportunity to walk your audience through the process while discussing how a transformer works.





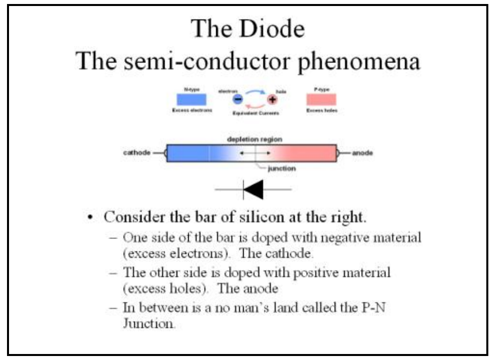
The diode is a devise that allows current to flow in only one direction. There are specialized diodes, the light emitting diode (LED) and the Zener diode that will be discussed later. However, the basic principal is the same, the current will flow in one direction, if current flow is attempted in the opposite direction, the flow will be blocked. Diodes find use in many electronic circuits.
The audience probably has heard that diodes convert AC to DC. This is an over simplification of how a diode operates, you will be clearing this misconception up in the following discussion.



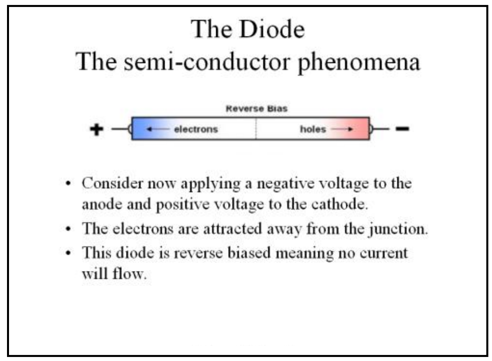
Refresh your audience's memory about the basic structure of an atom. The center nucleus is made up of protons (positive changes) and neutrons (no charge, just mass). Surrounding the nucleus are electrons (negative charges) that are contained in shells of varying energy levels. In an atom with no net charge, the number of protons equals the number of electrons. For numerous reasons, some atoms hold their associated electrons very tightly and the outer “shell” of electrons are not free to roam from one atom to the next. These atoms make up materials called insulators because electricity does not flow readily through the material. Other atoms do not hold on to the outer shell of electrons very tightly and allows these collective out electrons to form a sea of electrons that freely move from one atom to the next. These atoms make up materials called conductors. The overall net charge of the material is still neutral because the number of protons equals the number of electrons. However, if one electron is injected into the material on one end, one electron is ejected from the material from the other end.

There is a certain class of material called semiconductors. The electrons are held tightly, but not too tightly. Under certain conditions, the other shell of electrons can move from one atom to the next, in other conditions, the electrons are held firm. If impurity materials are added to the semiconductor material the properties of the material are changed. Adding impurities is called “doping.” For instance, if an impurity is added that does not hold on to its outer shell of electrons very tightly; these atoms become a source of free electrons that can move through the material. This material is called “N” type material. Alternatively, if an impurity is added that holds very tenaciously to it’s outer shell of electrons; the atoms become a source of electron holes or spaces where electrons will be drawn to as they move into the material. This material is called “P” type material. This would be a good time to discuss with your audience the concept of electrons holes. By historical convention in semiconductor electronics, current movement refers to the movement of electrons holes versus the movement of electrons. The electron holes are unfilled spaces that could hold an electron. The arrows noted on semiconductor device schematic diagrams indicate the direction that the holes travel, from the positive pole to the negative pole. Think of the ball moving across a hole pocked surface, as the ball (electron) moves from one hole to the next, the vacant holes in turn move the opposite direction of the moving ball.

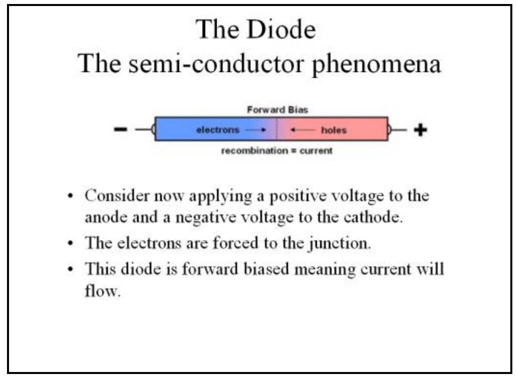
The left side of the Silicon bar is doped with impurities that have excess electrons, this side of the bar then has “N” type material. The right side of the bar is doped with impurities that have excess holes, or unfilled space for electros to reside. This side of the bar is “P” type material. In between the N and P material is a thin layer of just plain old Silicon material that keeps the P and N materials separated by its relative neutrality. Now you will take a look at what happens inside a diode when current is applied.



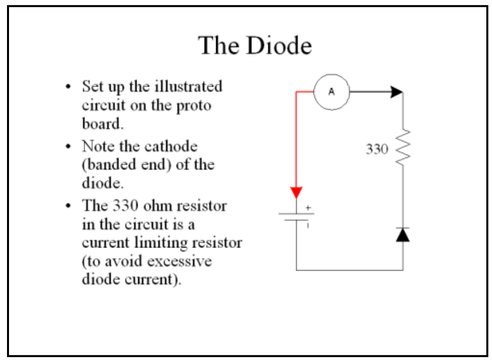
In the first case, a current source is applied to the diode so that the negative pole, a source of electrons, is connected to the anode (the P material side) and a source of electron holes, is connected to the cathode (the N material side). The free electrons within the N material are drawn further away from the P-N Junction by the positive pole of the source. The electron holes are drawn further away from P-N Junction by the negative pole of the source. (One way of looking at this is that the electrons from the source actually fill in the holes … same thing as the holes moving.) The P-N Junction now in essence has expanded and includes even more simple Silicon material that is holding on to the outer shell of electrons keeping them from moving. Current therefore does not flow. This diode is turned off; this condition is called reverse bias.



Now in this second case, the poles of the source are reversed. The electrons from the negative pole of the source add to the excess electrons in the N material. The electrons from the P material are drawn to the positive pole of the source to create more holes in the P material. The result is that the N-P Junction is no longer a no-mans land and the excess electrons and the holes come together allowing the current to flow. This situation is called forward biasing of the diode.

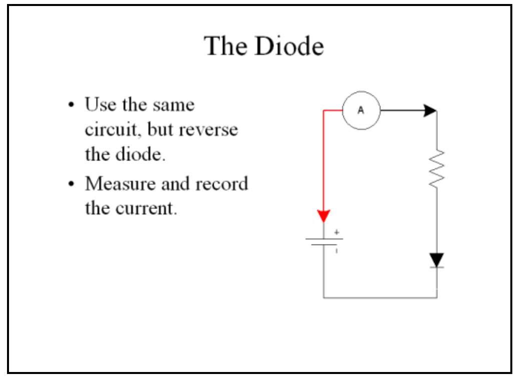


The following two activities reinforce what has just been presented. Work with the audience to ensure they can identify the banded (Cathode) end of the diode. This would be a good place to talk about the purpose of the current limiting resistor. When the diode is reversed biased, current will not flow through the diode and the protective resistor would not be needed. However, when the diode is forward biased, the diode conducts and is essentially a closed switch or closed circuit with very little internal resistance and the full current available would flow through the circuit potentially damaging the components within the circuit. Ask the audience to identify if the diode is reverse or forward biased. In turn ask them to predict what type of meter indication they would expect. If the current were to flow in this circuit, what would be the expected current? This type of calculation should be done ahead of time, before making the measurement, so that the proper meter range will be used.



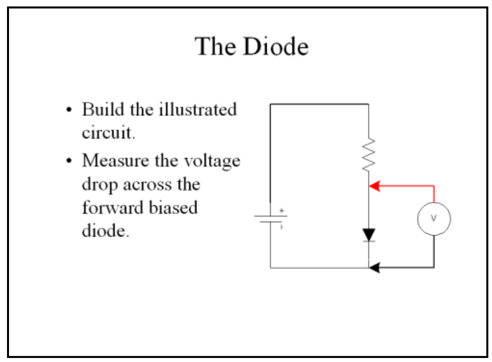
This circuit is reverse biased and no current flows.

Using a 9-volt battery and a 330-ohm resistor, assuming no resistance within the diode, using Ohm's law the current will be 27 milliamps. The 200m range would be appropriate in the next activity. In this case, the diode is forward biased and current will flow through the circuit. The predicted current flow is 27 milliamps, but the actual current flow through the circuit is 24 milliamps.



You can use this difference to discuss with the audience what is going on. They should come to the conclusion that there is less than predicted current flow because there is additional resistance somewhere in the circuit. You can lead them to the conclusion that perhaps there is resistance in the diode. How could that go about determining if the diode is the source of resistance?
One strategy is to use the circuit in the next activity.

In this circuit, the VOM is connected to read the voltage across the diode. On the test bed, the voltage drop was .709 volts. Using the current measured in the previous activity, 24 milliamps, and this voltage drop of .709 volts in Ohm's law results in a resistance within the diode of 29 ohms. Taking this a step further, the total resistance of the circuit is 330 + 29 = 359 ohms. Using Ohm's law, the current through this circuit with a 9-volt battery should be 25 milliamps … a little closer to the value observed.



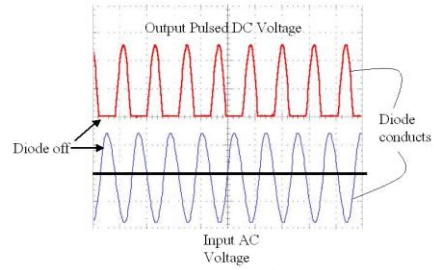
Here is where you can discuss with the audience that although the diode is forward biased and is conducting electrons (or holes depending on your point of view), there is some inherent internal resistance in the diode. The typical voltage drop they will experience with a conducting diode is approximately .7 volts.
The current carrying capacity of a diode must be considered in circuit design. While there is a .7-volt drop across the diode due to the internal resistance, this resistance will in turn create heat when current is flowing through the diode, and this heat must go someplace. Therefore diodes a rated by their ability to handle current as well as their ability to hold back voltage (maximum reversed bias voltage before failure). It is up to the designer to consider the current capabilities and limit the current by proper current limiting resistor choice.

The Diode with AC Current

- If AC is applied to a diode:
  - During one half of the cycle the diode is forward biased and current flows.
  - During the other half of the cycle, the diode is reversed biased and current stops.
- This is the process of rectification, allowing current to flow in only one direction.
- i.e., changing AC into DC

Diode rectifiers are primary components in power supplies. The diodes are arranged to clip the negative cycle of an AC wave and allow the positive side of the AC wave to pass to filter circuits that fill in the gaps to create a smoothed DC current. You can, depending on the level of the audience elect to go into the various types of rectifier circuits, their advantages and disadvantages.

The Diode with AC Current

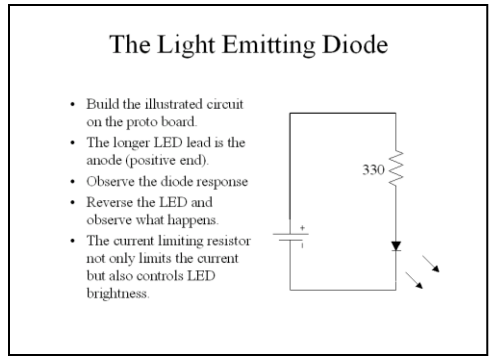


This graphic represents the input and output pattern of a half wave dipole rectifier. Use this graphic to explain that current flows during one part of the cycle and is cut off during the other part of the cycle, creating a pulsating current that travels in one direction … DC.

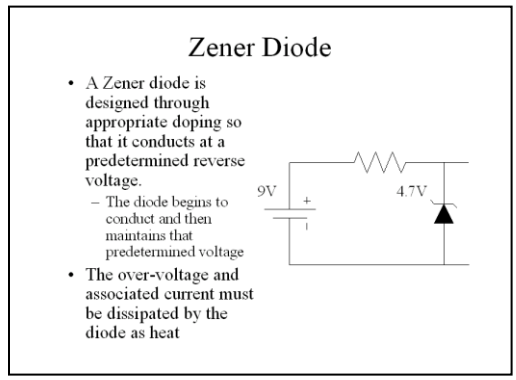
The Light Emitting Diode

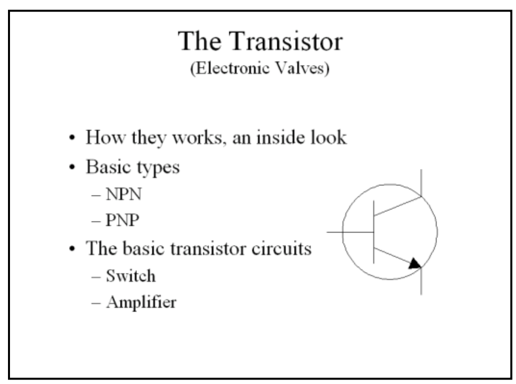
- In normal diodes, when electrons combine with holes current flows and heat is produced.
- With some materials, when electrons combine with holes, photons of light are emitted, this forms an LED.
- LEDs are generally used as indicators though they have the same properties as a regular diode.

Emphasize to the audience that although the limiting resistor controls brightness, the builder has to keep the maximum current rating in mind when determining the minimum value (maximum brightness) of the resistor.

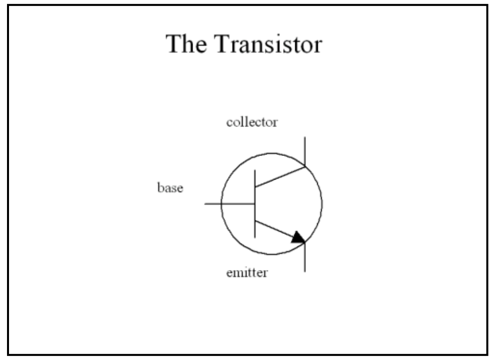


A Zener diode is constructed so that it will conduct when reversed bias above a certain voltage. The excess voltage and current then is conducted to ground and the energy is dissipated as heat. A Zener acts as a simple voltage regulator. In the case illustrated, a 9-volt source is passed through a current limiting resistor to drop the voltage somewhat (to take the pressure off the Zener). If the Zener were not in place, the amount of voltage drop across the resistor would depend on the amount of current being drawn from the circuit. With the Zener in place, the 4.7 volts would be maintained by the Zener acting as a path for the excess current that is not being drawn off. This excess current has to be dissipated as heat therefore there are current limits on Zeners that the designer needs to consider.

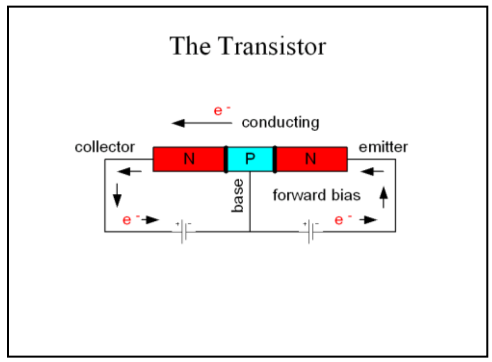




Though you cannot make a transistor simply by putting two diodes together back-to-back, it is useful to look at the transistor as made up of diodes to better understand what is happening inside.



Take a look at this representation of the inner workings of a PNP transistor. Close inspection reveals there are two diode like junctions with their P poles connected together. The P-N Junction is represented by the narrow black line. In an actual transistor, the P material would really be just a very narrow strip of material, not as represented in this graphic.

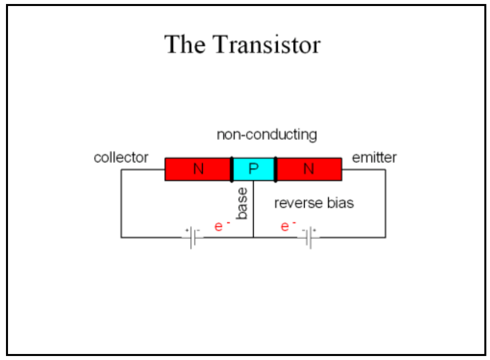


In this circuit, a power source is applied between the base and the emitter, the positive pole to the base, negative to the emitter. An additional power source is applied between the collector and the base, the negative pole to the base, the positive pole to the collector.

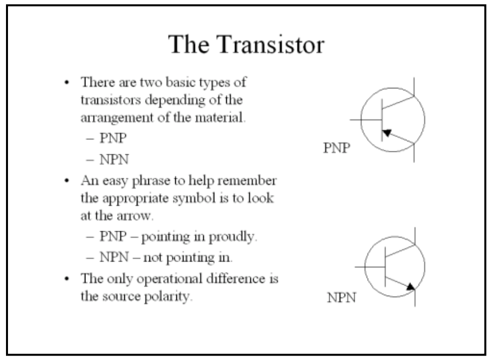
The base-emitter diode is forward biased, which causes that diode to conduct electrons allowing the electrons to move left to right, and the holes right to left. The base-collector diode in turn is reverse biased, which means the diode is turned off and not necessarily conducting.

Something interesting happens in this case though, the transistor effect. As the electrons from the base-emitter diode go across the P-N Junction, the P layer is so thin, and there are so few holes to accept the electrons, that the electrons continue to flow right on past and cause the base-collector diode to start conducting and allowing the current to pass through the transistor to the collector. In effect, a small forward bias on the base-emitter diode causes the transistor to turn on and pass current through the emitter to the collector.

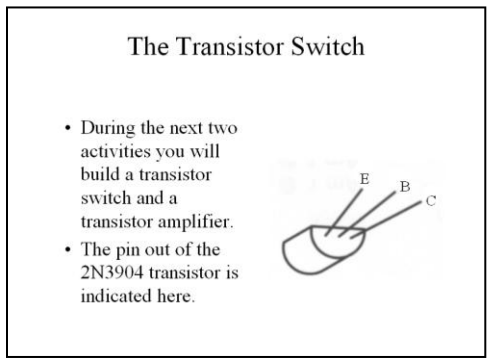
Now take a look at what happens when the base-emitter diode is reverse biased and the base-collector is also reverse biased. The base-emitter diode is non-conducting along with the base-collector diode, no current flows and the transistor is turned off.



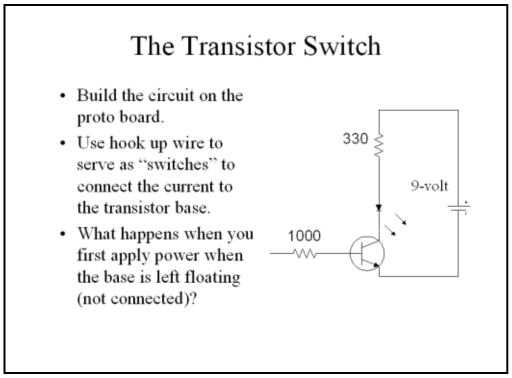
Point out to the audience that the symbols for PNP and NPN transistors have a subtle difference, the direction of the arrow. Remember the arrow, by convention, shows the direction that the holes move, not the flow of electrons.
The two types of transistors are used throughout an electronic circuit. The choice is usually based on the polarity of the power sources surrounding the transistor. The circuits are basically the same except the polarities of the power sources are reversed.



Spend some time with the audience to make sure they have the pin out of the transistor correct before building the circuit; it will save some time during the activity.



The audience will need some help in first determining the transistor pin outs and then installing the LED. Reminded them that the positive side (anode) of the LED is the longer lead.

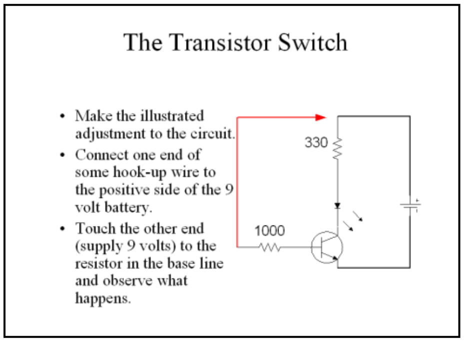


In this circuit, the 330-ohm resistor in the collector circuit limits the current through the LED. Remember when the transistor begins to conduct; the path through the transistor is very low resistance. Without the current limiting resistor, too much current could flow and damage the components.

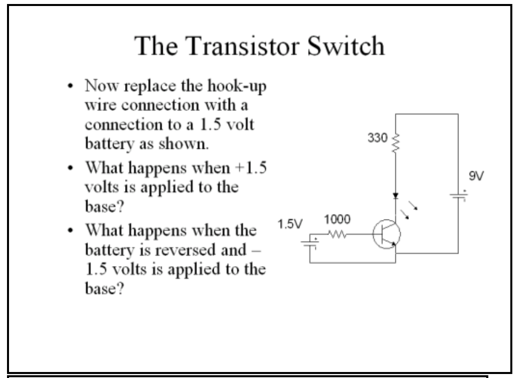
Additionally, the 1000-ohm resistor in the base circuit also limits current. In this case, when the base-emitter diode conducts, there is a low resistance path. Without current limiting, the transistor could be damaged.

When this circuit is completed, nothing should happen because the base-emitter diode of the transistor is not forward biased so the transistor does not conduct.

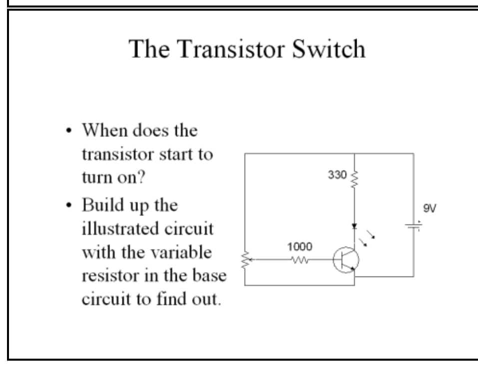
When the base is connected to 9 volts, the base-emitter diode is forward biased and conducts. This in turn turns on the transistor and the current flows through the LED to turn it on. The audience should note that LED goes off when the base voltage is removed.



When the voltage on the base is positive, the transistor conducts and the LED is lit. Point out to the audience that in this case, they are controlling a much larger current with a small current. This will become more important in the following circuits when a transistor amplifier is explored.



Take some time to explain to the audience how the variable resistor works and what is going on here.



The voltage across the variable resistor is the battery voltage. The wiper of the variable resistor taps off the resistor at different places depending on how the screw control on the variable resistor set. The variable resistor becomes a voltage divider so that the voltage on the base can range from ground (no voltage) to 9 volts and all voltages in between.
When the circuit is wired, task the audience to adjust the variable resistor through its range and stop when the LED is fully lit. Using the VOM, measure the voltage on the base of the transistor and record the value. On the test bed the voltage was .78 volts. Next, decrease the voltage by adjusting the variable resistor until the LED is just barely visible and again measure the base voltage. On the test bed the voltage was .68 volts. Finally, move the variable resistor until the LED is fully off and record the voltage. On the test bed the voltage was .63 volts.
Discuss with the audience what the voltages means in relation to the operation of the transistor as a switch.

Task the audience to research available ham radio literature and find a simple circuit that they would like to build. Their final exam will be the construction of this circuit and a classroom demonstration of it. During the demonstration, they will be asked to describe how the project demonstrates the concepts developed in the course.