Course Title: Basic Electricity and Ohms Law

Course description:
Introduces the student to basic electricity with an emphasis on Ohms Law.

Topics to be covered include:

1) Atomic structure
2) Electric charges
3) Definitions of power, voltage, current, and resistance and their relationship.
4) Units of measurement
5) Proper method to check voltage
6) Proper method to check current
7) Series circuits
8) Parallel circuits
9) Combination circuits
10) Basic resistive devices including resistors, thermistors, photocells, etc.

Textbook: Electrical Studies for Trades 3rd Edition by Stephen L. Herman
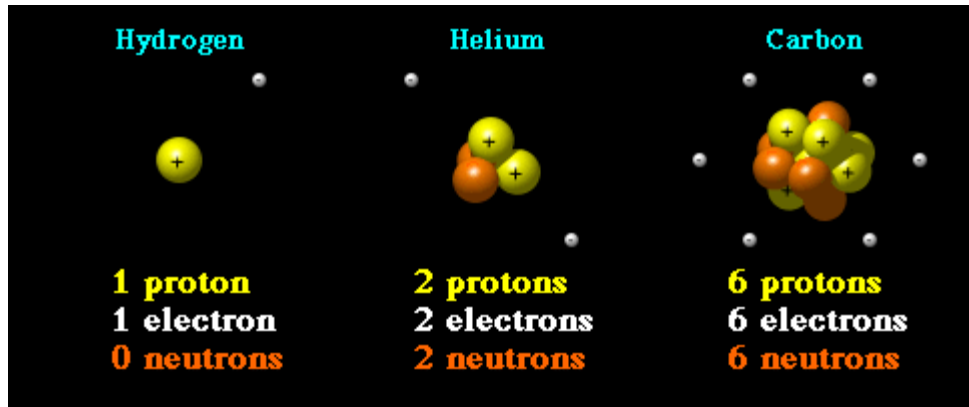
Basic Atom

Basic Electricity

What is electricity? Electricity is the movement (flow) through a conductor of electric charges. In solids such as metal wire, the charges consist of negatively charged electrons. In gases and liquids, we have both electron and ion flow.

As shown above a typical atom consists of a nucleus composed of positively charged protons and neutral (no charge) neutrons. Much like a solar system, atoms have rings of negatively charged electrons that orbit the positively charged nucleus. In a normal atom the number of positive and negative charges are equal, leaving the entire atom with no electric charge. The number of protons is also known as atomic number and determines what the chemical element is. Helium has two protons; copper has 29 protons, while aluminum has 13 protons.

The Law of Charges states that unlike charges attract while like charges repel. In the helium atom above, the attraction of two positively charged protons in the nucleus keep the two electrons from flying off into space. Centrifugal force from the electrons spinning around the nucleus keeps the electrons from falling inward.

If we were to add enough energy (heat, light, friction, etc.) to the atom, the electrons will spin faster and faster until one of them is thrown off and becomes a free electron. This would leave the atom with a net positive charge as we have two positive protons and one negative electron. This is called an ion and an ion can be negative or positive.

Note that ions and other charged particles can be influenced by a magnetic field.
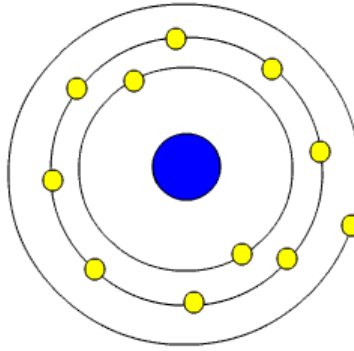
Conductors

As illustrated above many chemical elements have rings (shells) of electrons that vary from two to thirty two. In the electrical industry we are concerned only with the very outer ring known as the valence ring. The valence shell contains between one and eight electrons. The number of electrons in the valence ring determines if the atom is a conductor or an insulator.

The octet rule in chemistry says for an atom to be stable, it must have eight electrons. In the case of sodium above, we could add seven electrons or remove one electron. It's much easier to remove the one electron.

In general a conductor is an atom with one to three valence electrons. Copper, silver, and gold all have one valence electron. Iron, cobalt, nickel, and zinc have two, aluminum has three. Gold, silver, and copper are the best conductors. In electric wire we use mainly copper and aluminum. All are metals and besides being good electrical conductors, are also good heat conductors.

An alloy consists of mixture of two or more metals. Common alloys include brass, bronze, pewter, and stainless steel. Alloys have properties superior to the metals that went into them. Brass (mixture of copper and zinc) is harder and more durable than either copper or zinc. Stainless steel (iron mixed with carbon, chrome and nickel) resists rust and is stronger than iron alone. Tin mixed with lead makes electrical solder.

The electrical conductivity of an alloy falls between the metals that went into them. Brass is a better conductor than zinc, but not as good as copper. In copper wire we use pure copper to make the best conductor. The sodium above is a metal and would be a good conductor, but can't be used because it burns in the presence of air or water. Silver is a better conductor than copper, but the cost is too high to use for wire. A common alloy in the electrical industry is nichrome, an alloy of chromium and nickel. It's used to make heating elements.

Insulators

Chemical elements with five to eight valence electrons are insulators. Many of these elements are gases (oxygen, nitrogen, argon, helium, etc.) or unstable solids such a sulfur or phosphorus. In the real world insulators are often molecules and compounds. (Mixtures of atoms.) Common insulators include glass, rubber, mica, plastics, wood, etc. They are insulators because their chemical structures tightly bond the electrons. Think of it as electron super-glue.

If enough force is supplied, electrons can be stripped away, but often cling to the surface. Typical is walking across a carpet and getting a minor shock when one touches a metal doorknob causing an electric discharge. We call this **static electricity**. Lightning is also static electricity.

Semiconductors

A third class of materials is called semiconductors. They are neither good insulators nor good conductors, but somewhere in between. They have four valence electrons and include Carbon, silicon, and germanium. Silicon and germanium are used to make semiconductor devices such as diodes and transistors while carbon is not. Carbon in its diamond form is an insulator and in its graphite form is a conductor used to make motor brushes.
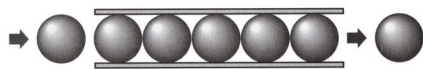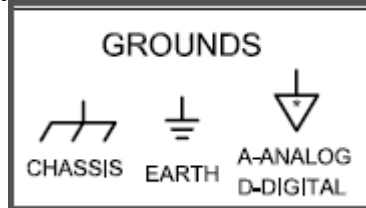

Electron Flow

Electricity is the flow of electric charges. In this discussion we will stick to solids. This is accomplished by by using some form of energy to knock a valence electron off one atom into the next atom to the next, etc. Think of this as a water pipe full of Ping-Pong balls where a ball is inserted into one end and a ball falls out the other end. Energy is transferred from one ball to the next ball down the line.

Metals have loose valence electrons and require little energy to dislodge them. The electrons are so tightly bonded in insulators massive amounts of energy are needed to dislodge an electron. The process often destroys the insulator. Electron flow goes from negative (-) to positive. (+) In this class we will use conventional flow.

Although it has been established that the electron theory is probably correct, the conventional current theory is still used to a large extent.

There are several reasons for this. Most electronic circuits use a negative ground or common. When this is done, the positive terminal is considered to be above ground, or hot. It is easier for most people to think of something flowing down rather than up, or from a point above ground to ground. An automobile electrical system (negative ground) is a good example of this type of circuit. Most people consider the positive battery terminal to be the "hot" terminal.

Various symbols for grounds. Do not assume they are connected to each other or are always the same!

Many of the people that work in the electronics field prefer the conventional current flow theory because all the arrows on the semiconductor symbols point in the direction of conventional current flow. If the electron flow theory is used, it must be assumed those current flows against the arrow. In the military and here I'll use electron flow.

ENGINEERING UNIT	SYMBOL	MULTIPLY BY	
Tera	T	1,000,000,000,000	$\times 10^{12}$
Giga	G	1,000,000,000	$\times 10^{9}$
Mega	M	1,000,000	$\times 10^{6}$
Kilo	k	1,000	$\times 10^{3}$
Base unit		1	
Milli	m	0.001	$\times 10^{-3}$
Micro	μ	0.000,001	$\times 10^{-6}$
Nano	n	0.000,000,001	$\times 10^{-9}$
Pico	p	0.000,000,000,001	$\times 10^{-12}$

Electrical measurements generally use engineering (and scientific) notation. Engineering notation differs from the standard metric in that
it uses steps of 1,000 instead of steps of 10.

For example if we have a 10 kilo-ohm (10k) resistor and want to convert to ohms, we multiply by 1000 to get ohms, in this case 10,000 ohms. If we have a 27,000-ohm resistor and want to convert to kilo-ohms, we divide by 1000 to get 27 kilo-ohms or 27k.

Another example is if we have .5 volts, we would change to milli volts (mV) by multiplying by 1000 to 500 milli volts (mV) or often expressed as 500 mV. If we want to change milli volts to volts we divide by 1000.

Note that milli amps (mA) is used in electronics more than electricity.

Ohms Law

Ohm's Law defines the relationships between (P) power, (E) voltage, (I) current, and (R) resistance. One amp flowing through one ohm produces one volt.

(I) Current is what flows on a wire or conductor like water water through a pipe. Current (electrons) flow from negative to positive through a conductor. Current is measured in (A) amperes or amps.

A coulomb is a quantity measurement of electrons. One coulomb equals 6,250,000,000,000,000,000 electrons. The definition of one amp (A) is one coulomb per second passing a point. The letter I, stands for intensity of current flow, or A, which stands for amps, are often used in Ohm's Law formulas.

(E) Voltage is the difference in electrical potential between two points in a circuit. It's the push or pressure behind current flow through a circuit, and is measured in (V) volts.

Voltage is the potential energy of an electrical supply stored in the form of an electrical charge, and the greater the voltage the greater is its ability to produce an electrical current flowing through a conductor.

This energy has the ability to do work. Voltage is sometimes called Electromotive Force, (EMF) with the circuit symbol V, although E is mostly used today. Here I'll use E.

(R) Resistance (electrical friction) determines how much current will flow through a component. Resistors are used to control voltage and current levels. Resistance is measured in Ohms, using the Greek symbol Omega. (Looks like an upside-down horseshoe.)

An ohm is a measurement of resistance (R) in an electric circuit. The letter R is used to represent Ohm's Law formula.

The watt (W) is a measurement of power in an electrical circuit. The letter P represents power in Ohm's Law formula while Watts is the unit of measurement.

(P) Power is the amount of current times the voltage. These are the main formulas to know:

Ohm's Law

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

Electric current = Voltage / Resistance

Also: P = I * V

Resistors

Resistors are used in two main applications: as voltage dividers and to limit the flow of current in a circuit. The value of a fixed resistor cannot be changed. There are several types of fixed resistors, such as composition carbon, metal film, and wire wound. Carbon resistors (not much used today) change their value with age or if overheated. Metal film resistors never change their value, but they are more costly than carbon resistors.

Fixed resistors

The advantage of wire wound resistors is their high power ratings. Resistors often have bands of color to indicate their resistance value and tolerance. Resistors are produced in standard values.
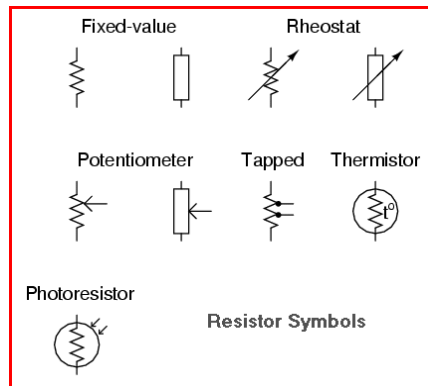
Test the Theory

Check the resistance of several resistors with an ohmmeter.

Thermistors

A thermistor is a resistor that changes value with temperature. The resistance decreases with increased temperature, we say the thermistor has negative temperature coefficient.   If the resistance increases with an increase in temperature, we say the thermistor has a positive coefficient. Thermistors can be used to measure temperature.

Photocells (also called photo resistors) decrease resistance in the presence of light based on light intensity. They are used to measure light intensity or as an "electric eye" in streetlights.
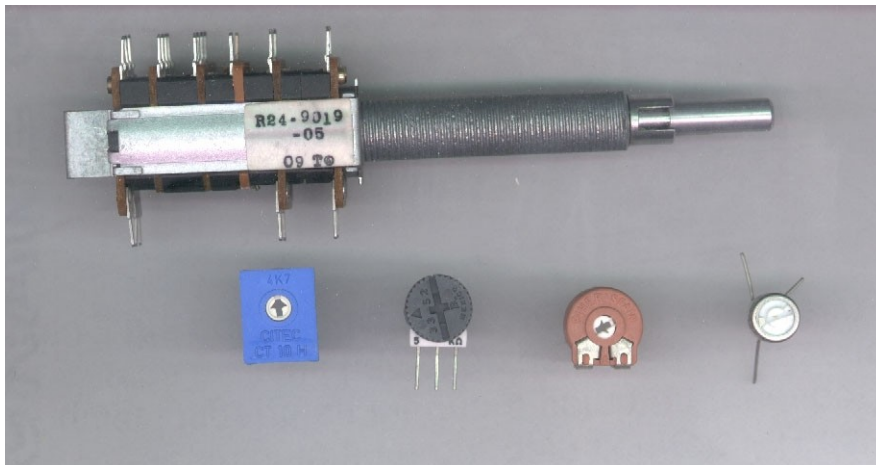
Variable resistors (or potentiometers) can change their value by turning a knob, etc. These are the older style "volume controls" used in consumer electronics.
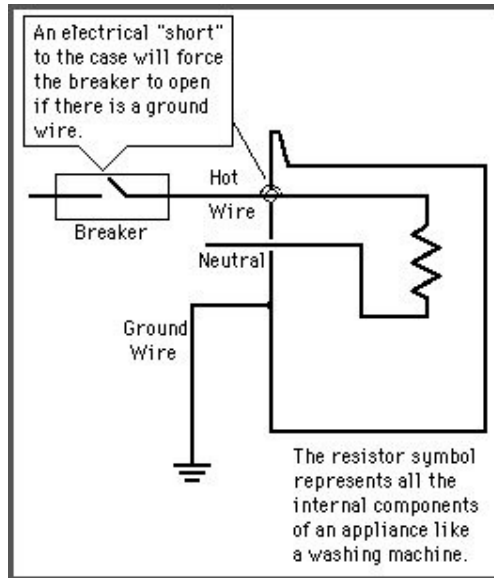
track

wiper
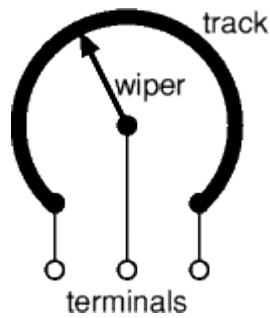
terminals

The internal construction of a potentiometer has a slider attached to the shaft which when adjusted changes resistance in relation to the two outer terminals.


+12 V_DC

CW

CWW
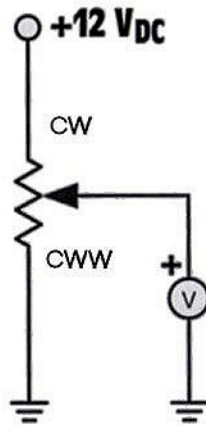
In the above circuit diagram a potentiometer is connected to a 12 volt DC source. As the control is adjusted the voltmeter will read 0-12 volts. Note the grounds donate a common connection.

Test the Theory

Check the resistance of a potentiometer with an ohmmeter. Then wire the circuit as shown above. What happens to the voltage as the shaft is turned clockwise? Counter clockwise?

An electrical "short" to the case will force the breaker to open if there is a ground wire.

Hot
Wire

Breaker

Neutral

Ground Wire

The resistor symbol represents all the internal components of an appliance like a washing machine.

A resistor symbol is also used to donate "loads" in general being they heating elements, light bulbs, etc. This previous page also illustrates a "short" or an unwanted connection. In this case the "hot" side of the power plug has shorted into the metal frame of the washing machine. If the ground was properly wired the circuit breaker back in the power box will "open." (Trip or kick in layman's terms.)
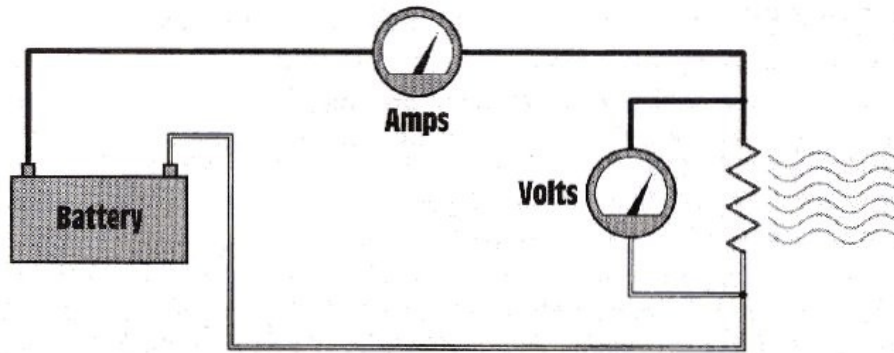
Proper Use of a Multimeter

In measuring current with a multimeter the student has to understand how to attach the meter. When measuring current the ampmeter must be placed in **series** by breaking the electrical path and inserting the ammeter into the path. Note that an ammeter should never be placed across (parallel) to any component or the meter will be damaged or blow a fuse. An ammeter has a very low internal resistance. More on that later.

This differs from a clamp-on ammeter that measures the magnetic field generated by electrical current flow. We will look more into that in the section on magnetics.

To measure voltage the meter must be placed in parallel as shown above. Voltmeters have a high internal resistance.
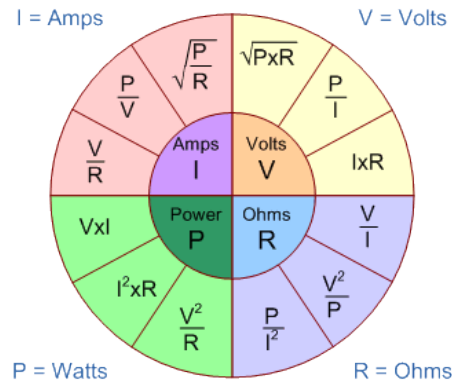
Pictured above is the Ohms Law pie chart that has twelve formulas broken into four quadrants.

Ohms Law

Above is our most basic electric circuit. We have a power source and a load R1. Current will flow from negative to positive as shown by the arrows and the resistance of R1 will limit the current.

Let's look at several sample problems and how to solve them. For this class we will find all values including I in amps, V in volts, R in ohms, and P in watts. Note that with resistive loads AC and DC work the same.

Note there are no multiply or divide keys on a computer keyboard, so we use / for divide and * for multiply.

Problem 1: an electric heating element has a resistance of 16 ohms and is connected to 240 volts AC. What is the current and how much heat is produced?

How to proceed: first we ask, "What do I know?" We know the resistance R = 16 ohms. We know voltage V = 240. And we know our two formulas stated earlier as I = V/R and I*V = P.

First we find I: I = V/R = 240/16 = 15 amps.

Now we find P (the heat produced in this case): P = I*V = 15*240 = 3600 watts.

Problem 2: a 480-volt circuit has a current flow of 3 amps. What is the resistance R and the power P?

What do I know? V = 480 volts; I = 3 amps.

P = I*V = 480*3 = 1440 watts.

To find R we must transpose the two formulas: I = V/R or 3 = 480/R;

Divide both sides of the equation by 480 (or multiply by 1/480) we get

3/480 = 1/R (the 480 cancel):

This comes out to be .00625 = 1/R; now we take the reciprocal of both sides of the equation: the reciprocal of 1/R = R; reciprocal of .00625 = 1/. 00625 = 160 ohms. (One can also use the reciprocal key on their calculator too.)

Thus R = 160 ohms.

For the student terrified of mathematics, we can use a pie chart.

In our previous problem we knew V = 480 volts, I = 3 amps,

and P = 1440 watts. Now we need to find R, we look at the formulas in the lower right-hand quadrant. Any of the three will work, but V/I is the easiest to use.

R = V/I = 480/3 = 160. We get the same answer. Whether one wants to use math or the pie chart is an individual choice. Often we use both.


Problem 3: an electric motor has an apparent resistance (more on apparent resistance in AC) of 15 ohms. With eight amps of current, what is the voltage and power?

What do we know? R = 15 ohms; I = 8 amps.

Using the pie chart to find P (lower left quadrant) knowing both R and I we use I squared times R;

P = (8*8) * 15 (do the 8 times 8 first); 64*15 = 960 watts.

To find V (upper right quadrant) we can use I*R = 8*15 = 120 volts.
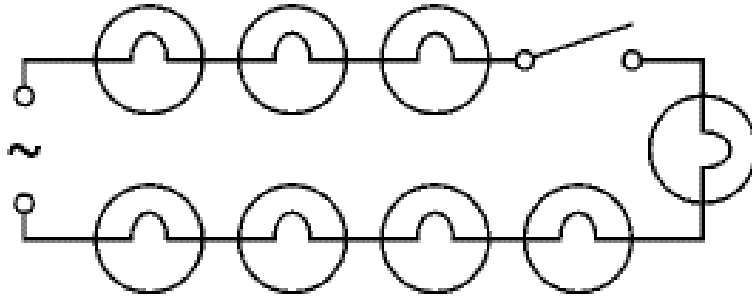
Series Circuits

Pictured above is a typical series circuit such as Christmas tree lights. When we close the switch, the lamps will light up as current flows through the lamp filaments generating intense heat, which produces light.

Properties of series circuits:

A) **The current through each device in a series circuit is equal**. In this case each light bulb has the same identical current through each individual filament. In we will assume each light bulb is 40 watts at 15 volts. Using I = P/V = 40/15 = 2.67 amps. The power source must supply 2.67 amps to power the circuit.

B) **Failure of any one element in the string will break the current path for all devices in the string.** If one light bulb burns out (opens), all of the lights would turn off regardless of the power switch. This is what happens to Christmas lights when a single bulb goes bad.

   Note that all of the voltage supplied to a series circuit will appear across the open element.

C) **The sum of the voltage drops across each element in a series circuit equals the voltage supplied by the source.** Let's assume each of the eight light bulbs is rated at 15 volts. 15 volts times eight equals 120 volts. That is the voltage that must be supplied from the source to light up all eight light bulbs.

D) **The power consumed by each element in a series circuit equals the total power supplied by the source.** In this case let's assume each light bulb uses 40 watts of power. 40 times eight equals 320 watts of power that must be supplied by the source.

E) **The total resistance of a series circuit is the sum of the individual resistances.** In the above example we have been using a string of 40-watt bulbs at 15 volts each. We use the formula V times V divided by P from the pie chart to get R = 5.625 ohms for each lamp. The total resistance of the circuit is 5.625 * 8 = 45 ohms.

There is another way to check this to see if we are right. I = 2.67 amps and P = 320 watts. 2.67 * 2.67 = 7.13, so 320 divided by 7.13 = 44.88 ohms. (This is a typical example of rounding errors.) So I now know the original answer was correct.
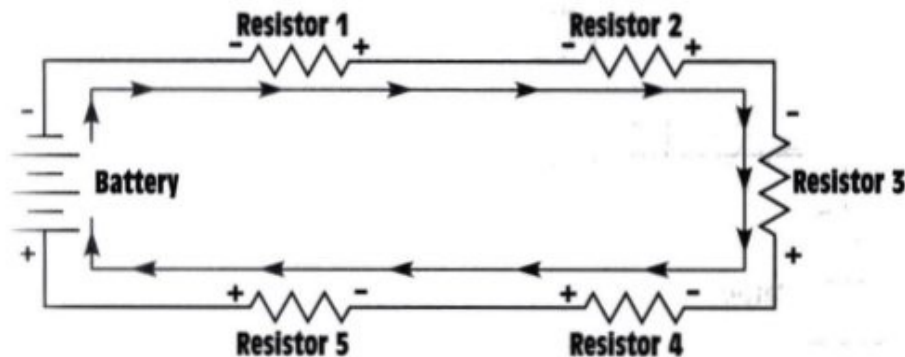
In the previous example we used eight light bulbs in series and all had identical power, resistance, and voltage ratings. All of the factors are directly related and depend on each other. So we had a nice uniform voltage drop and resistance from one circuit element to the next.

In the figure above we have replaced the light bulbs with five resistors. These could be resistors, heating elements, lamps, etc. Here I will assume resistors.

We are using a DC source and not an AC source. AC has no polarity but DC does. If one placed a DC meter across resistor 1 (red lead on the positive side, black lead to the battery side) we would read the voltage drop across the resistor. Reverse the meter leads and we will read a negative voltage, so turn the leads around.

The voltage across resistor 1 (R1) depends on the value of the resistor and the current through it. (Use the formula I*R from the chart.) For example if the resistance of R1 is 2000 ohms (2k) and the current 25 miiliamps (mA), how do we solve the problem?

First convert miiliamps (mA) to amps by dividing by 1000 to get .025 amps. Next multiply .025 by 2000 ohms (or 2k) to get voltage across R1 which is 50 volts. How much power does the resistor use?

Multiply 50 volts times .025 amps we get 1.25 watts. Resistors come in standard power ratings such as one-eight watt, quarter watt, 1 watt, 2 watt, etc. We would have to use at minimum a 2 watt or higher else the resistor will overheat and fail.

What about total power and total resistance? If all five resistors were the same value of 2k, it would be easy to multiply by five. But here we have different values for each resistor. R2 = 3k; R3 = 1.5k; R4 = 1.2k; R5 = 2.2k. Note the current is identical through each resistor at .025 amp.

The voltage across R2 = 3000 * .025 = 75 volts and P = 1.875 watts or 1875 mW.

The voltage across R3 = 1500 * .025 = 37.5 volts and P = .9375 watts or 937.5 mW

The voltage across R4 = 1200 * .025 = 30 volts and P = .750 watts or 750 mW.

The voltage across R5 = 2200 * .025 = 55 volts and P = 1.375 watts or 1375 mW.

Total P = 1.25 + 1.875 + .9375 + .750 + 1.375 = 6.1875 watts.

Total V = 50 + 75 + 37.5 + 30 + 55 = 247.5 volts.

Total R = 2k + 3k + 1.5k + 1.2k + 2.2k = 3.4k or 3400 ohms.

Check: total P = total V * total I = 247.5 volts * .025 amps = 6.1875 watts.

One last thing to note **is the voltage drop in a series circuit is proportional to resistance.** The higher the resistance, the higher the voltage drops. So the highest value resistor (3k) had the highest voltage drop at 75 volts.
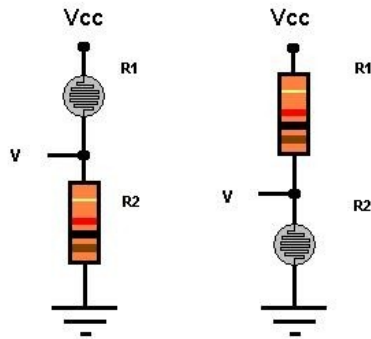
An application

Pictured above are two separate series circuits. We have a photocell in series with a 1000-ohm (1k) fixed resistor. If we connect meter from ground to point "V" what will our meter read? Remember a photocell *decreases* resistance in the presence of light. Let's assume VCC = +12 volts while ground is negative.

Let's assume in the dark the photocell resistance = 11,000 ohms. (11k) We have a total circuit resistance of 1k + 11K = 12k (which we will call Rt) which gives us a current of 12 volts divided by 12,000 ohms = .001 amp or 1 mA.

In the left-hand circuit the voltage drop across R1 (or VR1) = 11,000 ohms * .001 amps = 11 volts. The same current flow through R2 so VR2 = 1000 ohms * .001 amps = 1 volt. As in all series circuits the voltage drops when added together should equal the source voltage. 1 volt + 11 volts = 12 volts.

So the voltmeter on the left-hand circuit will read 1 volt while it will read 11 volts on the right-hand circuit.

Now we shine a bright light onto the photocell and its resistance drops to 1000 ohms. What will the meter read now? Our total resistance (Rt) = 1000 ohms + 1000 ohms = 2000 ohms. (2k)

Our current = 12 volts / 2000 ohms = .006 amp or 6 mA. VR1 = 1000 ohms * .006 = 6 volts. VR2 = 1000 ohms * 1000 = 6 volts. Now the voltmeter will read 6 volts on either circuit.

With the left-hand series circuit voltage increased with light intensity while it dropped on the right-hand circuit. By measuring the voltage across either circuit we can measure light intensity. This is exactly what light meters did on older cameras. We could have easily replaced the photocell with a thermistor (to measure temperature or any kind variable resistance sensor and got the same effect.
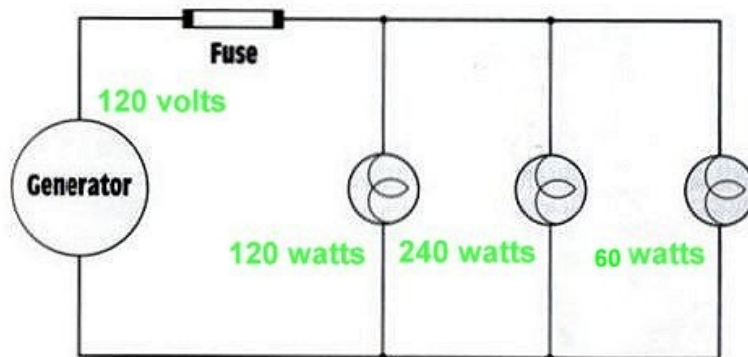
Parallel Circuits

Pictured above is a typical parallel circuit with the light bulbs connected in parallel and all three in series with a fuse. Fuses and circuit breakers as current operated devices are always connected in series. See page 340 in the textbook.

Parallel circuits differ from series circuits in several important ways:

1) **The voltage across each element is a parallel circuit is identical**. If the voltage from the generator is 120 volts, then the voltage measured across each light bulb would be 120 volts.

2) **The current through each element of a parallel circuit is different**. In this case we could have a 120-watt, a 240-watt, and a 60-watt light bulb all connected to the same power source without one effecting the other.

3) **The failure of one element in a parallel circuit will not effect the other elements**. For example in household electric wiring a blown (open) light bulb in the kitchen won't effect the living room.

4) **The total current drawn from the generator equals the sum of the currents from each circuit element**. From the examples above with three bulbs each at 120 volts, the 120 watt bulb draws 1 amp, the 240 watt bulb draws 2 amps, and the 60 bulb draws .5 amp, the total I = 1 + 2 + .5 = 3.5 amps. (Use P/V)

5) **The total power drawn from the generator is the sum of the power drawn by each element**. In the above example total P = 120 watts + 240 watts + 60 watts = 420 watts. Check: divide 420 watts by 3.5 amps = 120 volts.

6) **The total resistance of a parallel circuit is always less than the least resistance**. Using the examples above, the resistance of the 120 watt bulb = V divided by I = 120 volts divided by 1 amp = 120 ohms. The resistance of the 240 watt bulb = 120 volts divided by 2 amps = 60 ohms. The resistance of the third bulb = 120 volts divided by .5 amps = 240 ohms.

To see if the above statement is correct, let's divide the 120 volts by the total current (I) of 3.5 amps = 34.3 ohms. Note that the lower the resistance of an element in a parallel circuit the higher the wattage or power drawn from the generator, thus the 240 watt bulb has the least resistance.
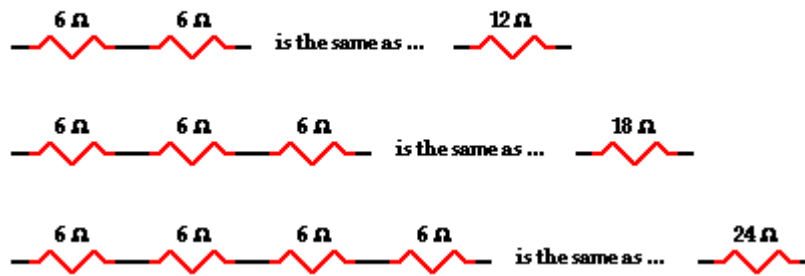
One final question: what size fuse should we use? Fuses also come in a number of sizes, so at 3.5 amps total we would have to use a fuse rating greater than 3.5 amps. 4 or 5 amps would be fine. 30 amps would be absurd because the idea is to blow the fuse before the wiring catches fire. *Never replace a fuse with a value higher than the original!*
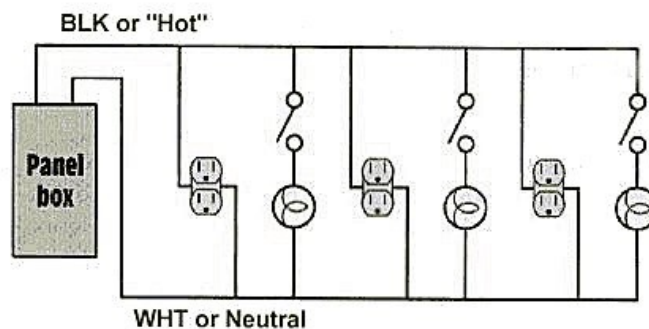
The above example is a simplified view of home electrical wiring. (120 volts) The wall outlets are wired in parallel. If one was to plug a 1200-watt hair dryer into one wall socket and a 1500-watt microwave into a neighboring wall socket, could a 20-amp breaker carry the load?
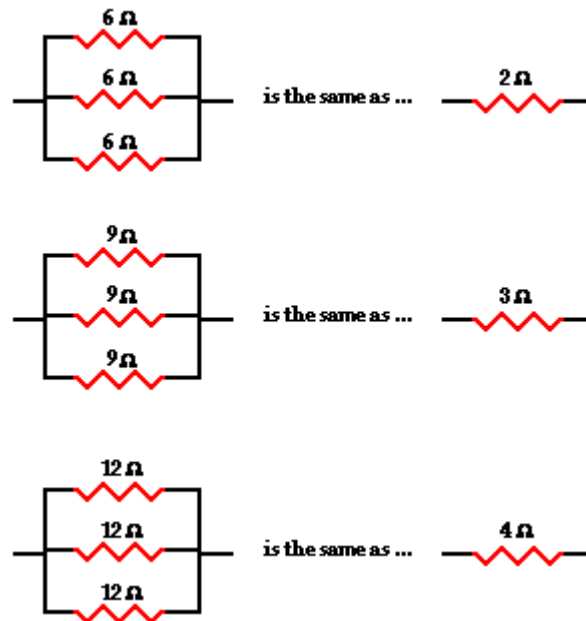
The answer is no. 1200 watts at 120 volts = 10 amps. 1500 watts at 120 volts = 12.5 amps. Total = 22.5 amps. Also note the light bulbs are wired in series with a switch, but both are wired in parallel with the wall sockets and all are wired parallel with the panel box. This is called a combination circuit. Most electrical/electronic devices use combination circuits.

Equivalent Resistance

6 Ω   6 Ω   is the same as ...   12 Ω

6 Ω   6 Ω   6 Ω   is the same as ...   18 Ω

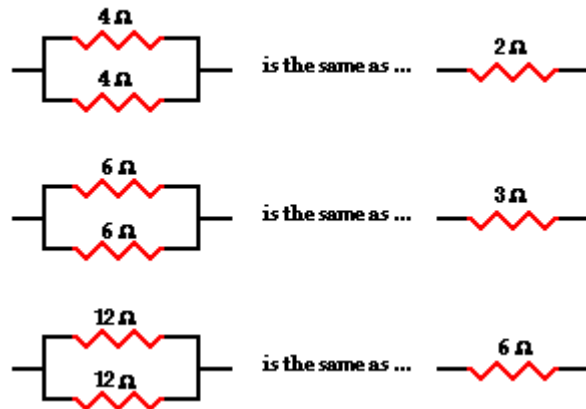6 Ω   6 Ω   6 Ω   6 Ω   is the same as ...   24 Ω

As the above circuit illustrates when resistors are wired in series, the total resistance is obtained by adding the resistor values.

Equivalent Resistance

6 Ω
6 Ω   is the same as ...   2 Ω
6 Ω

9 Ω
9 Ω   is the same as ...   3 Ω
9 Ω

12 Ω
12 Ω   is the same as ...   4 Ω
12 Ω

Equivalent Resistance

4 Ω
4 Ω   is the same as ...   2 Ω

6 Ω
6 Ω   is the same as ...   3 Ω

12 Ω
12 Ω   is the same as ...   6 Ω

Test the Theory

In the case of parallel circuits if the resistors have the same value take the value of one resistor and divide by the number of resistors. Take two 1000-ohm resistors and wire them in parallel. Measure the resistance. Did the measured value match the expected value?

R1   R2   R3
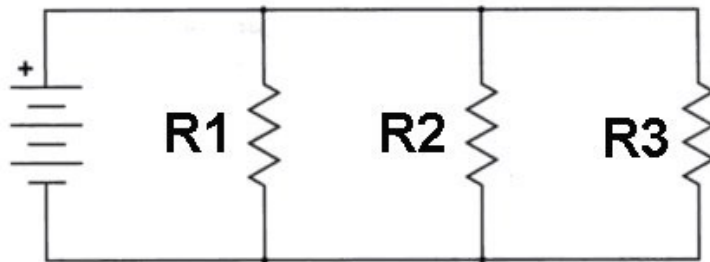
Test the Theory

For resistors that are not the same we use the reciprocal formula. (Page 138 in the textbook.) If R1 = 1000 ohms, R2 = 2000 ohms, and R3 = 3000 ohms, calculate the total resistance. With the battery voltage at 12 volts, calculate on paper the current though each resistor and the total current in amps and milli-amps.

Then measure the current through each resistor to see if they match the current supplied by the battery. How do we attach an ammeter to check current?

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$$R_{\text{total}} = \frac{R_1 \times R_2}{R_1 + R_2} \qquad \frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2}$$

Shown above are our two main parallel resistor formulas. Use the one on the right for more than two resistors.
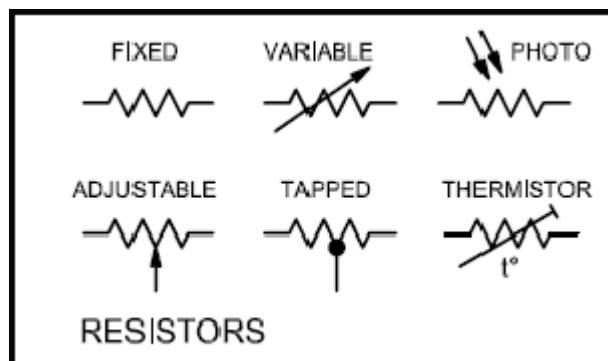
Test the Theory

Wire a 100-watt light bulb in series with a 40-watt light bulb. Apply power, which bulb is brighter? Why? Measure the voltage drop across each individual light bulb. Do the measured values when added equal the voltage supplied?

Resistor Information
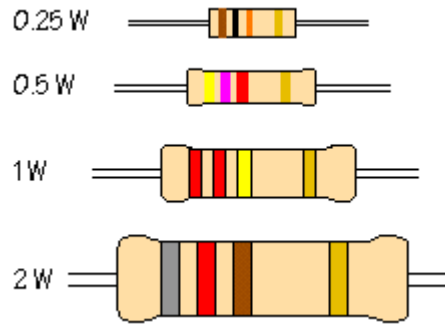

Europe   USA, Japan
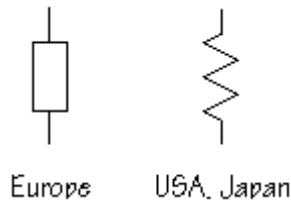
Resistor symbols differ in different countries.

More resistors symbols

How to read a color code on a resistor. For example a 3.3k (3300) ohm resistor color code would be orange-orange-red or 33 * 100. What is the color-codes for a 1k, a 2k, and a 3k resistor? See pages 42-50 in your textbook.

Different sizes of resistors