Electricity 1

Version 1.0

Index:

1. The electric circuit

1.1. Structure of the atom

As you already know from your science classes, all things are made up of atoms. At the center of the atom, known as the nucleus, there are two types of particles: protons (particles with a positive charge) and neutrons (particles with no charge). Electrons are particles with a negative charge. They revolve around the nucleus and they are responsible for forming the energy that we call electricity.

1.2. Conductors and insulators

In a material referred to as a conductor, such as a copper electrical wire, some of the electrons are very weakly joined to the atom. If a force is applied from the exterior (an electromotive force), the electrons can travel by jumping from atom to atom. The energy associated with the movement of these electrons is known as electrical energy or electricity.
Any material that allows electricity to pass through it, such as copper, iron, aluminum, etc., is known as a conducting material. Materials that do not allow electricity to pass through, such as wood, ceramics, plastic, etc., are known as insulating materials.

1.3. The electric current

When there are a very high number of electrons traveling through a conducting material, such as the cord for a lamp, we say that an electric current is circulating.

1.4. The electric circuit

An electric circuit is a closed path through which electrons flow. This type of path is made up of wires and other electrical components, such as batteries, light bulbs, and switches.
The purpose of an electric circuit is to allow electric current to perform a useful task, such as creating light, propelling a motor, powering a radio, etc. In an electric circuit a transformation of energies is produced. The electrical energy of the electrons in motion is transformed into energy in the form of light, mechanical action, sound, etc., depending upon the type of circuit.
An electric circuit can be very simple, like a light bulb connected to a battery, or it can be very complicated, such as the one inside of a computer mouse.
If we open up the case for a mouse, we can see the complex circuits hidden inside. Electric circuits with many components, but with only a small amount of current circulating, such as in the case of the mouse, are also known as electronic circuits. Electronic circuits can be found in televisions, stereos, computers, video game consoles, etc.

1.5. Families of electrical components

The elements that make up an electric circuit can be classified into four large groups or families. Each family of components performs a different function:
- GENERATORS. Supply electric current to the circuit. Example: batteries
- CONDUCTORS. Allow the electric current to circulate. Example: wires
- RECEPTORS. Transform the energy from the electric current into useful work. Example: a motor
- CONTROL ELEMENTS. These regulate the electric circuit. Example: a switch

Electrical components are represented graphically using a picture known as a symbol.

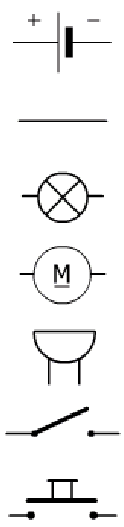
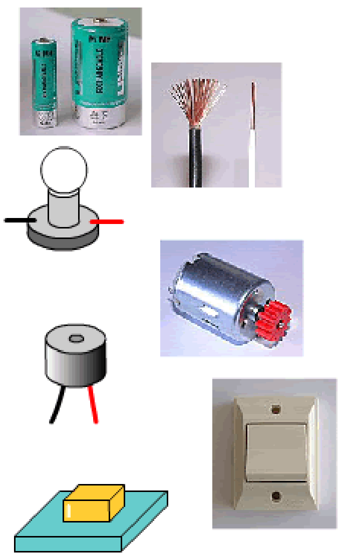
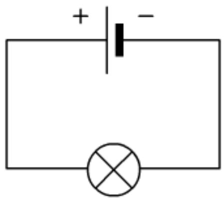
COMPONENT	ELECTRICAL SYMBOL	DRAWING OR PHOTOGRAPH
Battery		
Wire		
Light bulb		
Electric motor		
Buzzer		
Switch		
Button		

Table showing the symbols for the most common types of electrical components.

1.6. The electrical diagram



Electrical components are connected to each other to form electric circuits. We have seen how each electrical component has its own symbol, which is used to draw it in a simplified manner so that it can be easily understood by anyone. The same can be done for an entire circuit. The graphic representation of a circuit is known as an electrical diagram for the circuit, and it is made up by the symbols for all of the connected components. For example, an electrical diagram for the simple circuit we have already seen, made up of just a lantern battery, a light bulb, and two wires, looks like the one in the right.

1.7. Open or closed circuit?

When all of the components in a circuit are connected to each other, with no discontinuities, the electric current is allowed to circulate and we say that the circuit is closed. If there is a discontinuity (such as a broken wire, a disconnected component, or a switch turned off), the current will not be able to circulate, and we say that the circuit is open.

1.8. The direction of the current (a historical mix-up)

When we connect all of the components of an electric circuit, the generator produces a force known as an electromotive force, which causes a current of electrons to be formed.
The electrons leave the - pole of the battery and flow towards the + pole. This is known as the ACTUAL DIRECTION OF THE CURRENT.
In spite of where we just saw, in order to analyze circuits, design machines, or perform electrical calculations, the opposite interpretation is used: the electric current moves from the + pole of the battery towards the - pole. This is known as the CONVENTIONAL DIRECTION OF THE CURRENT, and from this point forward it is the one you will have to use, even though we know that the electrons move in the opposite direction.
There is a historical reason why this interpretation is used. The first scientists who studied electricity thought that current was caused by a flow of particles with a positive charge, with a direction of circulation from positive to negative. Only later was it discovered that the moving particles did not have a positive charge, but instead a negative charge (electrons), and that the direction of circulation was the opposite. However, the initial manner of interpreting and calculating electricity remained in use.

1.9. Basic electric circuits

In this section we will study three simple electric circuits:
Light bulb controlled by a switch
HOW THE CIRCUIT WORKS: When the switch is turned on the circuit becomes closed, and the current can then circulate and make the light bulb function. When the switch is turned off again, the circuit is opened, the current stops circulating, and the light bulb goes off.
Electric motor controlled by a switch
HOW THE CIRCUIT WORKS: When we turn on the switch, the circuit becomes closed. The current can circulate and the motor will then run. When the switch is turned off again, the circuit is opened, the current stops circulating, and the motor stops running.
Circuit 3. Buzzer controlled by a button
HOW THE CIRCUIT WORKS: When we press the button the circuit becomes closed, the current circulates, and the buzzer sounds (it sends us a message, like for example, a door buzzer). As soon as the button is no longer being pressed the circuit is opened, the current stops circulating, and the buzzing sound stops. This is a circuit similar to one used by a door buzzer at a house.

2. Electrical components

2.1. Families of electrical components

In the previous mini-unit we learned that there are 4 families of electrical components. In this unit we will study these in more depth.

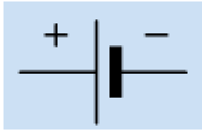
2.2. Generators

The family of the generators includes all of the electrical components that have the function of supplying an electric current to the circuit. There are many types of generators, such as those used at power plants, the dynamo used to power a bicycle light, solar cells for a solar-powered car, the battery in a mobile phone, etc. One of the most commonly used types of generator, and the most helpful for learning about electricity, is the battery.

2.2.1. Types of batteries

The most common types of batteries and some of their uses:
- Button batteries. Watches and cameras
- Prismatic batteries. Remote-controlled cars, measuring devices, etc.
- Lantern batteries. Lanterns
- Cylinder batteries. Flashlights, remote controls, alarm clocks, toys, etc.

2.2.2. Electrical symbol for batteries



Before we continue with learning about generators, it is important to keep one thing in mind. All of the elements in an electric circuit can be represented graphically using a small drawing known as an electrical symbol.
For example, the electrical symbol for a battery is the one on the right.
The "+" sign indicates the positive pole or terminal, and the "-" sign indicates the negative terminal.

2.2.3. Voltage for generators

As with all types of generators, with batteries it is very important to know their electrical voltage value (traditionally often referred to simply as voltage). The voltage tells us how much energy the electrons coming from the generator will have. Voltage is measured in volts (named after the Italian physicist Alessandro Volta, who studied electricity), which is abbreviated using the upper-case letter V.
Electrical voltage values for the most commonly used types of batteries:
- Prismatic battery: 9 volts
- Lantern battery: 4.5 volts
- Button batteries: 3 volts
- Cylinder batteries: 1.5 volts

2.2.4. Deposit batteries here...

Batteries contain chemical substances and elements that can cause harmful pollution, such as mercury (Hg). This is why used batteries must be disposed of in special receptacles so they can be properly treated as waste. You can put your used batteries in recycling containers, take them to certain stores selling watches or electrical appliances, or find a designated collection point in your town or city.

2.2.5. If you use a lot of batteries...

If you find yourself using a large number of batteries, it is a good idea to use rechargeable batteries. First you will need a battery charger. Rechargeable batteries cost more than disposable ones, sometimes up to four times as much, but just by recharging them a few times you can recovery the expense quickly while also helping to protect our environment.

2.3. Receptors

As their name suggests, receptors are the family of components that receive electric current and use it to perform useful work, such as creating light, powering a machine, sounding a warning buzzer, playing music recordings, etc. In this unit we will learn about three types of receptors: the light bulb, the electric motor, and the buzzer. There are many other types as well, such as stereo speakers, electromagnets, fluorescent tubes, electric ovens, radios, televisions, etc. In fact, any electrical appliance or device that consumes electrical energy is a type of receptor.

2.3.1. Voltage for receptors

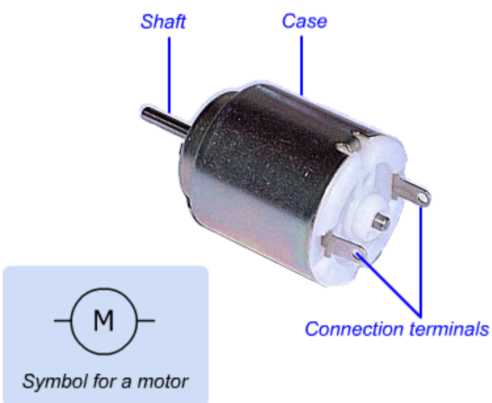
One of the most important facts to be aware of in relation to a receptor is the amount of voltage it needs in order to function. All devices that use electricity have a small plate or label, known as the specifications plate, which provides all of their electrical characteristics. In addition to other information, this plate specifies the voltage to which the device must be connected. If we connect a device to a voltage source that is too low it will not work properly, and if the voltage is too high the device may be damaged.

2.3.2. The light bulb

A light bulb is a type of receptor that transforms electrical energy into light energy, or in other words, into light. There are many types of light bulbs; like the incandescent light bulbs. The term incandescent refers to glowing or burning, and these bulbs are called this because the light-producing element is a filament (a very fine metal wire usually made of tungsten) that emits light by becoming very hot and glowing when an electric current is running through it.

2.3.3. The electric motor

An electric motor is a type of receptor used to transform electrical energy into mechanical rotation energy. In this photo you can see a motor that is used in low-power devices such as toys, walkmans, electric toothbrushes, etc.



The parts of an electric motor and its symbol.

2.3.4. The buzzer
A buzzer is a type of receptor that transforms electrical energy into sound energy, or in other words, into sound. These are found in many electronic devices where they serve the purpose of providing an audible notification. For example, they may be used in video games (to indicate movements or actions), in clocks (to wake us up), in ovens (to tell us the cooking time has ended), etc. Buzzers are also found in many homes where they function as a type of doorbell. A buzzer makes its sound by causing a metallic membrane to vibrate very rapidly, while an electric bell operates by causing a metal piece (the hammer) to strike against a metal bell.

2.4. Control elements
The control elements family includes all of the electrical components used to regulate circuits. The most basic functions they perform are those for turning a circuit on or off. The most commonly used electrical components from this family are switches and buttons, although there are also other very important components such as commutators, selectors, potentiometers, etc.
The function of switches and buttons is to turn a circuit on and off. When we flick a switch it stays in its new position, and the circuit it regulates will remain either on or off until we flick the switch back again. In the case of a button, its action (usually turning a circuit on) only has an effect while the button remains pressed. Once the button is released the circuit will stop operating again. In electrical terminology, when a circuit is turned off we say that it is open, and when it is turned on we say that it is closed.

2.5. Conductors
The family of conductors includes all of the elements that allow an electric current to circulate from the generators to the receptors and then back to the generator again. The most common type of conductors are wires. These are made up of one or more strands of a conducting material, usually copper, covered by a plastic sheath that insulates the outside of the conductor.
Wires with only a single conducting strand are known as unifilar wires. Wires with multiple conducting strands are known as multifilar wires.

2.5.1. There are many types of wires
Cables can be classified according to the number of conductors they contain. If a cable has only one conductor it is known as a monopolar cable. If it has two conductors it is called bipolar, with three wires tripolar, and with four wires tetrapolar. A cable with many conductors is known as multipolar.

2.5.2. Some conductors are neither wires nor cables
A computer mouse has an electronic circuit, which the rear part has conductors that are not wires, but instead copper traces that connect the electronic components to each other. This system allows for automated construction of electronic circuits and is known as a printed circuit board.
Printed circuit boards allow circuits to be built without the use of wires. Instead, flat strips of copper known as traces are used on a plastic board. These are used in all types of electronic devices, such as televisions, video players, radio equipment, etc.

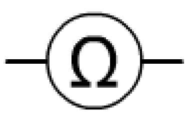
3. Electrical magnitudes

3.1. Electrical magnitudes
A magnitude is anything that can be measured, for example, a temperature, a length, a volume, or a speed. Electricity has three fundamental magnitudes: resistance, voltage, and amperage. In this unit we will study these in more depth.

3.2. Electrical resistance
Resistance is opposition to the passage of the electric current as caused by the components of a circuit. The unit of measurement for resistance is the ohm, which is abbreviated using a Greek letter, the upper-case omega (Ω). If we use an analogy between the flow of electricity and water, the resistance caused by an electrical component is like reducing the diameter of a pipe. Water can still flow through the pipe, but only a smaller amount. In an electric circuit, a component with high resistance reduces the amount of current that is able to circulate.

3.2.1. Sometimes we may want very little resistance, other times we want a lot
All of the elements included within a circuit have some amount of electrical resistance, which ‘applies the brakes’ to the circulation of current. Sometimes we want this effect to be low, such as in a wire, so that the current can pass through very easily. Other times we need high resistance to make it more difficult for the current to pass, such as in carbon resistors used to adjust electronic circuits or the resistance found in electric heaters or hair dryers, which is designed to produce heat.

3.2.2. Measuring resistance
Resistance can be measured using a device called an ohmmeter> (you can see its symbol in the right). However, a multimeter is often used instead, which is a multi-purpose measuring device that includes a built-in ohmmeter.



MEASURING ELECTRICAL RESISTANCE USING A MULTIMETER

In this example we are measuring the electrical resistance of a carbon resistor of the type used in electronic circuits. We will use a multimeter for this purpose.

1. First, make sure that the element to be measured is not receiving voltage: if voltage is being supplied it will distort the measurement and could also damage the multimeter. The best option is to remove the element from the circuit.
2. Just like there are different scales for weighing objects of various sizes – small for babies, medium for adults, large for trucks – an ohmmeter has a variety of measurement scales for measuring higher or lower resistances.

Rotate the selector dial on the multimeter to the position for measuring resistance, which is the area marked with the Greek letter omega (Ω). If you don't know the approximate value of the resistance you are going to measure, select the highest scale, used for the highest resistances.

3. Insert the probes into their connection points: the black into COM (for common) and the red into Ω (to measure resistance). Then connect the probes to the ends of the component you want to measure.
4. Look at the display. If you see a reading of zero (or multiple zeros), it means you have selected a scale that is too high. Turn the selector to the next lower scale. If you see zero again, or a very low value, change the scale again.
5. Sometimes the display will show a lower-case letter L for ‘large’. This means that the resistance you are trying to measure is too high for the scale you are using. In this case you must change the selector to a higher position.
6. To obtain a precise measurement, you need to have the highest number possible appearing on the display, with no zeros to the left, or if this is not possible, with the least number of zeros possible to the left.
7. If a number beginning with a decimal point appears on the display – for example: .82 – you should assume that there is a zero to the left of the decimal point. In other words, the value in the example would be 0.82.
8. Finally, you must add the units to the number appearing on the display. If you have the selector at the position 200 or 2,000, the measurement in ohms will be displayed directly: 820 Ω. If the selector is at 2K or any position with a K, the measurement will be 820 KΩ (820,000 Ω). Some multimeters also use the symbol M, which indicates millions of ohms.

3.3. Voltage

In order for an electric circuit to operate, there must be some type of generator to supply it. The fundamental characteristic of a generator is its electrical voltage, which is also called simply voltage or also electrical potential difference. Voltage is measured in volts, which is abbreviated using an upper-case letter v (V).

The electrical voltage of a generator is similar to the elastic tension in a spring: the more tightly a spring is compressed the more elastic tension it has, and the more force is required to counteract this tension.

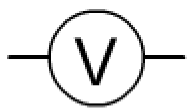
3.3.1. Voltage and electric currents

The more voltage an electrical generator has, the more propulsion it can provide to the electrons to cause them to flow through a circuit. This produces a larger electric current. This means that a 9 V battery has more voltage than a 4.5 V battery, and it will produces larger electric currents (more electrons per second).

The concept of voltage can be defined in the following manner: *Electrical voltage is the energy that a generator uses to propel the electrons flowing in an electric circuit.*

3.3.2. Measuring voltage

Voltage is measured using a device called an voltmeter (you can see its symbol to the right), although as in the case of measuring resistance, it is often more practical to use a multimeter.



MEASURING DIRECT CURRENT ELECTRICAL VOLTAGE

WARNING: This mini-unit explains how to measure the voltage of small direct current batteries. Do not attempt to measure the voltage coming from a building's electrical outlet without help from a teacher, since this is a very high and dangerous voltage (230 V).

1. Just like there are different scales for weighing objects of various sizes – small for babies, medium for adults, large for trucks – voltmeters have various measurement scales for measuring higher or lower voltages.

Rotate the selector dial on the multimeter to the position for measuring direct current voltage. This position is usually marked as DCV or with the symbol V . If you don't know the approximate value of the voltage you are going to measure, select the highest scale, which is 200 V.

2. Insert the probes into their connection points: the black into COM (for common) and the red into V (for measuring voltage). Then connect the probes to the ends of the element with the voltage you want to measure, in this case the terminals on the battery.
3. Look at the display. If you see a reading of zero (or multiple zeros), it means you have selected a scale that is too high. Turn the selector to the next lower scale. If you see zero again, or a very low value, change the scale again.
4. Sometimes the display will show a lower-case letter L for ‘large’. This means that the voltage you are trying to measure is too high for the scale you are using. In this case you must change the selector to a higher position.

5. To obtain a precise measurement, you need to have the highest number possible appearing on the display, with no zeros to the left, or if this is not possible, with the least number of zeros possible to the left.
6. If a number beginning with a decimal point appears on the display – for example: .957 – you should assume that there is a zero to the left of the decimal point>. In other words, the value in the example would be 0.957.
7. Finally, you must add the units to the number appearing on the display. If you have the selector at the position 20 or 200, the measurement in volts will be displayed directly: 0.957 V. If the selector is at 200m or 2,000m, the measurement will be 0.957 mV (millivolts)>. Since type-AA batteries are 1.5 V, if you measure only 0.957 V it means the battery is run down.

3.4. Electric current

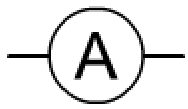
Electrical devices are able to operate because of the movement of a large number of electrons passing through them. This flow of electrons is called electric current. There are two types of electric current: direct current, where the movement of the electrons is always in the same direction (in circuits powered by batteries), and alternating current, where the direction of movement of the electrons changes – or alternates (in circuits powered by the electrical system of a building).

3.4.1. Amperage of the electric current

The amperage of an electric current, sometimes called intensity or simply amperage, is a magnitude that tells us whether the current is large or small. It can be defined as the amount of electric charge that passes through a cross-section of a conductor each second, and its unit of measurement is the ampere (A). One ampere is equivalent to the passage of $6.24 \cdot 10^{18}$ electrons per second.
The higher the amperage that a device requires in order to function, this higher its electricity consumption. This means a higher cost, or else a battery running down faster in a direct current device. Therefore, for economic reasons and environmental ones as well, we want the amperage flowing through any circuit to be as low as possible.

3.4.2. Measuring amperage

Amperage is measured using a device called an ammeter (you can see its symbol to the right), although a multimeter is often used as well. This is a multi-purpose measuring device that includes a built-in ammeter.



MEASURING DIRECT CURRENT AMPERAGE
WARNING: This mini-unit explains how to measure the amperage of direct current circuits powered by small direct current batteries. Do not attempt to measure the amperage of circuits connected to a building's electrical outlet without help from a teacher, since these circuits have a very high and dangerous voltage (230 V).
ANOTHER WARNING: Never connect an ammeter (or in our case, a multimeter with the selector set to measure amperage) directly to a generator, since this could product a short circuit that will damage the fuse in the multimeter and prevent it from functioning.
In this example we will measure the amperage of a current flowing through a circuit made up of a lantern battery and a small flashlight bulb. We will use a multimeter for this purpose.

1. Just like there are different scales for weighing objects of various sizes – small for babies, medium for adults, large for trucks – ammeters have various measurement.

Rotate the selector dial on the multimeter to the position for measuring direct current amperage. This position is usually marked as DCA. If you don't know the approximate value of the amperage you are going to measure, select the highest scale, the one for 10 A, although this will usually not be useful and you will probably have to select the 200m setting.

2. To measure the amount of water moving through a pipe – its flow – you would first need a container to hold the water, then you could cut the pipe and insert the end into the container. This would allow you to measure the amount of water flowing through the pipe. The electric current moving through a circuit can be measured in a similar way: first, we open the circuit, then insert an ammeter – which is a counter for electric current – and in this way we can measure the amperage passing through.
3. Insert the probes into their connection points: the black into COM (for common) and the red into mA (a low amperage measurement). You must then connect the multimeter in series at the point where you want to measure the amperage: open the circuit and insert it at that point, so that the current we want to measure will be moving through it.
4. Look at the display. If you see a reading of zero (or multiple zeros), it means you have selected a scale that is too high. Turn the selector to the next lower scale. If you see zero again, or a very low value, change the scale again. If you always see a 0, this could mean that the probes are not well connected or that the fuse in the multimeter has been blown.
5. Sometimes the display will show a lower-case letter L for 'large'. This means that the amperage you are trying to measure is too high for the scale you are using. In this case you must change the selector to a higher position.
6. To obtain a precise measurement, you need to have the highest number possible appearing on the display, with no zeros to the left, or if this is not possible, with the least number of zeros possible to the left.
7. Finally, you must add the units to the number appearing on the display. If you have the selector at the position 20m or 200m, the measurement will be in milliamperes (mA): 75 mA. If the selector is at 200μ or 2,000μ, the measurement will be 75 μA (microamperes).

4. Ohm's law

4.1. How can the amperage of a current be calculated?
When we connect a receptor to a generator, electric current will move through the receptor. But how can we calculate the amperage of the current that will be circulating without having to use any measuring instruments? Next, you will learn how this can be done using Ohm's law.

4.2. Before moving on to Ohm's law...
Before we cover Ohm's law in more detail, we will first take a look at two simulated experiments that will help us better understand the theory behind it. In these experiments we will use a circuit made of a battery and a resistance.

4.3. When voltage increases, amperage increases too
What happens if we modify the voltage being applied to a circuit:
- If the battery has a voltage of 0 V, the electrons do not have any energy causing them to flow, so there is no electric current.
- If the battery has a low voltage, the electrons do not have very much energy causing them to flow, so only a few can travel through the circuit. Amperage of the current is low.
- If the battery has a high voltage, the electrons have plenty of energy causing them to flow, so lots of them can travel through the circuit. Amperage of the current is high.

4.4. When resistance increases, amperage decreases
What happens if we modify the resistance of a circuit:
- If the resistance of the circuit is extremely high, infinite in theory, the electrons cannot flow through it. No electric current circulates.
- If the resistance of the circuit is high, only a low number of electrons can flow through it. The amperage of the electric current circulating is low.
- If the resistance of the circuit is low, lots of electrons can flow through it. The amperage of the electric current circulating is high.
- If a circuit has no resistance, or if the resistance is extremely low, this can produce what is known as a short circuit. This means that the amount of electrons flowing is so high that the circuit can be burned out, or in the case where the generator is a battery, the battery will run down very quickly.

4.5. Ohm's law
Experiments similar to the ones we saw were carried out in the 19th century by the German physicist and mathematician Georg Simon Ohm.
This scientist discovered that:
- When the voltage of a circuit is increased, more current will circulate through it.
- When the resistance of a circuit is increased, less current circulates through it.
Based on these discoveries, Ohm developed the law that now bears his name:
OHM'S LAW: *The amperage of a current circulating through a closed circuit is directly proportional to the voltage being applied, and inversely proportional to the circuit's electrical resistance.*

Ohm's Law is expressed mathematically using the following equation: $I = V / R$, where I is the Amperage of the electric current (amperes – A), V the voltage (volts – V) and R the resistance (ohms - Ω).

4.6. Three equivalent equations
Ohm's law shows the relationships among a circuit's amperage, voltage, and resistance. This law can be used for more than just calculating the amperage of an electric current, since if we know the values for any two of the variables, the third value can be easily found just by executing the equation.

4.7. The Ohm's law triangle
There is a very simple way to remember the three equations above: the Ohm's law triangle. By tapping with your finger on the magnitude you want to determine (amperage, voltage, or resistance), you can quickly obtain the equation that you will need to apply.