

## L623 Electrical Circuit Diagnosis

## Course Topics

### Electrical Circuit Diagnosis

**Module 1**

▶ Electrical Essentials

**Module 2**

▶ Diagnosis and Testing

**Module 3**

▶ Automotive Electricity

**Module 4**

▶ Using the EWD

**Module 5**

▶ Starting and Charging

**Module 6**

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### Additional Resources

▶ DVOM Fuses

▶ Automotive Batteries

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## L623 Electrical Circuit Diagnosis

### Module 1 Topics

#### Electrical Essentials

##### Electron Theory

Atoms, Electrons, Ions, Conductors,  
Insulators, Semiconductors

##### Effects of Current Flow

Heat, Light, Electromagnetism

##### Factors Affecting Resistance

Length, Diameter, Temperature,  
Condition, Material

##### Ohm's Law

Relationships, Power, Work

##### Circuit Symbols

##### Electrical Circuits

Types of Circuits

##### Series Circuits

Characteristics, Key Features

##### Parallel Circuits

Characteristics, Key Features

##### Series-Parallel Circuits

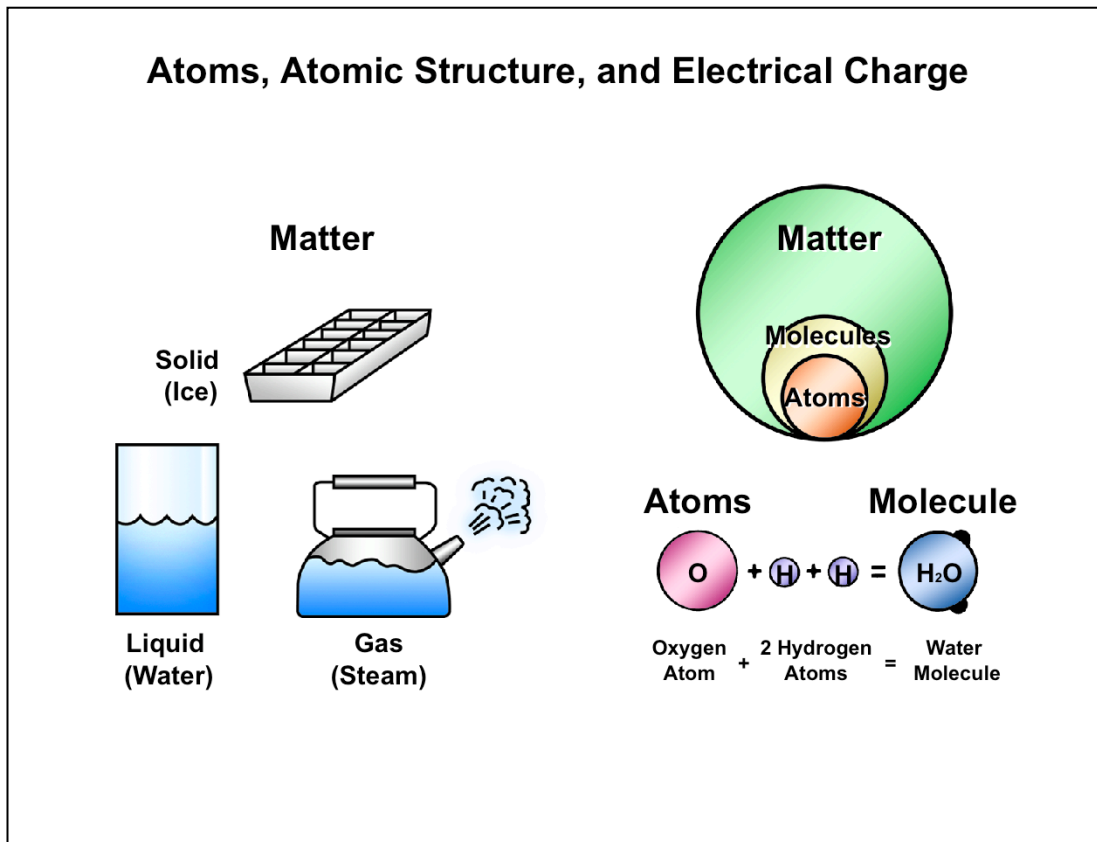
Characteristics, Key Features

[Electrical Essentials Worksheet](#)



**Notes:**

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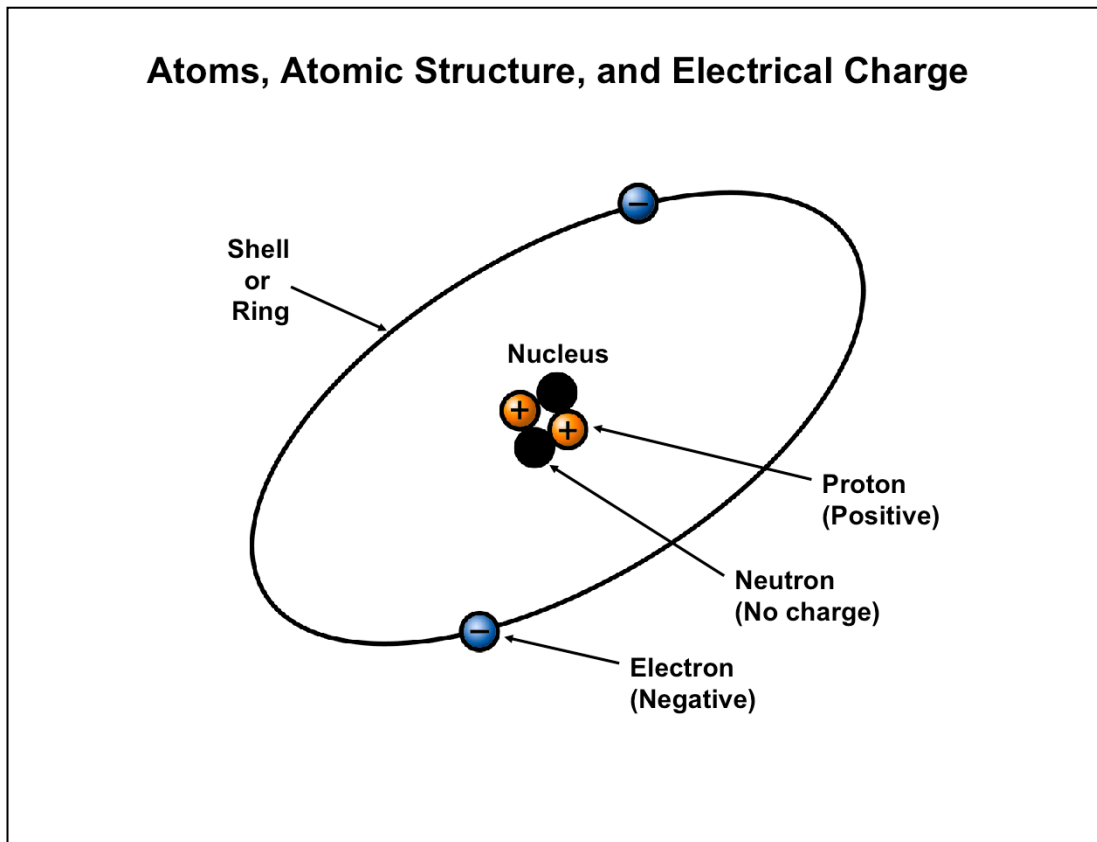


**Electron Theory** Electron theory explains electricity, and is based on the way matter is formed.

**Composition of Matter** Matter is anything that has mass and occupies space. All matter (solid, gas, and liquid) is made up of **molecules**, which are composed of **atoms**. Atoms are the smallest particles into which a substance can be divided without losing its properties.

Everything in our world is created from about 100 different types of atoms assembled into many thousands of molecules. The features that make one atom different from another also cause differences in their electrical properties.

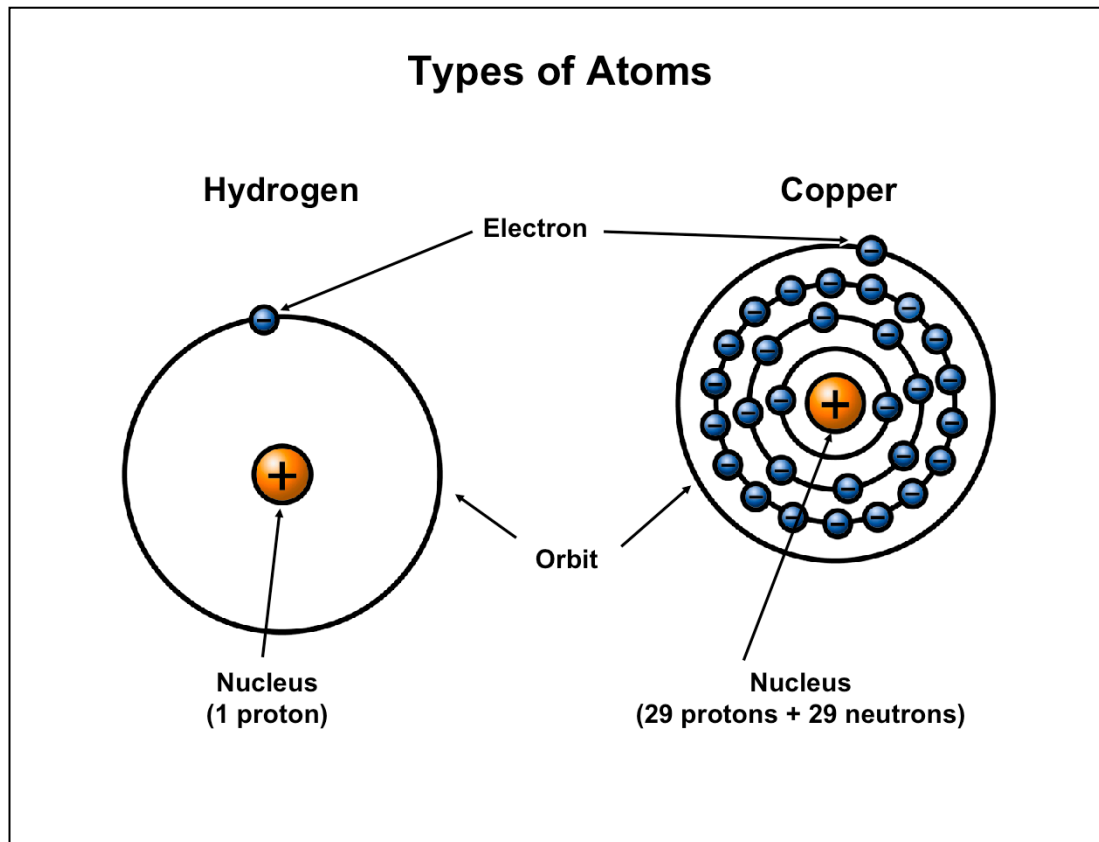
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**Atomic Structure** Atoms are made up of a positively charged **nucleus** containing protons and neutrons, surrounded by a system of negatively charged electrons.

- **Protons** have a positive electrical charge (+).
- **Neutrons** have no charge.
- **Electrons** have a negative electrical charge (-).

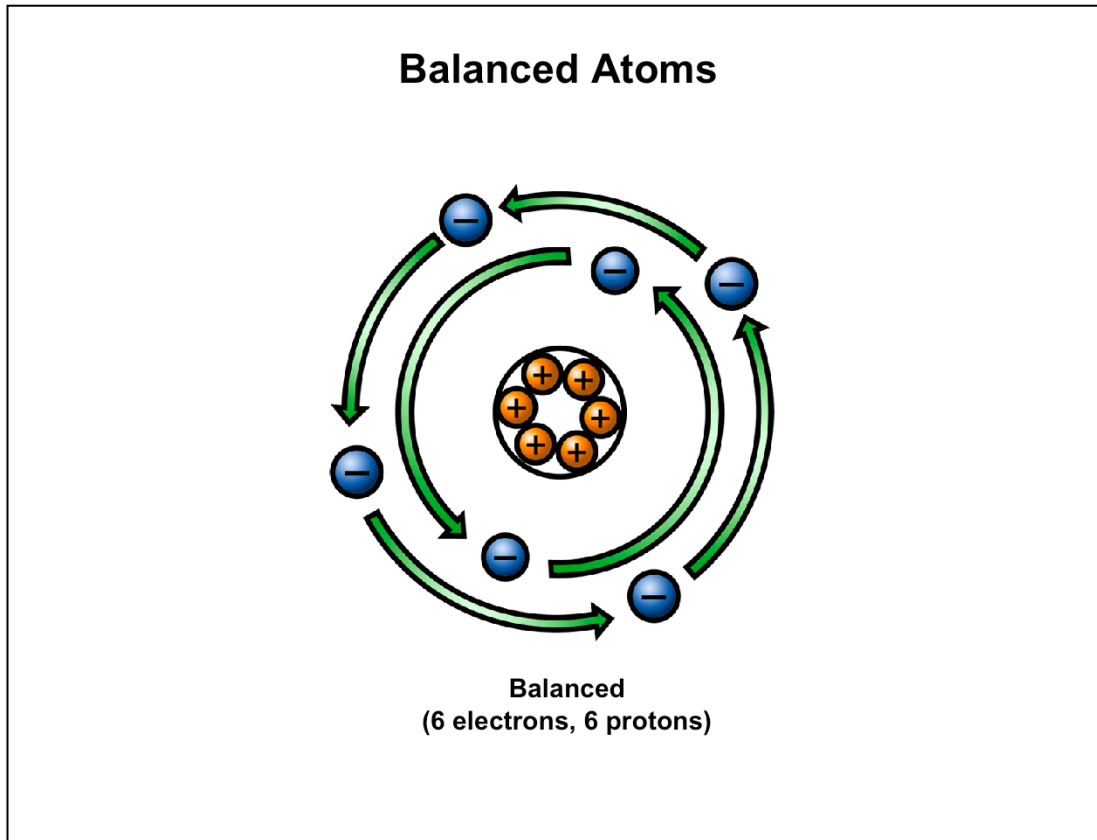
The electrons orbit around the nucleus in fixed paths called **shells** (or **rings**).



- Types of Atoms** Atoms differ based on the **number of protons and electrons** they contain.
- Hydrogen is the simplest atom with one proton and neutron in the nucleus and one electron in its valence shell.
  - Copper has a more complex structure with 29 protons and 29 neutrons in its nucleus. It also has 29 electrons orbiting in four valence shells.

Each shell within an atom can hold only a fixed number of electrons. For instance, the first 28 electrons in the copper atom orbit within the inner three shells. The 29th electron orbits in the fourth, outermost shell.

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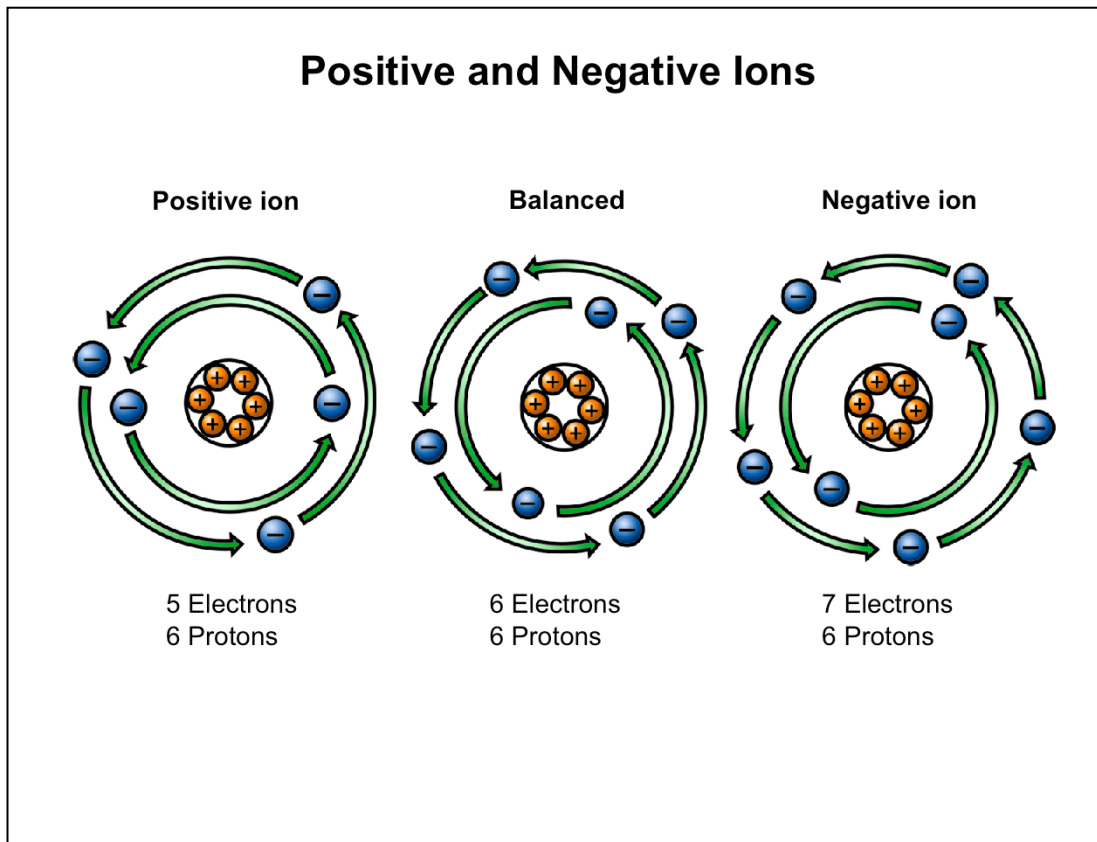


**Balanced Atoms** Because positive and negative electrical charges attract each other, the equal number of protons and electrons in a **balanced** atom hold the atom together.

As the electrons orbit around the nucleus, the centrifugal force that pushes them away from the nucleus is balanced by the attraction of the positively charged protons, holding them in their orbits.

Although the protons in the nucleus are all positively charged, and like charges repel each other, the neutrons in the nucleus cancel the repelling force between protons to hold the atom's core together.

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**Positive and Negative Ions**

Sometimes an atom loses a single electron or gains an extra electron.

When an atom gains an electron, it becomes a **negative ion** because it has an extra negative charge. A negative ion tries to shed its excess electron to a neighboring atom.

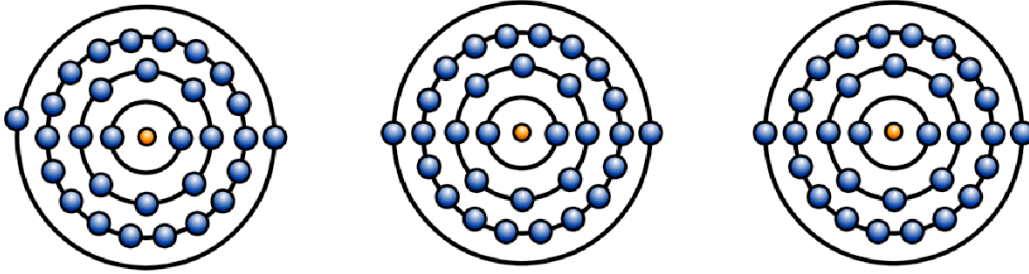
When an atom loses an electron, it becomes a **positive ion** because it has an extra positive charge. A positive ion attracts an electron from a neighboring atom to become balanced.

The movement of electrons between atoms causes **electron flow**.

**This is the fundamental concept of electricity.**



## Bound and Free Electrons



### Bound and Free Electrons

An atom's electrical properties are based on the structure of its electrons.

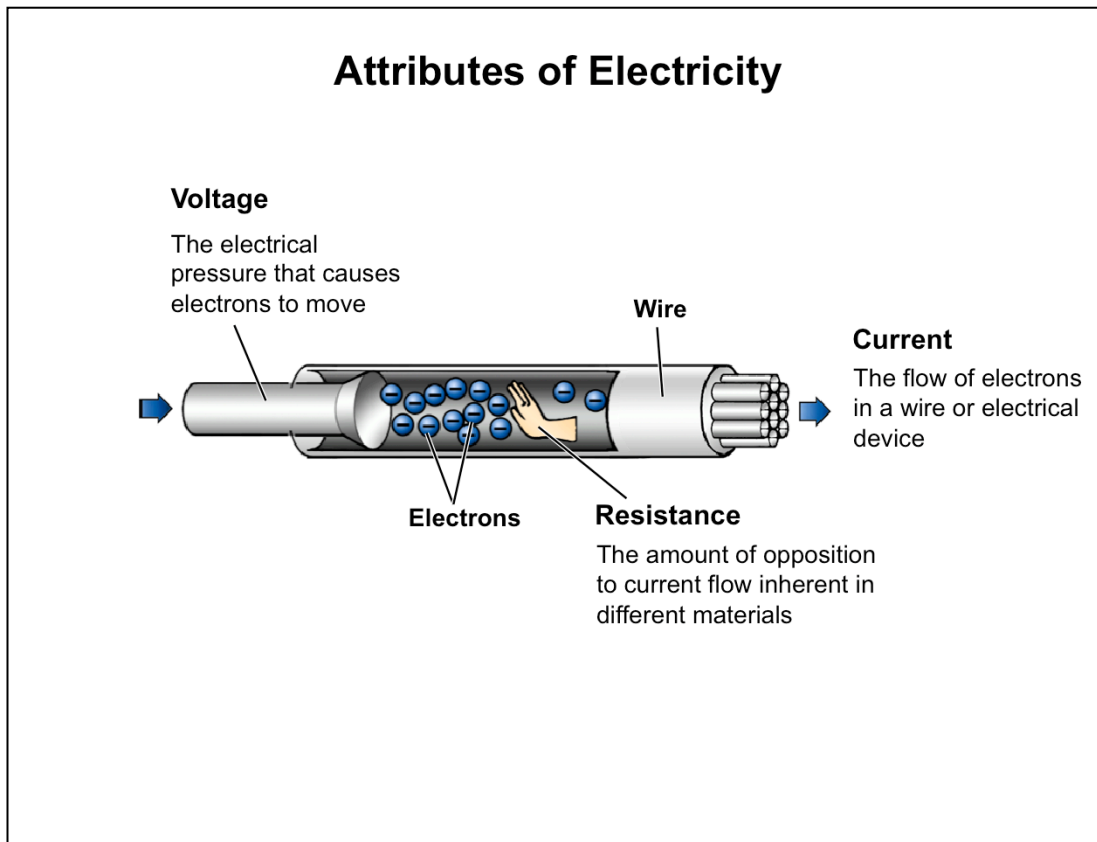
Electrons in the inner valence shells closest to the nucleus are strongly attracted to the protons, and are called **bound electrons**. Electrons in the outer valence shell, however, are farther away from the nucleus and may be freed from their orbit to move from one atom to another. These are **free electrons**.

It is the number of free electrons in the outermost valence shell that determine the atom's ability to conduct electricity.

Moving an electron from one atom to another requires an **electromotive force (EMF)**. EMF can be created by friction, heat, light, pressure, chemical action, or magnetic forces.

A stream of free electrons moving from atom to atom creates an **electrical current**.

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### Attributes of Electricity

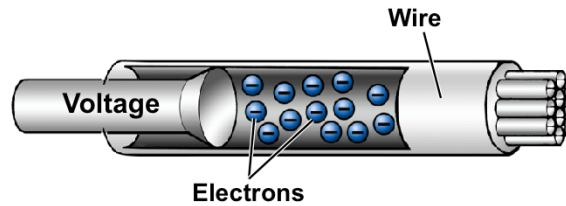
Electricity is the controlled movement of electrons through a conductor. It is a form of energy. The electrical energy itself cannot be seen, heard, touched, or smelled. However, certain electrical attributes can be detected and measured. The three primary attributes of electricity are:

- Voltage (pressure)
- Current (flow)
- Resistance (opposition to flow)

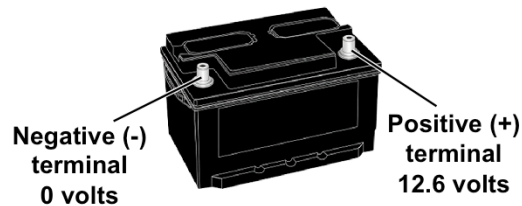
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### Voltage

**Voltage is electrical pressure.**



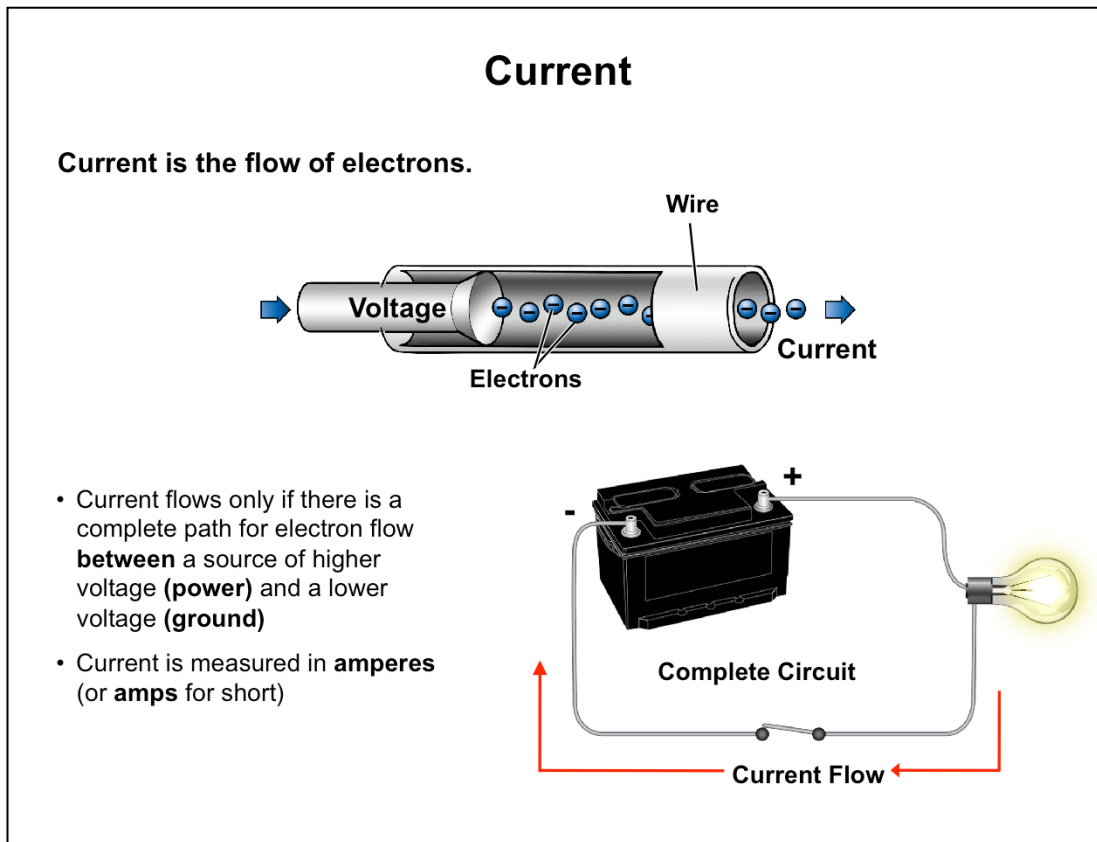
- Voltage is created by a difference in electrical charge between two points
- Voltage is measured in **volts**
- An automobile battery has approximately 12.6 volts difference between its terminals



**Voltage** Voltage is **electrical pressure** caused by a difference in electrical charge between two points. Voltage (pressure) can exist even when electrons are not flowing. Compare voltage to water pressure. Even when water is not flowing, the pressure is there.

Electrical pressure is created when electrons are freed from their atoms by friction, heat, light, pressure, chemical action, or magnetic forces. It is often called "**potential**," because voltage has the potential to cause electrons to flow (or to do work). Voltage is measured in volts.

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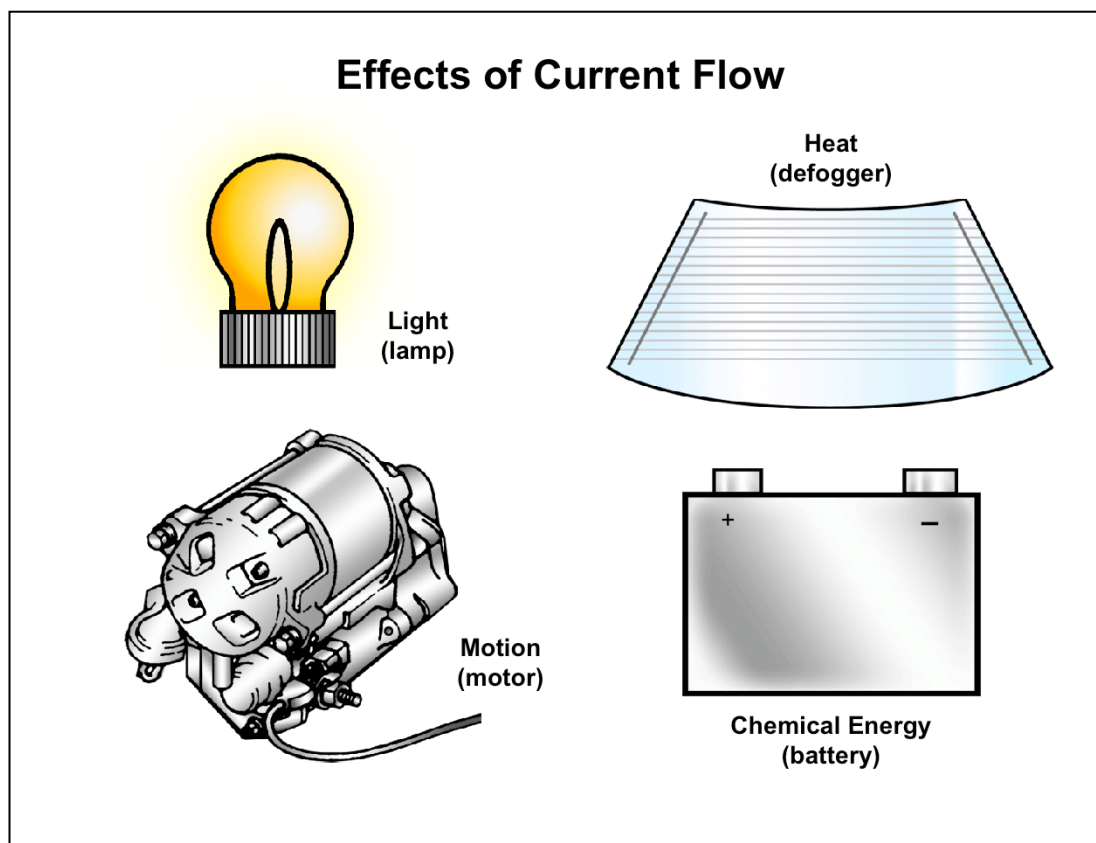
**Current** Current is the **flow of electrons** caused by electrical pressure.

Voltage (electrical pressure) can exist without current flow. However, current cannot flow without voltage.

Compare current to water flow. When a faucet is opened, water flows if there is water pressure. Without water pressure, there is no water flow.

Current is measured in **amperes**, or "**amps**" for short. Current may also be referred to as "amperage."

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### Effects of Current Flow

Electrical current flowing through a device can be converted into motion, light, heat, chemical energy, or electromagnetic force.

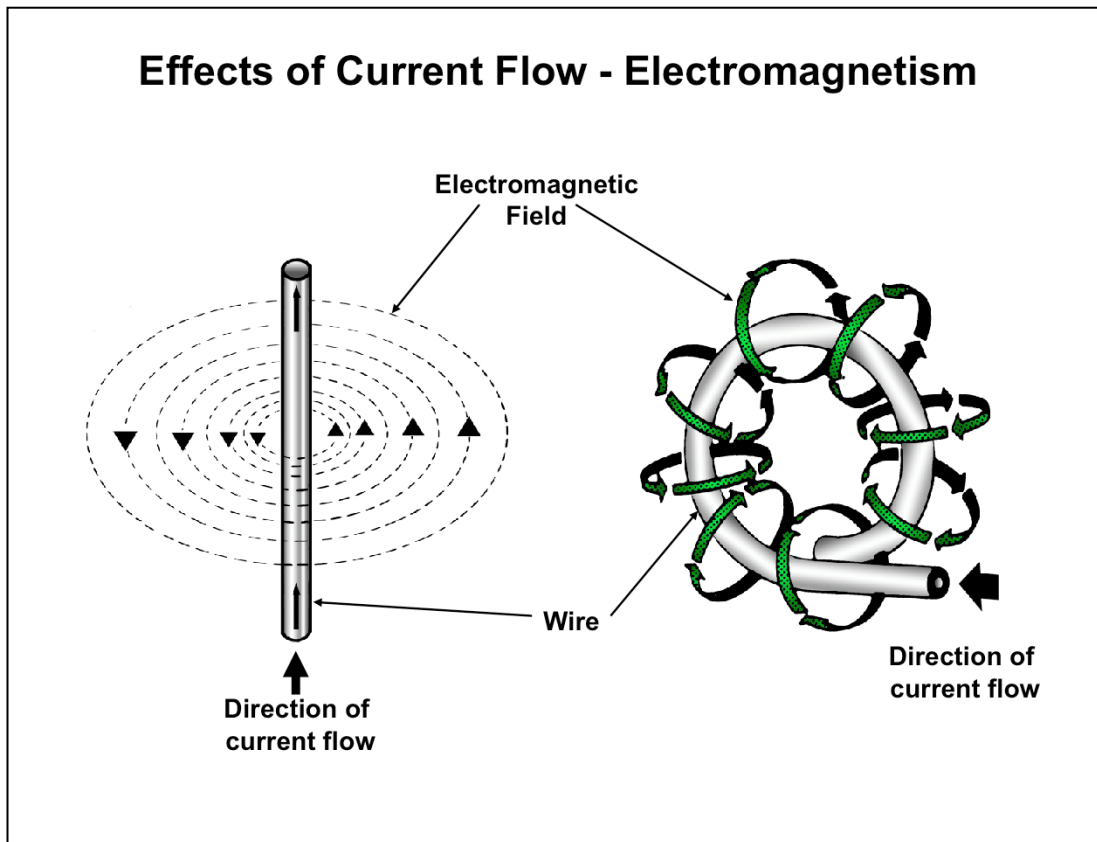
**Motion** – Current flowing through an electric motor is converted to rotary motion.

**Light** – Resistance to current flow causes the filament to glow in an electric light bulb.

**Heat** – In a cigarette lighter or a rear window de-fogger, electrical energy is converted to thermal energy (heat). High current can also melt the metal strip in a fuse, causing it to blow.

**Chemical Energy** – When charging a battery, electrical current causes a chemical reaction in the battery resulting in it building up a stored charge.

**Electromagnetic Force** – Current flowing through a coil of wire creates an electromagnetic field that can activate a relay or a solenoid.



**Electromagnetism**

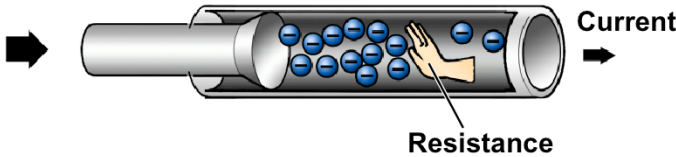
Electricity and magnetism are closely related; magnetism can be used to create electricity and electricity can be used to create magnetism.

- All conductors carrying current create a magnetic field; the higher the current, the stronger the magnetic field.
- Whenever current flows through a conductor, a magnetic field surrounds the conductor in a series of circular lines of force.
- If the conductor is looped (a coil), the lines of force are concentrated in the center of the coil to create a very strong field. Increasing the current or the number of coils increases the field strength.
- Placing a soft iron core inside a coil of wire creates a strong electromagnet when current passes through the coil.
- Reversing the direction of current flow reverses the electromagnetic force fields. If a magnet were attracted to the electromagnetic field, reversing the current would repel the magnet.

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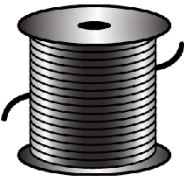
### Resistance

**Resistance is the opposition to current flow.**

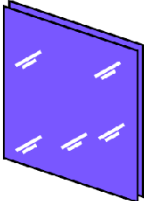


The diagram shows a horizontal pipe with blue spheres (electrons) inside. A hand is placed inside the pipe, blocking the flow. An arrow on the left points into the pipe, and an arrow on the right points out of the pipe, labeled 'Current'. A label 'Resistance' points to the hand.


- All materials have some resistance to current flow
- Resistance is measured in **ohms** (abbreviated  $\Omega$ )



**Conductors.** Have very low resistance to current flow.



**Insulators.** Have very high resistance to current flow.



**Semiconductors.** Can take on the properties of either a conductor or insulator.

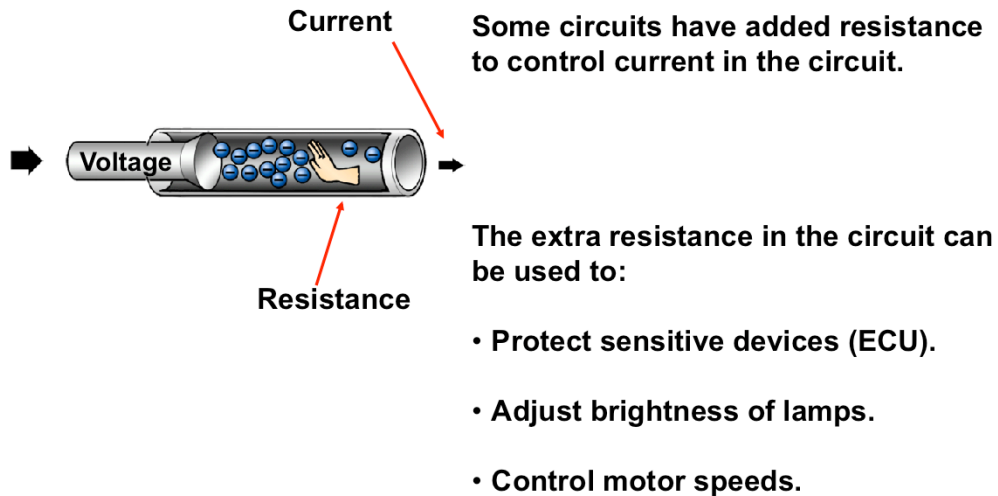
**Resistance** Every electrical component or circuit has resistance. **Resistance** opposes electron flow. It does not slow down the flow of electrons, but rather reduces the number of electrons flowing. Resistance changes electrical energy into another form of energy, such as heat or light, etc..

- Some materials have a **low resistance** to current flow. These are called **conductors** and include **copper, aluminum, silver and gold**.
- Some materials have a **high resistance** to current flow. These are called **insulators** and include **rubber, glass, paper, ceramics, plastics and air**.
- Materials that can take on the properties of **either a conductor or insulator** are called **semiconductors**. These include **carbon and silicon**.

Resistance is measured in ohms, abbreviated with the omega symbol –  $\Omega$ .

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## Added Resistance to Control Current



**Loads to Control Current** Some devices use resistance to control current.

- Ignition primary resistors, also called ballast resistors, maintain and protect the electronic control unit (ECU) from excessive current.
- The lamp rheostat adds or subtracts resistance to dim or brighten interior lamps.
- A carbon pile resistance in the Sun VAT 40 Tester loads the battery for cranking-voltage and charging system tests.
- A sliding contact resistance is used on some A/C and heating controls to adjust interior temperature by increasing or decreasing air volume and fan speed.
- A wire-wound resistor is used on some fuel pumps to reduce pump speed.

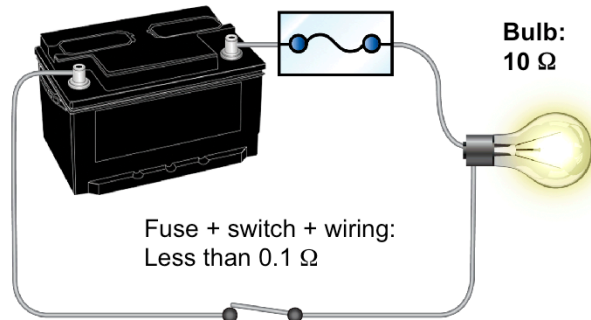


## L623 Electrical Circuit Diagnosis

### Component Resistances

**All of the components in a circuit have resistance, including wiring, switches, and fuses.**

The load(s) in a circuit have the most resistance of all the circuit components.



#### Component Resistances

All materials have some resistance, even conductors. The resistance of conductors, however, is very low. Wiring, fuses and switches in a circuit normally have less than 1/10 of an ohm ( $0.1 \Omega$ ) resistance.

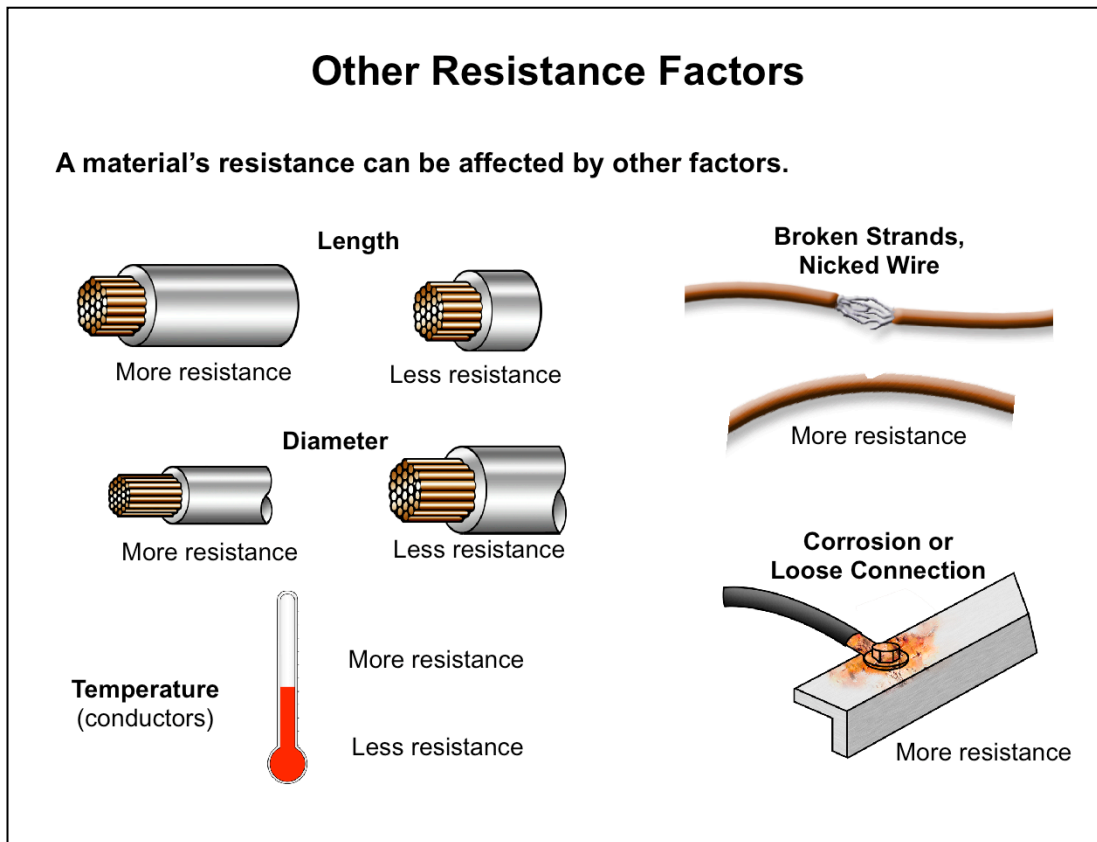
#### Loads

**Loads** are the devices in a circuit that use electricity to **perform work**. The purpose of the circuit is to deliver the electrical current necessary to operate the load. Typical loads include:

- Lamps
- Motors
- Horn
- Defogger
- Audio speakers
- Cigarette lighter

Other devices that can act as a load in a circuit are **resistors**. Resistors are electronic devices that add resistance to a circuit to **control current flow**. A blower motor control switch is an example. It has several resistance levels to control current flow to the blower motor and thus control blower speed.

The loads in a circuit – whether working loads or resistors – will have the most resistance of all the components in the circuit.



**Resistance Factors** **Length** – A longer wire has more resistance than a shorter one.

**Diameter** – A small gauge wire has more resistance than a larger gauge wire.

- Wire diameters are rated by **gauge**.
- Gauges 1, 2, 3 are thicker with less resistance and more current capacity.
- Gauges 18, 20, 22 are thinner with more resistance and less current capacity.

**Temperature** – Changes in temperature affect resistance differently in different materials.

- For most conductors, resistance increases as the temperature increases. For example, the resistance of a lamp's filament increases as it heats up.
- Insulators, on the other hand, have less resistance at higher temperatures.
- Certain semiconductor devices called thermistors exhibit decreasing resistance as temperature increases.

**Condition** – The condition of a wire or connector can increase resistance.

- A **nicked wire** or a wire with **broken wire strands** has higher resistance than an undamaged wire because the wire's diameter is effectively diminished.
- **Corrosion** can increase resistance because the conducting material is replaced by higher-resistance corrosion by-products.
- **Loose connections** are like wires with broken wire strands. Fewer contact points between the connecting components result in higher resistance.

**HINT**

When replacing a wire in a circuit, do not use a thinner wire or a longer wire because this will increase the resistance in the circuit.

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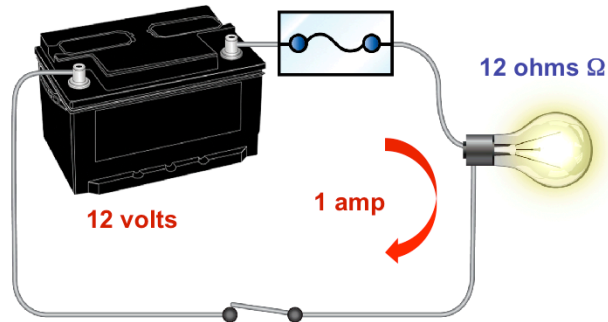
### Ohm's Law

**Ohm's Law states → Amps \* Resistance = Voltage**

In a circuit with **12 ohms resistance**,  
a **12 volt power** source causes  
**1 amp of current** to flow.

If **resistance** doesn't change:

- **Higher voltage** produces **more current**
- **Lower voltage** produces **less current**



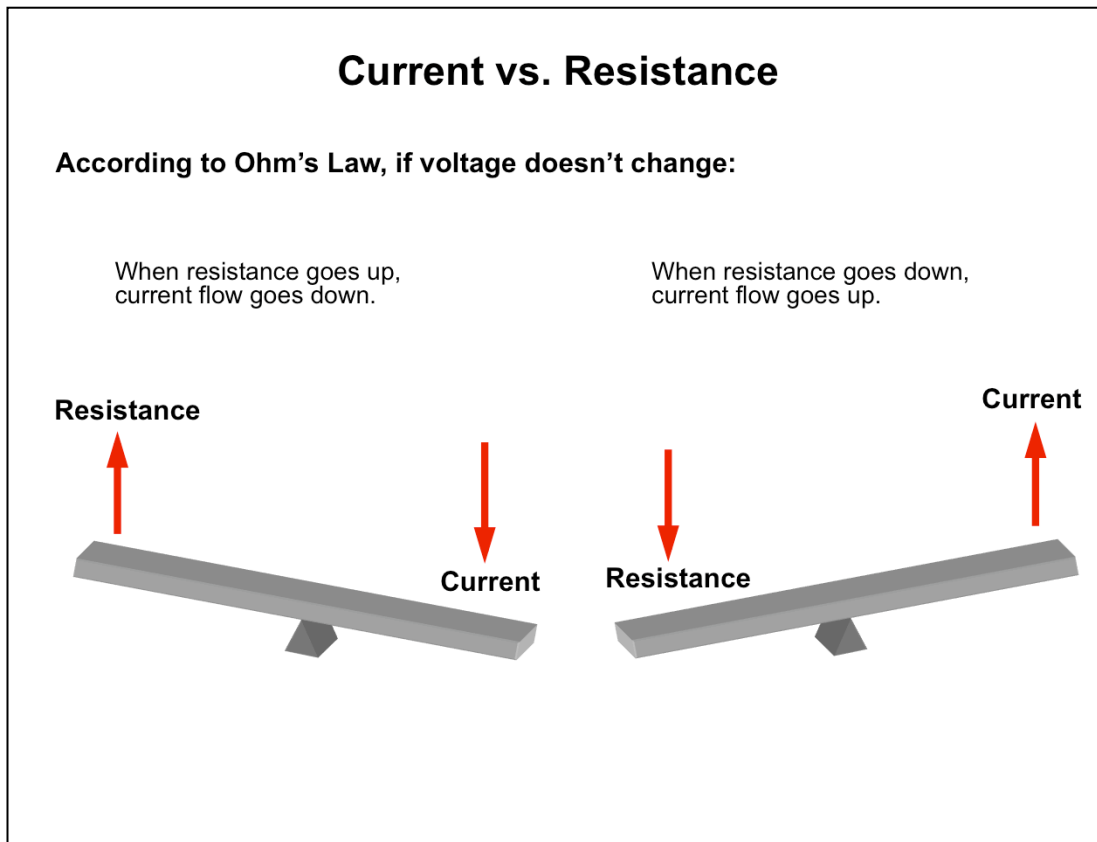
**Ohm's Law** **Ohm's Law** explains the relationship between voltage, current, and resistance. One part of Ohm's Law states:

- The current in a circuit is directly proportional to the applied voltage.

According to Ohm's Law, when resistance stays the same:

- If applied voltage increases, current flow increases.
- If applied voltage decreases, current flow decreases.

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**Current vs. Resistance**

**Ohm's Law** also states:

- The current in a circuit is inversely proportional to the amount of resistance.

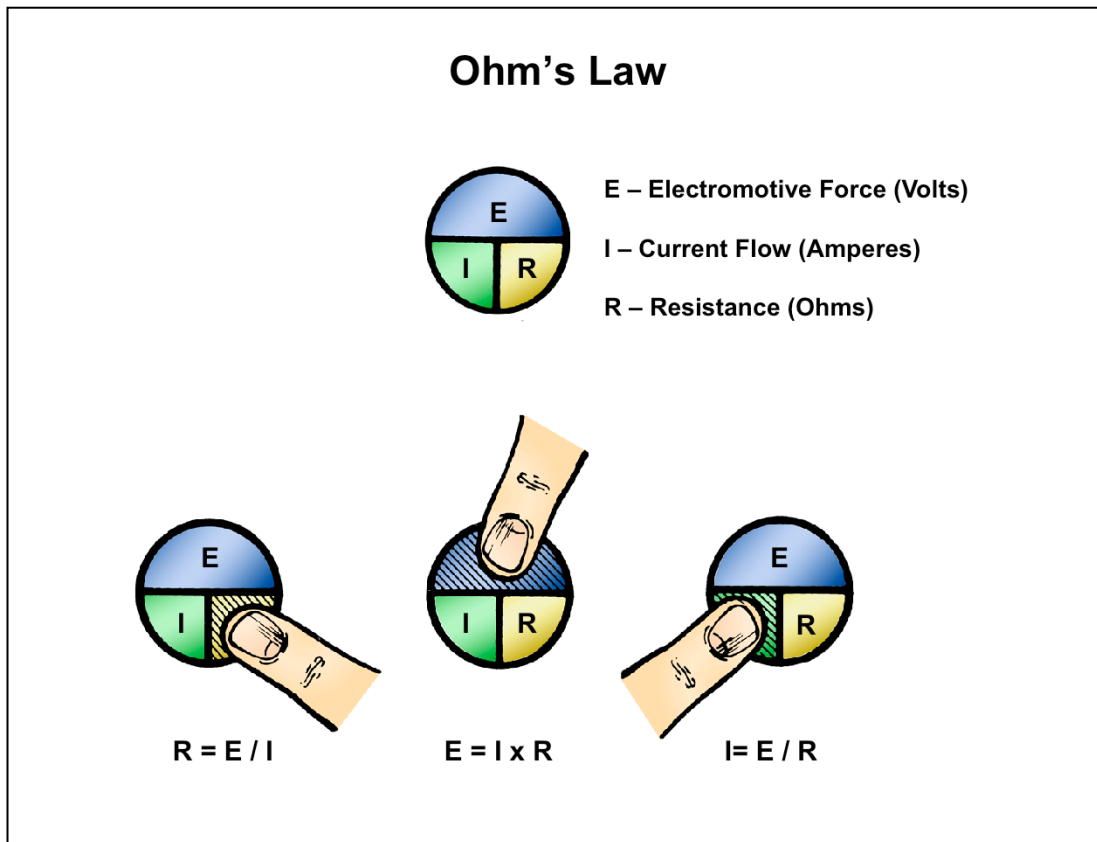
According to Ohm's Law, when voltage stays the same:

- If circuit resistance increases, current flow decreases.
- If circuit resistance decreases, current flow increases.

Resistance is not affected by either voltage or current. It is a characteristic of the combination of conductors and loads in the circuit. Resistance can be OK, too low, or too high.

- If resistance is too low, current will be higher than normal.
- If resistance is too high, current will be low if there is sufficient voltage, or there will be no current if the voltage is not enough to overcome the resistance.

## L623 Electrical Circuit Diagnosis



### Calculating Volts, Amps, or Ohms

The formula for Ohm's Law is  $E = I \times R$  where:

- E = Electromotive force (in volts)
- I = inductance, or current flow (in amps)
- R = Resistance (in ohms)

If you know any two values in a circuit, you can calculate the third value using Ohm's law.

### Examples

If you know the voltage in a circuit is 12 volts and the current is 2 amps, you can calculate the circuit resistance:

$$R = E / I$$

$$R = 12 \text{ volts} / 2 \text{ amps}$$

$$R = 6 \text{ ohms}$$

If you know the resistance in a circuit is 3 ohms and the current is 4.2 amps, you can calculate the circuit voltage:

$$E = I \times R$$

$$E = 4.2 \text{ amps} \times 3 \text{ ohms}$$

$$E = 12.6 \text{ volts}$$

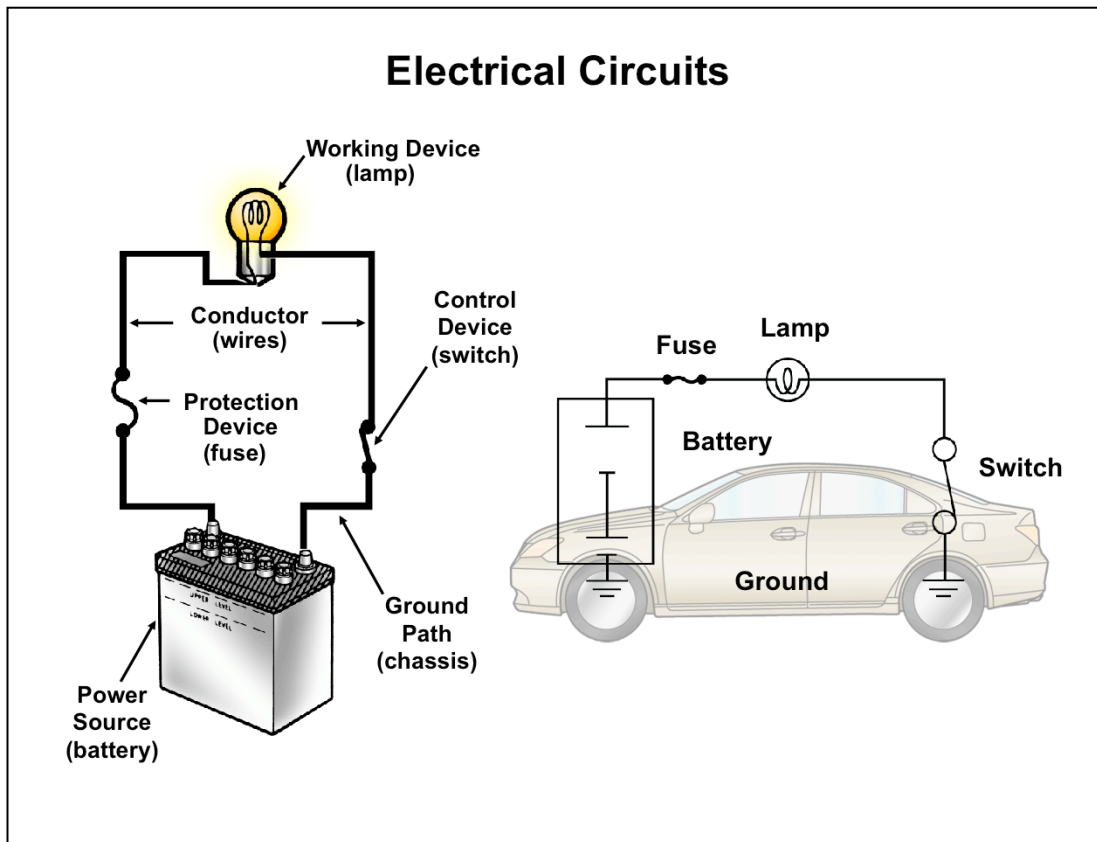
If you know the voltage in a circuit is 12 volts and the resistance is 4 ohms, you can calculate the circuit current:

$$I = E / R$$

$$I = 12 \text{ volts} / 4 \text{ ohms}$$

$$I = 3 \text{ amps}$$

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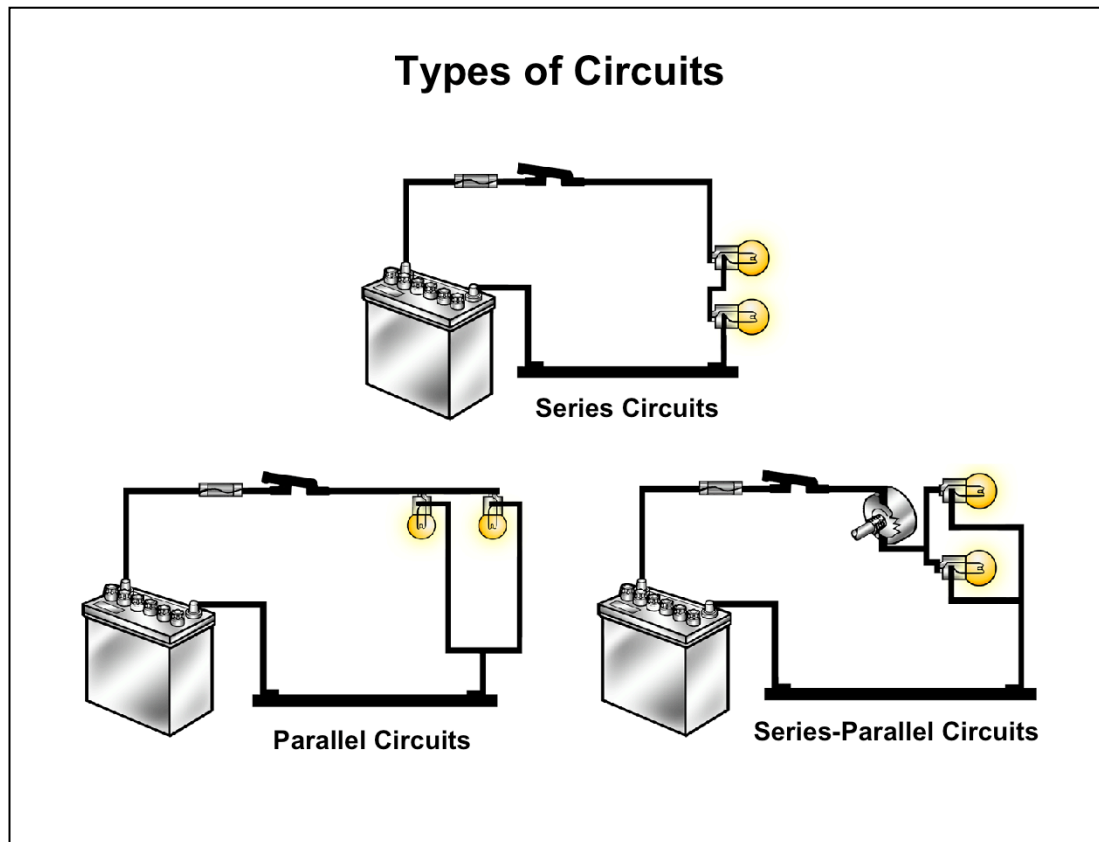


### Electrical Circuits

A complete path, or **circuit**, is required for voltage to create current flow through resistances and perform work. Every electrical circuit on a vehicle contains:

- **Power source** to produce voltage or electrical potential
  - A battery or an alternator
- **Conductors** to provide a path for current flow
  - Wires or printed circuit boards (on the power side of the circuit)
  - Vehicle frame or chassis (on the ground side of the circuit)
- **Loads** or working devices to convert electrical energy into another form of energy to perform work
  - Lamps, motors, horn, defogger, cigarette lighter, etc.
- **Protection devices** to interrupt the current path and prevent damage to conductors and working devices from too much current
  - Fuses, circuit breakers, fusible links
- **Control devices** (switches) to open or close the current path, or to vary the amount of current in the circuit and regulate how the load works (dimmer switches)
  - On/off switches, potentiometers, relays, transistors, ECUs

## L623 Electrical Circuit Diagnosis

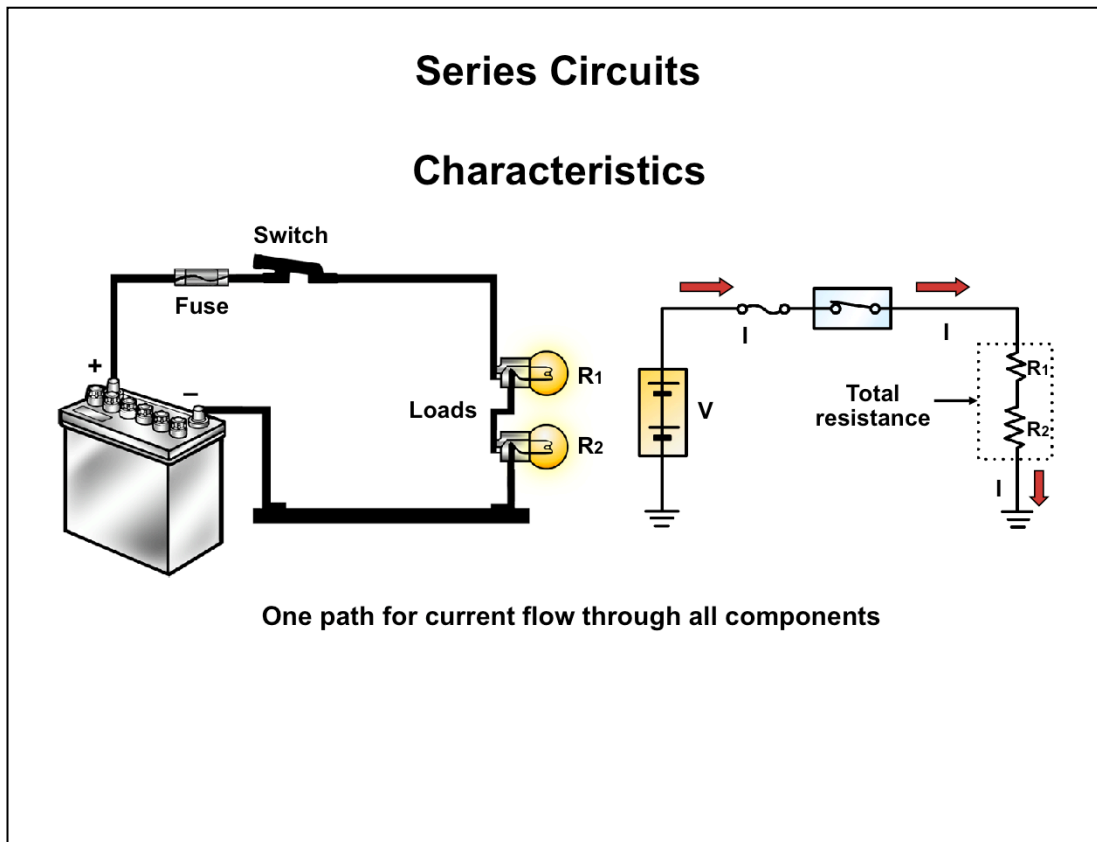


**Types of Circuits** The circuit type is based on how the components — power source, protection devices, conductors, control devices and grounds — are connected.

There are three types of circuits:

- **Series** – loads connected together with a common single path to ground
- **Parallel** – each load has its own alternate path to ground
- **Series-Parallel** – some loads on a single path, and others on alternate paths

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- Series Circuits** In a series circuit, all circuit components have only one path for current flow.
- No current can flow unless there is continuity through the entire circuit.
  - If any part of the circuit is either disconnected or broken, the entire circuit will stop working.

The resistance of each device in a series circuit may be different, and the voltage drop across each device may be different.

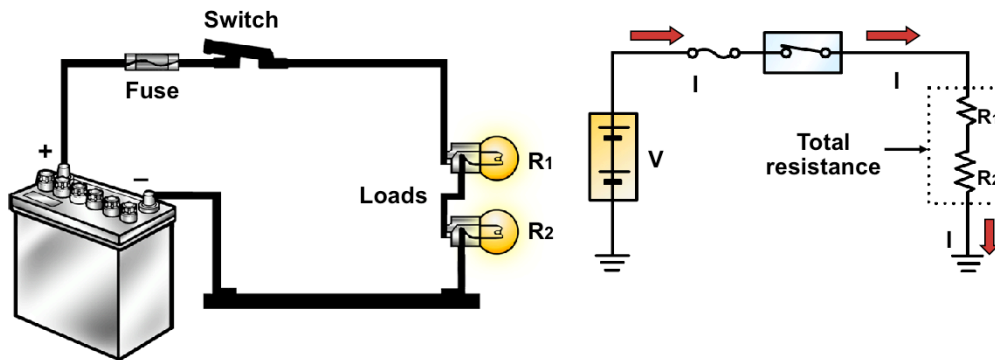


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### Series Circuits

#### Key Features

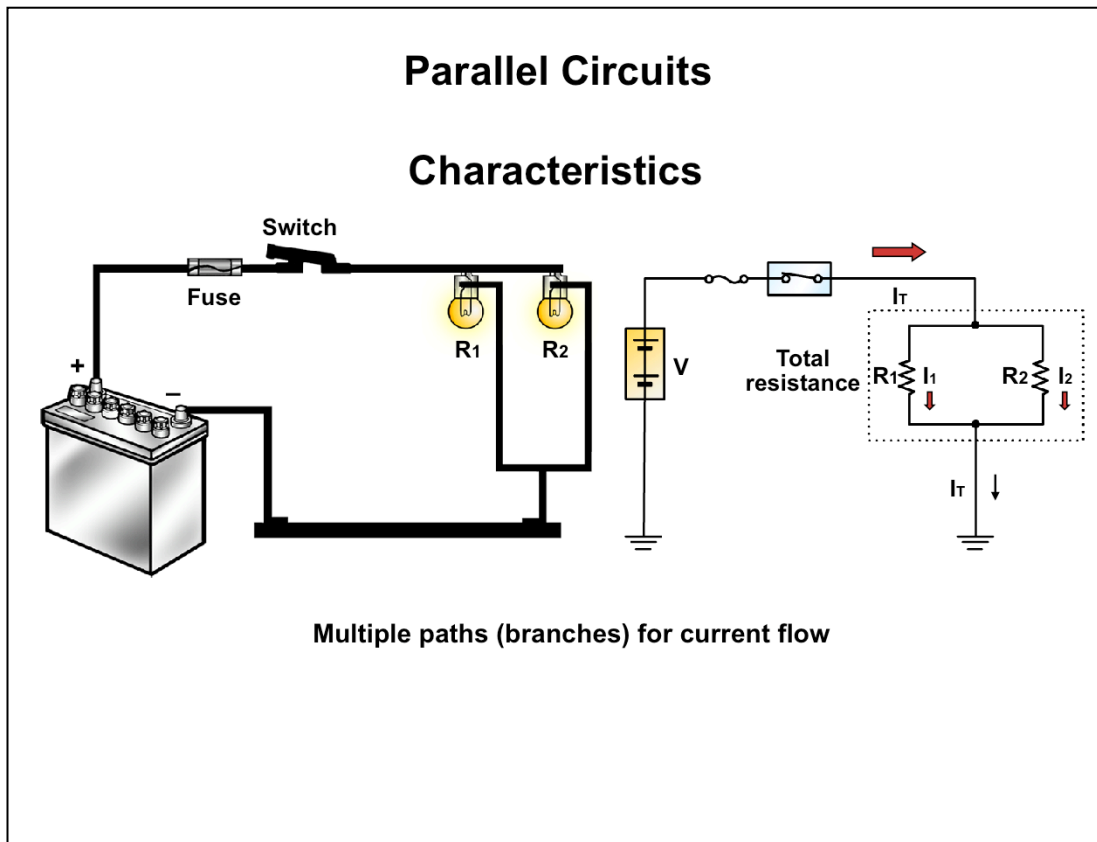
- Current flow through the circuit is the same throughout the circuit.
- Total resistance in the circuit is the sum of the load resistances.
- Voltage is divided between the loads.
- Total voltage drop equals source voltage.
- There is only one path for current to flow.
- An open disables the entire circuit.



**Key Features** In addition to the circuit features listed above, the following facts can be helpful in isolating circuit problems.

- Lower voltage reduces current and higher voltage increases current.
- More resistance reduces current and less resistance increases current.
- Reduced current affects component operation (dim lamps, slow motors).
- Increased current affects component operation (early failure, blown fuses).
- A broken wire or disconnected component (an open) prevents the circuit from operating because there is no path to ground.
- Poor connections and corrosion can increase resistance.

## L623 Electrical Circuit Diagnosis



**Parallel Circuits** A parallel circuit has more than one path for current flow.

Parallel paths are referred to as **branches**. If one branch is broken, current will continue to flow through the other branches because each branch has its own path to ground.

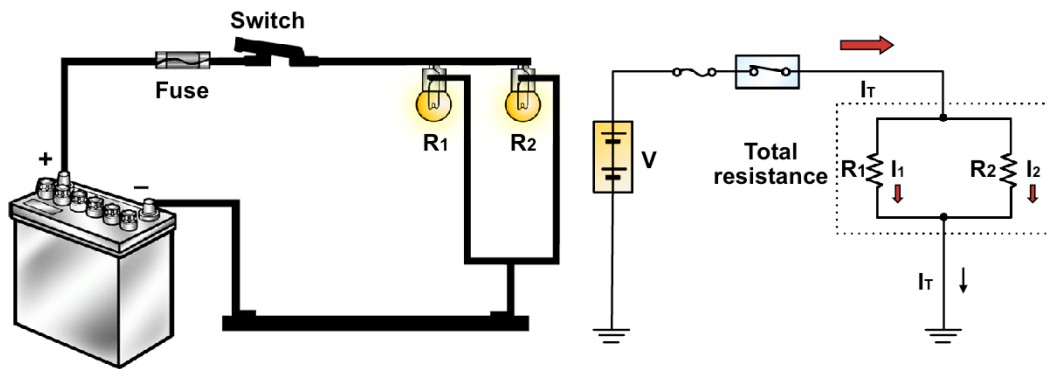
The more branches in a circuit, the more the total current flow. The points where the current paths split and rejoin are called **junctions**.

## L623 Electrical Circuit Diagnosis

### Parallel Circuits

#### Key Features

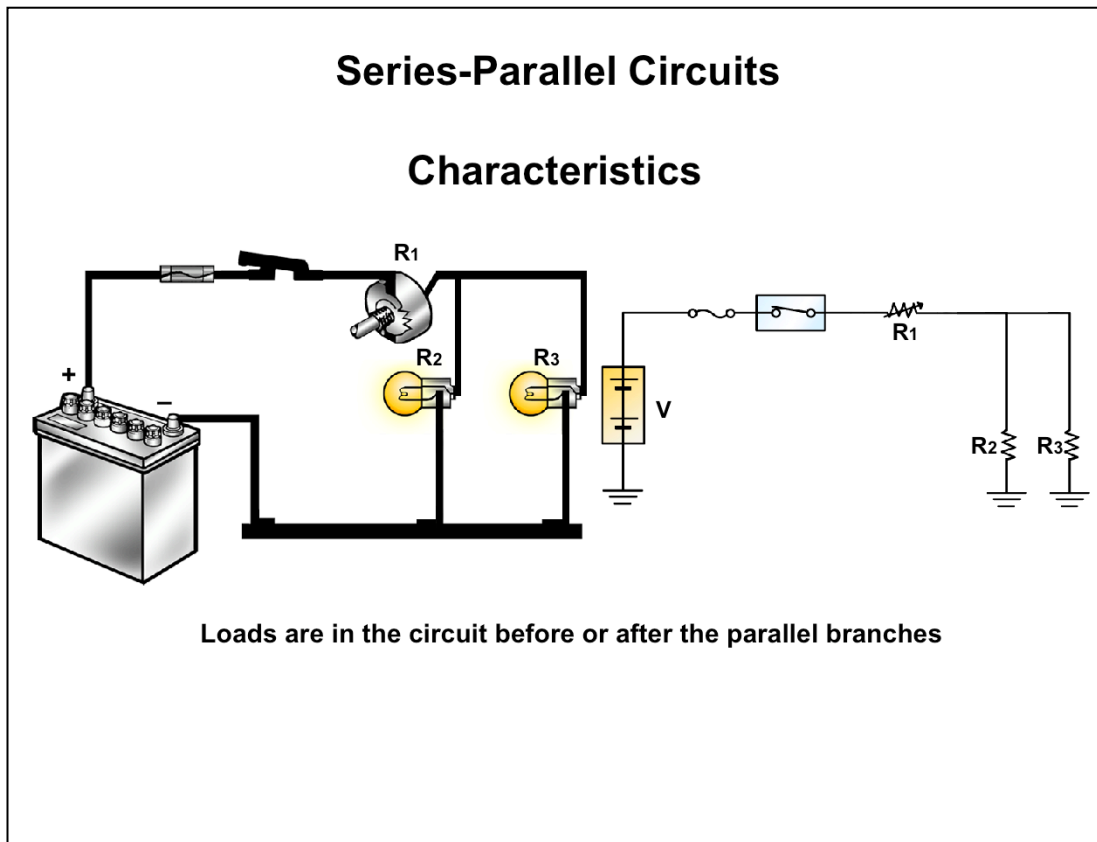
- Voltage drop across each load resistance is the same as the source voltage.
- Current flow is divided between the loads.
- Total resistance of the circuit is *less* than the lowest single load resistance.
- Total current in the circuit equals the sum of the branch currents.
- If you add a branch, resistance goes down, current flow goes up.



#### Key Features

In addition to the circuit features listed above, the following facts can be helpful in isolating circuit problems.

- An open circuit in any branch increases resistance and reduces current in the entire circuit.
- Higher resistance in one branch may only affect the component operation in that one branch. However, if the resistance increases enough to create an open circuit, the circuit effectively loses a branch and resistance increases and current decreases for the entire circuit.
- Low source voltage or higher resistance before/after the parallel branches reduces current in the entire circuit.
- High voltage or a short circuit to ground before the loads increases current, can blow fuses, and damage components.



### Series-Parallel Circuits

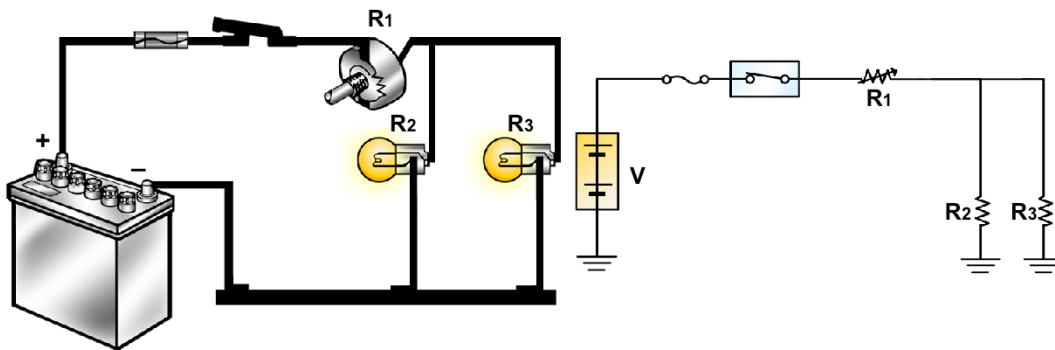
A series-parallel circuit has some components in series and others in parallel.

The power source, protection devices, and control devices are usually in series and the loads are usually in parallel. In this circuit, the dimmer switch in the series part of the circuit is a type of resistor and is considered a load.

## Series-Parallel Circuits

### Key Features

- Total current in the series portion equals the sum of the branch currents.
- Total circuit resistance is the sum of the parallel equivalent resistance and the series resistances.
- Voltage applied to the parallel branches is the source voltage minus any voltage drop across loads wired in series.

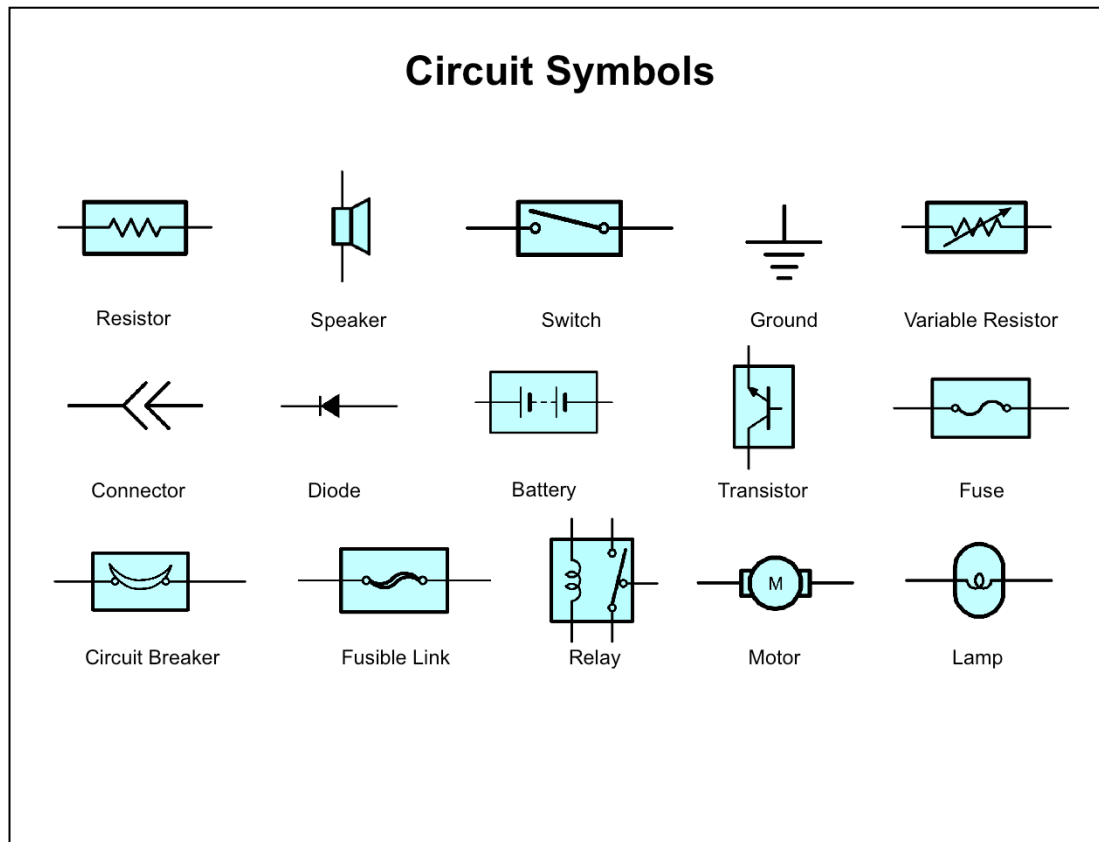


### Key Features

In addition to the circuit features listed above, the following facts can be helpful in isolating circuit problems.

- Problems in the series part of the circuit can affect the entire circuit, while a problem in one leg of a parallel branch may or may not affect the entire circuit.
- An open in the series part of the circuit stops current flow in the entire circuit. An open in a parallel branch leaves current flowing in the series part and the remaining branches.
- Very high resistance in one branch would reduce the total circuit current, but increase current in the other branches.
- Very low resistance in one branch would increase total circuit current and possibly cause little or no current flow in other branches.

## L623 Electrical Circuit Diagnosis



**Circuit Symbols** Pictorial diagrams of complex automotive circuits can become very complicated.

As a result, most car makers, including Lexus, use wiring diagrams with various symbols for devices, conductors, connectors, and ground points. Some common symbols are shown here.

For a more complete listing of circuit symbols, see RESOURCES.

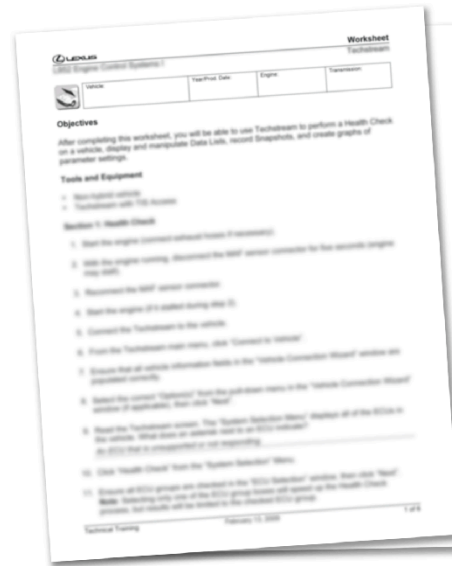
## L623 Electrical Circuit Diagnosis

### Worksheet

#### Electrical Essentials Worksheet

##### Objectives:

- Identify electrical symbols
- Build series, parallel, and series-parallel circuits, and describe their operation



*Use this space to write down any questions you may have for your instructor.*

##### NOTES:

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