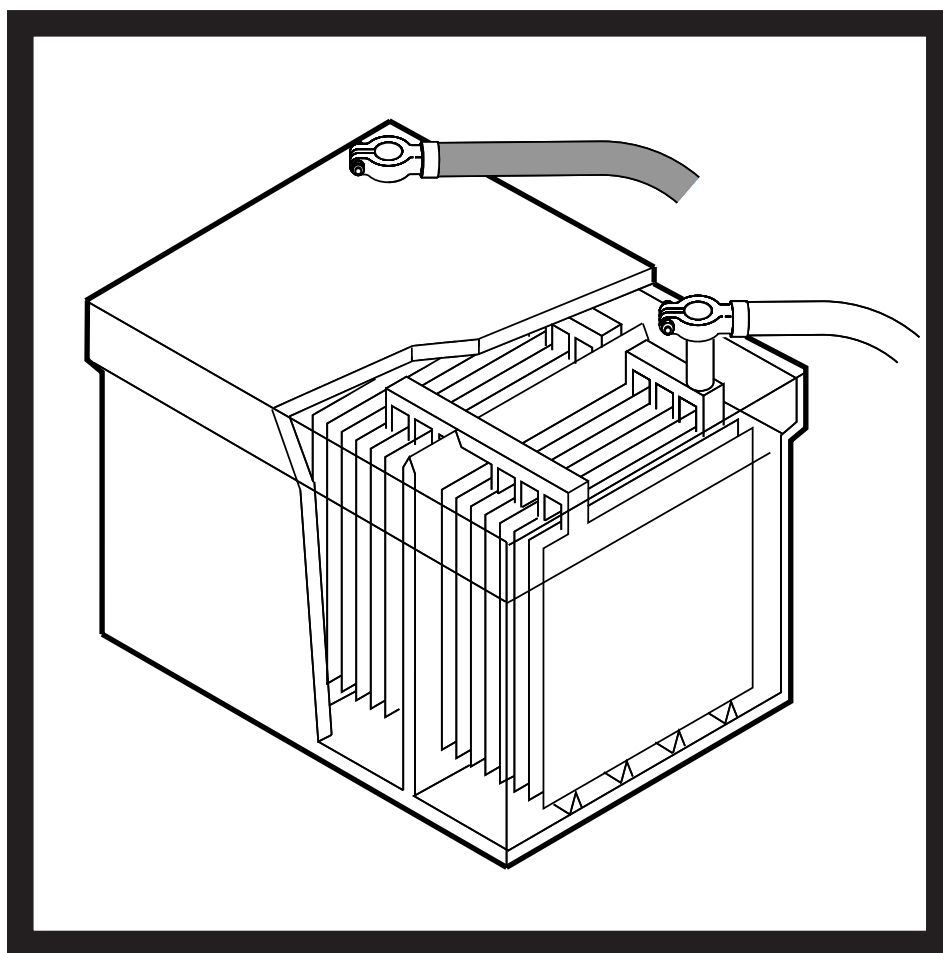


Technical Service Training

Global Fundamentals

Curriculum Training – TF1010011S

Electrical Systems



Student Information

Ford Motor Company



VOLVO

 **mazda**

 **LINCOLN**



Mercury 

 **JAGUAR**


ASTON MARTIN

Global fundamentals training overview

The goal of the Global Fundamentals Training is to provide students with a common knowledge base of the theory and operation of automotive systems and components. The Global Fundamentals Training Curriculum (FCS-13203-REF) consists of nine self-study books. A brief listing of the topics covered in each of the self-study books appears below.

- Shop Practices (FCS-13202-REF) explains how to prepare for work and describes procedures for lifting materials and vehicles, handling substances safely, and performing potentially hazardous activities (such as welding). Understanding hazard labels, using protective equipment, the importance of environmental policy, and using technical resources are also covered.
- Brake Systems (FCS-13201-REF) describes the function and operation of drum brakes, disc brakes, master cylinder and brake lines, power-assist brakes, and anti-lock braking systems.
- Steering and Suspension Systems (FCS-13196-REF) describes the function and operation of the power-assisted steering system, tires and wheels, the suspension system, and steering alignment.
- Climate Control (FCS-13198-REF) explains the theories behind climate control systems, such as heat transfer and the relationship of temperature to pressure. The self-study also describes the function and operation of the refrigeration systems, the air distribution system, the ventilation system, and the electrical control system.
- Electrical Systems (FCS-13197-REF) explains the theories related to electricity, including the characteristics of electricity and basic circuits. The self-study also describes the function and operation of common automotive electrical and electronic devices.
- Manual Transmission and Drivetrain (FCS-13199-REF) explains the theory and operation of gears. The self-study also describes the function and operation of the drivetrain, the clutch, manual transmissions and transaxles, the driveshaft, the rear axle and differential, the transfer case, and the 4x4 system.
- Automatic Transmissions (FCS-13200-REF) explains the function and operation of the transmission and transaxle, the mechanical system, the hydraulic control system, the electronic control system, and the transaxle final drive. The self-study also describes the theory behind automatic transmissions including mechanical powerflow and electro-hydraulic operation.
- Engine Operation (FCS-13195-REF) explains the four-stroke process and the function and operation of the engine block assembly and the valve train. Also described are the lubrication system, the intake air system, the exhaust system, and the cooling system. Diesel engine function and operation are covered also.
- Engine Performance (FCS-13194-REF) explains the combustion process and the resulting emissions. The self-study book also describes the function and operation of the powertrain control system, the fuel injection system, the ignition system, emissions control devices, the forced induction systems, and diesel engine fuel injection. Read Engine Operation before completing Engine Performance.

To order curriculum or individual self-study books, contact Helm Inc.

Toll Free: 1-800-782-4356 (8:00 am – 6:00 pm EST)

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Objectives

Upon completion of this lesson, you will be able to:

- Explain the purpose and function of electricity.
- Identify the components of electricity.
- Explain the basic theory and operation of electricity.

Introduction

Modern automobiles rely on a wide variety of electrical/electronic components and systems to operate properly. Electricity plays a major role in the proper functioning of the engine, transmission, even brakes and suspension systems in many cases. A fundamental knowledge of how electricity works is important for any person associated with the automobile repair industry.

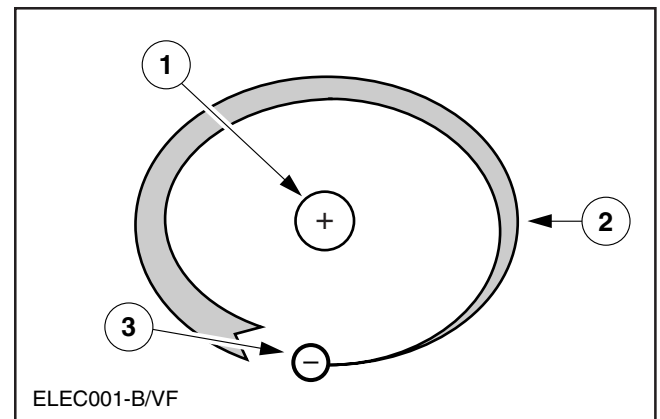
Components of electricity

Matter, atoms and electrons

Electricity is defined as “the flow of electrons through a conductor when a force is applied.” To understand this statement, we need to understand the structure of matter. Everything around us (solids, liquids, and gases) is considered matter. Matter is made from many different atoms and combinations of atoms.

Atoms are made up of protons (which carry a positive [+] electrical charge), neutrons (which have no electrical charge), and electrons (which carry a negative [-] electrical charge).

The nucleus, at the center of the atom, is made of protons and neutrons. Since protons have a positive charge and neutrons have no charge, the nucleus itself is positively charged. The negatively charged electrons orbit the nucleus, similar to the way the planets in our solar system orbit the sun.

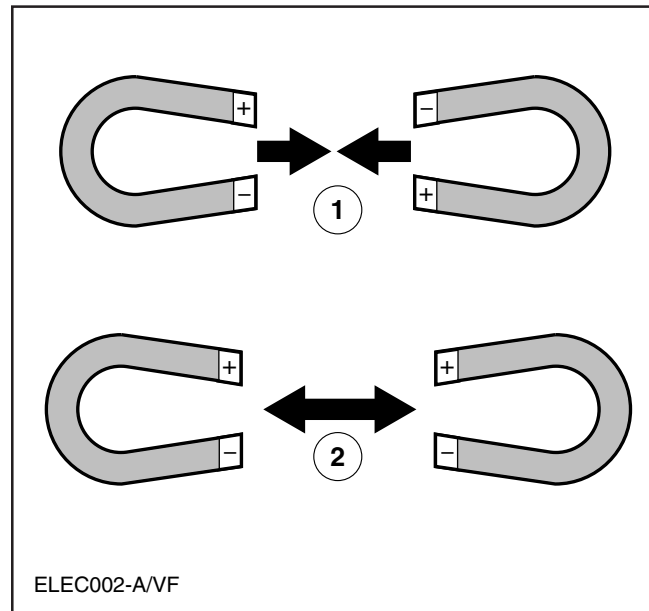


Construction of an atom

- 1 Nucleus (protons and neutrons)
- 2 Electron orbit
- 3 Electron

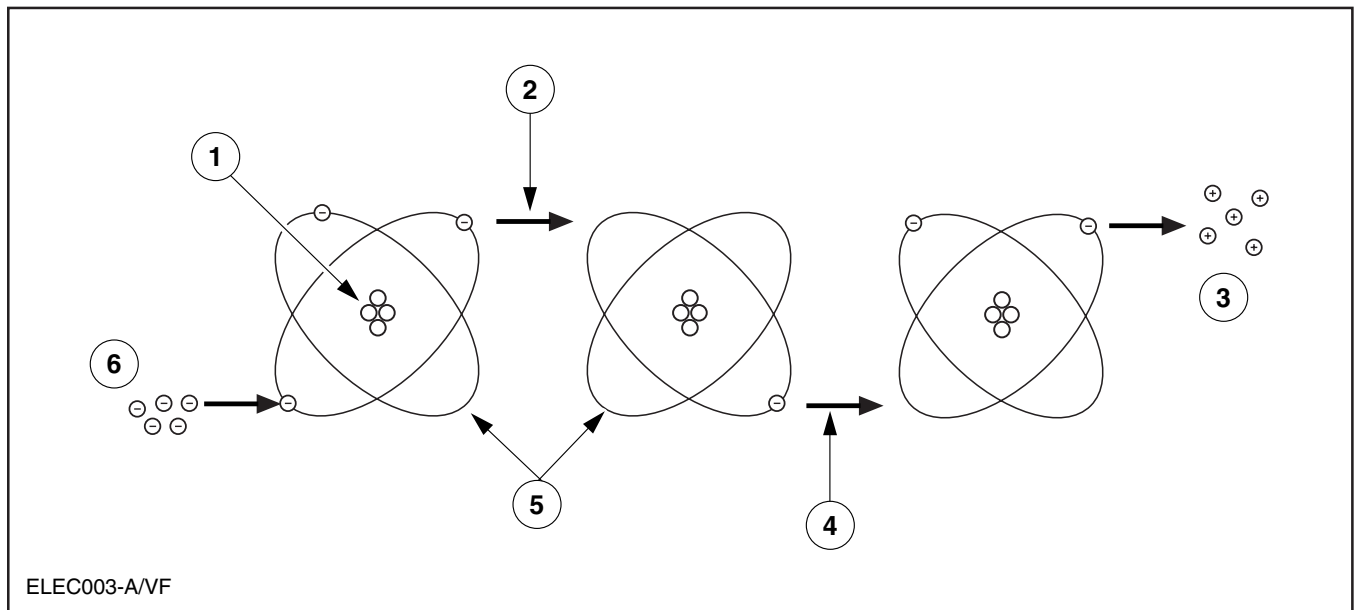
Components of electricity (continued)

Opposite electrical charges attract each other and similar electrical charges repel. The negatively charged electrons stay in their orbit because they are attracted to the positively charged nucleus. This attraction is similar to the way the north (positive) and south (negative) poles of two magnets move toward each other when placed closely together.

**Concept of attraction and repulsion**

- 1 Unlike charges attract
- 2 Like charges repel

Electron movement



Electron Flow

- | | |
|-----------------------------|-------------------------------|
| 1 Nucleus | 4 Free electron |
| 2 Free electron | 5 Atoms in conductor |
| 3 Protons (positive charge) | 6 Electrons (negative charge) |

An electron travels around the nucleus at exactly the speed needed to hold its orbit. The balance between the pull toward the nucleus and the centrifugal force of the moving electron keeps each electron in its respective orbit (shell). The electrons in the outer shell are called valence electrons. Valence electrons are further from the nucleus and easier to force out of orbit. When there is a good path or conductor, electrons can flow from one atom to another. When electrons flow from one atom to another, electric current flow exists.

An atom that is missing an electron is called a positive ion. An atom with an extra electron is called a negative ion. Ions seek balance – positive ions want to gain an electron and negative ions want to get rid of one. These attracting and repelling forces make up the electrical pressure called Electromotive Force (EMF). Another name for EMF is “voltage”, which is discussed in greater detail later. Electrons flowing from one atom to another create electrical current. The ease or difficulty with which electrons flow through a material determines its classification as either a conductor or insulator.

Conductors and insulators

Atoms are different from material to material. The more valence electrons a material has, the harder it is to get them to move. Conversely, the fewer number of valence electrons, the easier it is to move them. The difference between a conductor and an insulator is determined by the number of valence electrons.

Conductors

A good conductor is any element that has less than four electrons in the outer shell. Copper is a common conductor used in automotive wiring because it is strong, relatively inexpensive, and has very little resistance to electron flow. Other good conductors include (in order from best to worst):

- Silver
- Gold
- Aluminum
- Tungsten
- Iron
- Steel
- Mercury

Although silver and gold are the best conductors, they are too expensive for common automotive use. Silver and gold are used only for critical applications. Since gold resists corrosion, it is used on some automotive connectors.

Insulators

An insulator is any element that has more than four electrons in the outer shell. Insulators are materials that prevent or block current flow. The material around wires insulates the wire, protecting the wire and also preventing electrical shock. Some examples of good insulators include:

- Plastic
- Glass
- Rubber
- Porcelain
- Distilled water (although minerals in drinking water will conduct electricity)

Semiconductors

Semiconductors are elements that have exactly four electrons in the outer shell. Semiconductors only conduct electricity under very specific conditions. Semiconductors are used on printed circuit boards in computers, radios, televisions, etc.

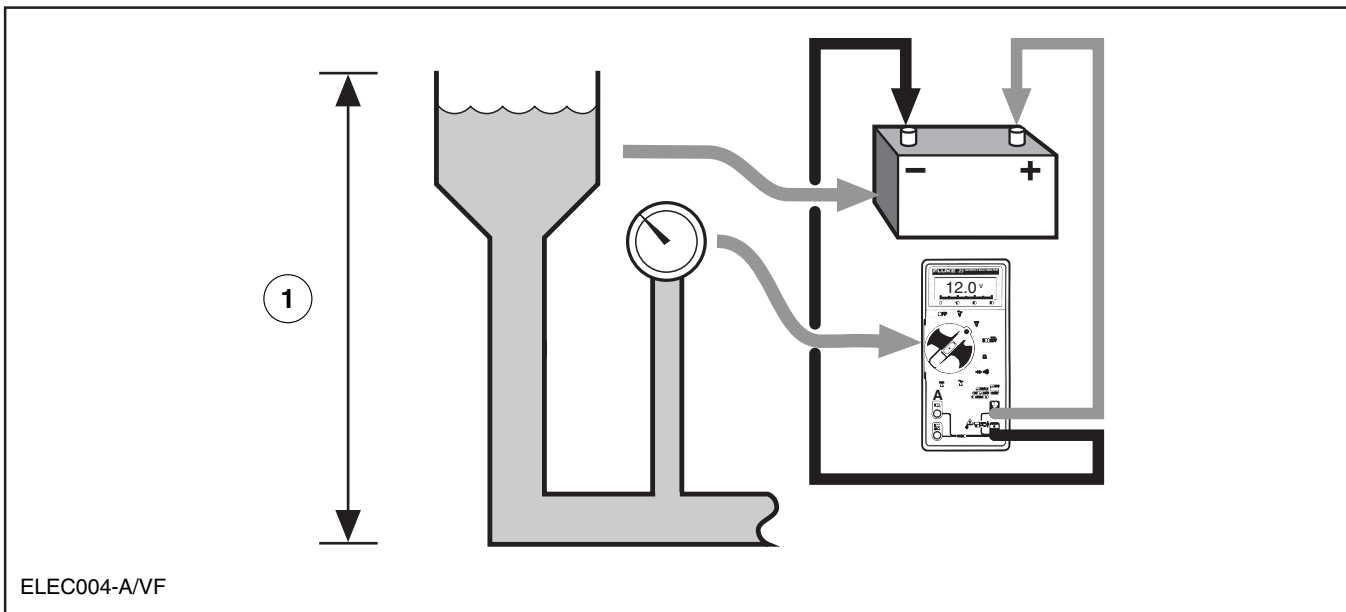
Objectives

Upon completion of this lesson, you will be able to:

- Explain the characteristics of electricity.
- Define Ohm's Law.
- Apply Ohm's Law to solve for electrical values.

Characteristics of electricity

Voltage



Voltage compared to a water tower

1 Difference of potential

Voltage is the pressure (Electromotive Force) that causes current to flow through a conductor. The force of voltage is created by a “potential difference” between two atoms, the difference between the quantity of positive (+) and negative (-) charges, which create an out-of-balance condition.

Voltage can be compared to hydraulic pressure created in a water tower. The pressure results from the potential difference between the top of the tower (equivalent of 12 volts) and the bottom of the tower, or ground (equivalent of 0 volts).

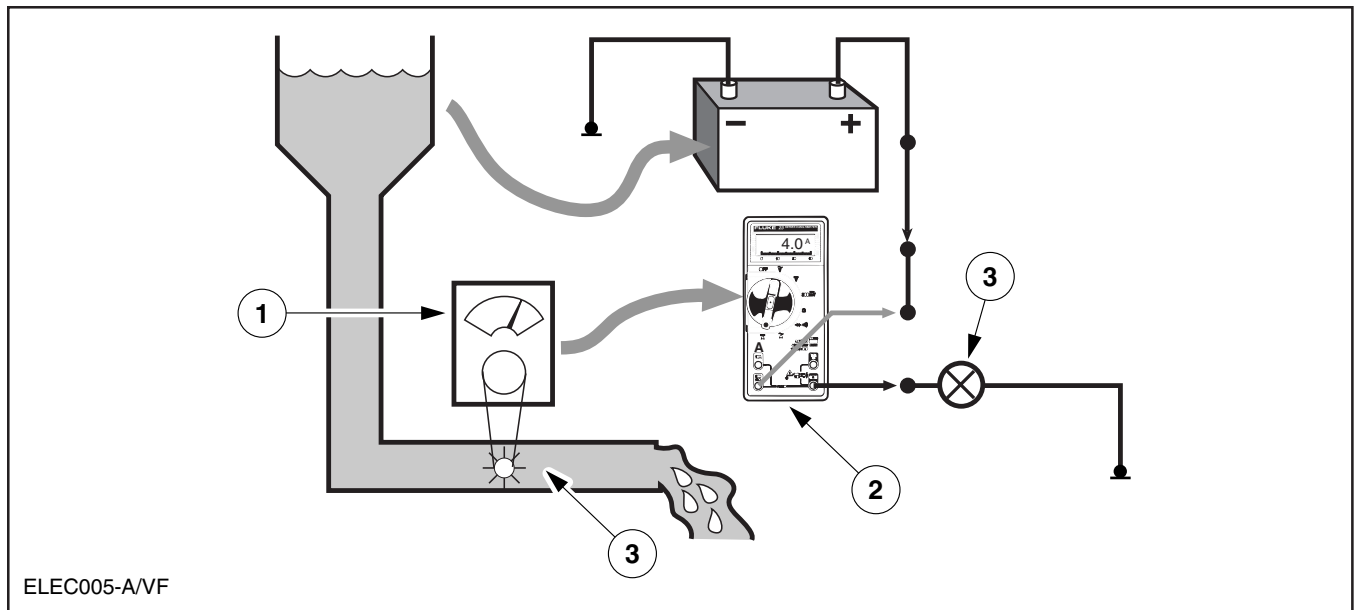
Voltage is measured in units called volts, which is commonly abbreviated as V. Most automotive circuits operate from the vehicle’s battery or generator and are

12-volt systems. Older vehicles use 6V, and some trucks are 24V. With the addition of so many automotive electronic systems in today’s modern vehicles, you can expect to see more and more passenger cars operate with 24V and even 42V.

If you measure the voltage produced by a car battery, between the battery positive terminal and chassis ground, you find that the difference between the two terminals is what pushes current through the circuit, and the difference in this case is 12V.

Current cannot flow without voltage and a complete path to ground. Voltage and current work together to create power to get work done, such as illuminating a light bulb or making a motor run.

Current



Current flow compared to water flow

- 1 Water flow
- 2 Current flow
- 3 Load

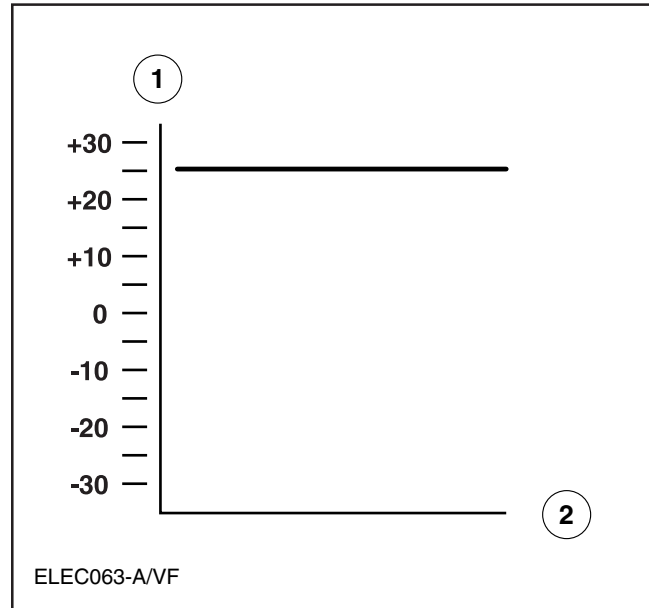
Current is the flow of electrons from one atom to the next. Current is measured in amperes (amps), commonly abbreviated with the letter A. One amp means 6,280,000,000,000,000 (6.28 billion, BILLION) electrons passing a fixed point in one second. As an example of how powerful current is, less than one tenth of an amp flowing through the human body can cause serious bodily harm.

Using the water tower example, we can compare current flow with the mass of water flowing from the tower to a faucet. Again, voltage is the potential difference between the negative and positive terminals, and current is the actual flow or movement of electricity. In the water tower example, the actual flow of water from the tower to the ground is similar to electrical current flow. Keep in mind that current only flows when there is voltage (pressure) to force it.

Characteristics of electricity (continued)

Direct Current (DC)

Direct current occurs when there is a surplus of electrons at one battery terminal, resulting in a flow to the other terminal where there is a scarcity of electrons. Direct current only flows in one direction. One advantage of DC is that it can be stored electro-chemically in a battery.



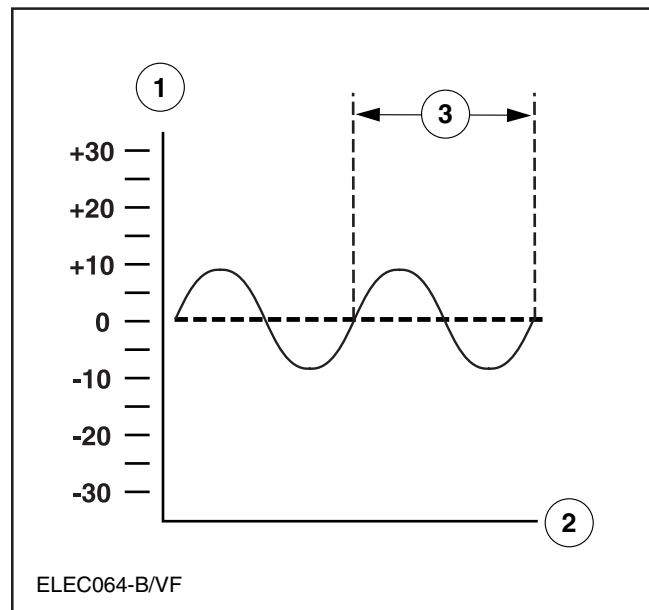
DC displayed as a scope pattern

- 1 Volts
- 2 Time

Alternating Current (AC)

Alternating current (AC) is produced when current flows back and forth under the influence of changing polarity (positive or negative). AC is constantly changing its direction so that current first flows in one direction (positive) one moment, and then in the opposite (negative) direction the next moment. This is referred to as one cycle.

A cycle is usually represented as a sine wave because it follows the mathematical characteristics of a sine function. A cycle is one complete occurrence of the wave. The number of cycles per second is measured in Hertz (Hz). This is also referred to as the frequency of the AC current.



AC displayed as a scope pattern

- 1 Volts
- 2 Time
- 3 Cycle

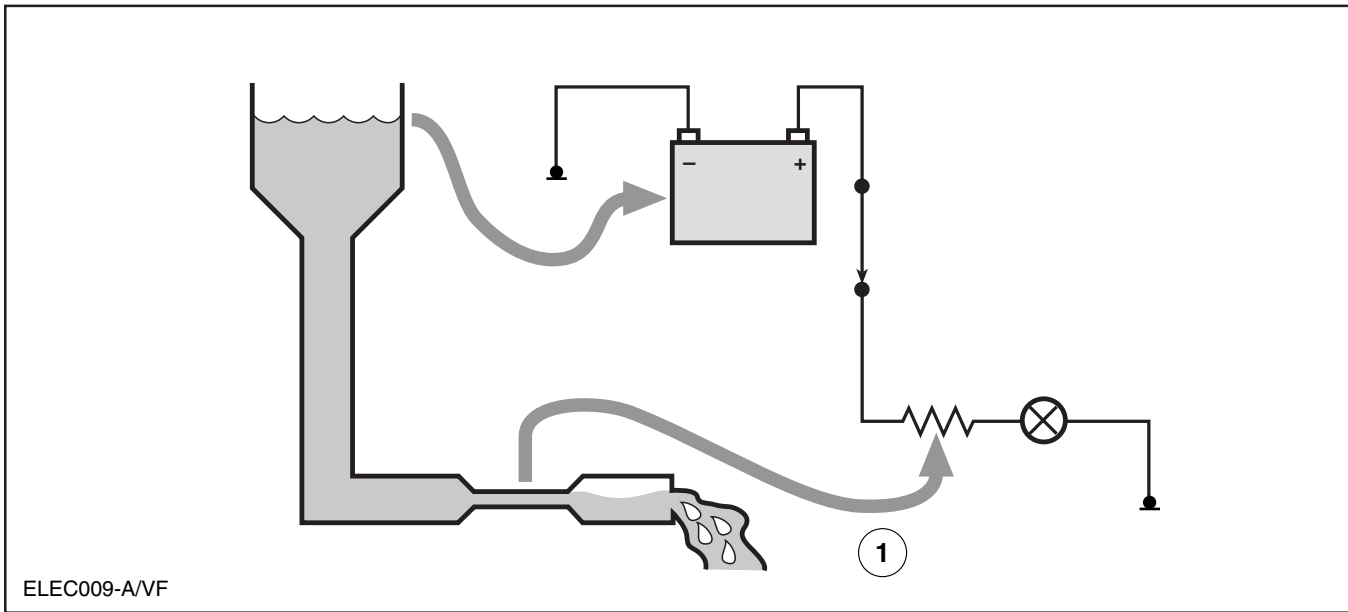
Rectification

Since automotive electrical systems use DC voltage, the AC voltage generated by the generator must be converted. Rectification is the process of converting alternating current into direct current.

To rectify AC into DC, tiny semi-conductors called diodes are used. Diodes are devices that pass current in only one direction, either positive or negative. Diodes are explained in greater detail later.

Characteristics of electricity (continued)

Resistance



Resistance compared to restriction in water line

1 Resistance in a water line and in an electrical circuit

Resistance opposes or restricts the flow of current in a circuit. All circuits have some resistance. All conductors, like copper, silver and gold, have some resistance to current flow. We measure resistance in units called ohms. The symbol for resistance is the Greek letter omega (Ω).

Not all resistance is bad. In a normally operating lamp circuit, the lamp itself is usually the only measurable source of resistance. The resistance in the lamp's filament resists current flow and heats up to the point that it glows.

Unwanted resistance in a circuit robs the circuit of its full current flow and causes the load to operate incorrectly or not at all. The more resistance in a circuit, the less current flow. The figure shown illustrates that resistance is like a bottleneck in a pipe. Resistance slows down or restricts the flow of current. Three factors that affect resistance are temperature plus the length and diameter of the wire.

Factors that affect resistance

Temperature

Temperature affects different materials in different ways. For example, the resistance of copper and steel increases as their temperature increases. When heat is applied to these materials, their electrons maintain tighter orbits, making it more difficult for the electrons to flow from one atom to another.

Size

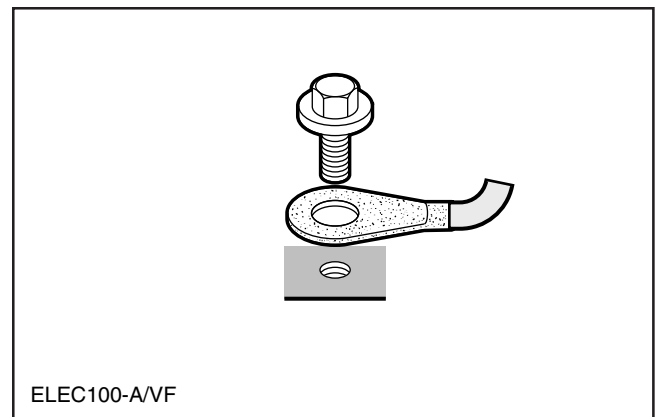
A second factor that affects resistance is the size of the material used as a conductor. A larger conductor means more electrons can flow through at the same time. In smaller conductors, fewer electrons can flow through at the same time. When a wire is used as a conductor, the narrower the wire, the greater the resistance. As the diameter of the wire increases, the resistance decreases.

Length

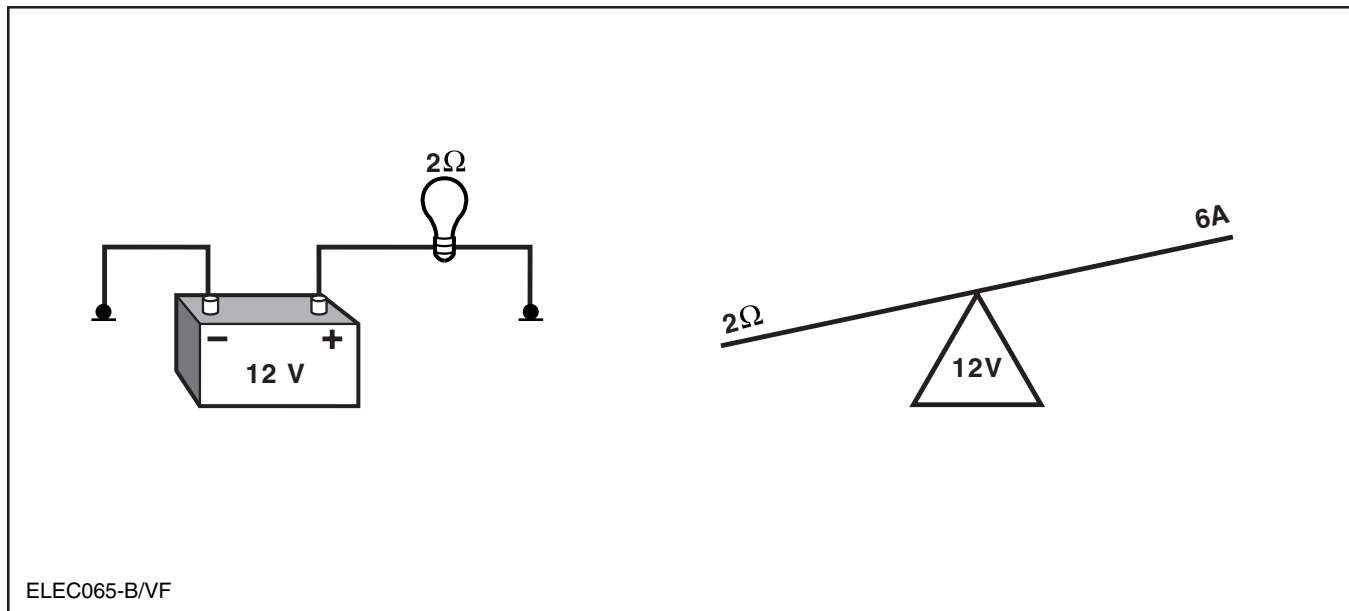
The final factor is the length of the wire. As the length increases, so does the resistance. This is because electrons have to pass through more atoms. Electrons traveling through shorter wires encounter fewer atoms and less resistance.

Corrosion

Corrosion in a circuit also has an effect on resistance. Corrosion can result from exposure to the elements such as salt, water and dirt. If corrosion is present, resistance increases.



Ohm's Law



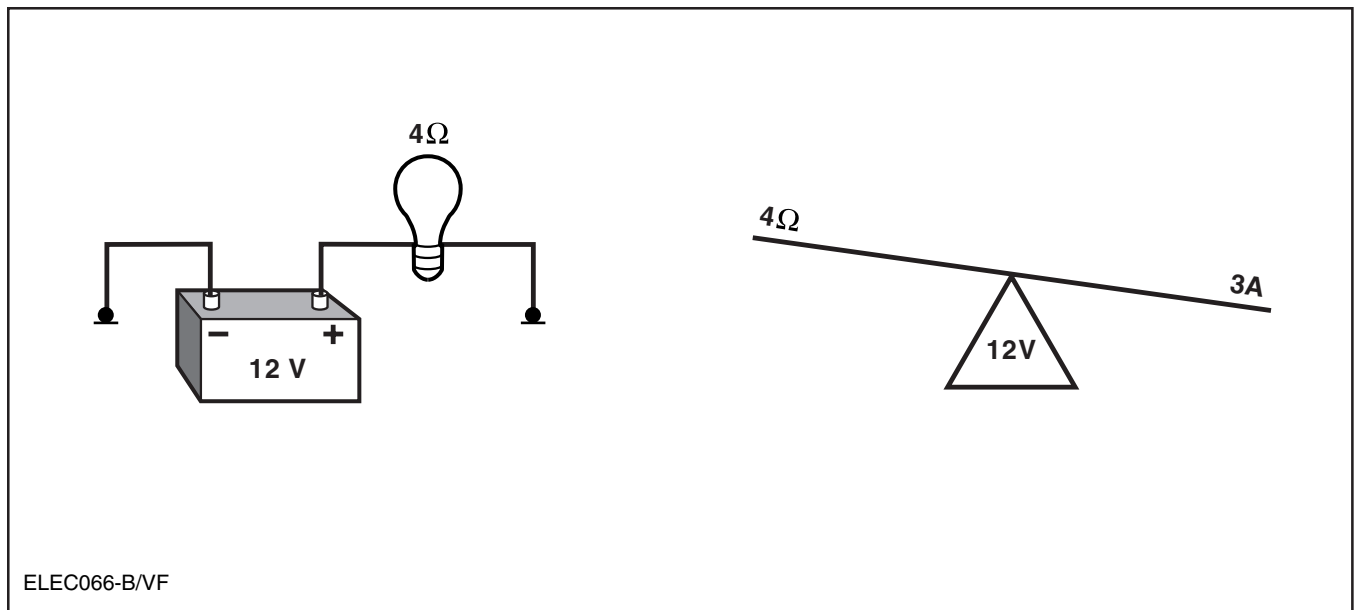
Ohm's Law illustrated

Voltage, current, and resistance have a specific relationship to each other. It is important to understand this relationship and be able to apply it to electrical circuits, since this relationship is the basis for all electrical diagnosis.

George Ohm, a scientist of the early 1800s, found that it takes one volt of EMF to push one amp through one ohm of resistance. Current is directly proportional to the applied voltage and inversely proportional to resistance in a basic circuit. Ohm's Law is expressed as an equation that shows the relationship between voltage (E for Electromotive Force), current flow (I for Intensity), and resistance (R):

$$E = I \times R \text{ or Voltage} = \text{Amps} \times \text{Resistance}$$

The illustration shows a circuit with a 12 volt power source, 2 Ohms of resistance and current flow of 6 amps. If the resistance changes, so will current.



Effect of increasing resistance

The illustration shows that resistance is increased to 4 Ohms. Ohm's Law states that current is inversely proportionate to resistance. As shown, current is reduced to 3 amps.

Ohm's Law (continued)

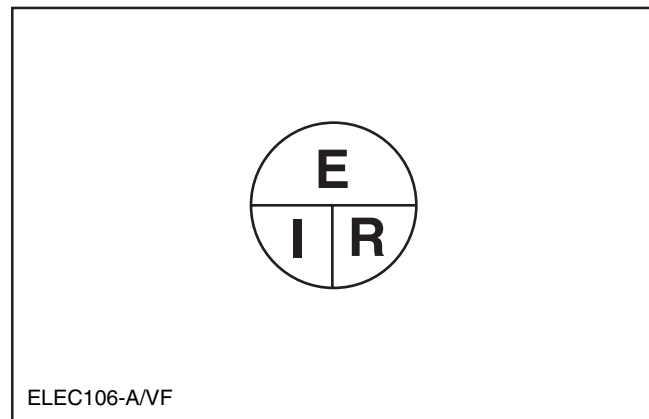
Using the Ohm's Law circle

An easy way to remember the basics of Ohm's Law is to use the Ohm's Law circle shown below. The horizontal line means "divided by" and the vertical line means "multiply". Cover the letter representing the value you are trying to determine.

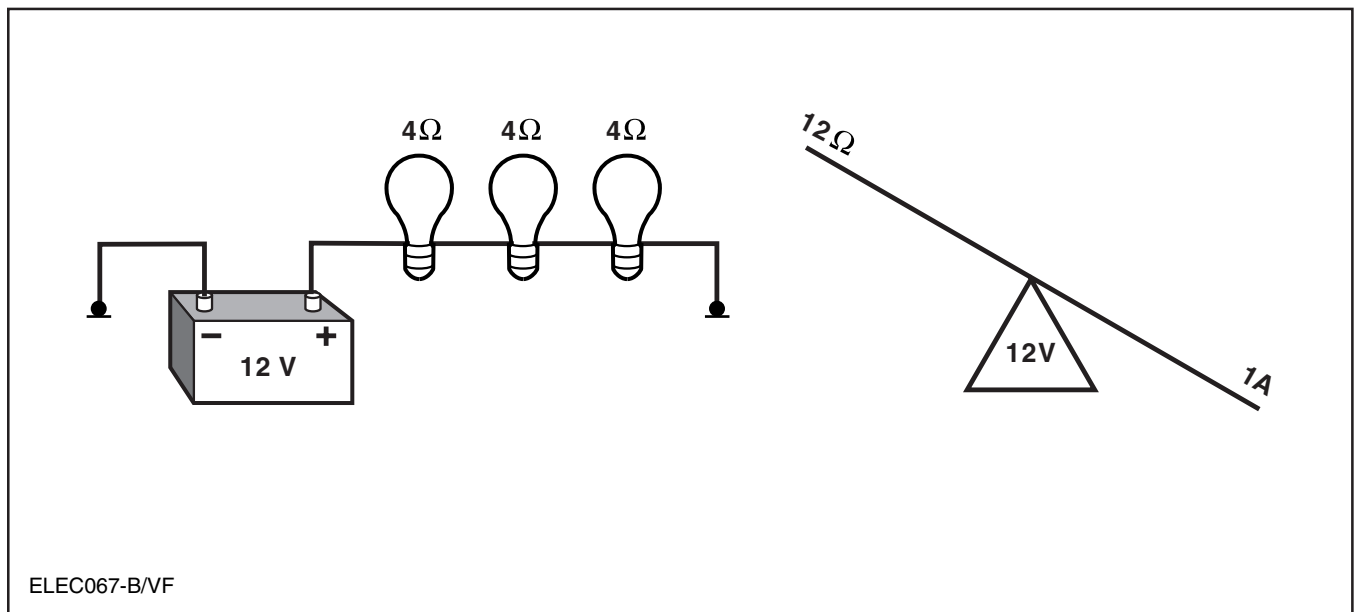
If you know two of the three values for a given circuit, you can find the missing one. Simply substitute the values for amps, voltage, and resistance in the equation, and solve for the missing value.

- To determine:
 - **Resistance** cover the R. The resulting equation is: E/I (volts divided by amps = resistance)
 - **Voltage** cover the E. The resulting equation is: $I \times R$ (amps multiplied by resistance = voltage)
 - **Current** cover the I. The resulting equation is: E/R (volts divided by resistance = amperage)

It is important to understand that the letters used to represent voltage and current may vary. For example, in some cases voltage is indicated simply with the letter "V". In the Ohm's Law explanation used here the letter "E" means "Electromotive Force", which is another term for voltage. Additionally, current may be represented by either the letter "I", the letter "A", or the letter "C".



Ohm's Law circle ($E = I \times R$)



Effect of increasing resistance

In the illustration, resistance has increased to 12 ohms. Current flow is reduced to 1 amp.

When voltage is constant:

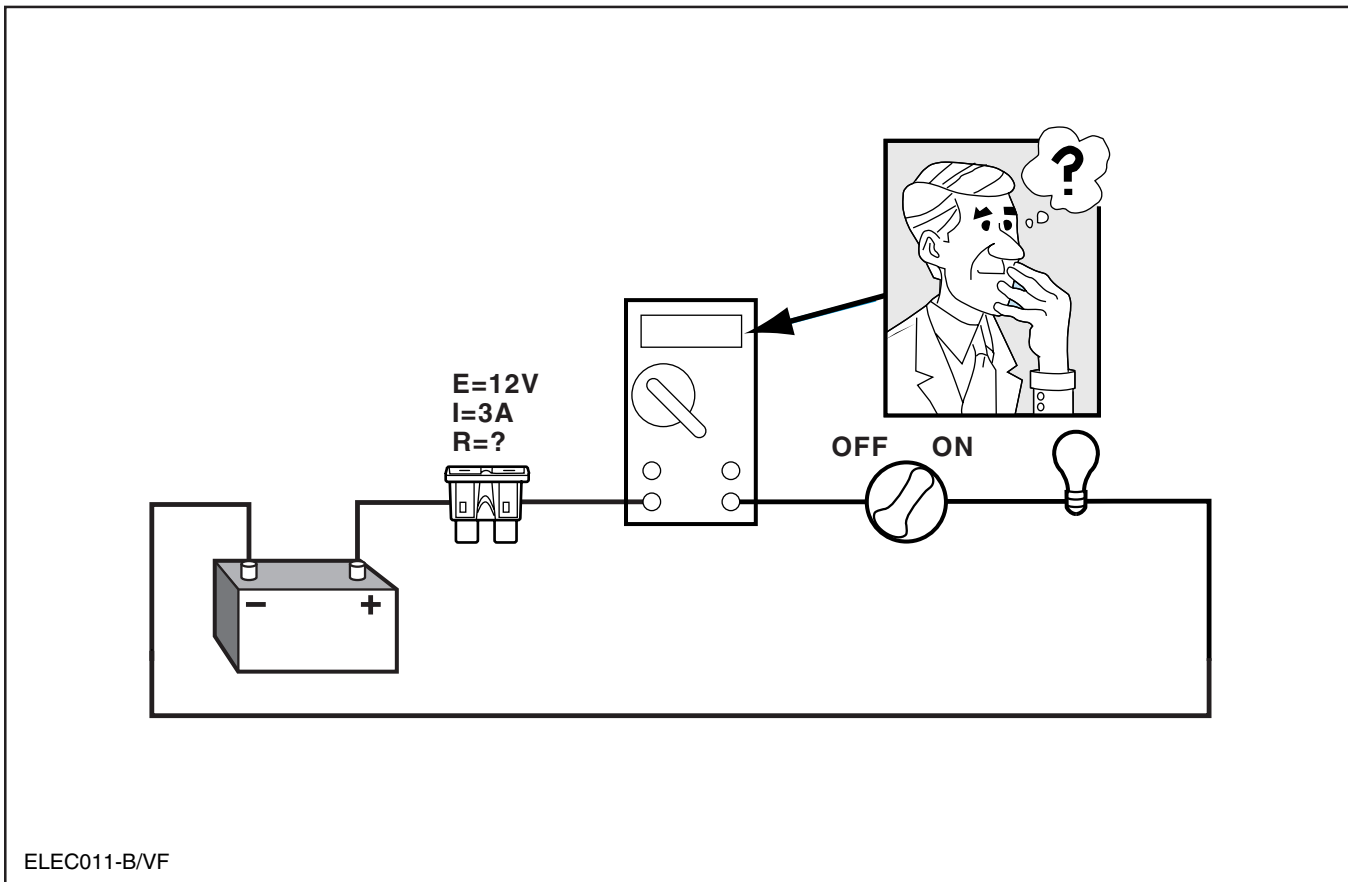
- current flow decreases when resistance increases.
- current flow increases when resistance decreases.

When resistance is constant:

- current flow increases when voltage increases.
- current flow decreases when voltage decreases.

Ohm's Law (continued)

Applying Ohm's Law

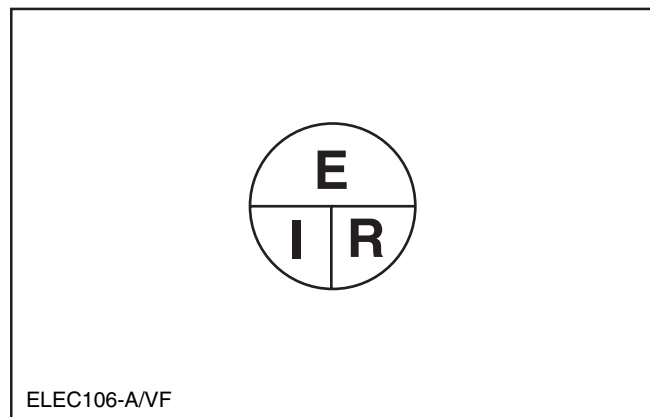


ELEC011-B/VF

Sample circuit for applying Ohm's Law

Use the Ohm's Law circle to solve the problem shown above. The illustration shows a light bulb in a circuit that has a current flow of 3 amps being pushed by 12 volts. We want to determine the resistance. Here's how you would work out this problem:

- $R = E / I$
- $R = 12 \text{ volts} / 3 \text{ amps}$
- $R = 4 \text{ ohms}$



ELEC106-A/VF

Ohm's Law circle ($E = I \times R$)

Watts

Many electrical devices are rated by how much power they consume, rather than by how much they produce. Power consumption is expressed in watts.

746 watts = 1 imperial horsepower

735 watts = 1 metric horsepower

The relationships among power, voltage, and current are expressed by the Power Formula:

$$P = E \times I$$

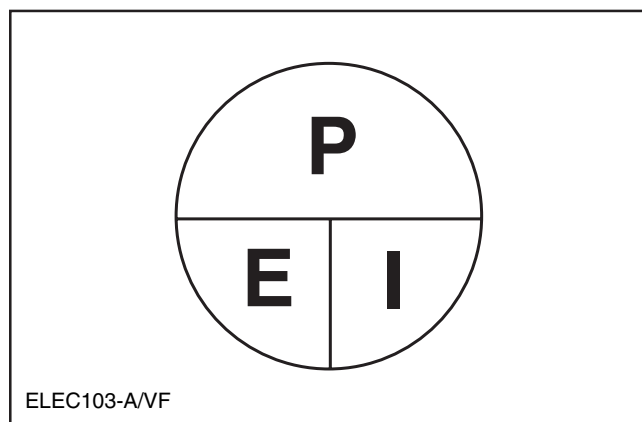
In other words, watts equals volts multiplied by amps.

For example, if the total current in a circuit is 10 amps and the voltage is 120 volts, then:

$$P = 120 \times 10$$

$$P = 1200 \text{ watts}$$

In a circuit, if voltage or current increases, then power increases. If voltage or current decreases, then power decreases. The most common application of a rating in watts is probably the light bulb. Light bulbs are classified by the number of watts they consume.



Units of measurements

Electrical values are often very large or very small.

Electrical values are indicated by metric numbers.

The metric measurements used are Mega, Kilo, Milli, and Micro.

Mega (M) means one million. For example, a circuit with one million ohms of resistance can be written as 1,000,000 Ohms. If the decimal is moved to the left, the value can be written as 1 Megohm, or 1 MΩ.

Kilo (K) stands for one thousand. A circuit with twelve thousand volts can be written as 12,000 volts. Or, with the decimal moved three spaces to the left, it can be written as 12 Kilovolts, or 12 Kv.

Milli (m) means one thousandth. A circuit with 0.015 amperes of current can be written as 0.015, or by moving the decimal three places to the right, it can be written as 15 Milliamperes, or 15 mA.

Micro (μ) means one millionth. For explanation purposes, assume that there is a circuit with 0.000015 amperes. By moving the decimal six places to the right, this can now be written as 15 microamperes, or 15 μa.

Objectives

Upon completion of this lesson, you will be able to:

- Describe a complete circuit.
- Identify the components of a complete circuit.
- Identify basic types of circuits.
- Explain the theory and operation of a complete circuit.

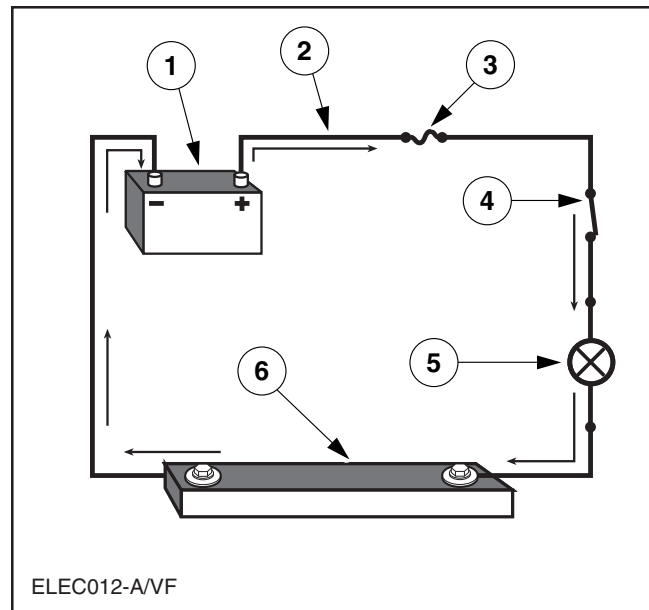
Complete electrical circuit

Electricity is current flowing through a complete circuit. A typical modern vehicle may contain over 1,000 individual electrical circuits. Some are very complicated, but they all operate on the same basic principles.

In order for a complete circuit to exist, there must be a power source, a conductor, a load, and ground. Most automotive circuits include:

- Power source (battery or generator)
- Conductor (wire or cables)
- Ground path (car chassis and battery ground cable)
- Load (light bulb or motor)
- Protection device (fuse or circuit breaker)
- Control device (switch or relay)

Regardless of the number or location of components, current always flows in a complete loop. In automotive circuits, current flows from the power source, through the electrical load, and back to ground. The illustration shows the path current follows in a typical automotive circuit.



Typical automotive electrical circuit components

- 1 Power source
- 2 Conductor
- 3 Fuse
- 4 Switch
- 5 Load
- 6 Chassis ground

Components of a complete electrical circuit

Conductor

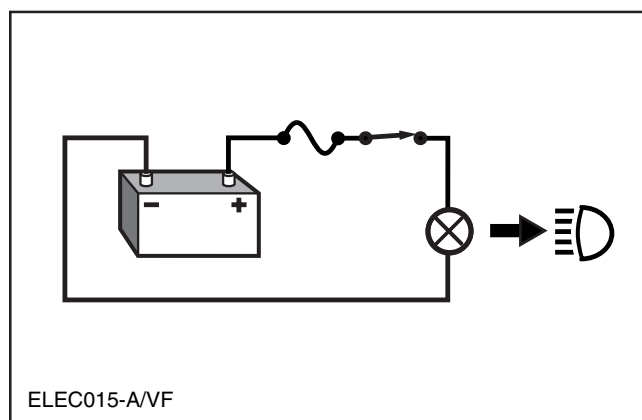
Any material that allows current to flow easily is a conductor. The use of copper as a common automotive conductor, and some of the factors that affect how well a conductor works were discussed previously.

Voltage source

The voltage source in a circuit supplies voltage, or electrical pressure. Automotive power sources are batteries and generators.

Load device

A load converts current flow into heat, light, or motion. Examples of loads include rear window defoggers (heat), light bulbs (light), and motors (motion). As shown, the symbol for the load represents a headlamp, or other illumination device.



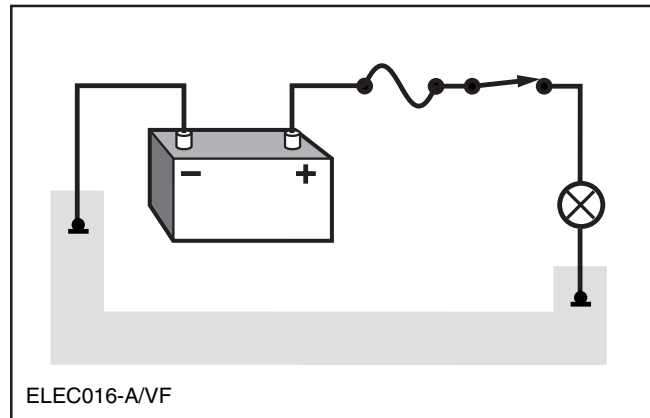
Load device in a circuit

Components of a complete electrical circuit (continued)

Ground path

Ground completes the path back to the voltage source. Voltage is at its lowest potential when it is on the ground side of the circuit. On most vehicles, the negative side of the battery connects to ground.

In a vehicle, it is not practical to have separate ground wires returning to the battery for each system. A “body ground” completes most automotive circuits. Body grounds use the vehicle’s body, engine, or frame as the return path to the voltage source. The steel in these parts of the vehicle provides an excellent return path for electrical current.

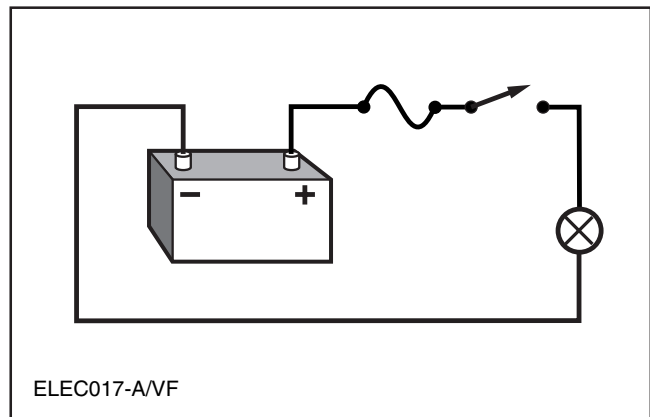


Body ground

Control devices

Control devices, such as switches or relays, make a circuit more usable by allowing current to be turned on and off at specific points in the circuit. A closed switch in a circuit completes the path and allows current to flow. Opening the switch breaks the path, and stops current flow.

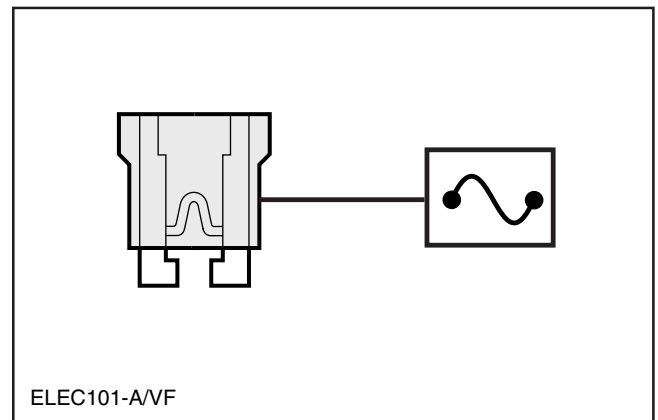
In a simple circuit, the location of the switch makes no difference. If the path is broken, current cannot flow, as shown. Even if the switch is positioned on the ground side of the switch, the bulb will not illuminate unless the circuit is complete.



Effect of an open switch

Circuit protection devices

Each electrical circuit contains one or more circuit protection devices to prevent damage to electrical wiring and electronic components. These devices can be fuses, fusible links, circuit breakers, or a combination of these.

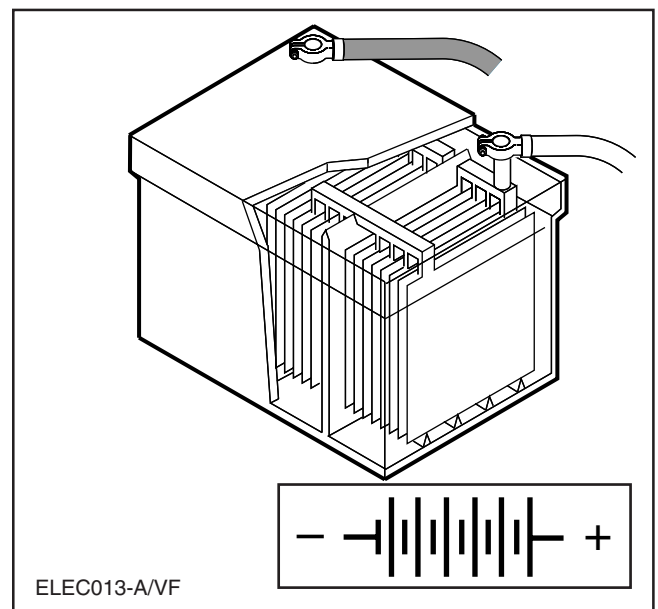


Fuse and schematic symbol

Battery

During starting, the battery supplies electricity to the starter motor, ignition, and fuel system components. The battery provides all vehicle power when the engine is off. Once the vehicle is running, the battery serves as an additional electrical source when vehicle demands temporarily exceed the output of the charging system.

A battery produces electricity through a chemical reaction between positive and negative plates submerged in a solution of sulfuric acid and water. The illustration shows the battery plates and the schematic symbol for a battery.



Battery and schematic symbol

When the battery is fully charged, the chemical difference between the positive and negative plates is high. There is a surplus of electrons at one of the terminals. As the battery discharges, the plates become more alike – the potential difference (voltage) drops.

Charging a battery produces a chemical reaction that increases the potential difference of the plates. A fully charged battery outputs between 12.7 and 12.9 volts.

Components of a complete electrical circuit (continued)**Battery (continued)**

Automotive batteries are manufactured in various sizes to meet the needs of many different applications. The capacity of the battery is usually given in cold cranking amps (CCA). Cold cranking amps indicate the amount of current the battery can deliver at -17.8°C (0°F) for 30 seconds while maintaining 7.2 volts, and after 90 seconds maintaining 6V.

In some regions of the world, batteries are rated in ampere-hours. Ampere-hours refers to how much current the battery can deliver during 20 hours at 25°C (77°F) while maintaining 10.5V. A 100 ampere-hour battery can deliver 5A during 20 hours. The average automobile battery has a capacity of approximately 60 ampere-hours.

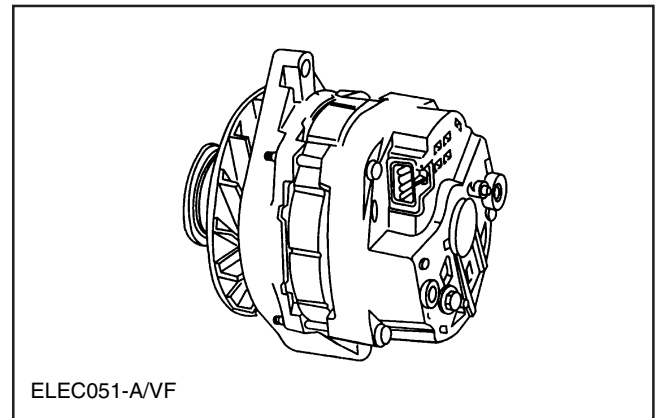
The two common types of batteries used in automobiles are “low maintenance” and “maintenance-free”. Maintenance-free batteries are completely sealed and do not require addition of water. Low maintenance or standard lead batteries are not sealed and require periodic water level inspection.

Reserve capacity

The reserve capacity is determined by the length of time in minutes that a fully charged battery can be discharged at 25 amperes before battery cell voltage drops below 1.75 volts per cell. The reserve capacity rating gives an indication of how long the vehicle can be driven, with the headlights on, if the charging system should fail.

Generator

A generator converts an engine's mechanical energy into usable electrical energy. The generator produces AC by a principle called electromagnetic induction. A conductor moving through a magnetic field creates magnetic induction. Because generators produce AC, an internal rectifier changes the current from AC to DC, as mentioned previously.



Typical AC generator

Voltage regulator

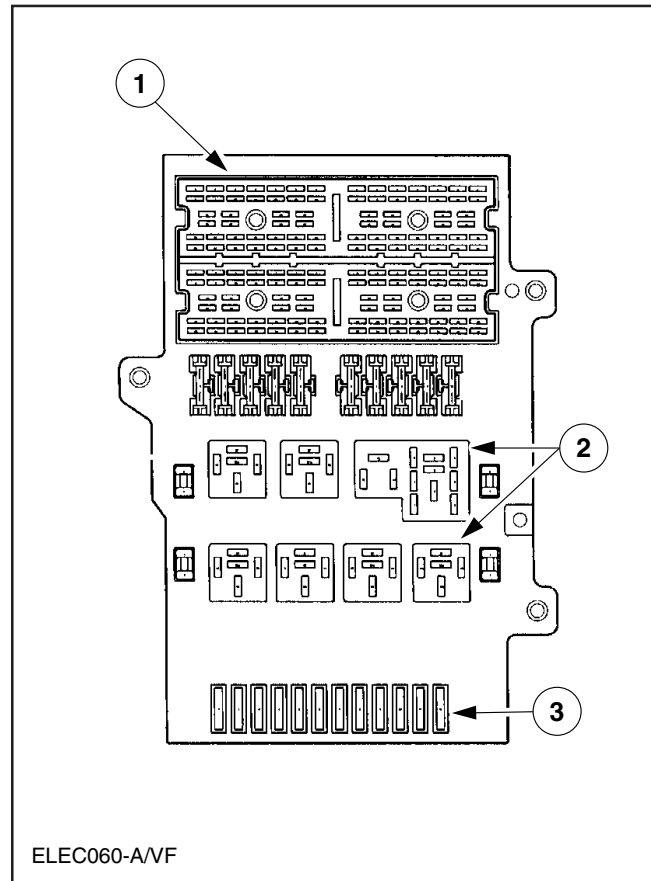
A voltage regulator maintains voltage to the battery recharging circuit at a predetermined level, eliminating power surges and overloads from the generator. Since the generator connects directly to the battery, an overload could cause a fire. Today's voltage regulators are an integral part of the generator. In vehicles manufactured before the mid 1970s, the voltage regulator was usually a separate unit.

When the generator produces enough current to recharge the battery, the voltage regulator opens the flow to the battery recharging circuit and monitors the voltage. Generally, a 12-volt battery requires about 14.0 volts of input to recharge. When the generator slows down or stops, the voltage regulator halts flow to the battery recharging circuit.

Power distribution system

Power distribution usually begins at the power distribution box in a vehicle. The high-current power distribution box contains high-current fuses and may be located under the hood near the battery. The low-current fuses are usually in a fuse junction panel which can be located just about anywhere on the vehicle, depending on manufacturer. Both are designed to hold fuses and supply power to several circuits.

In modern vehicles, the fuse block is arranged with circuits directly from the battery and others that are controlled by the ignition switch. To reduce the number of wires at the fuse block, a single battery circuit and a single ignition circuit may be connected to a bus bar to distribute power to numerous systems through several fuses.

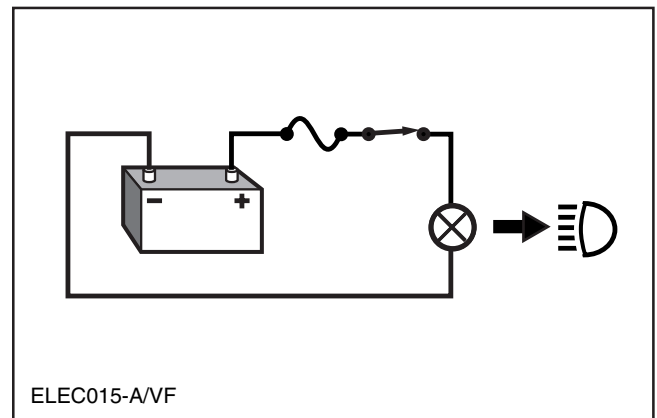


Power distribution center

- 1 Internal connectors
- 2 Relays
- 3 High current fuses

Series circuits

A series circuit is one in which there is only one complete path for current to flow. As shown, when the switch in the circuit is closed, current only has one path to follow. Series circuits are the simplest type of electrical circuits.



Simple series circuit

Voltage and voltage drop

Components or loads in a complete circuit must consume a certain amount of voltage to operate. Voltage “drop” describes the voltage that is used up as it passes across the load. A voltage drop occurs only when current is flowing.

The dropped voltage (energy) is converted to heat or motion. In the case of a simple lamp circuit, the voltage dropped across the lamp causes it to illuminate (voltage converted to heat). If additional loads or lamps are in series, the voltage drops across each device proportionally.

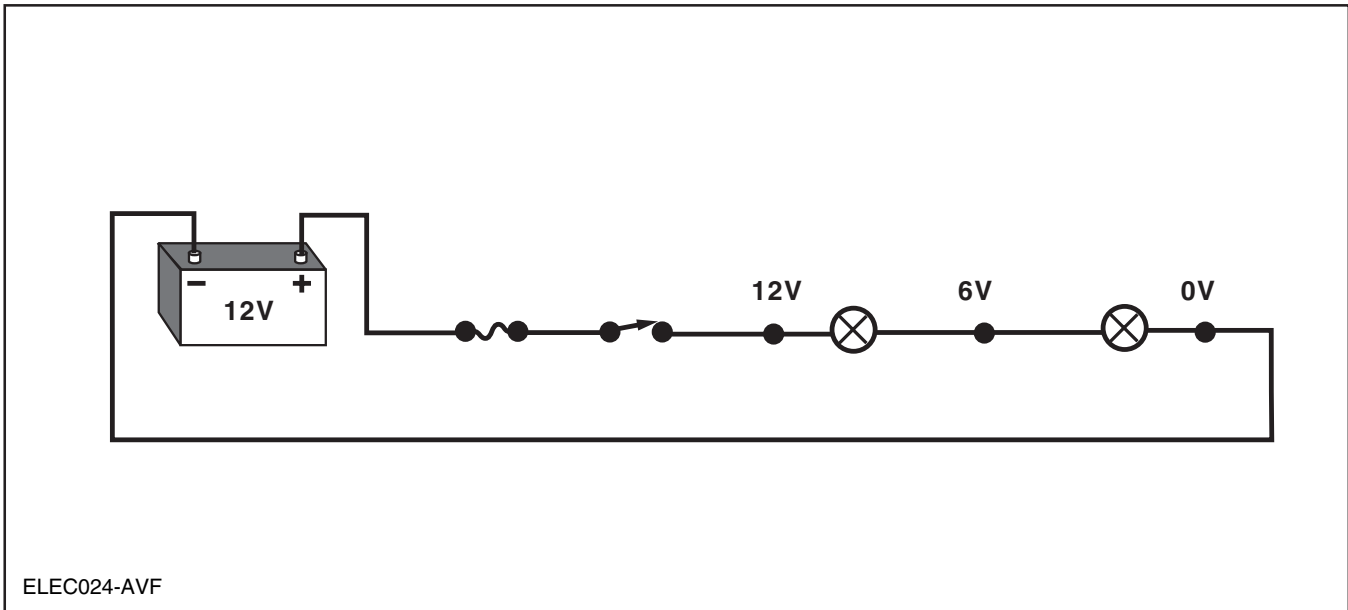
The load with the most resistance drops the most voltage, and the total voltage drop in a series circuit equals the source voltage.

Sometimes a voltage drop represents a defect in the circuit. For example, the resistance caused by corroded wires or connectors can consume voltage originally intended for the load.

Voltage should always be near zero (less than 0.1 volt) on the ground side of the last load.

Series circuits (continued)

Voltage drop in a series circuit



Voltage drop (series circuit shown)

In series circuits, voltage drops proportionately across each load when current is flowing. Adding loads to the circuit decreases the available voltage. For example, adding an extra lamp in series causes all lamps to get dim.

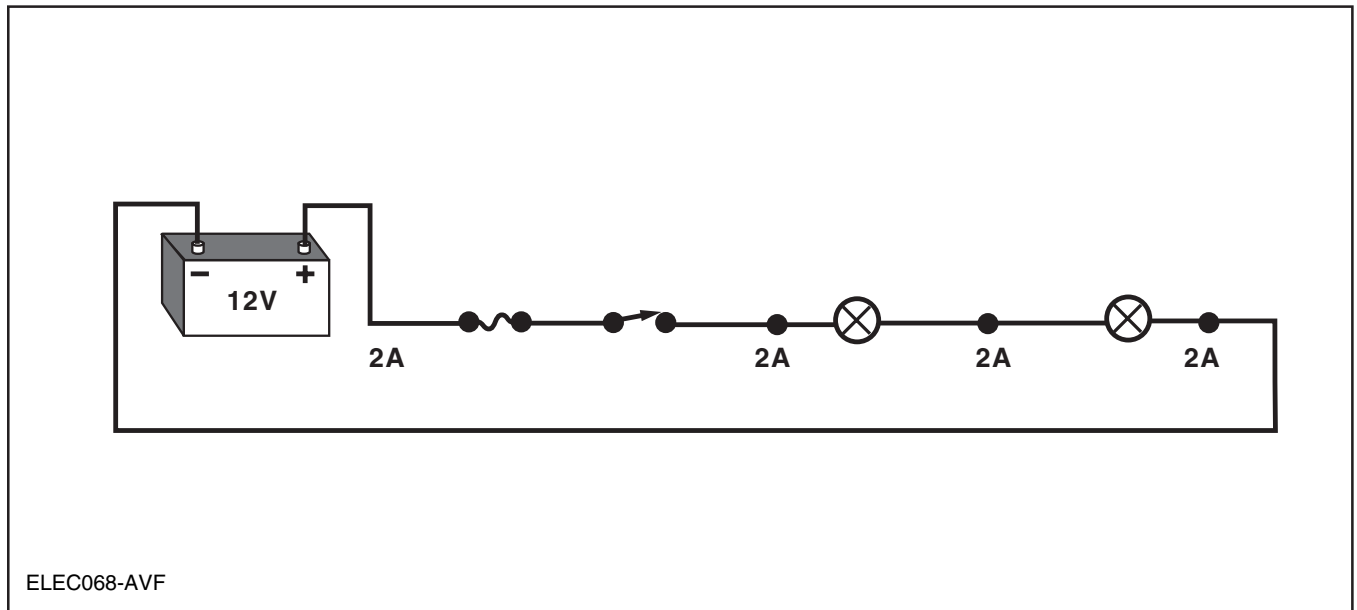
In a circuit with one load, the single load should consume all the source voltage. If you measure the voltage, you see 12V before the load and 0V after. The load consumes all 12 volts.

In a circuit with two loads, equal loads share the voltage. In the figure shown, if you measured the voltage before the first load, you would see 12V.

After voltage was dropped across the first load, you would see 6 volts remaining for the second load. This voltage is dropped across the last load, leaving 0 volts. Each load dropped 6 volts. If you add all the voltage drops, the total is 12V ($6V + 6V = 12V$). The total of all voltage drops must equal the source voltage.

Adding loads in series decreases the voltage available to each load, and reduces current flow in the circuit. For example, adding lamps causes all lamps to dim. When a switch is open in a circuit, source voltage is present, but current cannot flow. Part of a circuit can have voltage even though no current is flowing through the circuit.

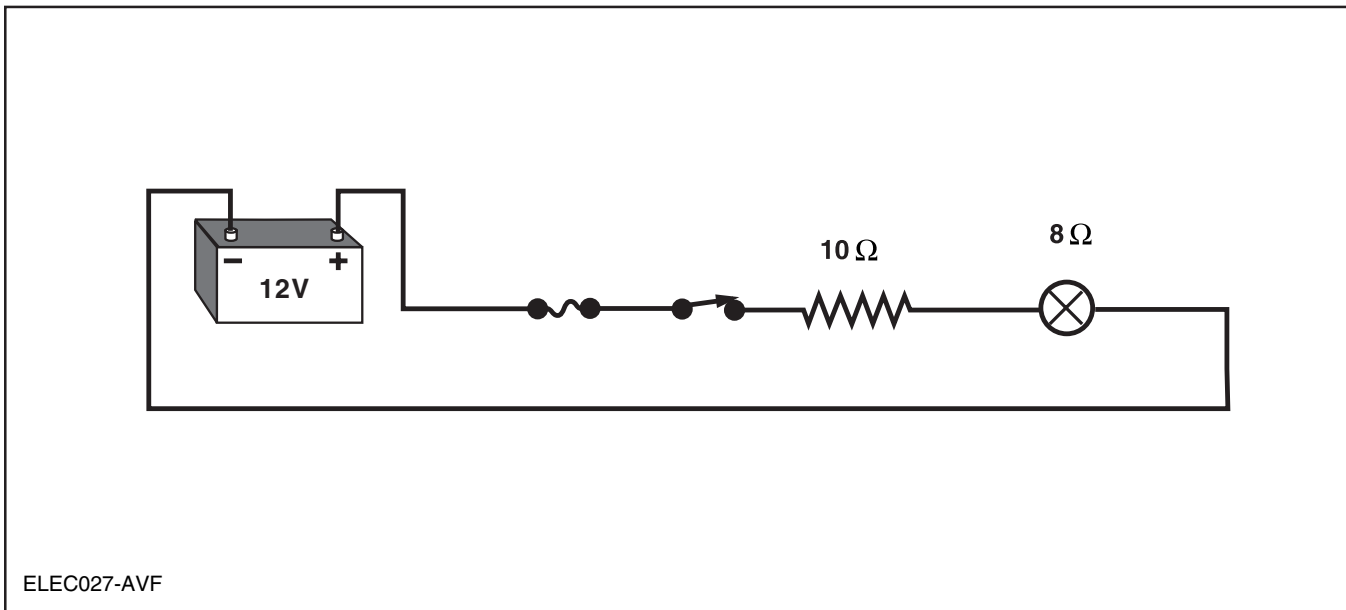
Current in a series circuit



Current (series circuit shown)

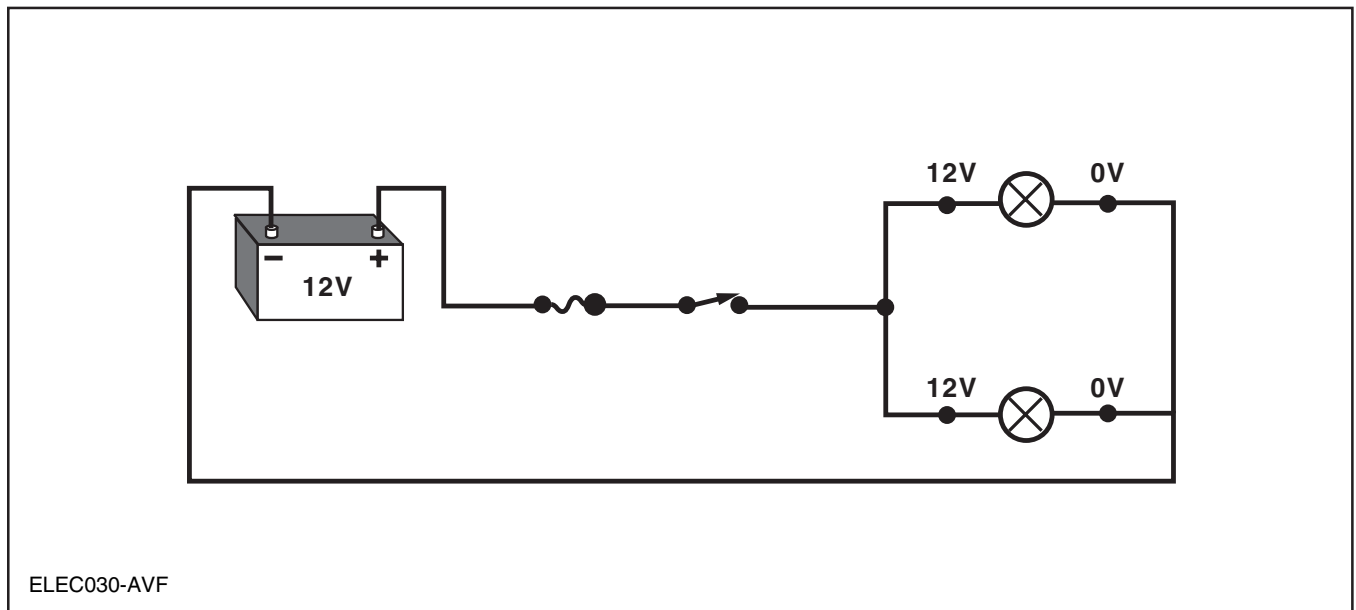
In a series circuit, there is only one path for current flow. Current passes through each load and returns to the battery through ground. Because there is only one path for current in a series circuit, a break anywhere in the circuit (a break is known as an open circuit) stops current flow.

Each load has some resistance to current flow. The more loads you connect in series, the higher the total resistance in the circuit and the lower the current flow. This means the amount of current flow in a circuit depends on the amount of source voltage as well as the circuit resistance.

Series circuits (continued)**Resistance in a series circuit****Resistance (series circuit shown)**

To determine the total resistance in a series circuit, add the individual resistances together. It does not matter where the resistance is located in the circuit. For example, the circuit shown has a total resistance of 18 ohms. The calculation is $10 \Omega + 8 \Omega = 18 \Omega$.

Parallel circuits



Basic parallel circuit

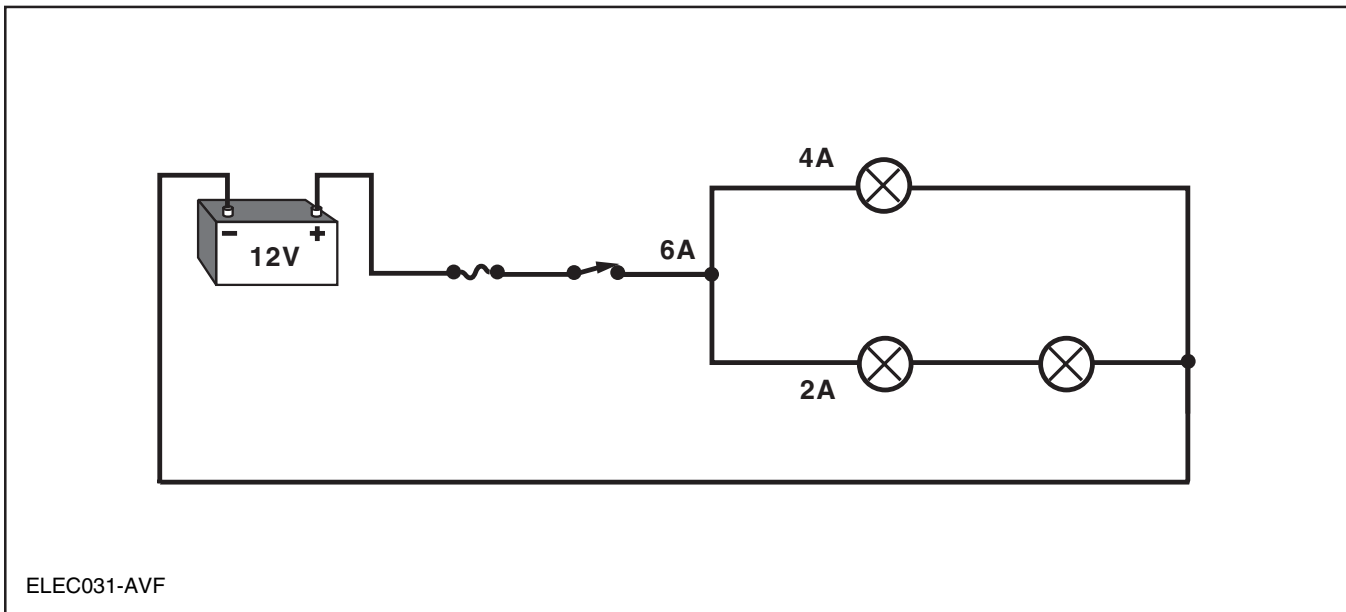
A parallel circuit is one in which there is more than one path for current to flow. Although voltage, current and resistance still affect parallel circuits, their effect is different from a simple series circuit.

In parallel circuits, each branch has battery voltage. Adding branches does not decrease available voltage. In other words, each branch of a parallel circuit acts like a separate series circuit.

Most automotive circuits are parallel. Parallel circuits have one great advantage: if one of the loads or branches develops high resistance, the other branches still operate normally.

Voltage in a parallel circuit

The voltage applied to each branch of a parallel circuit is the same as the source voltage. The voltage drop across each of the loads in the figure shown is equal also.

Parallel circuits (continued)**Current in a parallel circuit****Current (parallel circuit shown)**

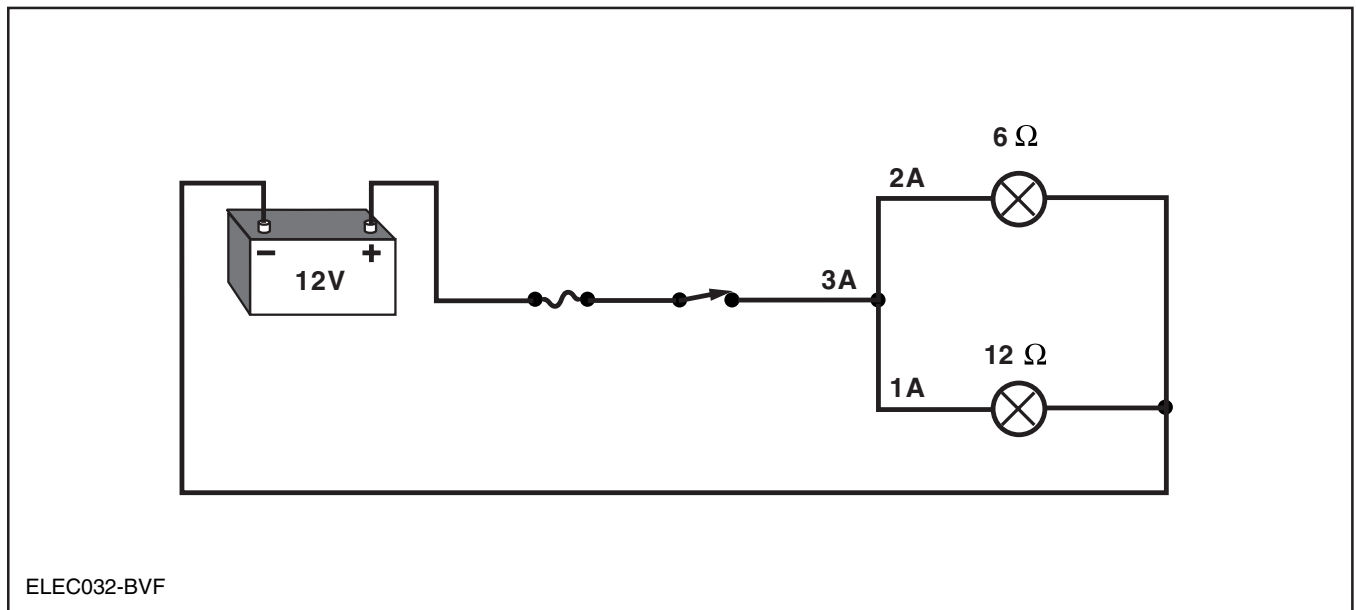
When a circuit contains more than one path, current flow may be different in each branch (depending on the resistance of each branch), but the voltage to each branch does not change.

The figure shows a typical parallel circuit. Current divides into two branches at the splice, and each branch has its own load and separate ground path. In parallel circuits, total current flow is equal to the current flow of all branches added together. So in this sample circuit, total current flow equals $4A + 2A$, or $6A$. If one branch of a parallel circuit develops high resistance, the other branches are not affected.

In a parallel circuit, adding more branches and loads in parallel increases total current flow because there are more paths for current to follow.

This characteristic of parallel circuits explains why installing aftermarket devices can cause problems. Incorrectly splicing these devices (stereos, alarms, etc.) into existing circuits may increase current flow to the point that the circuit fuse blows.

Resistance in a parallel circuit



Resistance (parallel circuit shown)

Calculating the total circuit resistance in parallel circuits is a little more difficult. Finding total circuit resistance in parallel circuits may not be practical, so it is best to simply remember that in parallel circuits, the total circuit resistance is less than the resistance of the smallest individual resistance. For example, in the figure shown, the smallest resistance value is 6 ohms, but the total circuit resistance is 4 ohms.

The actual calculation is done by taking the source voltage for the circuit and dividing it by the combined current draw of each branch. The source voltage is 12V. The current draw is 2A for one branch, and 1A for the other. The total circuit draw is $1A + 2A = 3A$. $12V / 3A = 4$ ohms total circuit resistance.

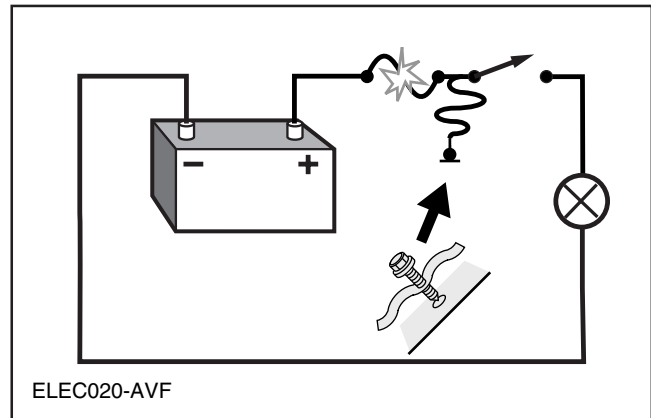
Common circuit faults

Short-to-ground

A short-to-ground is an unwanted path between the positive and ground side of a circuit. When this happens, current flows around the intended load because electrical current always tries to flow through the path of least resistance.

Since the resistance produced by a load reduces the amount of current flowing in a circuit, a short may allow a very large amount of current to flow.

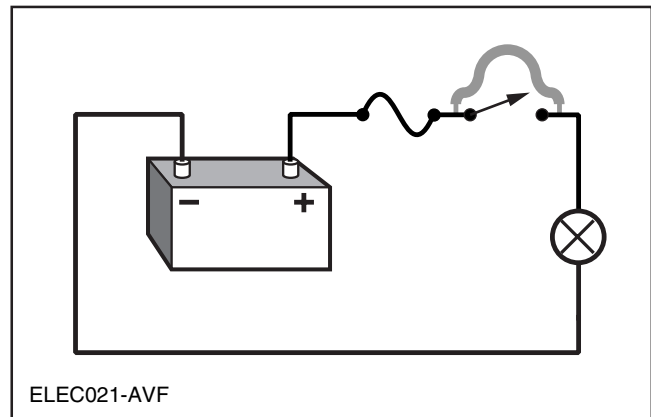
Excessive current flow normally opens (or blows) the fuse. In the figure, the short bypasses both the open switch and the load, and goes directly to ground.



Short to ground

Short-to-power

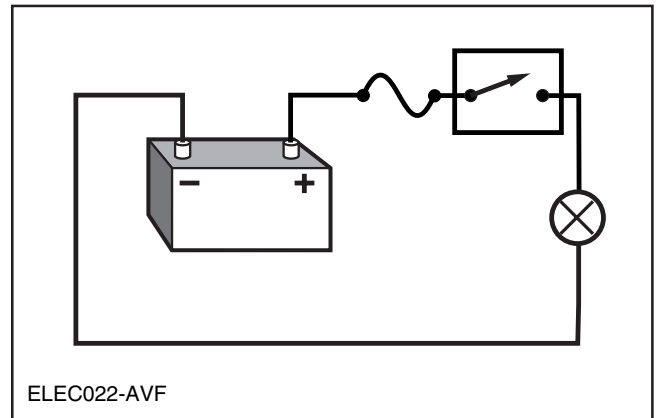
A short-to-power is also an unplanned path for current flow. In the figure shown, a path flows around the switch in the circuit directly to the load. This causes the bulb to illuminate, even though the switch is open.



Short to power

Open circuit

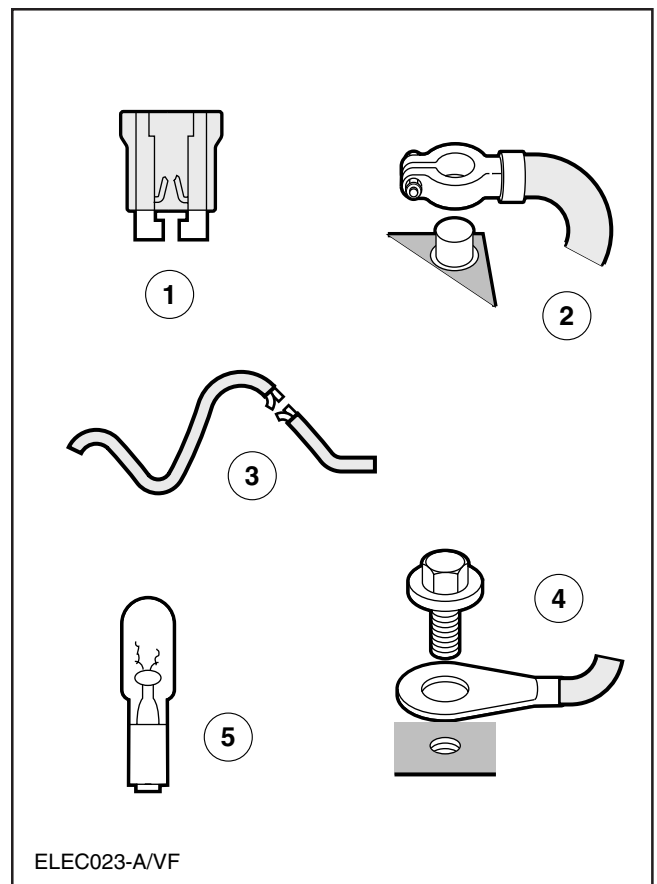
Removing either the voltage source or the ground side conductor breaks a circuit. Because there is no longer a complete path, current does not flow, and the circuit is “open”. In the figure shown, the switch opens the circuit and stops the flow of current.



ELEC022-AVF

Open Circuit

Some opens are planned, while others are unintentional. The figure shows some examples of unplanned “opens”.



ELEC023-A/VF

Examples of opens

- 1 Blown fuse
- 2 Disconnected from voltage source
- 3 Broken wire
- 4 Disconnected from ground
- 5 Burned out bulb

Objectives

Upon completion of this lesson, you will be able to:

- Describe common electrical/electronic devices.
- Identify the types of common electrical/electronic devices.
- Explain the theory and operation of common electrical/electronic devices.
- Describe common solid state devices.
- Identify the types of common solid state devices.
- Explain the theory and operation of common solid state devices.
- Describe common electrical/electronic circuit protection devices.
- Identify the types of common electrical/electronic circuit protection devices.
- Explain the theory and operation of common electrical/electronic circuit protection devices.
- Describe common electrical/electronic electromagnetic devices.
- Identify the types of common electromagnetic devices.
- Explain the theory and operation of common electromagnetic devices.

Control devices

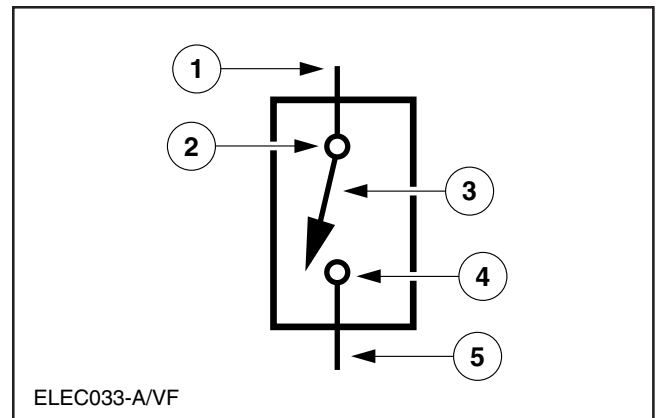
Switches

Switches serve as OFF/ON devices in a circuit by opening or closing the circuit. Switches can be manually controlled or operated automatically, based on a circuit or vehicle condition.

Switches can be normally open (NO) or normally closed (NC). Normally open means the at-rest position of the switch opens the circuit. Normally closed means the at-rest position of the switch closes the circuit.

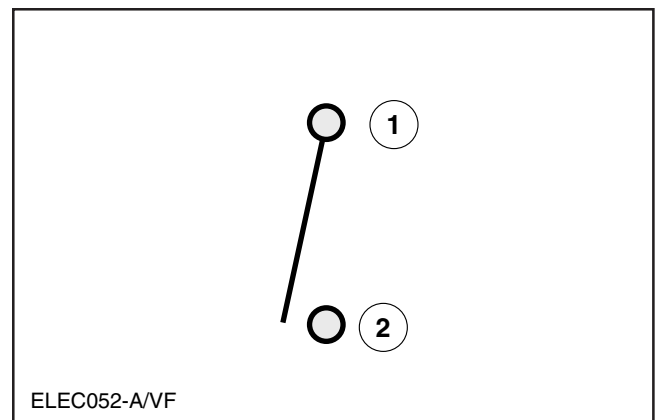
A hinged pawl switch is the simplest type of switch. It either opens or closes the circuit.

Switches have one or more poles (inputs) and throws (outputs). For example, a single-pole, double-throw switch has one input and two outputs. A ganged switch has two or more wipers that operate in unison (mechanically linked) from a single control. The following illustrations show three types of switches.



Simple switch

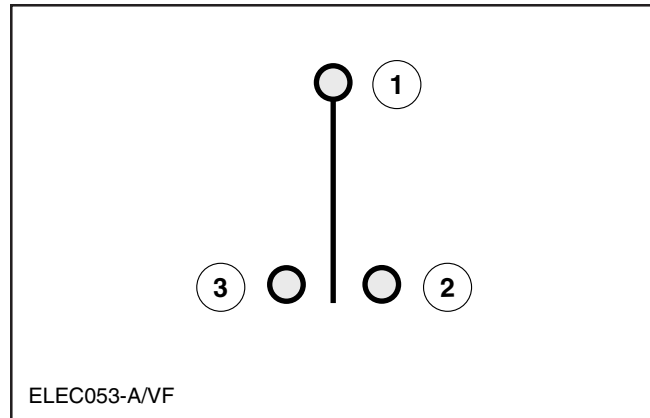
- 1 In
- 2 Hinged pawl switch
- 3 Wiper
- 4 Contact
- 5 Out



Single Pole, Single Throw (SPST) switch

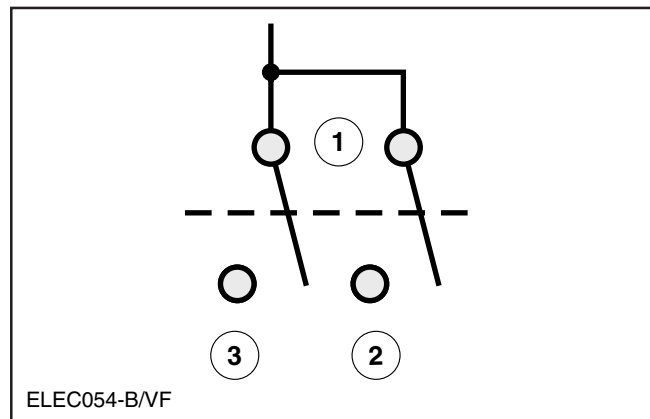
- 1 In
- 2 Out

Control devices (continued)



Single Pole, Double Throw (SPDT) switch

- 1 In
- 2 Out
- 3 Out



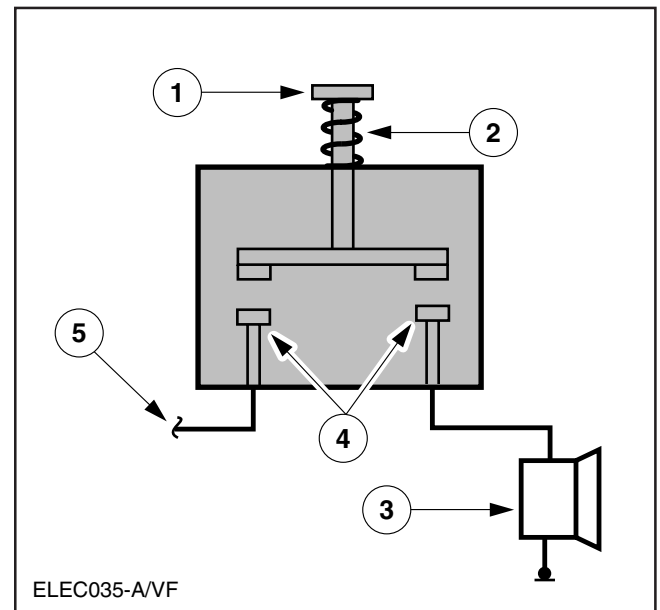
Double Pole, Double Throw (DPDT) switch

- 1 In
- 2 Out
- 3 Out

Momentary contact switch

The momentary contact switch has a spring-loaded contact; the spring keeps the contact from completing the circuit.

A typical example of a momentary contact switch is the horn button. When the button is pressed, the horn sounds. Releasing the button breaks the contact and the sound stops.

**Momentary contact switch operation**

- 1 Operation button
- 2 Spring
- 3 Horn (load)
- 4 Contacts
- 5 From power source

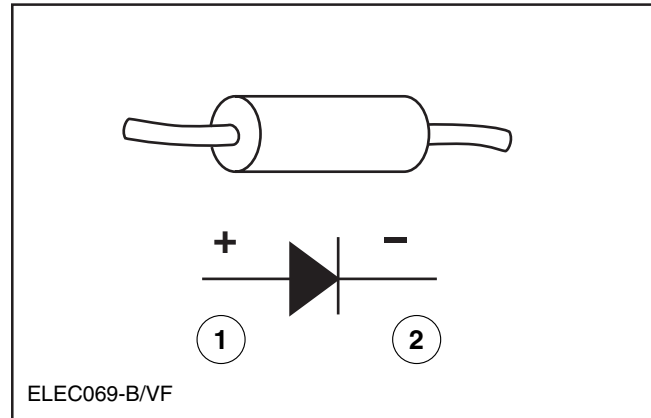
Control devices (continued)

Diodes

A diode is a semiconductor device used to prevent current flow in an undesired direction or path. Diodes are often made of specially modified silicon that acts as an insulator until enough voltage of the correct polarity is applied. When voltage is present in the correct direction (polarity), the diode changes to a conductor and current flows in the circuit. If the applied voltage or current flows in the wrong direction, the diode remains an insulator and blocks current flow.

There are many different types of diodes used in automotive applications. Diodes are used for:

- rectification – changing AC to DC
- controlling voltage spikes and surges that could cause damage to solid state circuits
- indicators on instrument panels
- voltage regulation



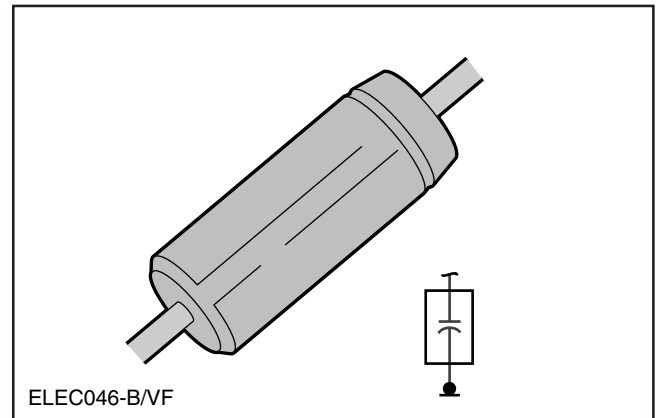
Regular diode and symbol

- 1 Positive (anode)
- 2 Negative (cathode)

Capacitor

Capacitors absorb or store electrical charges. The capacitor is made of two or more conducting plates with non-conducting material between them. Direct current cannot flow through a capacitor, but alternating current can.

The slight flow of direct current that does occur is useful in soaking up voltage spikes, preventing arcing across opening contacts. Capacitors also serve as “noise” filters when used in audio applications. Capacitors are rated in units called Farads (F).



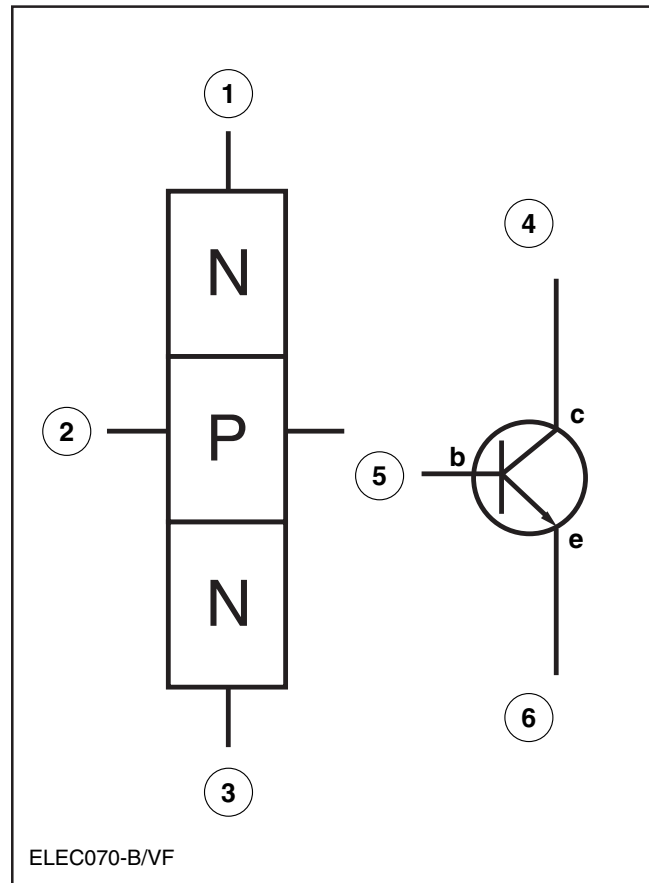
Capacitor and symbol

Control devices (continued)

Transistors

Transistors are semiconductor devices with three leads. A very small current or voltage at one lead can control a much larger current flowing through the other two leads. This means transistors can be used as amplifiers and switches.

The three layers of a transistor are the emitter, base and collector. The base is very thin and is less conductive than the emitter and collector. A very small base-emitter current causes a much larger collector-emitter current to flow.

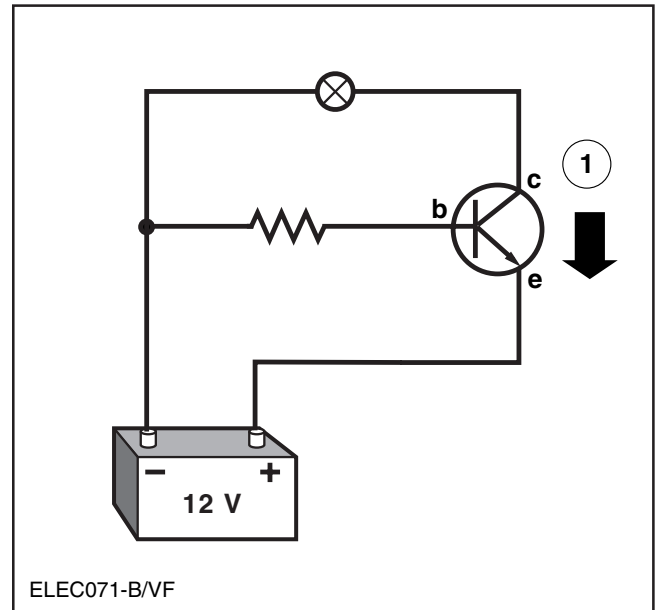


NPN transistor and symbol

- 1 Negative
- 2 Positive
- 3 Negative
- 4 Collector (c)
- 5 Base (b)
- 6 Emitter (e)

Though there are many different types of transistors, the most common used in automotive circuits is the NPN (negative-positive-negative) transistor.

When the voltage difference between the base-emitter is less than 0.6V, the transistor is closed. If the voltage difference is increased to 0.6V the transistor opens, and current flows through the load and through the transistor from collector to emitter. The amount of current is dependent on the amount of current flowing from base to emitter.

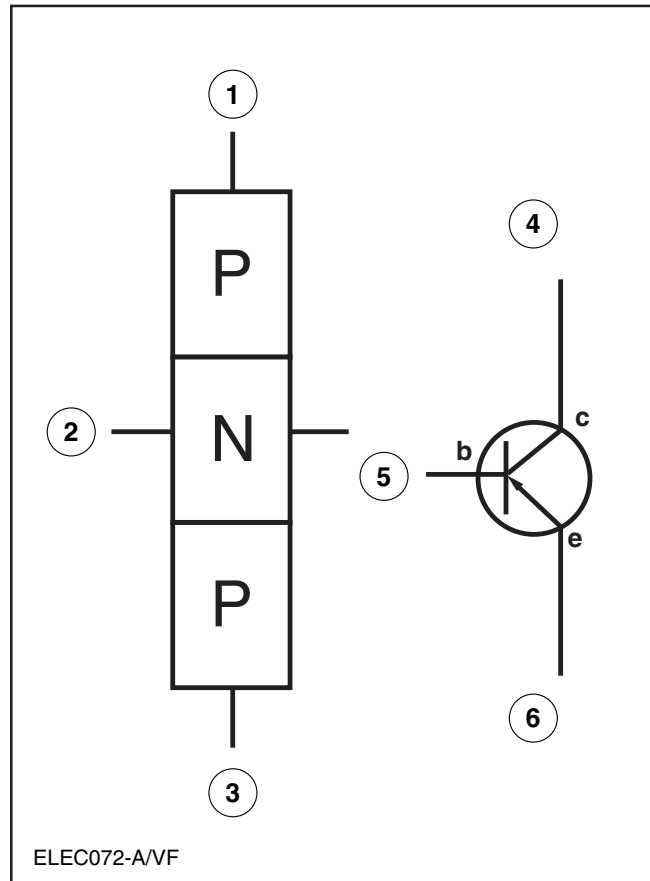


NPN transistor used in a circuit

1 Direction of current flow

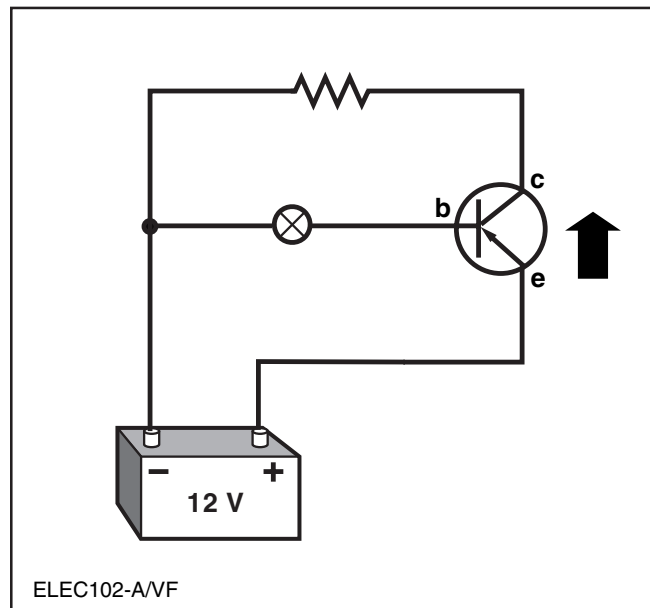
Control devices (continued)

Another type of transistor is the PNP. A PNP transistor operates similar to an NPN transistor except a PNP transistor opens when the voltage difference between the emitter and base is 0.6V.



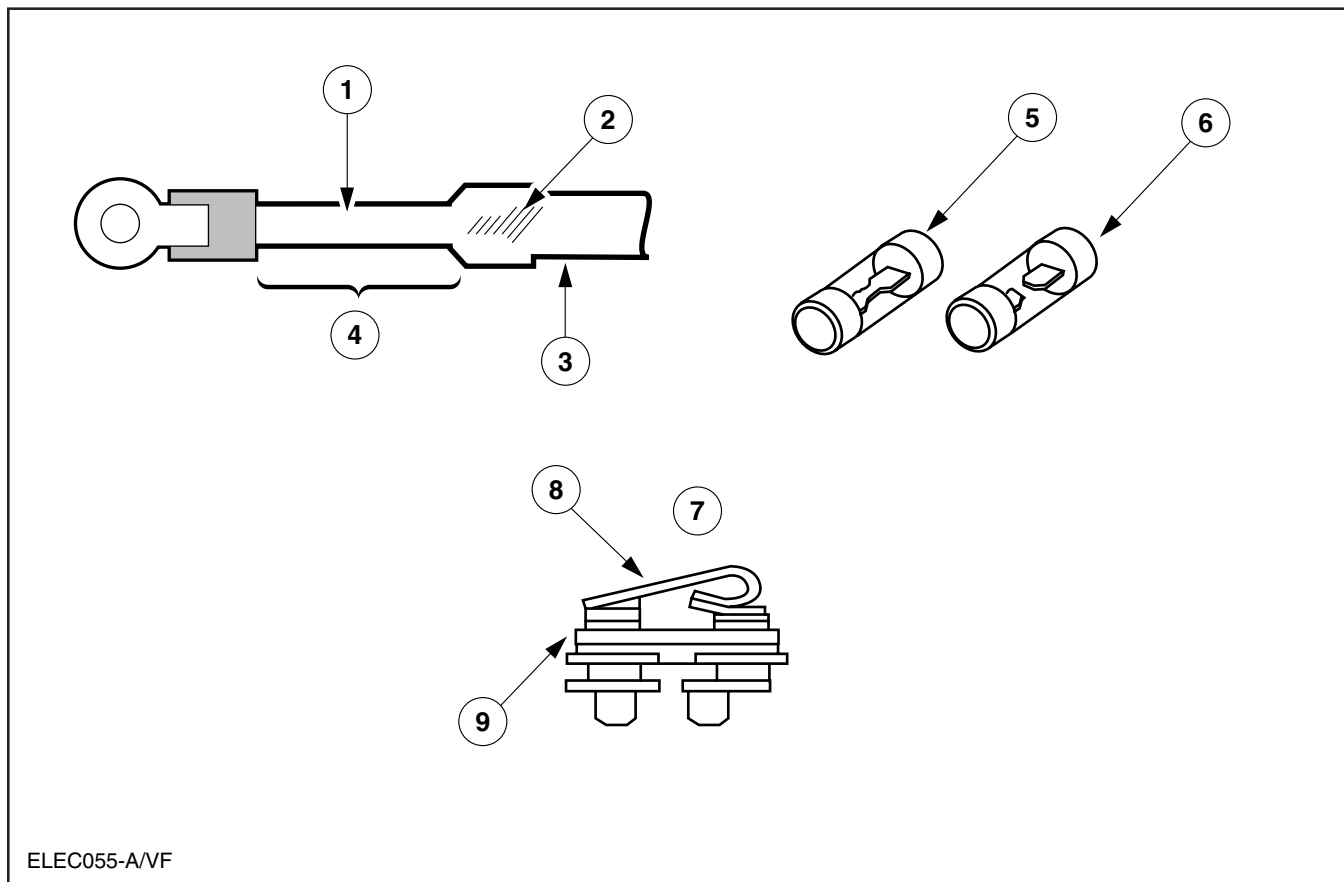
NPN transistor and symbol

- | | |
|------------|-----------------|
| 1 Positive | 4 Collector (c) |
| 2 Negative | 5 Base (b) |
| 3 Positive | 6 Emitter (e) |



Circuit protection

Circuit protection devices



ELEC055-A/VF

Common circuit protection devices (not actual size)

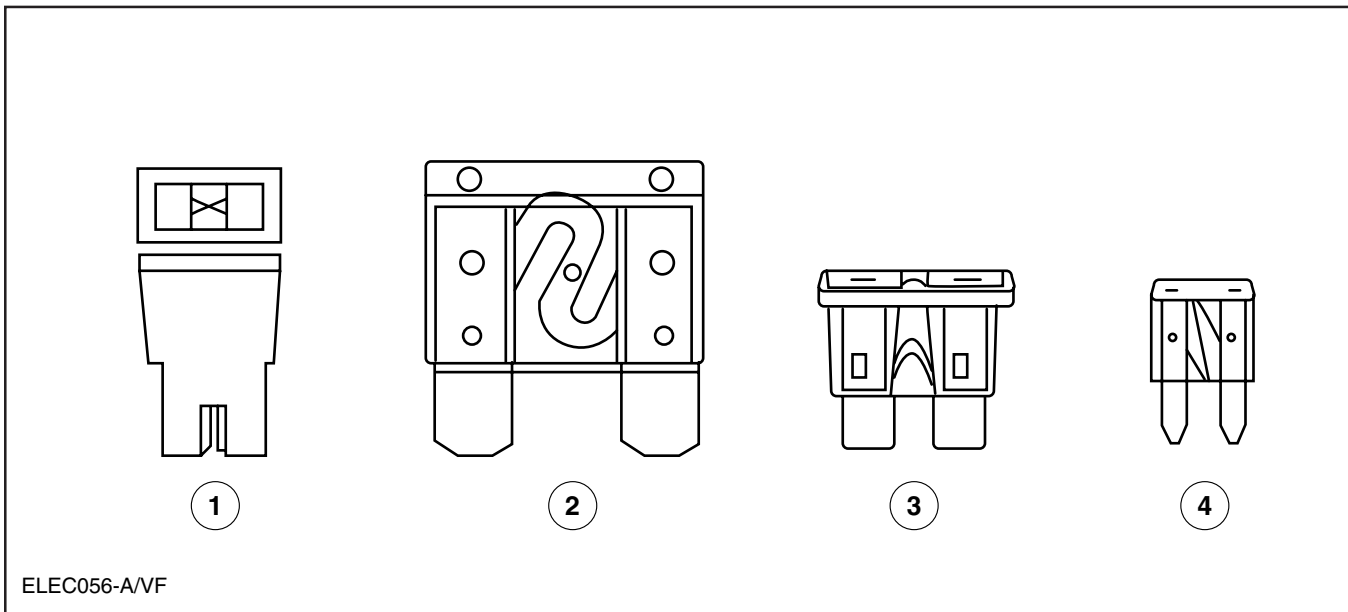
- | | |
|---------------------|-------------------|
| 1 Small wire | 6 Blown fuse |
| 2 Splice | 7 Circuit breaker |
| 3 Circuit conductor | 8 Bi-metal arm |
| 4 Fusible link | 9 Contacts |
| 5 Good fuse | |

In some instances, high current flow can exist in a circuit. Without some means of protecting the circuit, a short allows the total amount of available current to flow. If the current is more than the circuit was designed to carry, the wiring may overheat and burn.

Each electrical circuit contains one or more circuit protection devices to prevent damage to electrical wiring and electronic components. These devices can be fuses, fusible links, circuit breakers, or a combination of these. Some computers on an automobile protect themselves by shutting down in an overload or when voltage exceeds specifications.

Circuit protection (continued)

Fuses



Types of fuses

- 1 Cartridge fuse
- 2 Maxifuse
- 3 Standard blade type fuse
- 4 Miniature blade type (minifuse)

Fuses are plug-in devices with two terminals connected by a conductor that is designed to melt (blow) when a specified amperage rating is exceeded. Fuses must be replaced after the circuit problem has been corrected.

There are basically four types of fuses: the cartridge fuse, high-current (or maxifuse), the standard blade type, and the miniature blade type. Blade type fuses are the most common and have a specific amperage rating and are color-coded. They are permanently marked with the amperage rating and the voltage rating. Two slots in the fuse body allow the technician to check for voltage drop, available voltage, or continuity.

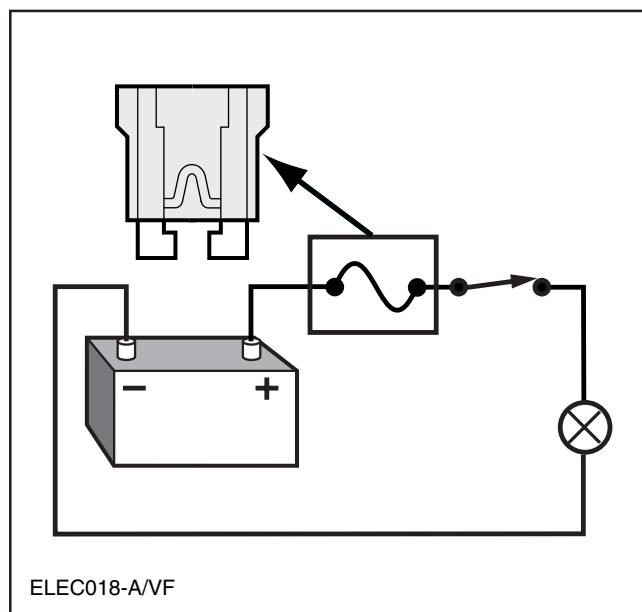
Fuses are constructed so that if current reaches a certain level, the metal melts and breaks, causing an open in the circuit. This opens the circuit and protects circuit wiring and components from excessive current flow.

Fuses are rated by amperage handling ability. For example, a 10 amp fuse opens if current in the circuit increases too far above 10 amps for a certain length of time.

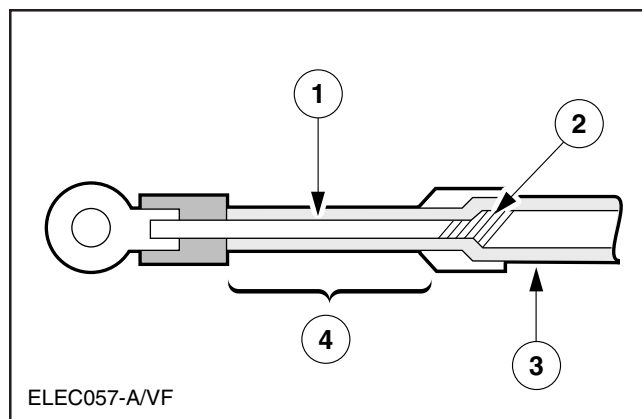
Never replace a fuse with a higher rated fuse. Always consult the workshop manual or owner manual to be sure that you replace each circuit protection device with the exact equivalent specified.

Fusible links

The fusible link is installed close to the voltage source. The fusible link usually protects large portions of the vehicle wiring where fuses or circuit breakers are not practical. If an overload occurs, the lighter gauge wire in the fusible link melts and opens the circuit before damage can occur.



Fuse in a circuit used as a protection device



Fusible link construction

- 1 Small wire
- 2 Splice
- 3 Circuit conductor
- 4 Fuse link burn out in this area when too much current flows through

Circuit protection (continued)

Circuit breakers

A circuit breaker can be a separate plug-in assembly or can be mounted in a switch or motor brush holder. A set of contacts inside these devices opens the circuit temporarily when a specified amperage rating is exceeded.

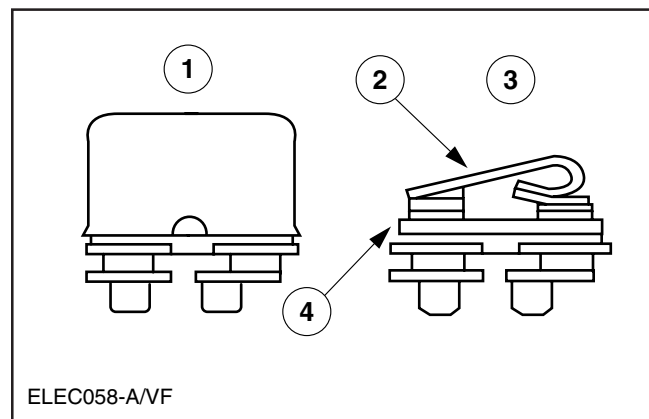
Unlike fuses, circuit breakers do not have to be replaced each time they open. However, if a circuit opens, the cause of the overload or short in the circuit must still be found and repaired, or further damage to the circuit results.

Generally, there are two types of circuit breakers – cycling and non-cycling.

Cycling circuit breakers

The cycling circuit breaker contains a strip built from two different metals. Each metal expands at a different rate when heated. When an excessive amount of current flows through the bi-metal strip, the high-expansion metal bends due to the heat build-up and opens the contact points. With the circuit open and no current flowing, the metal strip cools and shrinks until the contact points again close the circuit.

In actual operation, the contact opens very quickly. If the overload is continuous, the circuit breaker repeatedly cycles (opens and closes) until the condition is corrected.



Cycling circuit breaker construction

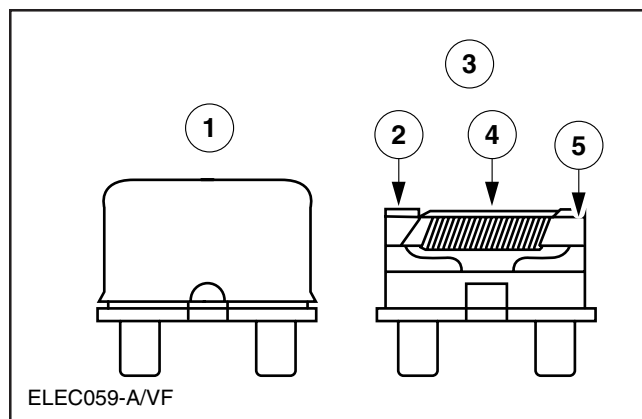
- 1 Side view (external)
- 2 Bi-metal arm
- 3 Side view (internal)
- 4 Contacts

Non-cycling circuit breakers

A non-cycling circuit breaker uses a wire coil wrapped around a bi-metal arm which maintains a high-resistance current path in the circuit even after the contact points open. The heat from the wire coil does not allow the bi-metal strip to cool enough to close the contact points until the source voltage is removed from the circuit.

When voltage is removed, the bi-metal strip cools and the circuit is restored. With a non-cycling circuit breaker, once the breaker opens the circuit, voltage must be removed from the circuit to reset the breaker.

A non-cycling of circuit breaker cannot be used in crucial circuits such as headlamps, because a temporary short terminates the circuit voltage until the breaker can be reset.



Non-cycling circuit breaker construction

- 1 Side view (external)
- 2 Contacts
- 3 Side view (internal)
- 4 Coil
- 5 Bi-metal arm

Electromagnetic devices

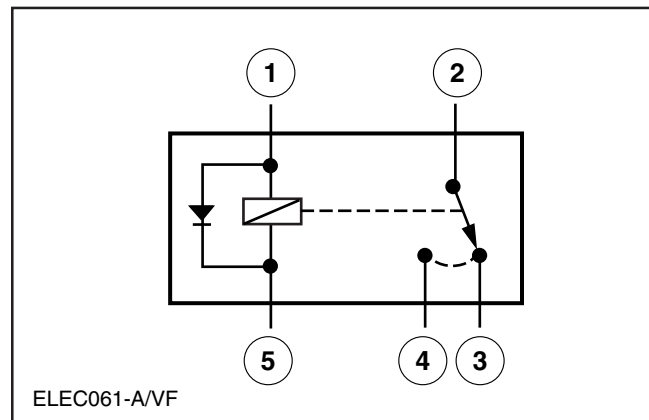
Many electrical devices operate on the principle of electromagnetic induction. Electromagnetic induction is the process of producing electrical current in a conductor as the conductor passes through a magnetic field or another current-carrying conductor, such as a coil.

Relays, motors, generators and solenoids are examples of electromagnetic devices.

Relays

A relay is an electric switch that uses a small current to control a larger current. Relays consist of a control circuit, an electromagnet, an armature, and a set of contacts, as shown.

Applying a small current to the control circuit energizes the electromagnet which moves the armature. The movement of the armature either opens or closes the contacts mounted on the armature.

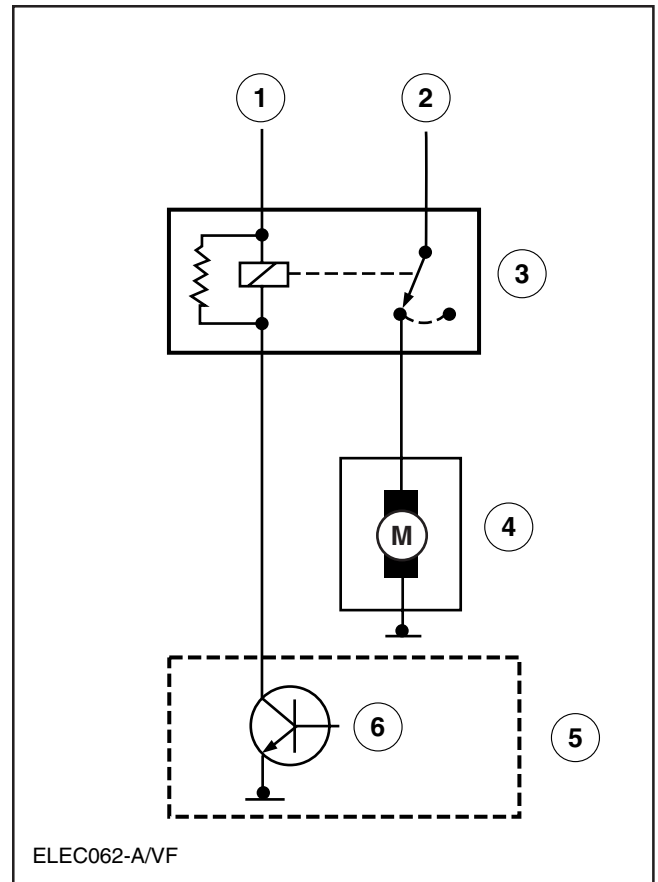


Relay

- 1 From power source
- 2 From power source
- 3 Normally closed contact
- 4 To load
- 5 Ground (control circuit)

When the control circuit for the relay is closed, the electromagnet draws the armature toward the core. This closes the contact points and provides the larger current for the load. When the control switch is open, no current flows to the relay coil. The electromagnet is de-energized and the armature returns to its normal, or rest position.

There are many automotive applications for relays including the fuel pump, horn, and starter system.

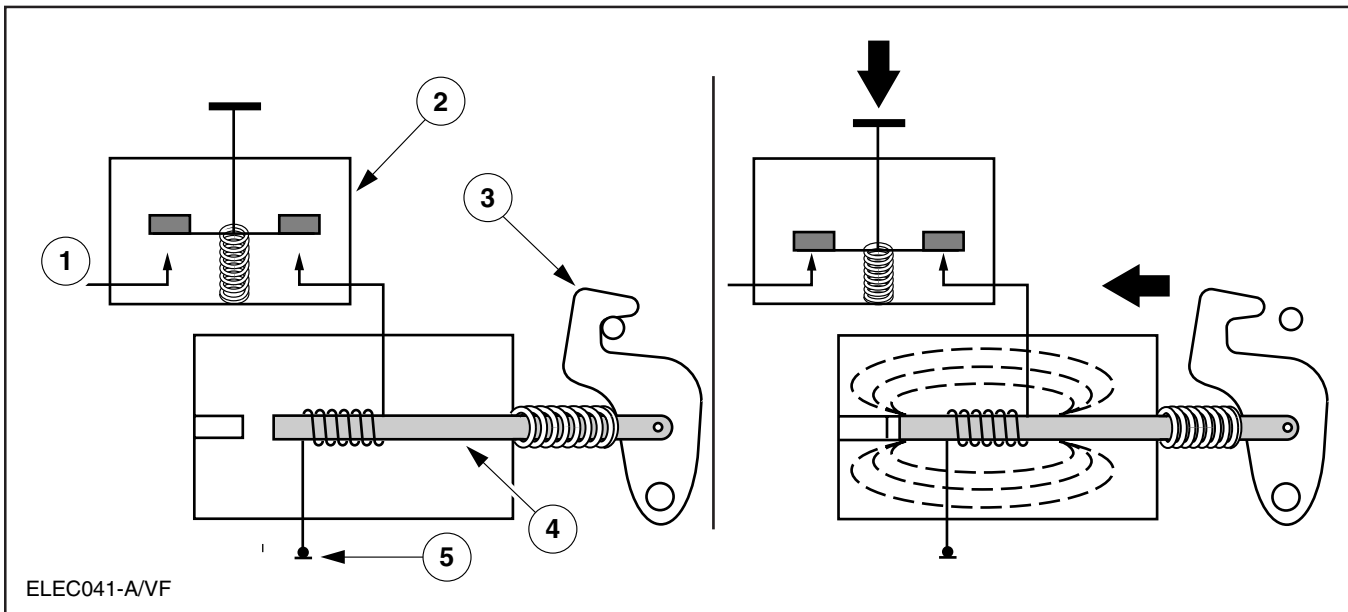


Application of a relay

- 1 From ignition switch
- 2 From battery
- 3 Fuel pump relay
- 4 Fuel pump motor
- 5 Powertrain control module
- 6 Fuel pump relay control

Electromagnetic devices (continued)

Solenoids

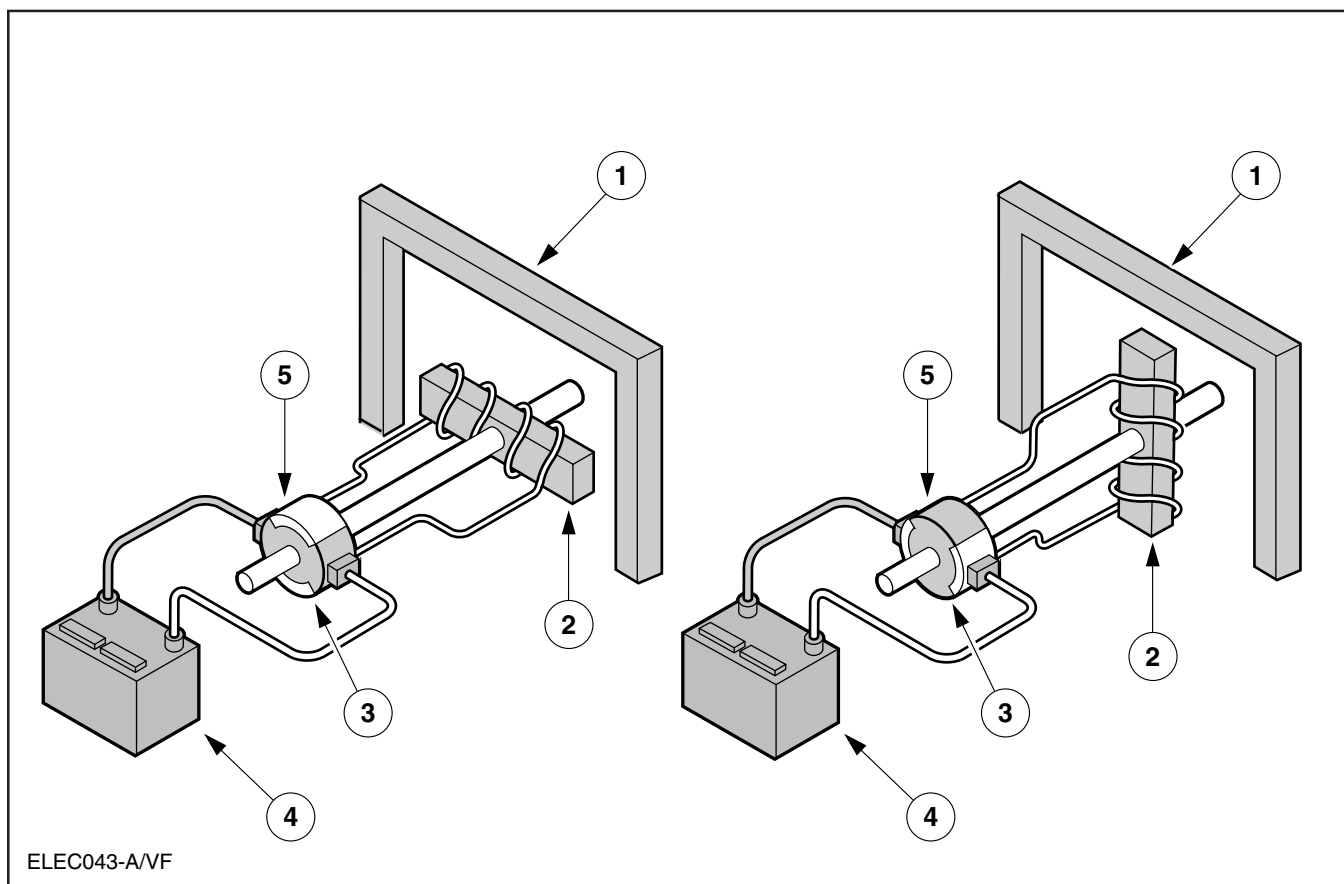


Solenoid operation

- | | |
|----------------------------|-------------------|
| 1 Voltage source | 4 Core or plunger |
| 2 Momentary contact switch | 5 Ground |
| 3 Trunk latch | |

Solenoids are electromagnets with a moveable core or plunger. The core or plunger converts electrical current flow into mechanical movement. The figure shows a typical automotive solenoid application, the remote latch mechanism in the luggage compartment.

Motors



Motor operation

- 1 Permanent magnet
- 2 Armature
- 3 Commutator

- 4 Battery
- 5 Conductor

Motors are devices that convert electrical energy into mechanical motion. Electric motors can meet a wide range of service requirements that include starting, accelerating, running, braking, holding, and stopping a load.

The figure shows the construction of a simple DC motor which consists of a horseshoe-shaped permanent magnet with a wire-wound coil (armature), mounted so it can rotate between the north and south poles of the magnet. The commutator reverses the current fed to the coil on each half-turn. The armature rotates due to the force exerted on a conductor carrying the current in a magnetic field.

Objectives

Upon completion of this lesson, you will be able to:

- Explain the purpose of automotive wiring diagrams.
- Identify wiring diagram symbols and which electrical components they represent.

Wiring diagrams

A wiring diagram shows all the wiring, components, and grounds of a vehicle's electrical system in detail. A wiring diagram is like a road map of the vehicle's electrical system, showing how all the circuits and components are connected. You should always refer to the wiring diagram for the proper procedure to trace a fault and to remove and repair connectors.

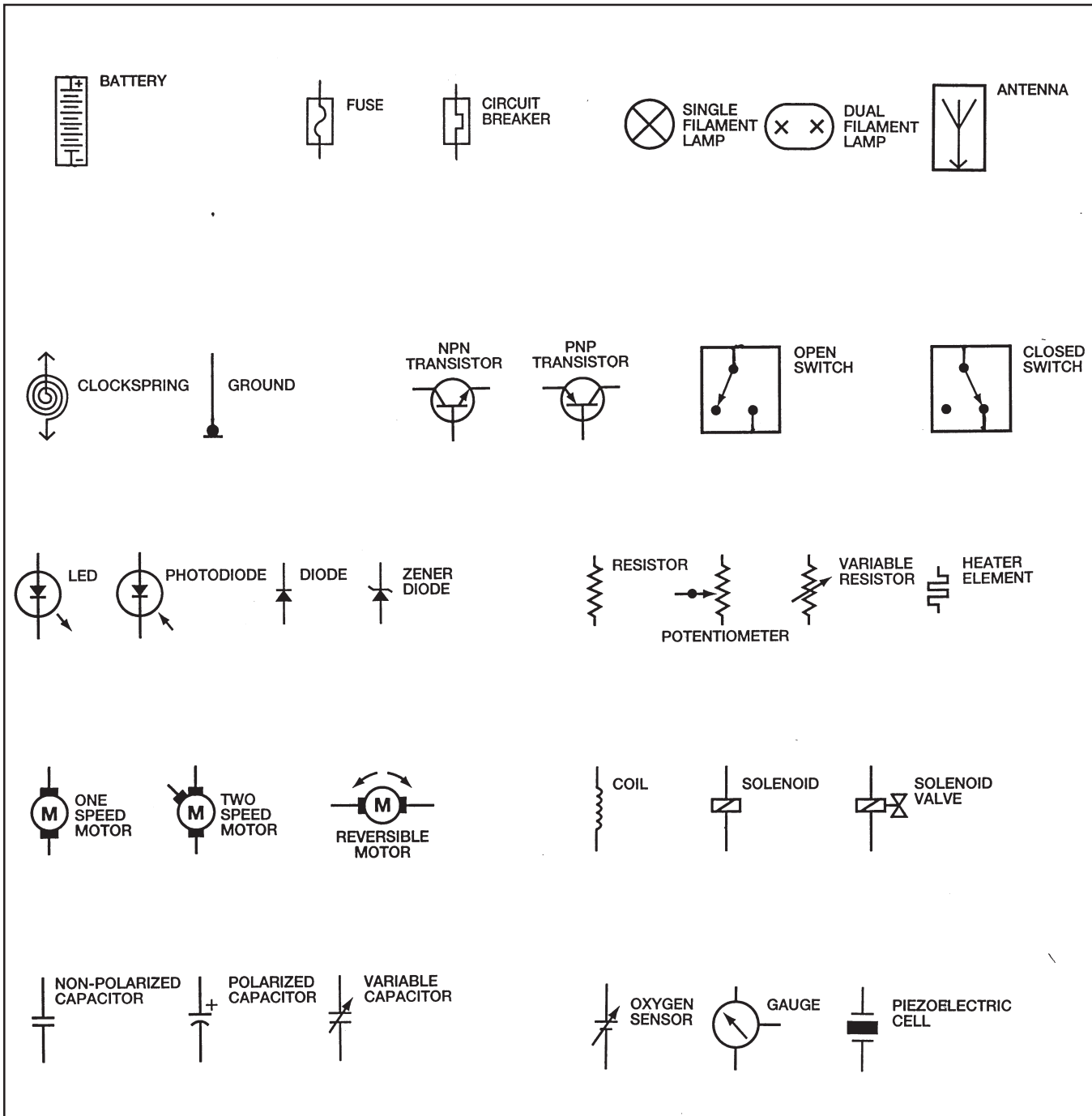
Wire color codes

Wiring used in automotive electrical systems is color-coded for identification. Each wire on the wiring diagram has a code letter placed next to it. These codes help you identify the correct wire on the vehicle.

Wires are not always one color. Two-color wires are typically indicated by a two-letter symbol. When a wiring diagram shows two code letters, the first letter is the basic wire color, and the second letter is the color of the marking (stripes, dots, or hash-marks) on the wire.

For example, a wire labeled B/R is black with red marking. A GY/O wire is gray with an orange stripe or marking. A black wire with a white stripe is designated B/W. Always refer to the wiring diagram for the current information on wire color codes.

Schematic symbols



Common wiring diagram symbols

You are already familiar with common electrical schematic symbols such as chassis ground, battery, fuses, and switches. Wiring diagrams use even more symbols to represent electrical system components.

To read and use a wiring diagram successfully, you must be able to identify electrical component symbols and their meanings. The following graphic shows some of the additional schematic symbols commonly used in wiring diagrams.

Reading a wiring diagram

Always read and analyze the wiring diagram before attempting to repair an electrical problem. Carefully analyzing the circuit and being able to predict its normal operation saves time and effort. Knowing where to make measurements helps avoid removing and replacing components unnecessarily.

Use the following procedure to read a wiring diagram:

1. Make sure you have the correct wiring diagram for the vehicle you are working on.
2. Carefully review the General Information section to familiarize yourself with the wire color codes, common connectors, ground points, etc.
3. Locate the wiring diagram section that contains the problem circuit or component. Find the component's ground point and follow the circuit up to its power source. Make sure you can trace the complete circuit path from the power source through all fuses, switches, relays, etc., to the component and back to the power source through the ground.
4. Determine if the circuit is in series, parallel, switch-to-ground, load-to-ground, etc. Determine the direction of current flow in the circuit.
5. Predict the normal operation of the circuit. Divide the circuit into smaller sections and locate a convenient point to test the circuit or suspected problem component.
6. Find the test point on the vehicle and predict the voltage, current, or resistance at the test point. Test the circuit using the appropriate testing device (ohmmeter, voltmeter, ammeter, etc.). Do the test results match your predicted circuit operation values or the specifications in the Workshop Manual?

Objective

Upon completion of this lesson you will be able to:

- Explain the Symptom-to-System-to-Component-to-Cause diagnostic procedure and provide an example.

Symptom-to-system-to-component-to-cause diagnostic procedure diagnosis

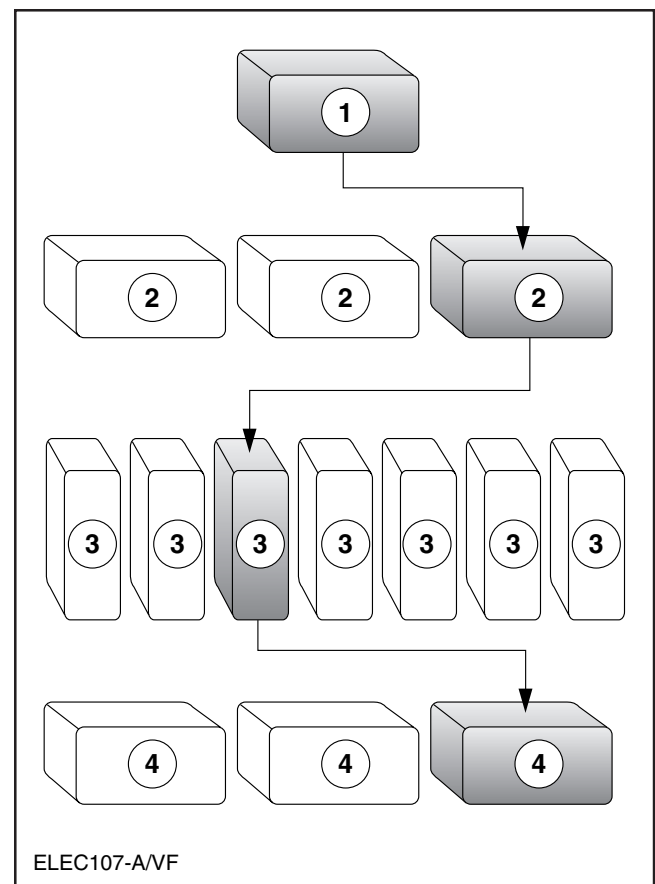
Diagnosis requires a complete knowledge of the system operation. As with all diagnosis, a technician must use symptoms and clues to determine the cause of a vehicle concern. To aid the technician when diagnosing vehicles, the strategies of many successful technicians have been analyzed and incorporated into a diagnostic strategy and into many service publications.

Symptom-to-system-to-component-to-cause diagnostic method

Using the “Symptom-to-System-to-Component-to-Cause” diagnostic routine provides you with a logical method for correcting customer concerns:

- First, confirm the "Symptom" of the customer's concern.
- Next, you want to determine which “System” on the vehicle could be causing the symptom.
- Once you identify the particular system, you then want to determine which “Component(s)” within that system could be the cause for the customer concern.
- After determining the faulty component(s) you should always try to identify the cause of the failure.

In some cases parts just wear out. However, in other instances something other than the failed component is responsible for the problem.



- 1 Symptom
- 2 Vehicle systems
- 3 Components
- 4 Causes

Symptom-to-system-to-component-to-cause diagnostic procedure diagnosis (continued)**Symptom-to-system-to-component-to-cause process example**

An example of the “Symptom-to-System-to-Component-to-Cause” diagnostic routine in use is highlighted in this example. As you read this example, the steps in the process and how they relate to finding the actual cause of the concern are stated.

The first step of the diagnostic process is verifying the symptom(s) of the concern. A customer brings a vehicle in for service because of a concern regarding an inoperative speedometer. A test drive verifies the concern. The test drive validates the “Symptom” portion of the diagnostic process.

The next step in the diagnostic process is to isolate the system(s) that are affected by the symptom. Visual inspection does not show any obvious signs relating to the wiring, connectors, and the vehicle speed sensor. Using the appropriate electronic diagnostic equipment, diagnostic trouble code information indicates a problem with the controlling computer for the vehicle speed signal. The test data provided in the manual validates the “System” portion of the diagnostic process.

Next in the diagnostic process is to isolate the component(s) that relate to the system and symptom. In this case, the vehicle speed signal goes from the sensor to the Powertrain Control Module (PCM) and the PCM sends the signal to the instrument cluster. Using the procedures in the appropriate workshop manual, the vehicle speed sensor is identified as giving faulty input to the PCM. The sensor is the component at fault. Following the workshop manual procedures provides validation of the “Component” portion of the diagnostic process.

Finally, the diagnostic process determines what the “Cause” of the component failure is. In this case a test of the sensor finds faulty internal circuitry within the sensor. This validates the “Cause” relating to the component failure.

Replacing the sensor returns the vehicle to proper operating condition.

Workshop literature

The vehicle workshop literature contains information for diagnostic steps and checks such as: preliminary checks, verification of customer concern/special driving conditions, road tests and diagnostic pinpoint tests.

A	Amps, amperage amperes or C or I	NO	Normally Open
AC	Alternating Current	NPN	Negative, Positive, Negative
C	Current or Amps or Intensity	Orbit	Shell
C°	Celsius	P	Power or watts
DC	Direct Current	PNP	Positive, Negative, Positive
DPDT	Double Pole, Double Throw	PTC	Positive Thermal Coefficient
E	Volts or V or electromotive force or U	R	Resistance, or ohms, or Ω
EMF	Electromotive Force or volts or V or E	Shell	Orbit
F	Farads	SPDT	Single Pole, Double Throw
F°	Fahrenheit	SPST	Single Pole, Single Throw
Hz	Hertz	U	Units is voltage
I	Intensity or current flow or A or C	V	Volts, or voltage or electromotive force or U
k	Kilo or one thousand	W	Watts
LED	Light Emitting Diode	μ	micro or one millionth
M	Mega or one Million	Ω	Omega, or ohms, or R
m	Milli or one thousandth		
NC	Normally Closed		

