

Electrical Systems I

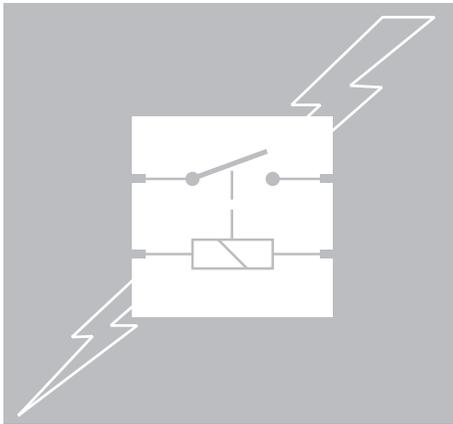
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 WARNING: WHILE SERVICING AND TESTING VEHICLES AND VEHICLE SYSTEMS, TAKE ALL NECESSARY SAFETY PRECAUTIONS TO PREVENT THE POSSIBILITY OF BODILY INJURY OR DEATH.

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ELECTRICAL SYSTEMS I



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2 CIRCUITRY / OHM'S LAW

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ELECTRICAL THEORY

Electrical current is produced by magnetism and magnetism can be produced by electrical current; therefore, Fundamentals of Electricity and Magnetism, the two sections of this chapter go hand-in-hand in forming the basis for understanding how electrical current is generated and produces work in automobile electrical circuits.

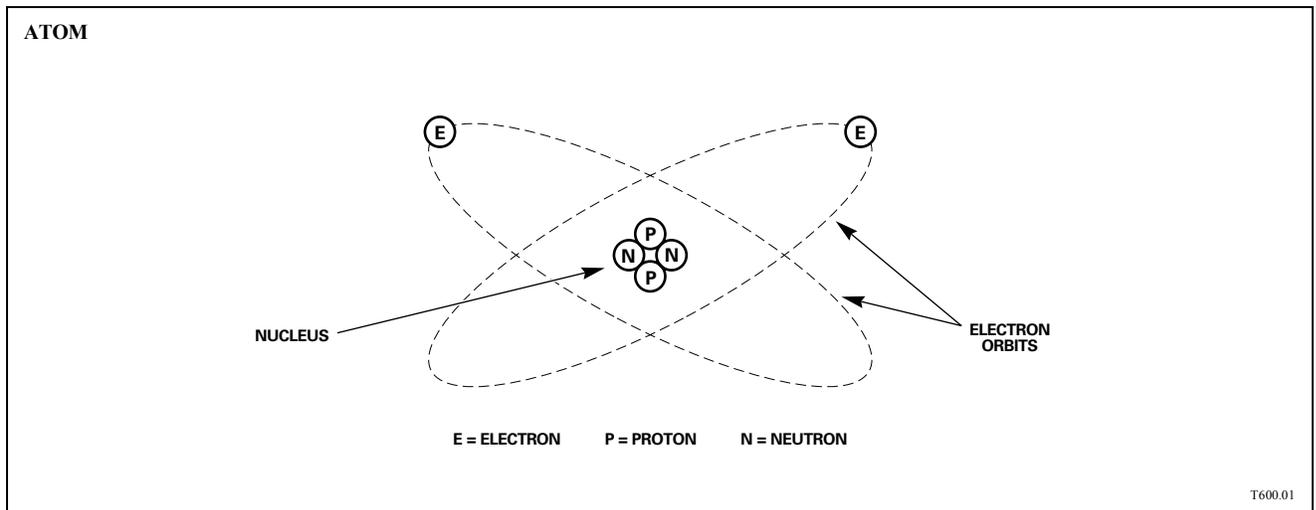
Fundamentals of Electricity

Electricity is the movement of electrons from atom to atom in a conductor. In order to have a basic understanding of this phenomena, it is necessary to understand the structure of an atom and the actions of charged particles.

Atomic Structure

Atoms

All matter is made up of elements, of which more than 100 are known to exist. The smallest particle into which an element can be reduced (and still retain its identity) is an atom. An atom consists of electrons in orbit around a nucleus containing protons and neutrons. Protons have a positive electrical charge; neutrons have no electrical charge; electrons have a negative electrical charge.

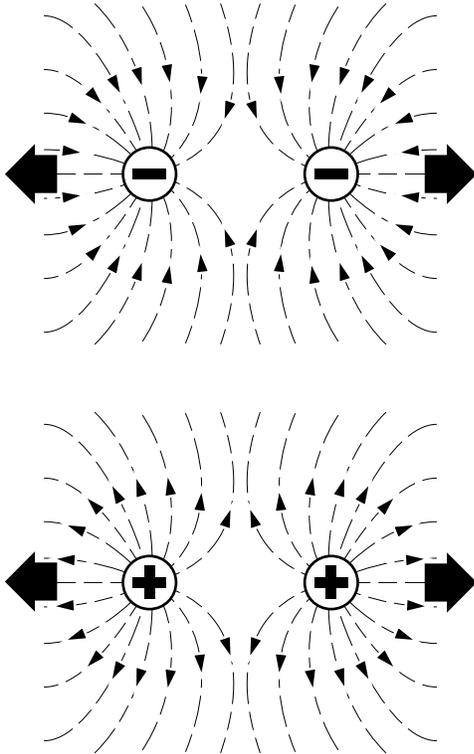


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ELECTRICAL THEORY

Fundamentals of Electricity

LIKE CHARGES



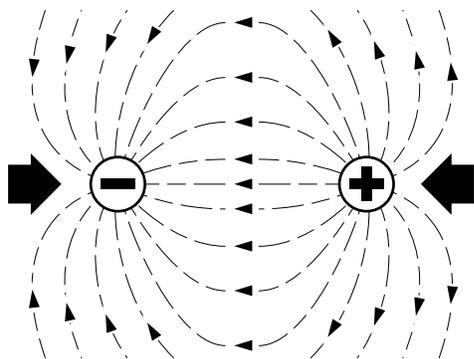
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The action of charges

Like charges (negative / negative or positive / positive) repel each other. Unlike charges (negative / positive) attract each other.

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UNLIKE CHARGES



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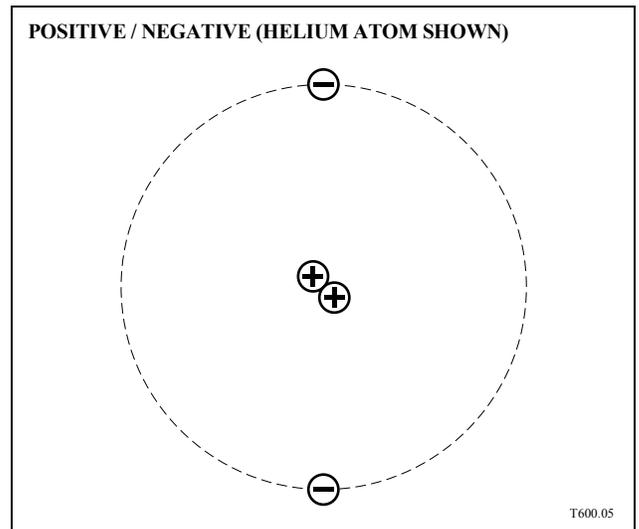
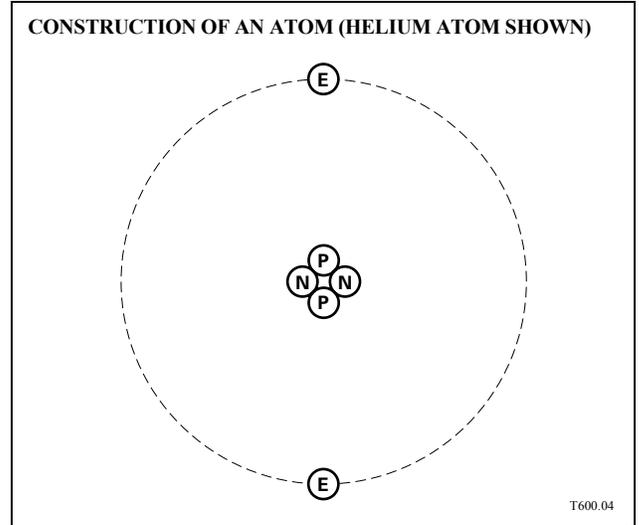
Construction of an atom

The construction of a simple atom shows two protons and two neutrons in the nucleus and two electrons in the same orbit. The neutrons prevent the like charged protons from moving apart. The two electrons with like charge remain equidistant as they orbit the central core. The protons exert an attractive force on the electrons to hold them in their orbits.

Positive / negative signs

The positively charged protons can be identified with a plus sign; the negatively charged electrons can be identified with a minus sign. Since they do not move or attract, the neutrons are not shown.

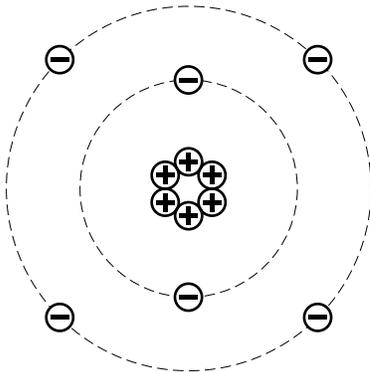
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ELECTRICAL THEORY

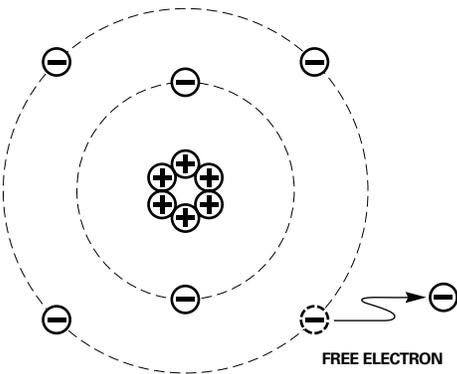
Fundamentals of Electricity

NEUTRAL ATOM (CARBON ATOM SHOWN)



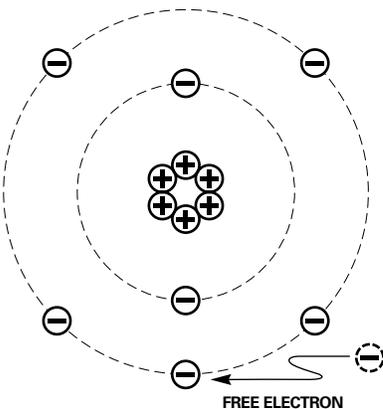
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POSITIVE ION (CARBON ATOM SHOWN)



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NEGATIVE ION (CARBON ATOM SHOWN)



T600.08

Electricity and Ions

Neutral atom

A neutral (electrically balanced) atom has an equal number of protons and electrons. The four electrons occupy two orbits that are at different distances from the nucleus.

Positive ion

If an atom loses an electron, the atom becomes a positive ion — it has more protons than electrons.

Negative ion

If an atom gains an electron, it becomes a negative ion: it has more electrons than protons.

Since electricity is the flow of electrons in a conductor, the atoms of the conductor material will become ions as part of this action.

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Static Electricity

Electricity at rest

Static means “at rest”, therefore, static electricity is electricity at rest. Static electricity can build in material in many ways: through friction with other material (walking on a carpet on a dry day), through contact, or through induction.

Materials that are charged with static electricity either attract or repel each other depending upon their charge. If atoms are deficient in electrons, they are considered positively charged (positive ion); if atoms have excess electrons, they are considered to be negatively charged (negative ion).

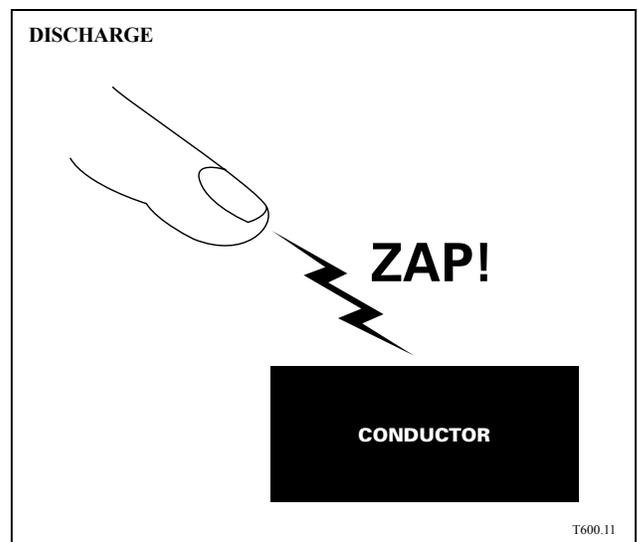
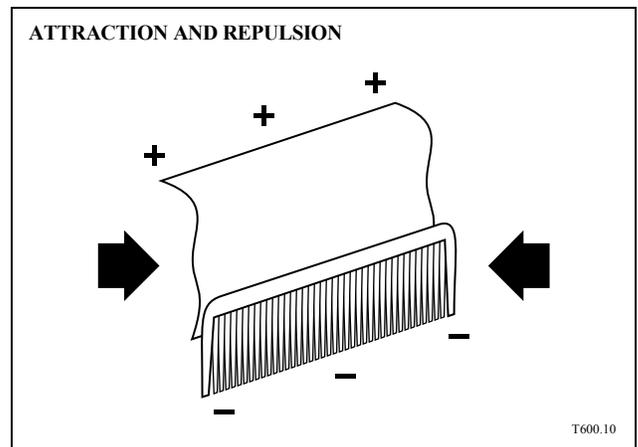
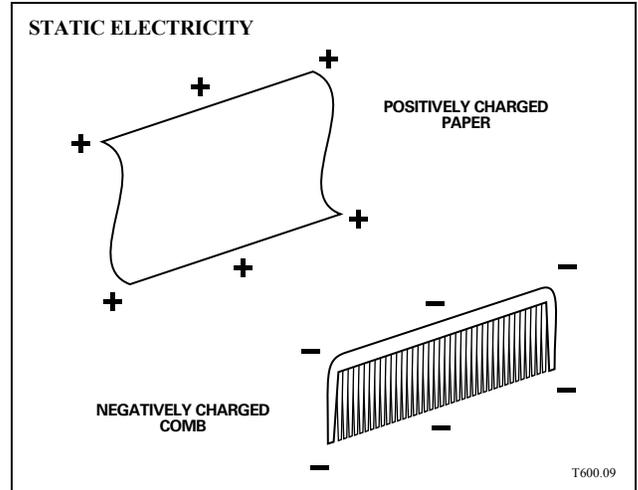
Attraction and repulsion

Attraction between unlike charges occurs because the excess electrons of negatively charged atoms move toward atoms with a positive charge. Atoms with like charges (negative / negative, positive / positive) repel each other.

Discharge

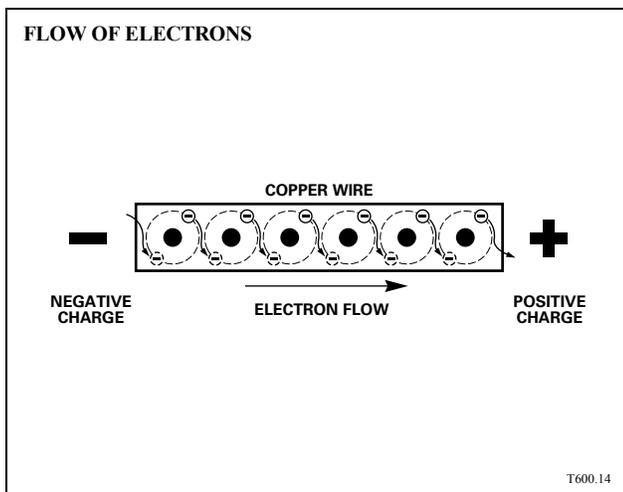
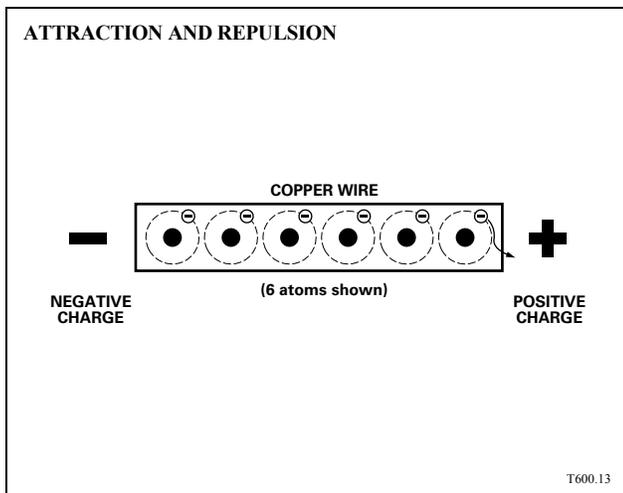
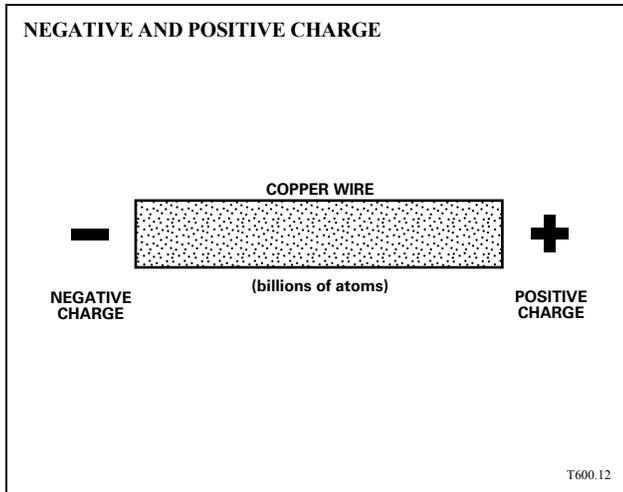
Static electricity will discharge when the charged material comes in contact with a conductor. When discharge occurs, the electricity is no longer static.

NOTES



ELECTRICAL THEORY

Fundamentals of Electricity

**Dynamic Electricity****Electricity in motion**

Dynamic means "in motion", therefore dynamic electricity is electricity in continuous motion. Dynamic electricity is created through an external force and is used to perform work.

Neutral atoms have an equal number of protons and electrons. An external source of energy (battery, AC generator) can cause electrons to leave neutral atoms. This action is used to create positive and negative charges at opposite ends of a conductor.

Attraction and repulsion

If a copper wire has a negative charge located at one end and a positive charge located at the other end, electrons will flow in the wire as follows:

In the example shown, an electron (electrons have a negative charge) in an atom near the positive end of the wire is attracted toward the positive charge, and leaves its atom.

Flow of electrons

This atom then becomes positively charged (it is deficient one electron) and exerts an attractive force on an outer orbit electron in a neighboring atom. The neighboring atom gives up one electron to the first atom while at the same time attracting an electron from a neighboring atom. This chain reaction continues resulting in the movement of electrons through the wire. The negative charge provides a repelling force equal to the attractive force provided by the positive charge.

The general definition of electricity is the flow of electrons from atom to atom in a conductor.

NOTES

Voltage

Electromotive force

Because they have the potential to perform work by causing electrons to flow through the wire, the charges at the wire ends possess “potential energy”. This potential difference is called “electromotive force” (EMF) and is measured in volts. Voltage is represented by the letter V.

Voltage defined

Voltage is the measurement of an electromotive force in a circuit. Voltage is present in a circuit whether or not a current consuming

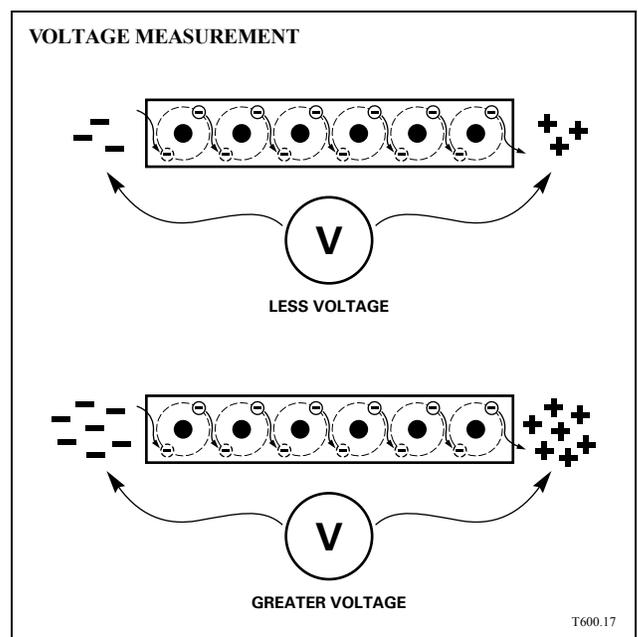
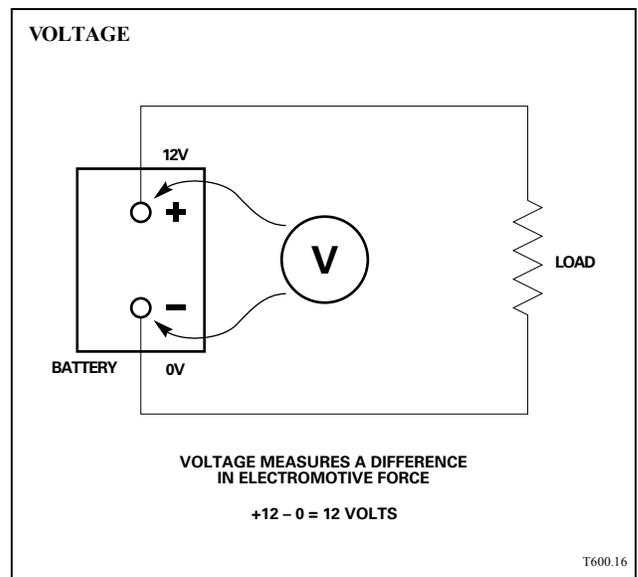
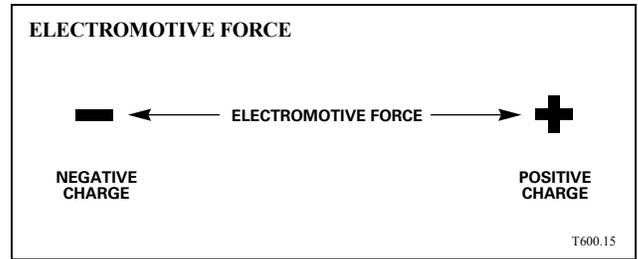
device is connected to the source of the voltage. An example of this is the voltage measurement across battery terminals.

There are several possible sources of energy for an electrical circuit: a battery, a generator, heat (thermocouple), or a solar generator.

Voltage measurement

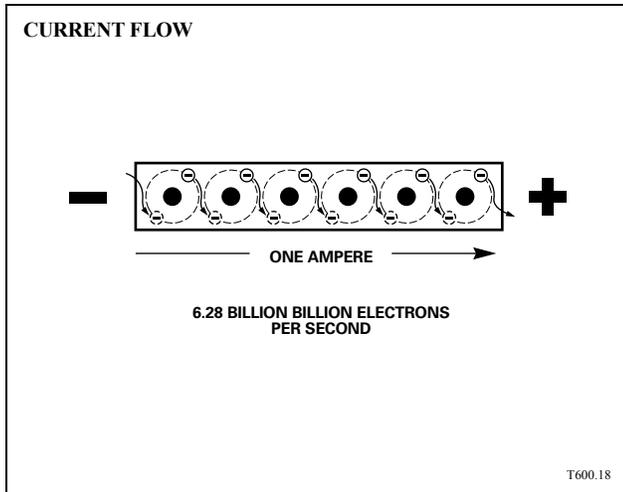
Voltage is present between two points when a positive charge exists at one point and a negative charge exists at the opposite point. The greater the deficiency of electrons at the positive potential and the greater the excess of electrons at the negative potential, the greater the voltage.

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ELECTRICAL THEORY

Fundamentals of Electricity



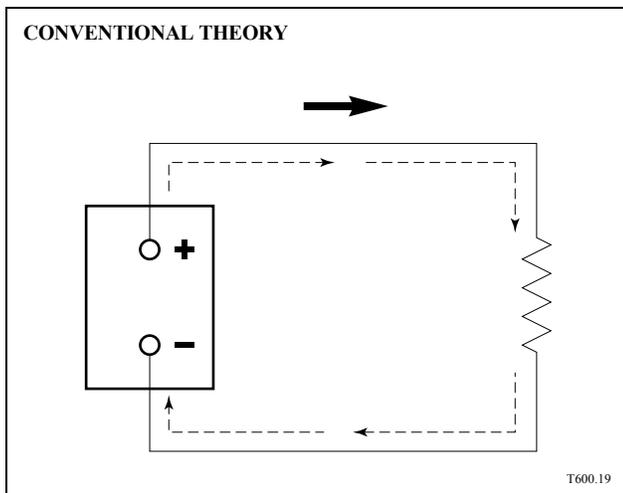
Amperage

Current flow

The flow of electrons through a conductor is called current. It is also referred to as inductance. The rate of electric current is measured in amperes and is represented by the letter A. The electric current is one ampere when 6.28 billion billion electrons move past a given point in a conductor in one second. There are two ways of describing current flow: the Conventional Theory and the Electron Theory.

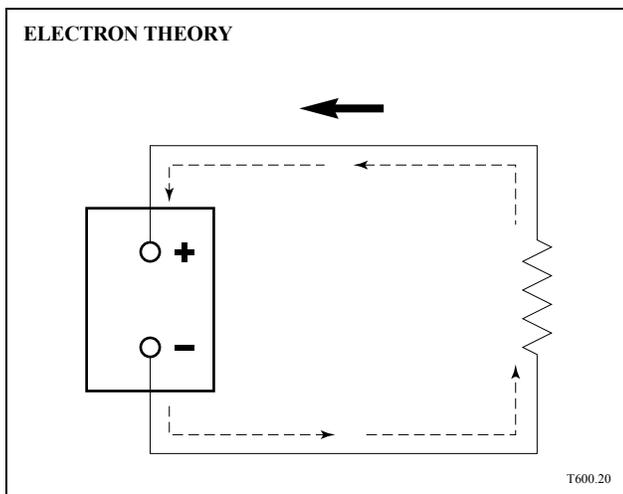
Conventional Theory

In the Conventional Theory, current flows from the positive terminal of the voltage source through the circuit to the negative terminal of the voltage source. The Conventional Theory is used by the automotive industry.



Electron Theory

In the Electron Theory, current flows from the negative terminal of the voltage source through the circuit to the positive terminal of the voltage source.



NOTES

Polarity

In automotive electrical diagrams, plus [+] and minus [-] signs next to the terminals of the power source indicate the direction of current flow. (Remember that in the Conventional Theory, electrons flow from the positive terminal and return to the negative terminal.)

Direct current

A battery or generator supplies direct current (DC). Current flows in one direction from the positive terminal to the negative terminal.

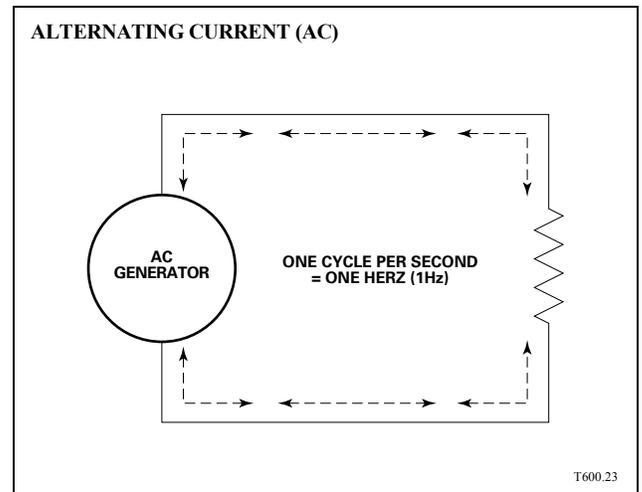
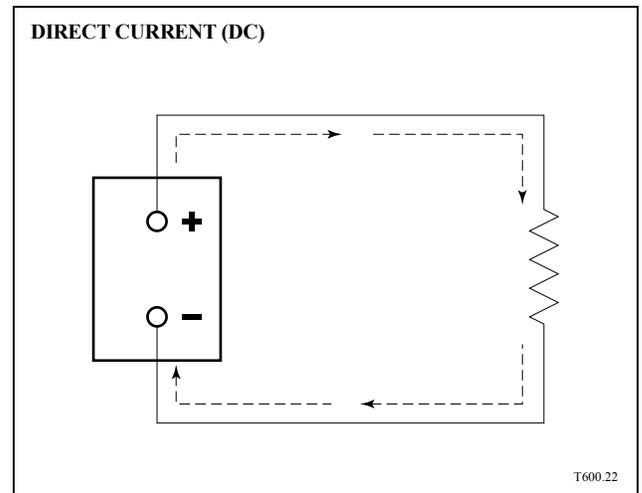
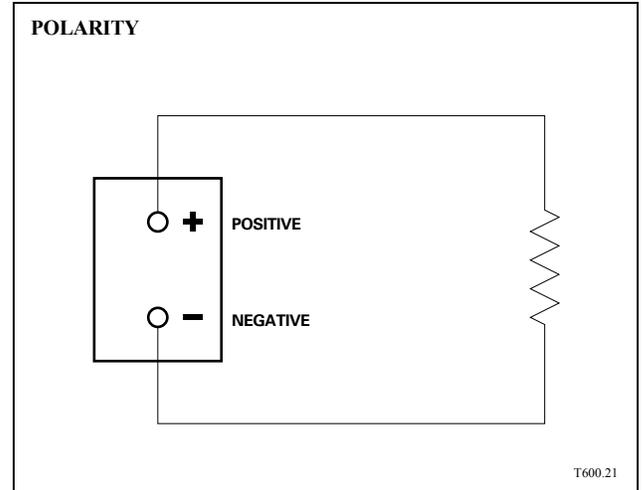
Most automotive circuits operate with direct current.

Alternating current

Alternating current flows first in one direction, then in the opposite direction. This continuous action occurs many times per second and is referred to as a cycle. One cycle per second is equal to one Hertz (Hz).

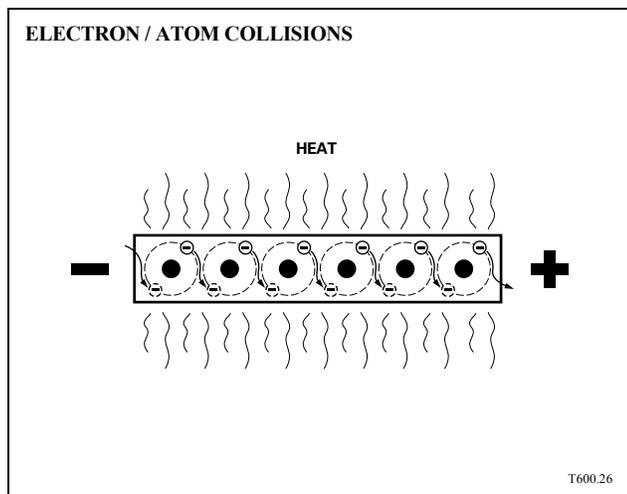
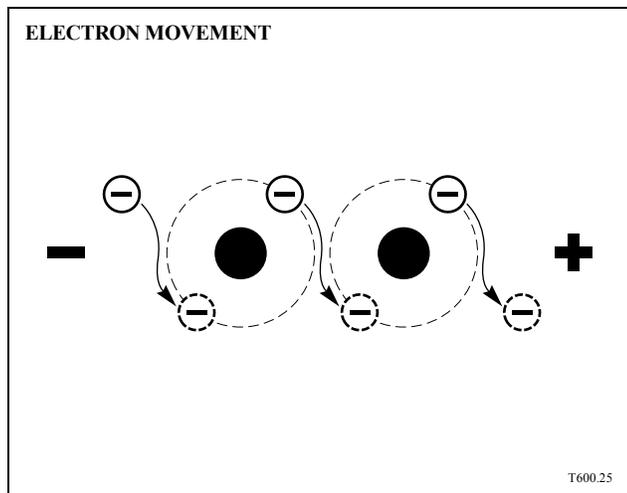
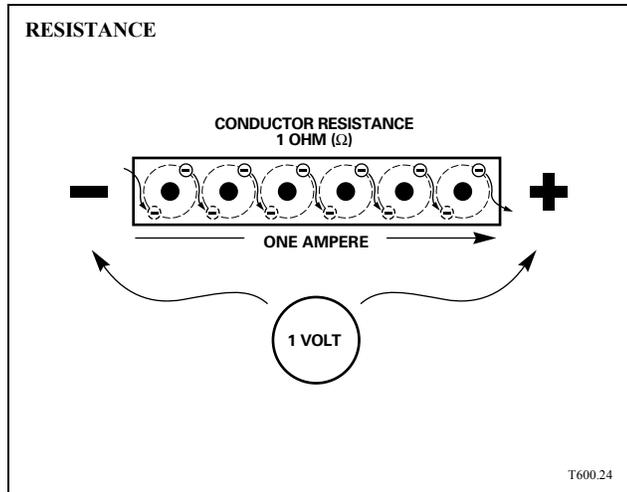
Automobiles have AC generators that produce alternating current that is changed to direct current.

NOTES



ELECTRICAL THEORY

Fundamentals of Electricity



Ohms

Resistance

All electrical conductors offer some measure of resistance to current flow. Resistance is measured in Ohms. One Ohm is defined as the resistance that will allow one ampere to flow when the potential is one volt. The symbol Ω is used to represent Ohms.

Resistance results primarily from two factors: electron movement and electron / atom collisions.

Electron movement

The first factor is that atoms resist the loss of electrons due to the attraction of unlike charges.

Electron / atom collisions

The second factor involves the many billions of collisions between electrons and atoms as electrons move through the conductor. The collisions create resistance and cause heat to appear in the conductor.

Mass, type of material, temperature and condition of the material determine the resistance of a conductor. All electrical components have resistance.

NOTES

Properties of Conductors, Insulators and Semiconductors

Conductors

Elements that form good paths for the movement of electrons are called “conductors”.

Most metals are conductors, with the best being copper, iron and aluminum. Copper is an excellent conductor of electricity because a copper atom has only one electron in its outer orbit.

Elements that have less than four electrons in their outer orbit are conductors of electricity because the electrons are free to leave the atom.

Insulators

Elements that strongly oppose the movement of electrons are called “insulators”.

Elements that have an excess number of electrons (more than four) in their outer orbit are insulators because the electrons are not free to leave the atom and thus block current flow.

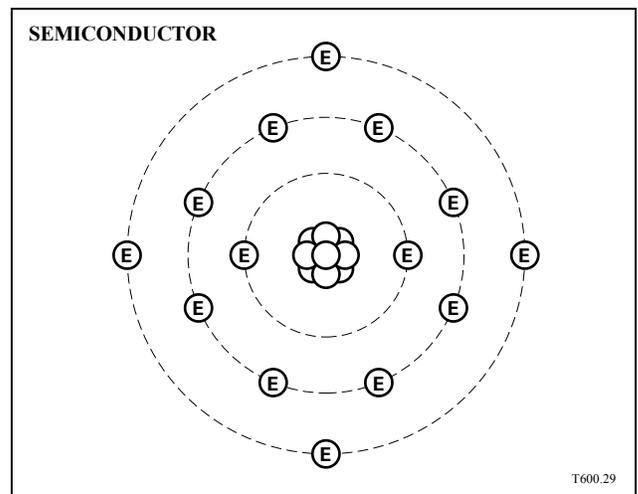
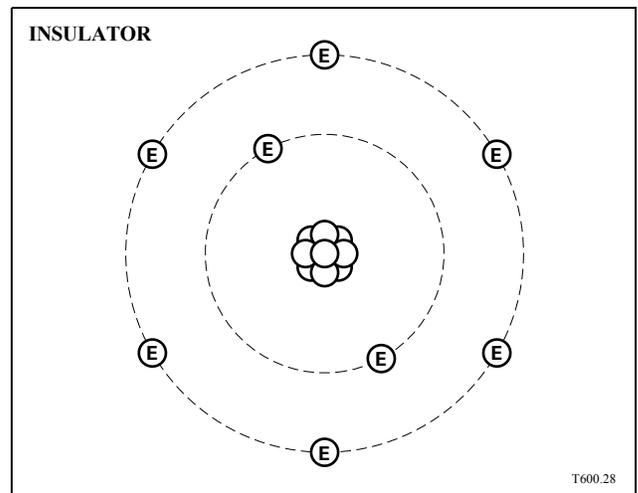
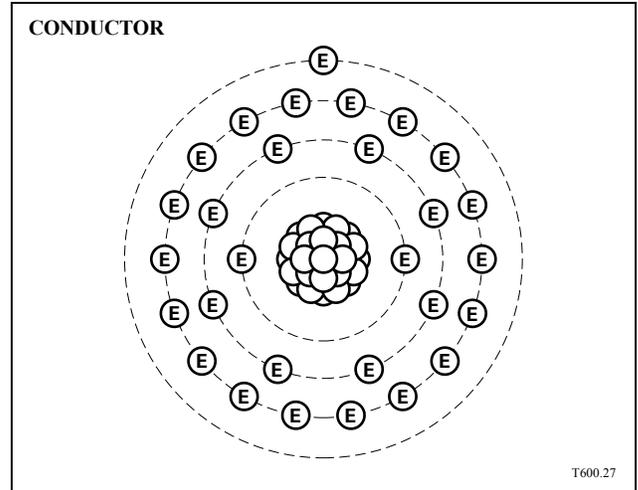
The best insulators have eight electrons in their outer orbit. Rubber, most plastics and glass are good insulators.

Semiconductors

Elements that are in a class between conductors and insulators are called “semiconductors”.

Elements that have exactly four electrons in their outer orbit are semiconductors. Silicone and germanium are the two most commonly used semiconductors.

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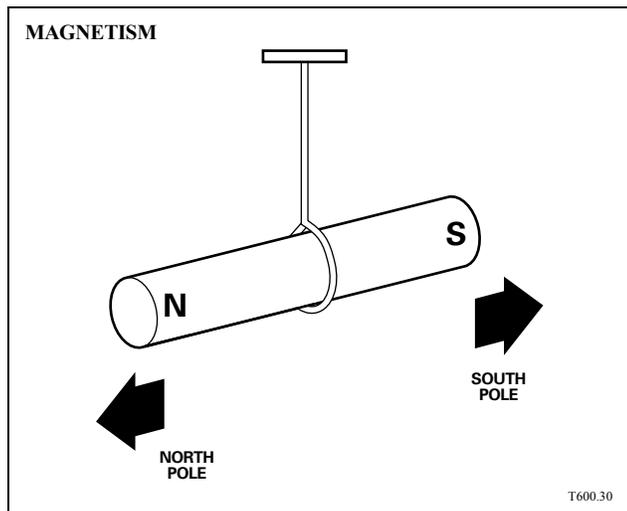


ELECTRICAL THEORY

Fundamentals of Magnetism

Magnetism is a connecting link between electricity and mechanical energy. Mechanical power is used to produce electrical energy and electrical energy is used to produce mechanical power.

Through the use of magnetism in an automobile AC generator, some of the mechanical power developed by the engine is changed into electricity to perform work such as charging the battery, lighting the headlights and operating the ignition. Current flowing from the battery is changed by magnetism into mechanical power. For example, when a magnetic field is set up in the starter motor, the motor turns and cranks the engine.



Magnetic Field and Flux

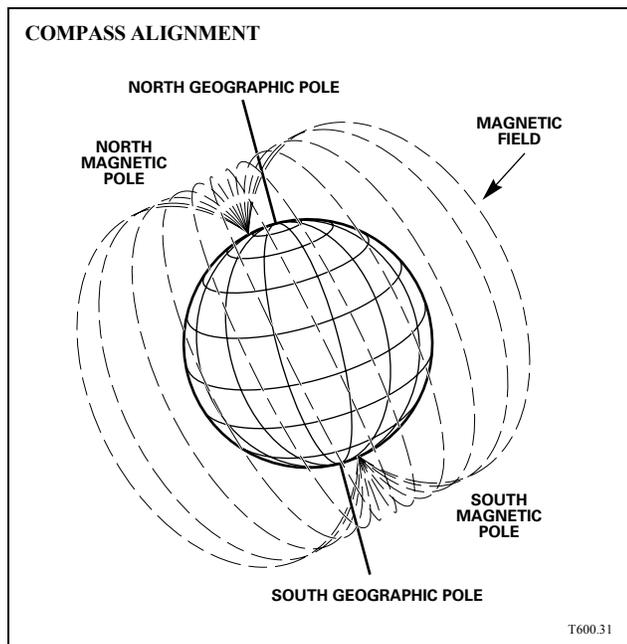
Magnetism

An iron bar suspended in air will align itself so that one end will always point to the North pole of the Earth. Because of this alignment, the ends of the bar are labeled north (N) and south (S). This discovery is used in a simple magnetic compass.

Compass alignment

Since the Earth is a huge magnet with north and south poles, a compass needle will always align itself with the poles. An attractive force known as a force field or magnetic field exists around a magnet.

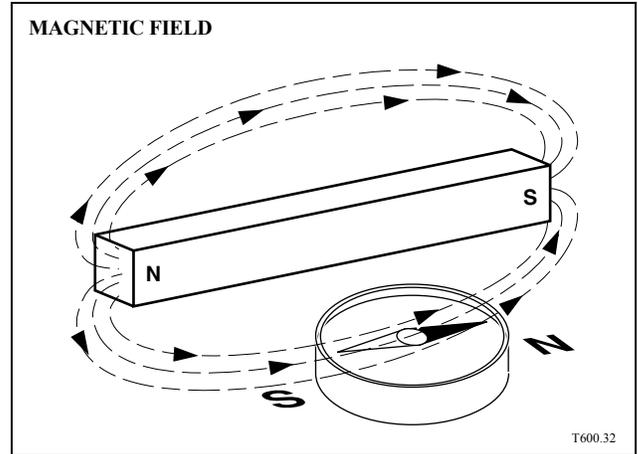
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Magnetic field

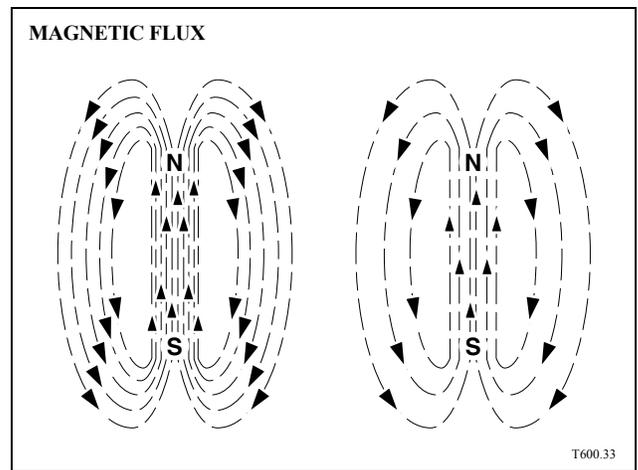
A magnetic field can be illustrated by lines of force that are assumed to leave the north pole and enter the south pole. The concentration or number of lines at each pole is equal and the attractive force at each pole is equal. The attractive force is greatest where the concentration of magnetic lines is greatest (the north and south poles).

If a compass (the needle is a small magnet) is located in the magnetic field of a strong bar magnet, the needle will align itself with the lines of force. The alignment of the needle illustrates two things: the lines of force leave the north pole and enter the south pole; unlike poles are attracted towards each other.



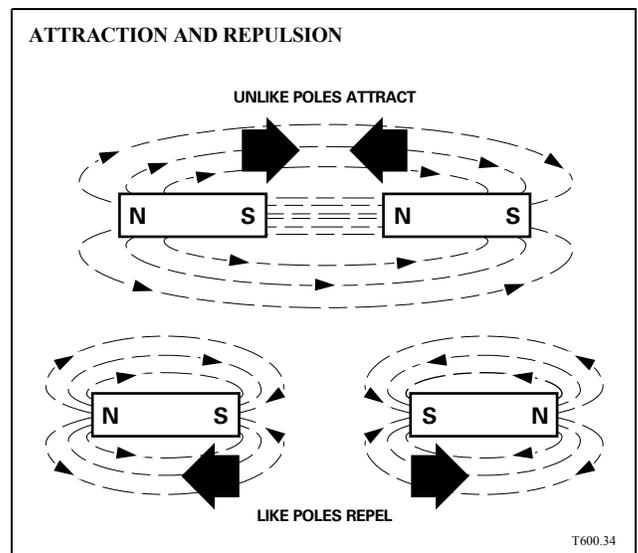
Magnetic flux

The lines of magnetic force are heavily concentrated at the poles of a magnet and spread out into the surrounding air between the poles. The lines of magnetic force are called magnetic flux. When the magnet is strong, the magnetic flux density is greater than when a magnet is weak.



Attraction and repulsion

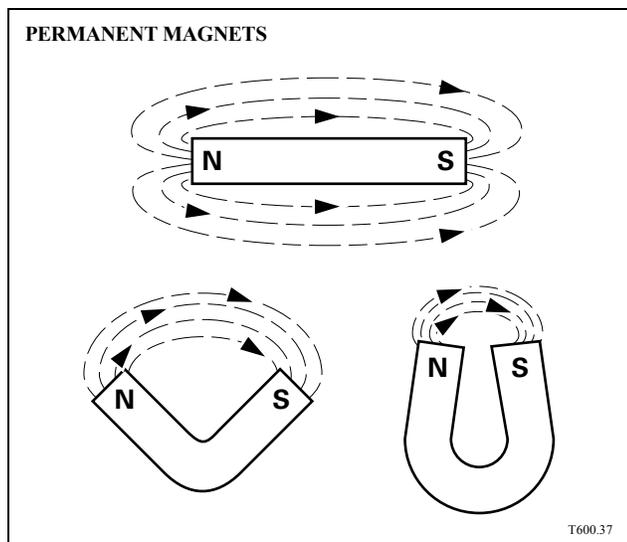
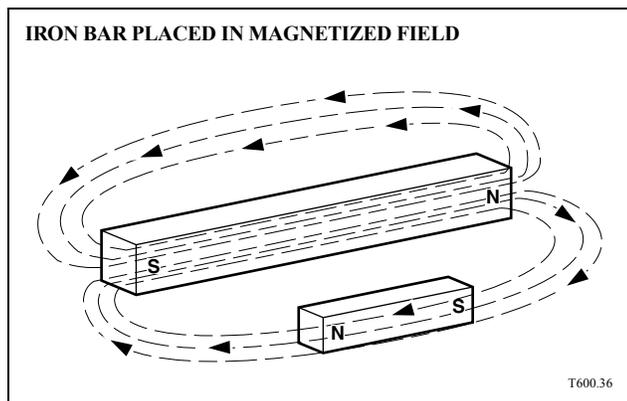
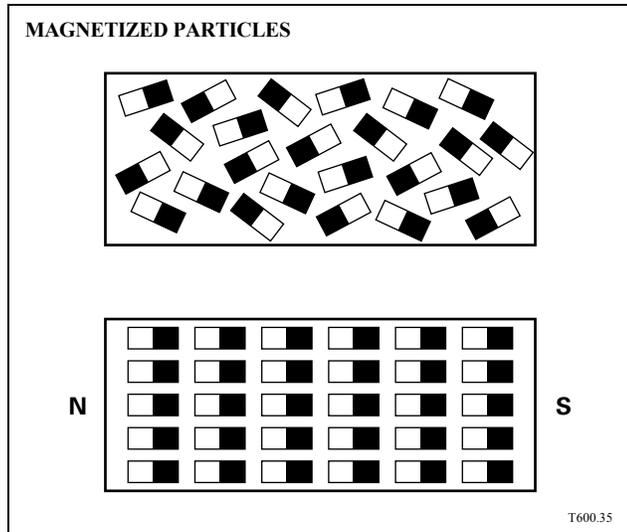
When two magnets are aligned with like poles they repel each other. When two magnets are aligned with unlike poles, they are attracted to each other, and will combine lines of force.



NOTES

ELECTRICAL THEORY

Fundamentals of Magnetism



Magnetic Theory

Two theories exist to explain how magnets work:

The first theory states that a large quantity of small magnetized particles exist in a magnet. If the bar is not magnetized, the particles have a random alignment; however, when the bar is magnetized, the particles align with each other.

The second theory states that each electron in the atoms of the bar material has a circle of force around it. When magnetized, the electron orbits align so that the circles of force combine.

Magnetic Induction

Not all materials can be magnetized. Some metals, wood and ceramics are examples. Iron is an excellent material to magnetize. There are two ways in which magnetic induction can be accomplished:

One method is to stroke the iron bar with a bar that is already magnetized.

The other method is to place the iron bar in the magnetic field of a strong magnet. The lines of force passing through the iron bar will cause it to become magnetized.

Permanent magnets

Some materials can become permanent magnets. Most of these are hard metal alloys. Permanent magnets can have varied shapes and have limited application in electrical circuitry.

NOTES

Electromagnetism

Current / magnetic field

Current flowing through a wire will create a magnetic field around the wire. This can be demonstrated by holding a compass near a wire carrying current. The compass needle will align itself perpendicular to the wire.

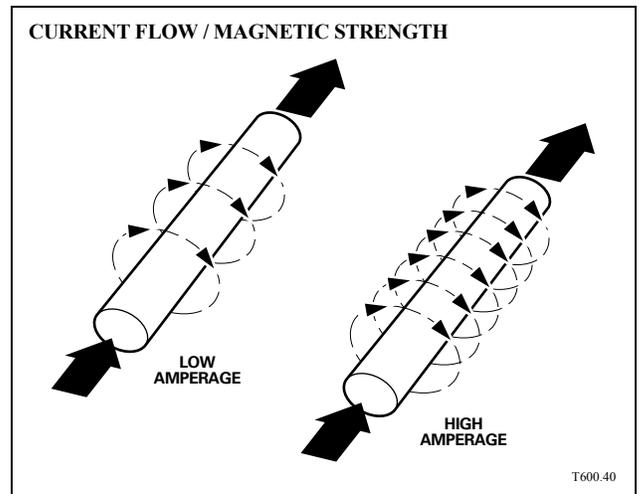
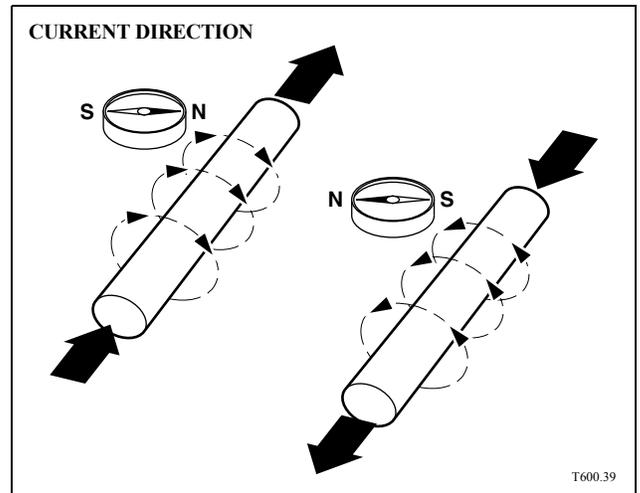
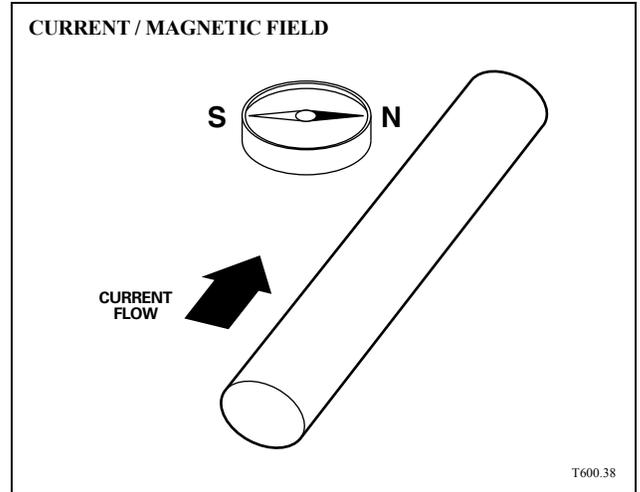
Current direction

The flux lines have direction and change dependent on the direction of current flow in the wire. The flux lines enter the south pole of the compass needle and leave the north pole.

Current flow / magnetic strength

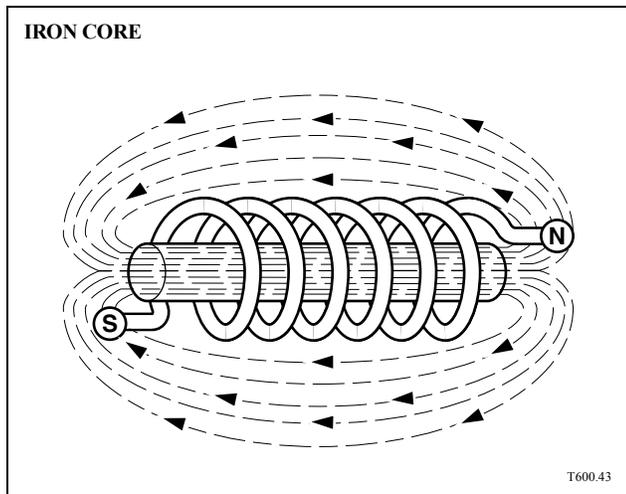
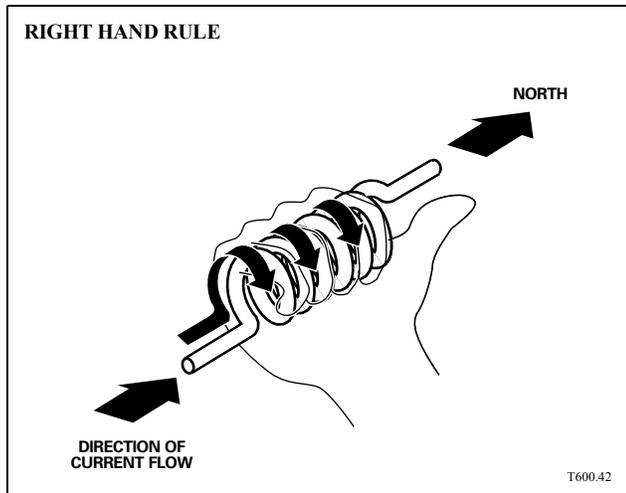
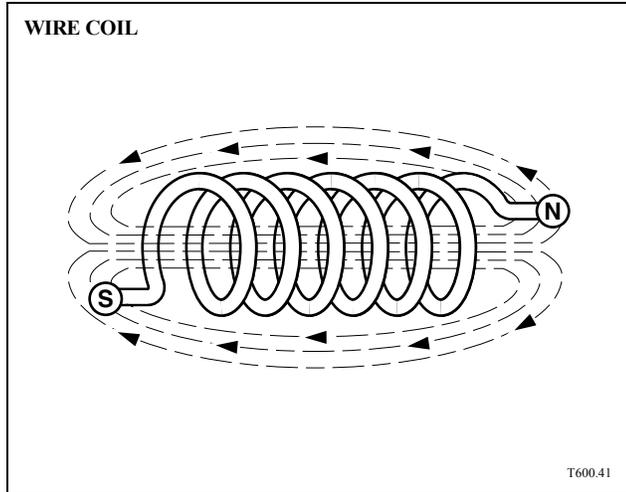
The density of the magnetic flux lines increases as the current flow through the conductor increases. The greater the current (more amperes), the stronger the magnetic field around the conductor.

NOTES



ELECTRICAL THEORY

Fundamentals of Magnetism



Electromagnetism (continued)

Wire coil

When a wire carrying electrical current is wound into a coil, a magnetic field identical to a bar magnet is created. The strength of the magnet is governed by two factors. The greater the number of turns and / or the amperage, the stronger the magnetic field will be.

Right hand rule

The “right hand rule” can be applied to determine the direction of the flux lines around a conductor or coil. Hold the wire or coil with the thumb pointing in the direction of current flow (positive to negative — conventional theory). The fingers will point in the direction in which the flux lines surround the conductor.

Iron core

If an iron core is inserted into the coil of wire, the magnetic field will become much stronger, as iron makes a better path for the magnetic lines than air.

A coil with an iron core is called an electromagnet. A coil without the core (air core) is called a solenoid. Electromagnets and solenoids are used throughout the automobile electrical system.

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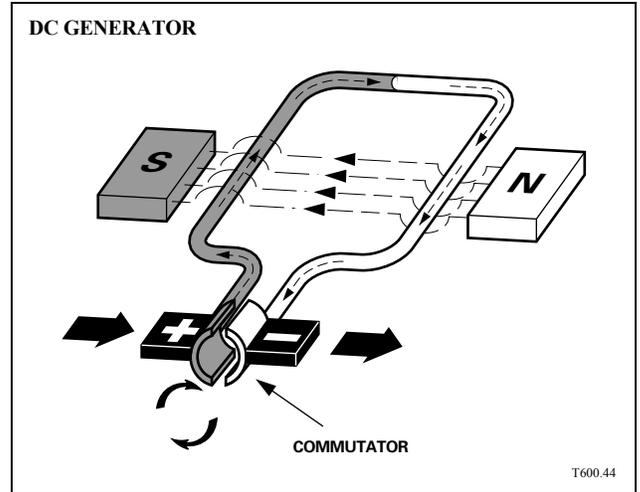
Electromagnetic Induction

In order to induce voltage in a conductor it is necessary to have relative motion between the conductor and the magnetic field. Motion can occur in one of three ways as illustrated by observing the operation of a generator, AC generator and an ignition coil.

DC Generator

In a DC generator, the conductor moves (rotates) through a stationary magnetic field inducing voltage at the commutator, which connects to the circuit through brushes.

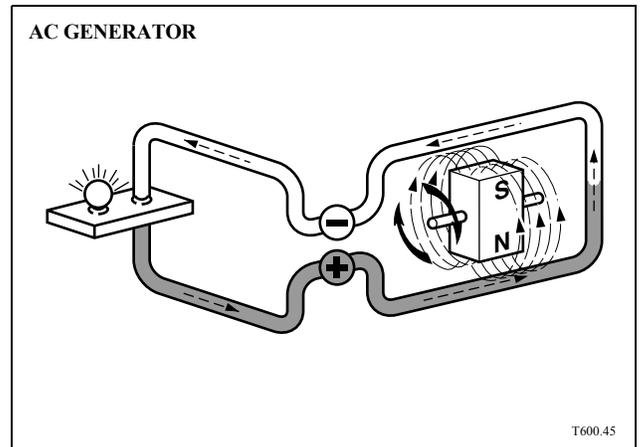
The voltage induced by a DC generator produces direct current (DC).



AC Generator

In an AC generator, the magnetic field moves (rotates) through the stationary conductor producing voltage in the circuit.

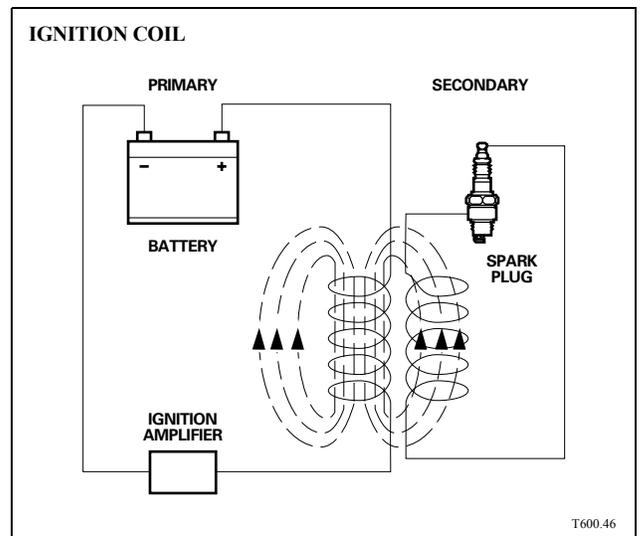
The voltage induced by an AC generator produces alternating current (AC) that must be changed to direct current for automotive use.



Ignition coil

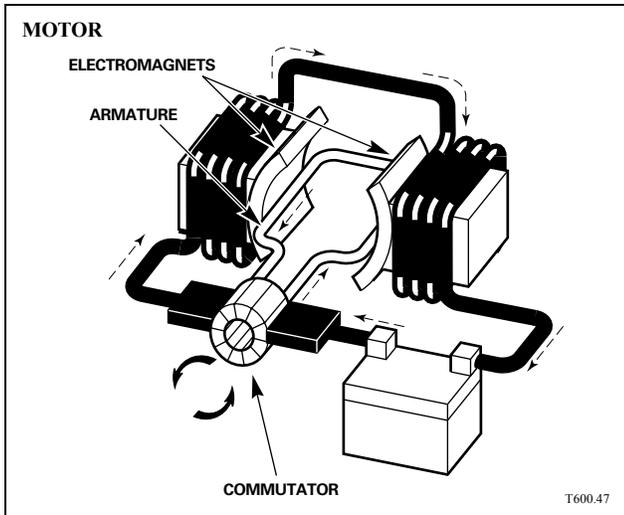
Voltage can also be induced by the building or collapsing of a magnetic field across a stationary conductor. An example of this is an ignition coil.

NOTES



ELECTRICAL THEORY

Fundamentals of Magnetism



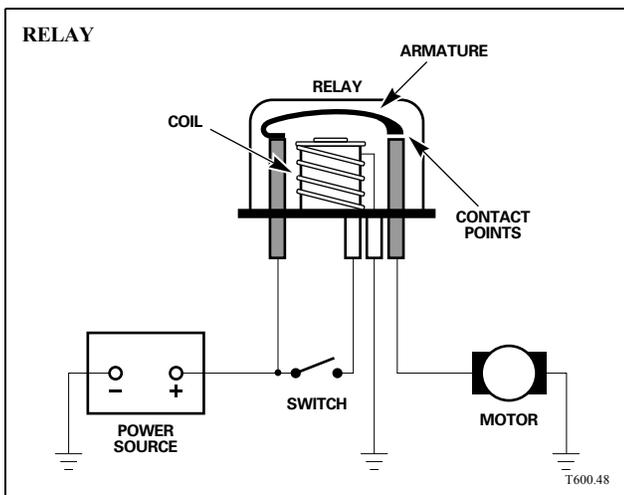
Electromagnetic Components

Motor

A motor is similar to a generator. In the case of the motor, an external circuit supplies current to the armature through the brushes and commutator. The armature becomes a powerful electromagnet that rotates in the magnetic field produced by the electromagnets in the motor's frame.

Relay

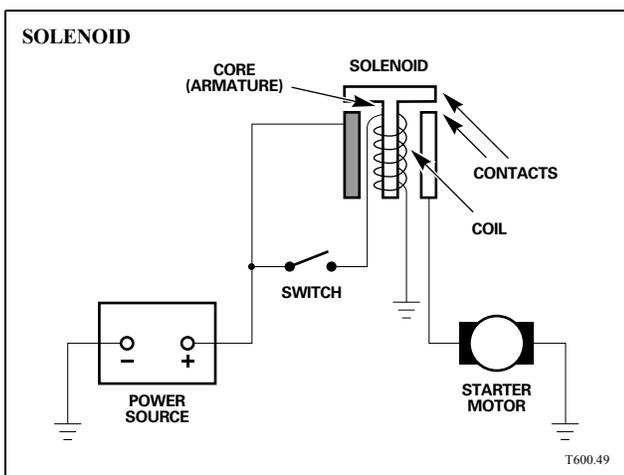
The contacts in a relay are opened or closed by the action of an electromagnet. When energized, current flowing through the coil creates an electromagnet, which in turn attracts an armature to make or break the contacts.



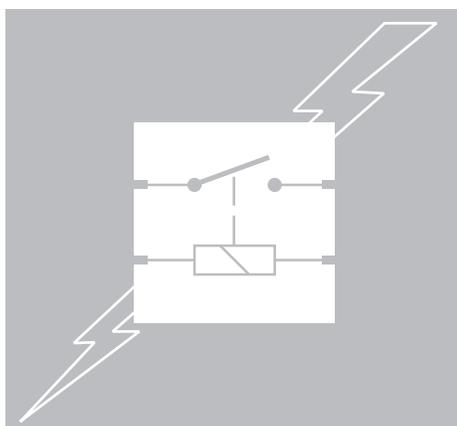
Solenoid

Solenoids are tubular coils used to produce a magnetic field. An iron core is free to move within the air core so that when current flows in the coil, the core moves to perform work. This work includes switching of electrical, hydraulic and vacuum circuits.

NOTES



ELECTRICAL SYSTEMS I

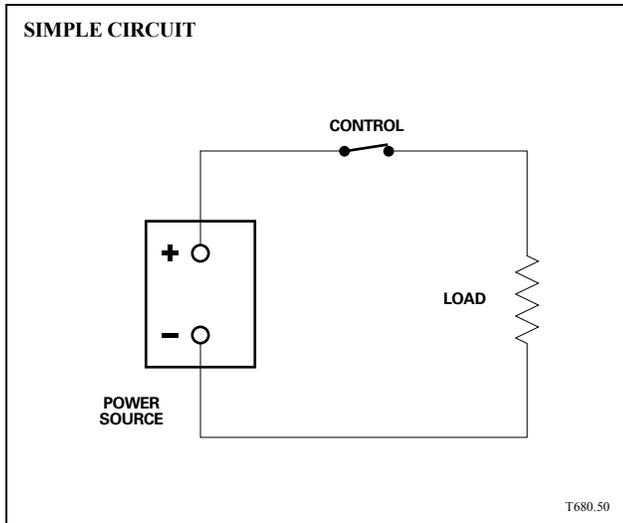


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- 2 **CIRCUITRY / OHM'S LAW**
- 3 CIRCUIT COMPONENTS
- 4 CIRCUIT DESIGN
- 5 CIRCUIT ANALYSIS
- 6 GLOSSARY
- 7 TASK SHEETS



CIRCUITRY / OHM'S LAW

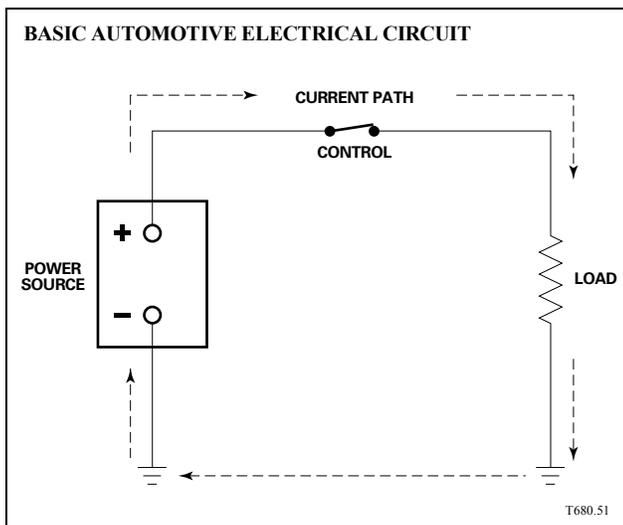
Basic Circuits

**Simple Circuit**

All electrical circuits contain four basic components: a power source, a method of control, a consumer of electricity (load) and a conductor that connects the power source, control and the load. Three types of automotive circuits are used:

- Series circuit
- Parallel circuit
- Series / parallel circuit

For a circuit to perform its function, the path for current flow from the power source back to the power source must be complete. In automotive electrical systems, the connecting conductor is usually made up of wire or printed circuit, with the vehicle acting as the return path to the power source.

**NOTES**

Series Circuit

A series circuit is laid out with only one current path through two or more loads. Current flows through all the components so that a break in the current path at any point in the circuit will disable the entire circuit.

A series circuit has the following characteristics:

- More than one load
- Only one path for current

The current flowing in a series circuit is the same at any point in the circuit.

Parallel Circuit

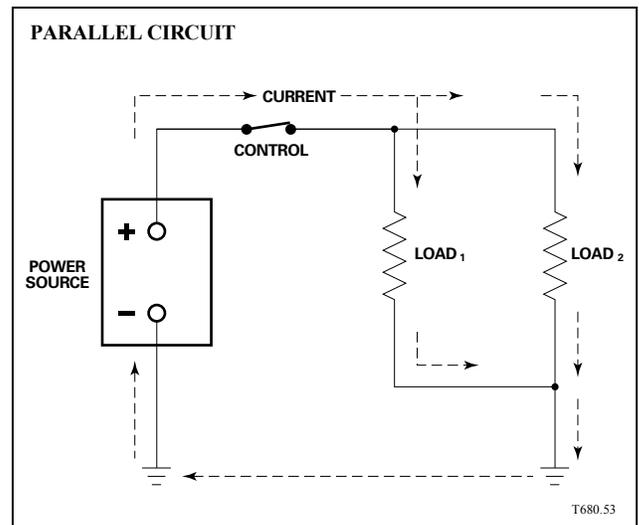
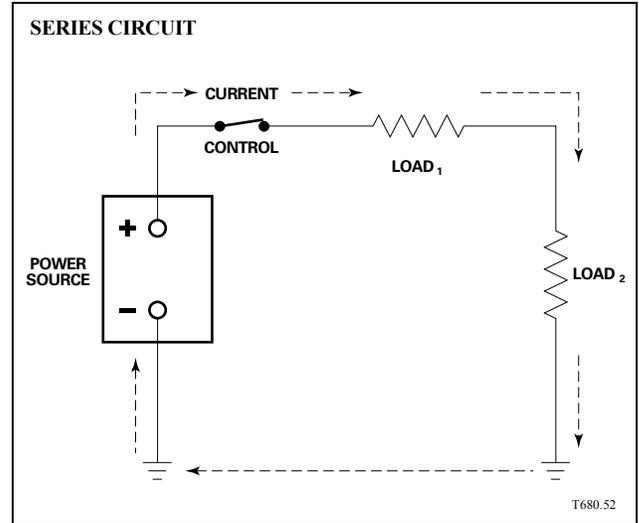
A parallel circuit is laid out with more than one current path, each through a load. After control, current flows through separate paths for each component. A break in one current path (after control) will disable only that path in the circuit.

A parallel circuit has the following characteristics:

- More than one load
- More than one path for current

The current flowing in a parallel circuit divides among the separate branches of the circuit. The total circuit current is equal to the sum of the individual branch currents.

NOTES



CIRCUITRY / OHM'S LAW

Basic Circuits

Series / Parallel Circuit

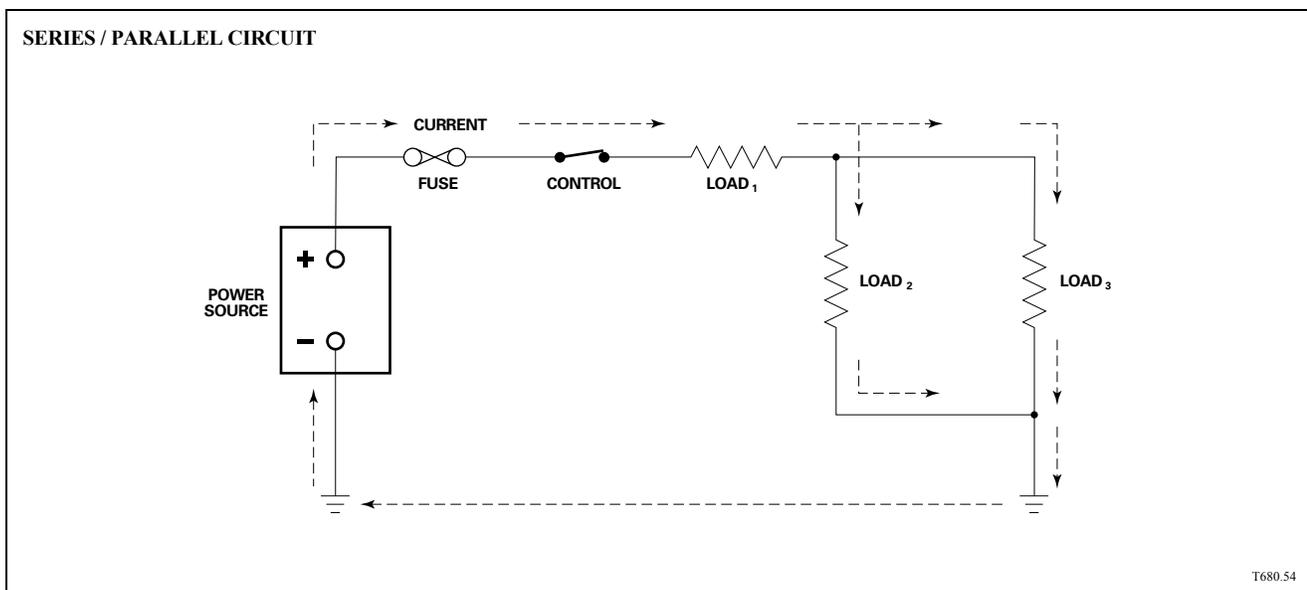
A series / parallel circuit combines the series and parallel circuits. The series and parallel portions of the circuit can be arranged in many ways as illustrated.

A series / parallel circuit has the following characteristics:

- More than one load
- Loads connected in series and in parallel
- More than one path for current

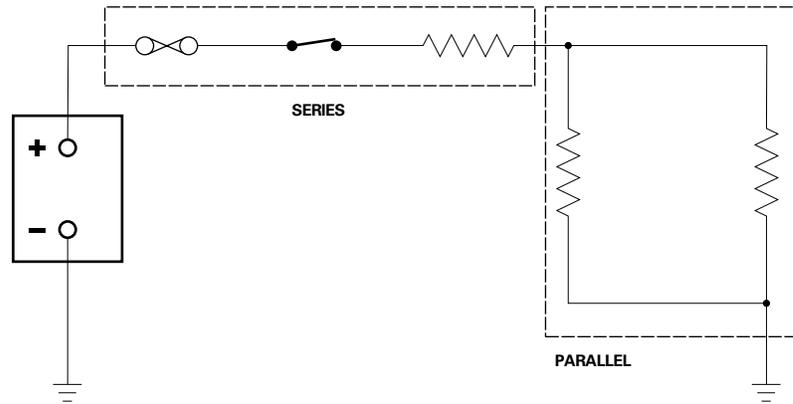
The current flowing in a series / parallel circuit divides among the separate branches of the parallel portion of the circuit. The current flowing in the series portion of the circuit is the same at any point. The total circuit current in the parallel portion of the circuit is equal to the sum of the individual branch circuits.

Most automotive circuits are series / parallel circuits.



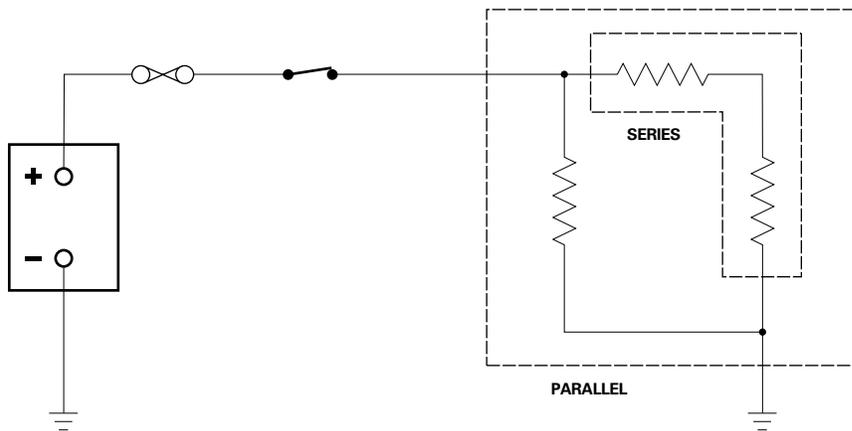
NOTES

SERIES PARALLEL CIRCUIT



T680.55

SERIES PARALLEL CIRCUIT



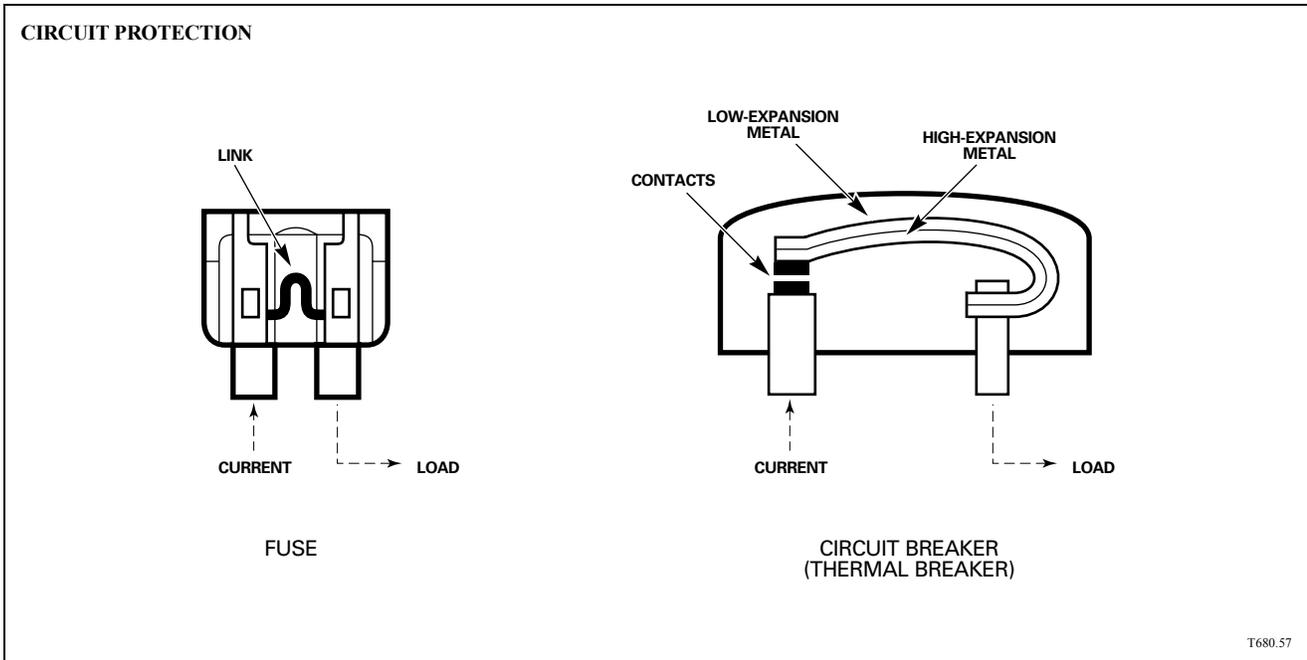
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CIRCUITRY / OHM'S LAW

Basic Circuits

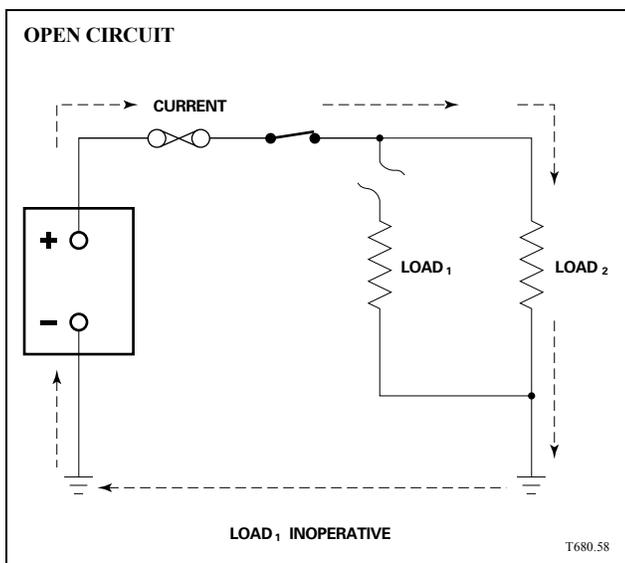
Circuit Protection

Electrical circuits are protected from overload by fuses and circuit breakers. Both devices interrupt current flow when excess heat is generated in the circuit. The fuse link melts to break the circuit; the contacts of the circuit breaker open to break the circuit.



Circuit Faults

Circuit faults can occur in any of three ways: open circuit, short circuit and grounded circuit.



Open circuit

Open circuit describes a complete break at some point in the circuit. Depending on where an open circuit occurs, one or more of the loads will not function.

NOTES

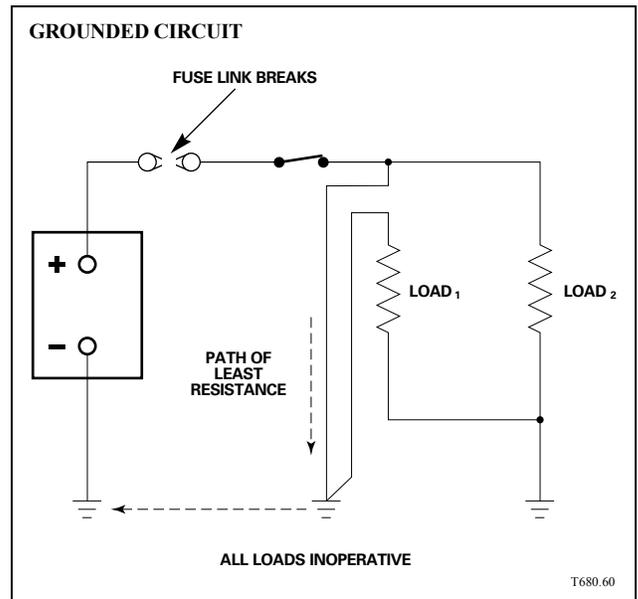
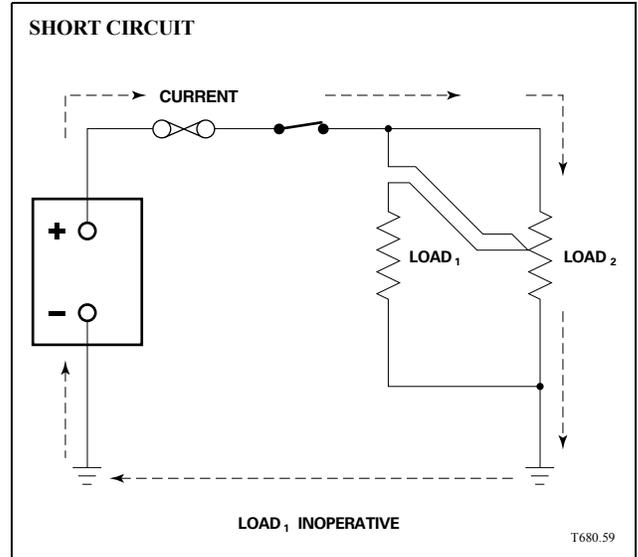
Short circuit

Short circuit describes an accidental bypass of a load or loads in the circuit. Since electricity will always take the path of least resistance, the result of a short circuit will be higher current flow and excess heat. Depending on where the short circuit occurs, the loads may or may not function.

Grounded circuit

A grounded circuit describes an accidental bypass of a load or loads to the ground path returning to the power source. Since electricity will always take the path of least resistance, a grounded circuit will cause very high current flow and excess heat. Without circuit protection, a grounded circuit will burn or melt circuit components.

NOTES



CIRCUITRY / OHM'S LAW

Ohm's Law

Ohm's Law states that voltage (E = electromotive force), amperage (I = impedance) and resistance (R = Ohms) are related. This relationship can be described in three ways:

OHM'S LAW

$$I = E \div R$$

(AMPERES = VOLTS \div OHMS)

$$R = E \div I$$

(OHMS = VOLTS \div AMPERES)

$$E = I \times R$$

(VOLTS = AMPERES \times OHMS)

T680.61

One volt (E) in a circuit with a resistance of one Ohm (R) will cause a current of one ampere (I).

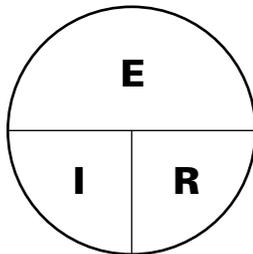
If resistance (R) remains the same, a change in voltage (E) will cause a similar change in current (I).

If voltage (E) remains the same, a change in resistance (R) will cause an opposite change in current (I).

The diagram below left simplifies remembering the three formulas of Ohm's Law. By covering the value needed, the relationship of the two remaining values will provide the answer.

NOTES

OHM'S LAW DIAGRAM



T680.62

Amperage

To find amperage:

- cover the I
- E and R remain
- horizontal line indicates “divide by”
- divide the voltage (E) by the resistance (R) to provide the amperage (I)

Resistance (Ohms)

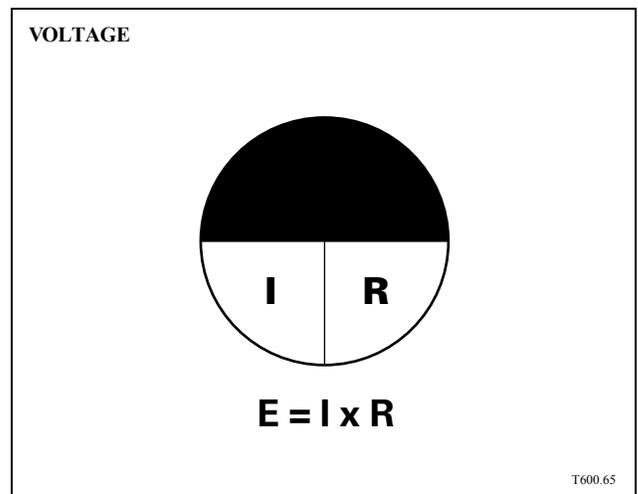
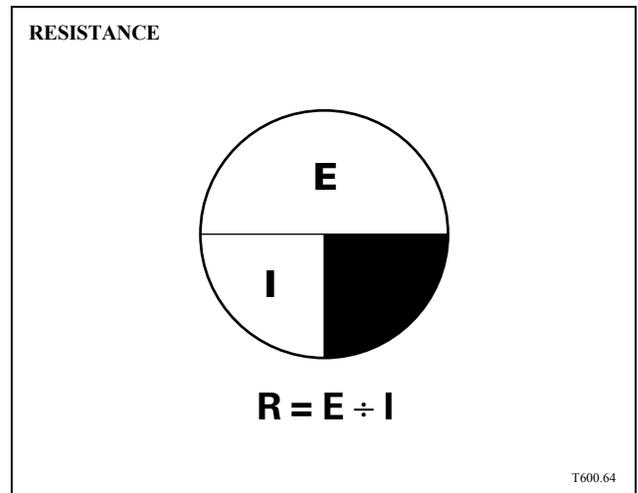
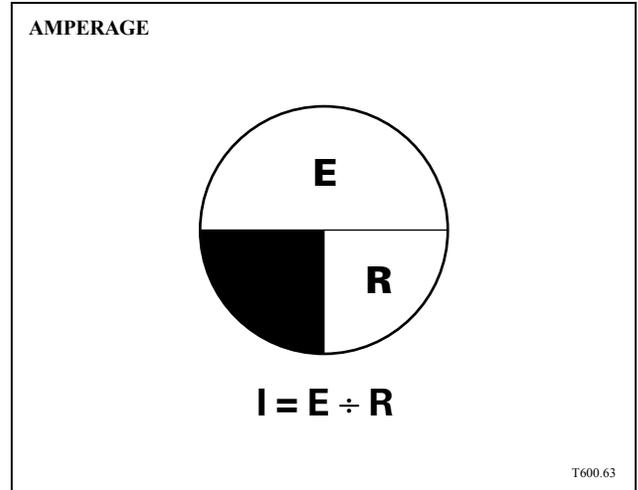
To find resistance:

- cover the R
- E and I remain
- horizontal line indicates “divide by”
- divide the voltage (E) by the amperage (I) to provide the resistance (R)

Voltage

To find voltage:

- cover the E
- I and R remain
- vertical line indicates “multiply by”
- multiply the amperage (I) by the resistance (R) to provide the voltage (E)



CIRCUITRY / OHM'S LAW

Ohm's Law

OHM'S LAW RELATIONSHIP TABLE

VOLTAGE	RESISTANCE	AMPERAGE
↑	↓	↑
↑	↔	↑
↑	↑	↔
↔	↓	↑
↔	↔	↔
↔	↑	↓
↓	↔	↔
↓	↑	↓
↓	↔	↓

↑ UP ↓ DOWN ↔ SAME

T680.108

Ohm's Law Relationship Table

The Ohm's Law relationship between voltage, amperage and resistance is shown in the table at right.

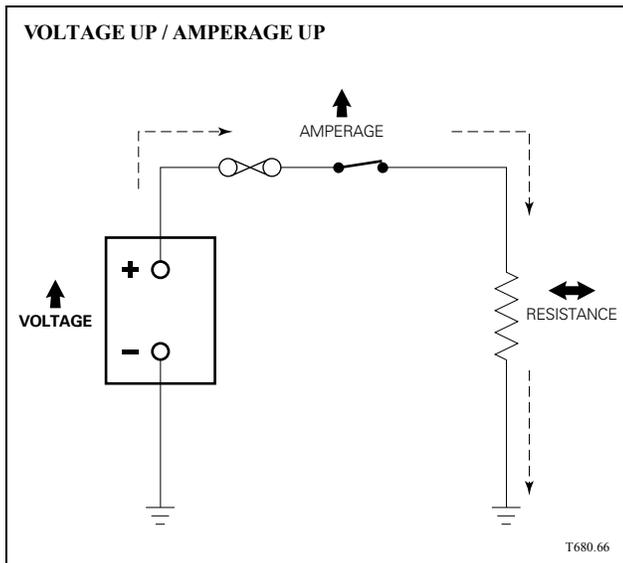
Ohm's Law Used in Circuit Diagnosis

Examples of the practical application of Ohm's Law to the diagnosis of a simple circuit follow.

Voltage up / amperage up

If an alternator is over charging, the voltage rises while the resistance remains the same. The result will be that amperage will rise, possibly causing damage to electrical loads in the circuit.

NOTES



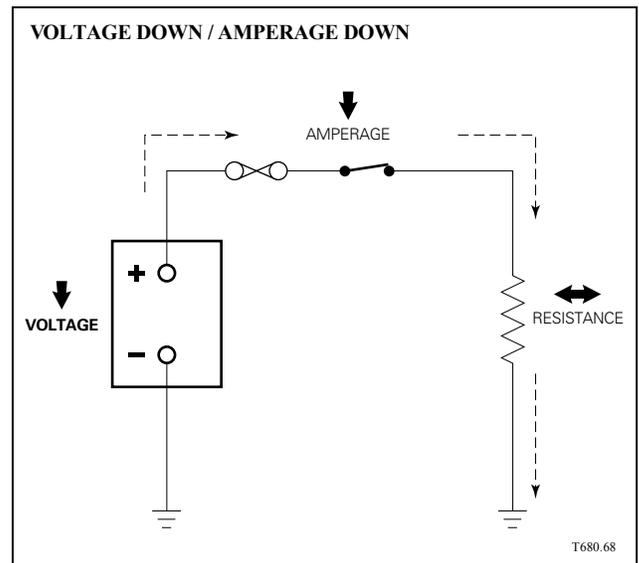
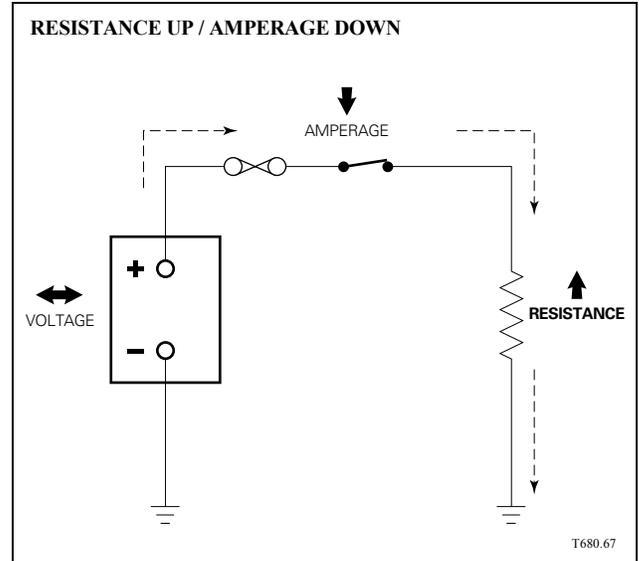
Resistance up / amperage down

If corrosion on electrical terminals or contacts occurs, resistance will increase in that area. The result will be that amperage will lower causing the performance of electrical loads to lower.

Voltage down / amperage down

If the battery voltage is low, the performance of a load such as the starter motor will decrease. The resistance remains the same; therefore, the amperage lowers.

NOTES



CIRCUITRY / OHM'S LAW

Ohm's Law

Ohm's Law: Series Circuits

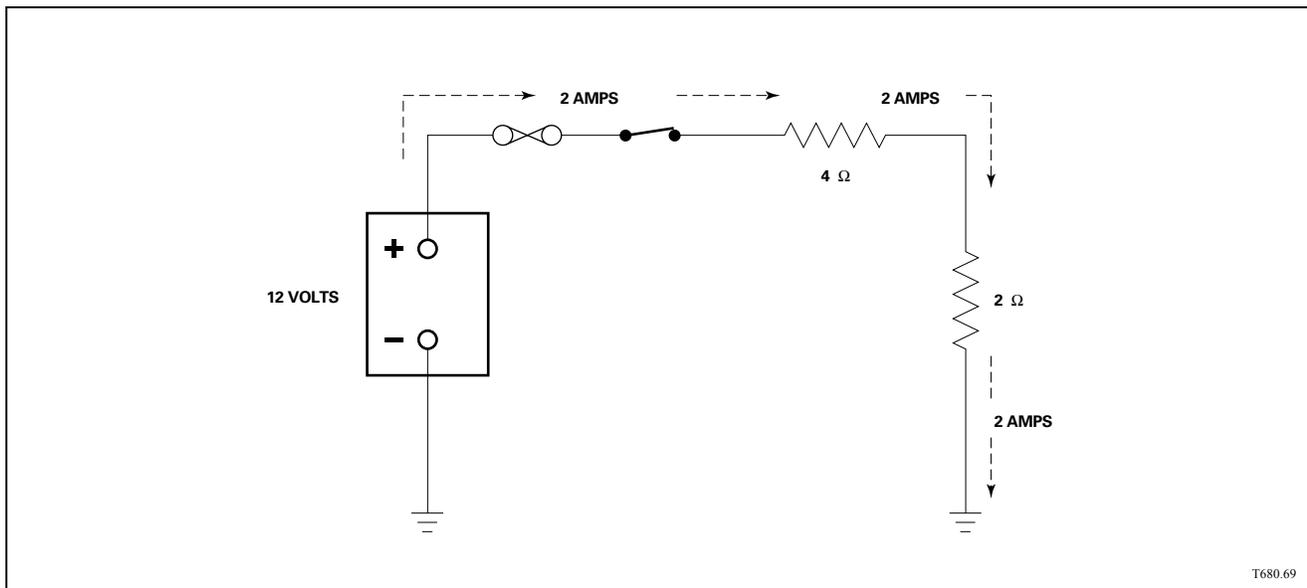
Series circuits have characteristics related to the use of Ohm's Law:

- 1 The current through each resistance is the same.
- 2 The sum of individual voltage drops is equal to the source voltage.
- 3 The total circuit resistance is equal to the sum of the individual resistances.

Examples of each of these characteristics follow. A series circuit with two loads (resistance) is used as the example. The circuit current is 2 amperes. One resistance is 4 Ohms, the other 2 Ohms.

- 1 The current through each resistance is the same.

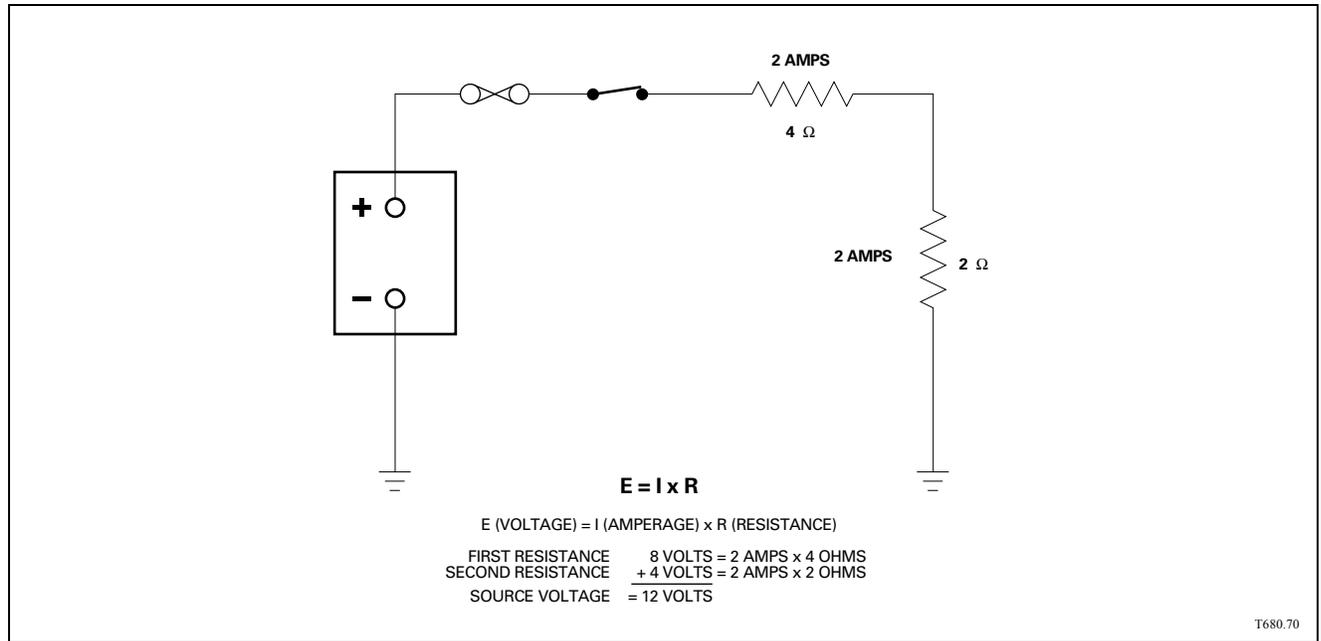
Since a series circuit has only one path for current, current through each resistance is the same.



NOTES

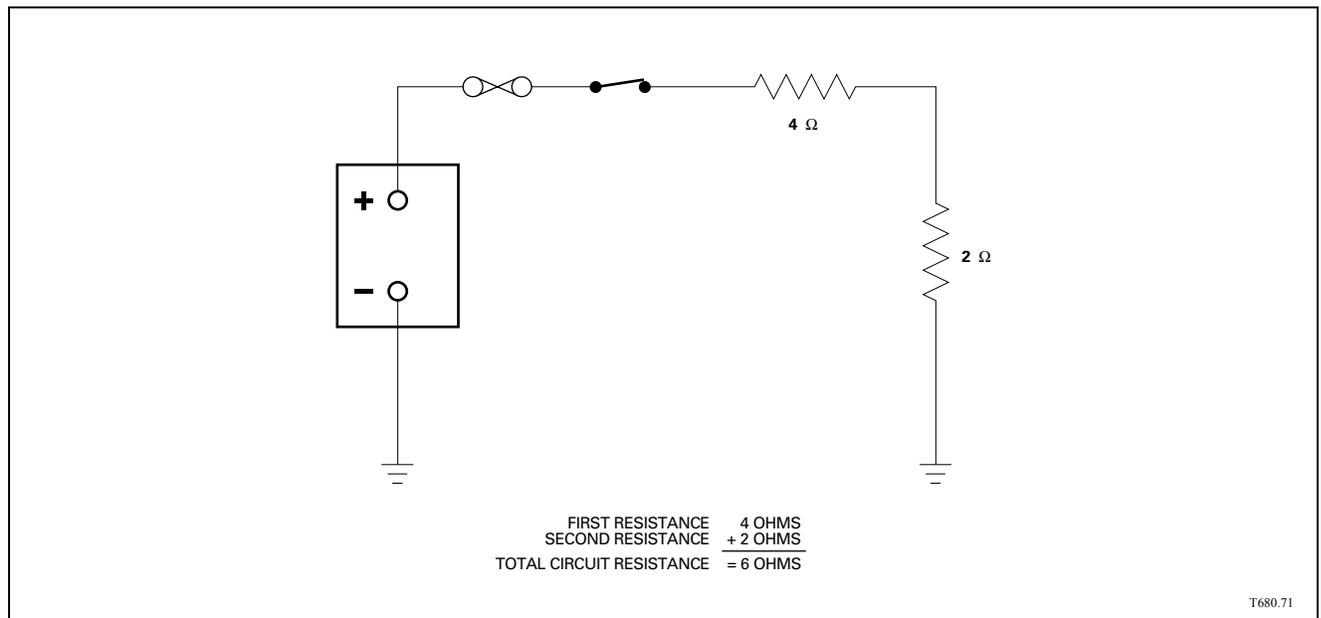
2 The sum of individual voltage drops is equal to the source voltage.

“Voltage drop” is the difference in the voltage before and after a resistance. Voltage drop for each resistance can be determined using the formula $E = I \times R$. Add the individual voltage drops in the circuit to determine the source voltage.



3 The total circuit resistance is equal to the sum of the individual resistances.

To determine the total circuit resistance, add the values of all the resistors.



CIRCUITRY / OHM'S LAW

Ohm's Law

Ohm's Law: Parallel Circuits

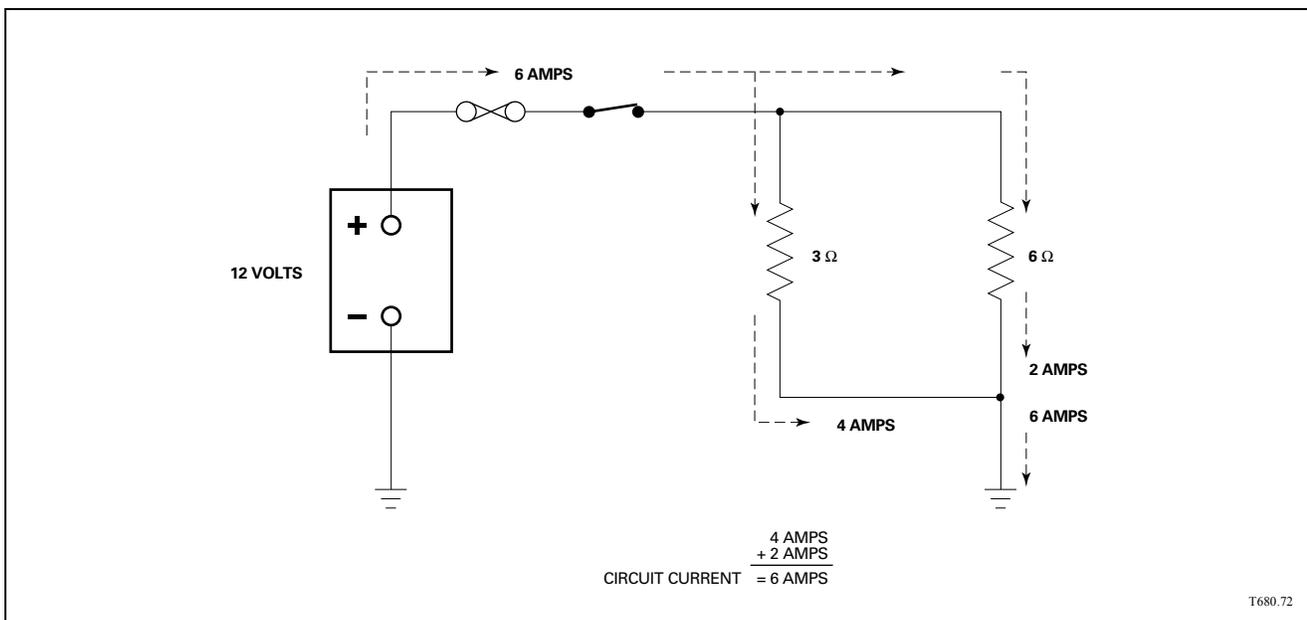
Parallel circuits also have characteristics related to the use of Ohm's Law:

- 1 The sum of the branch circuit currents is equal to the total circuit current.
- 2 The voltage drop across each branch circuit is the same.
- 3 The current in each branch circuit is different if the resistance values are different.
- 4 The total circuit resistance (equivalent resistance) is less than the value of the lowest resistance.

Examples of each of these characteristics follow.

1 The sum of the branch circuit currents is equal to the total circuit current.

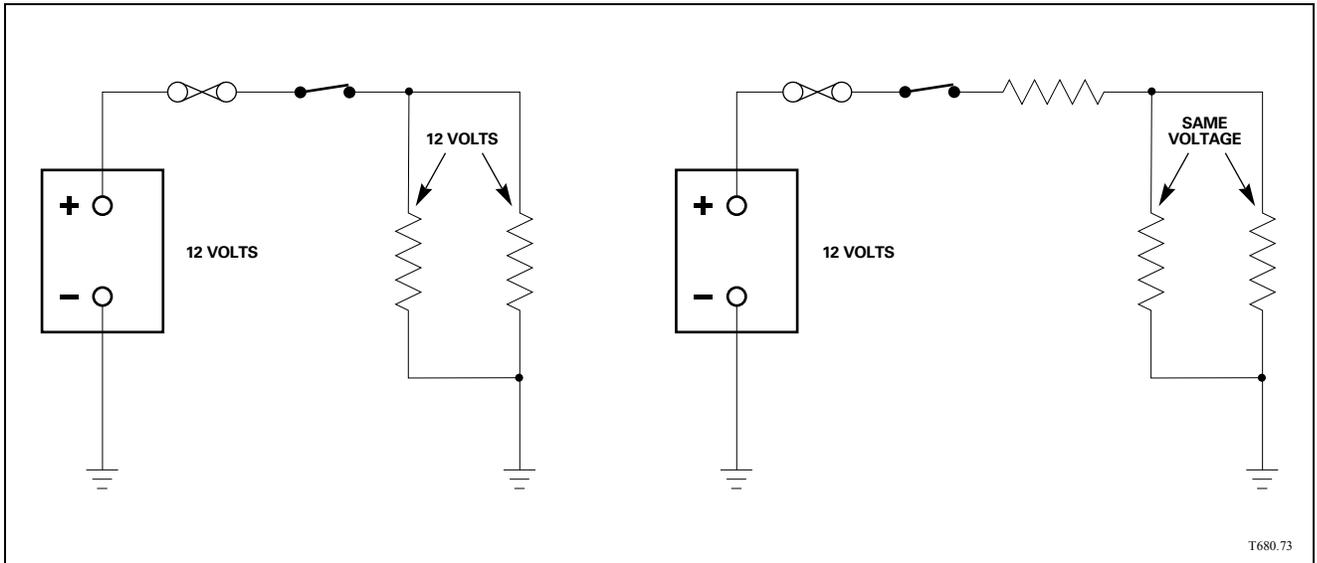
A parallel circuit provides a current path through each branch circuit; therefore, the total current at the power source is the total current combined from the branch circuits.



NOTES

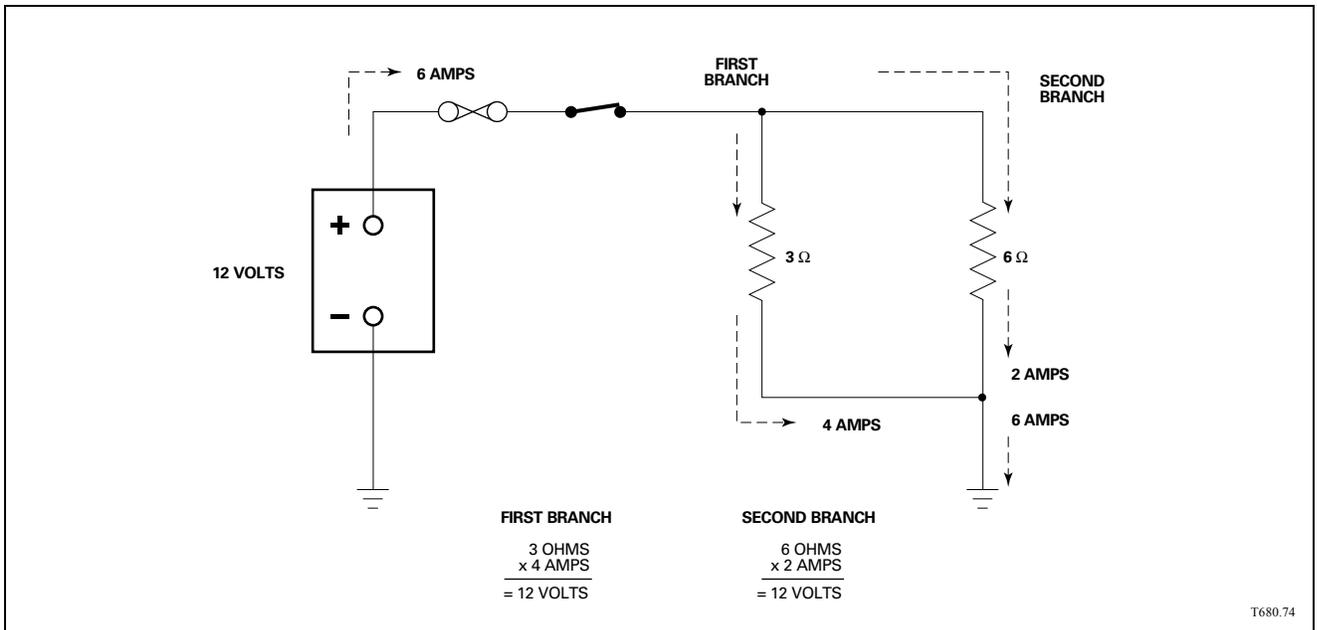
2 The voltage drop across each branch circuit is the same.

Because each branch circuit is a separate current path, the same voltage is available to each branch.



3 The current in each branch circuit is different if the resistance values are different.

Because each resistance in a parallel circuit uses the same voltage, the amount of resistance in each branch determines the amount of current in the branch.



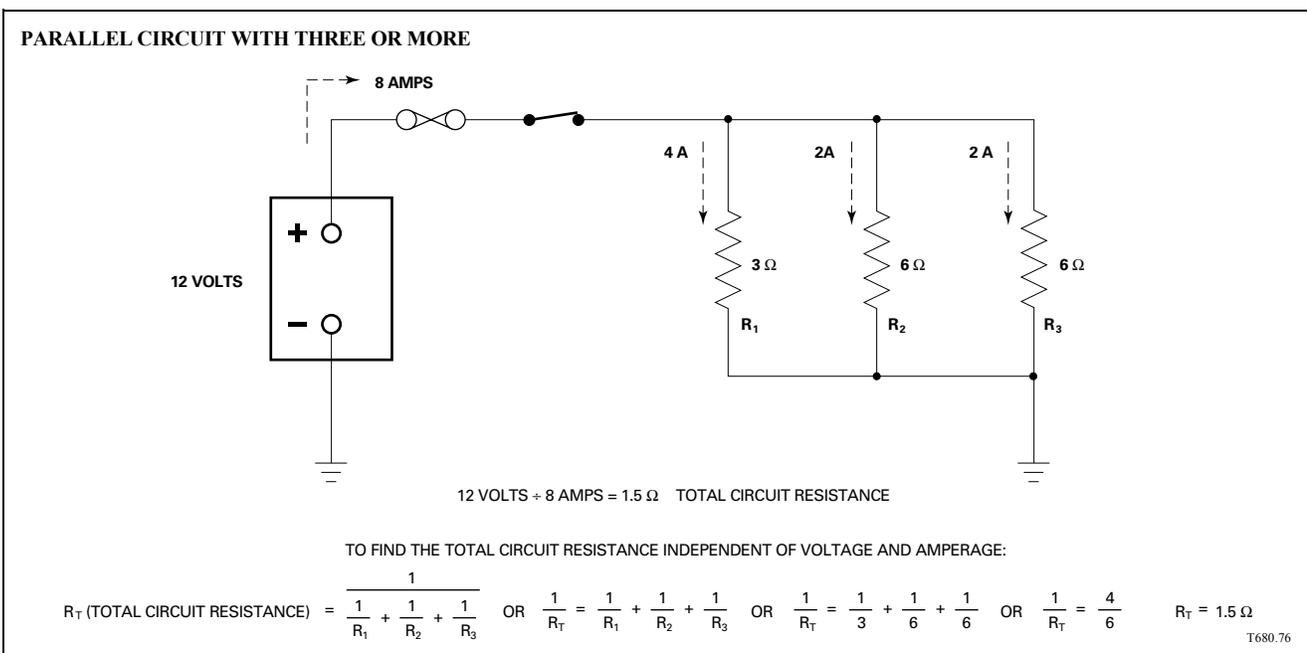
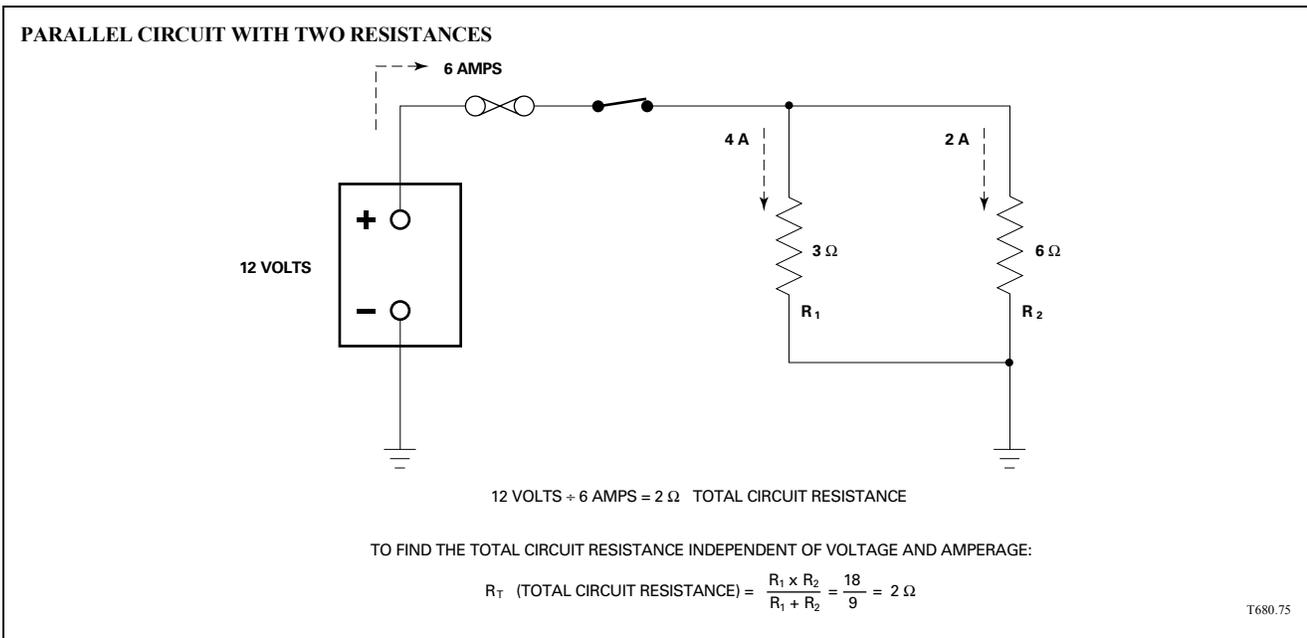
CIRCUITRY / OHM'S LAW

Ohm's Law

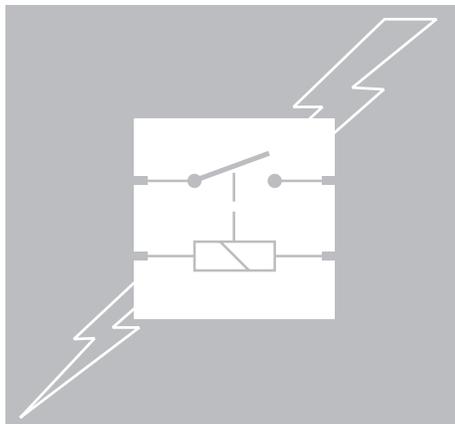
Ohm's Law: Parallel Circuits (continued)

4 The total circuit resistance (equivalent resistance) is less than the value of the lowest resistance.

The total circuit resistance in a parallel circuit is referred to as "equivalent resistance". The equivalent resistance will always be less than the value of the lowest resistance because the circuit current will flow through more than one resistance. Think of a plumbing arrangement with one supply pipe connected to more than one smaller pipes.



ELECTRICAL SYSTEMS I

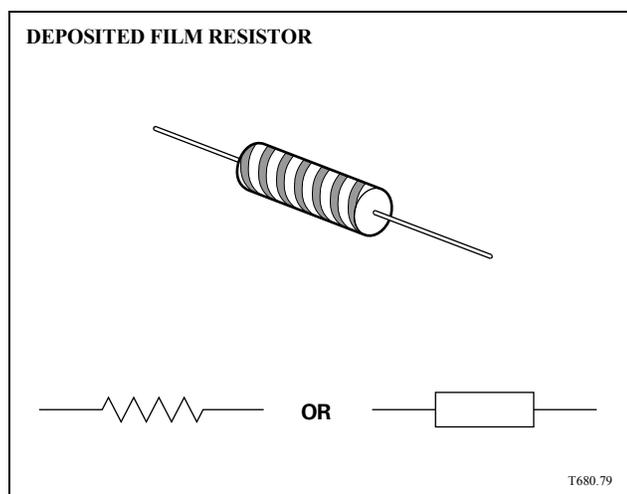
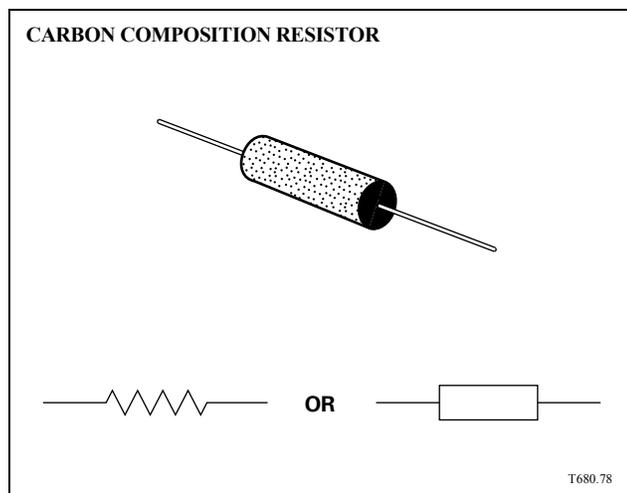
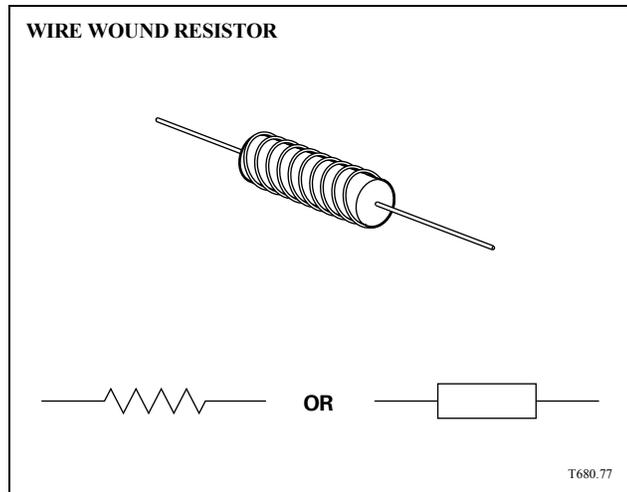


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CIRCUIT COMPONENTS

Resistance Components



Resistors

A resistor is an electronic component that has a specified resistance value. The resistor is used in a circuit to introduce a desired amount of resistance into the circuit. Three methods of construction are employed to manufacture resistors: wire wound, composition and deposited film.

Wire wound resistor

The wire wound resistor consists of a specified length of small gauge wire wound around an insulator such as a ceramic tube.

Carbon composition resistor

The element carbon is a semiconductor and makes an ideal material for resistors. By combining carbon granules and a powdered insulating material in various proportions, a wide range of resistor values can be achieved.

Deposited film resistor

The deposited film resistor operates similarly to the wire wound resistor. A carbon film is deposited on an insulator rod. Then a resistance value is set by cutting a spiral groove through the film. The result is a long flat ribbon around the tube. The groove adjusts the width and length of the ribbon to achieve the desired resistance value.

NOTES

Thermistor

The resistance of materials can change with a change in temperature; therefore, resistors can have changing resistance value dependent on temperature. A thermistor is a resistor that can achieve a large change in resistance for a small change in temperature. Thermistors normally have a negative temperature coefficient — the resistance decreases as temperature increases.

Variable Resistors

Two types of variable resistors are used in automotive circuits. Variable resistors are used to vary the control of circuits and to provide a means of converting mechanical position into a voltage.

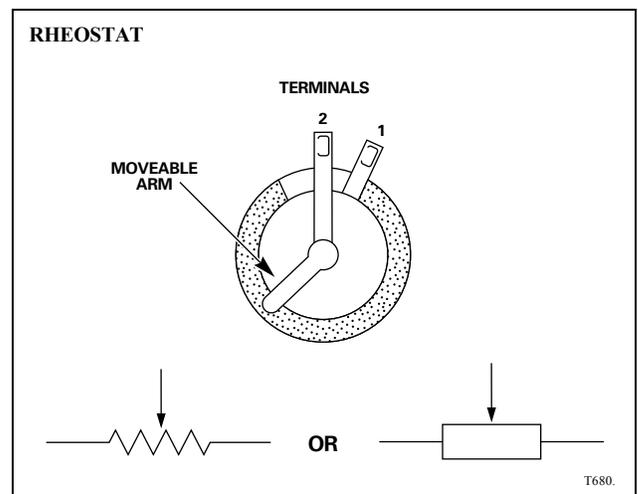
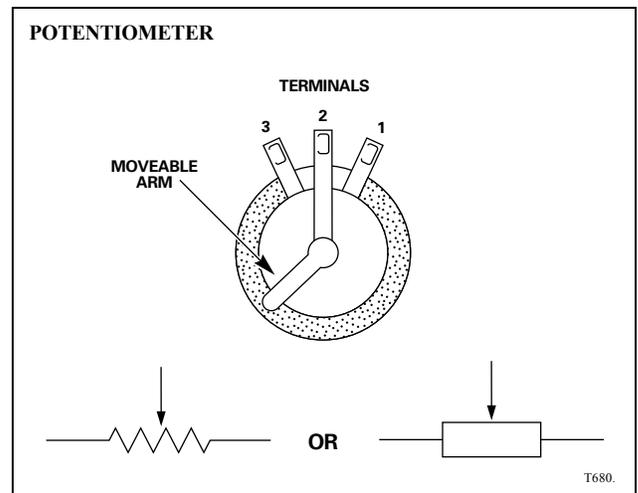
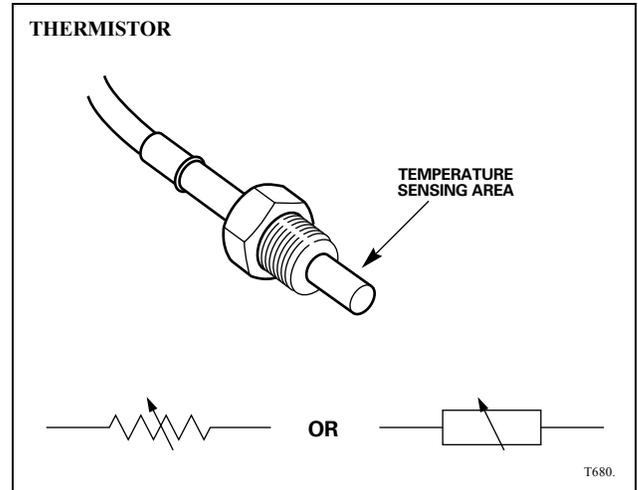
Potentiometer

A potentiometer is made up of a circular flat carbon ribbon connected to two terminals (1 and 3) with a third terminal (2) connected to a moveable contact. The contact moves along the resistance as the shaft turns, increasing or decreasing the relative resistance between terminals 1 and 2 and terminals 3 and 2.

Rheostat

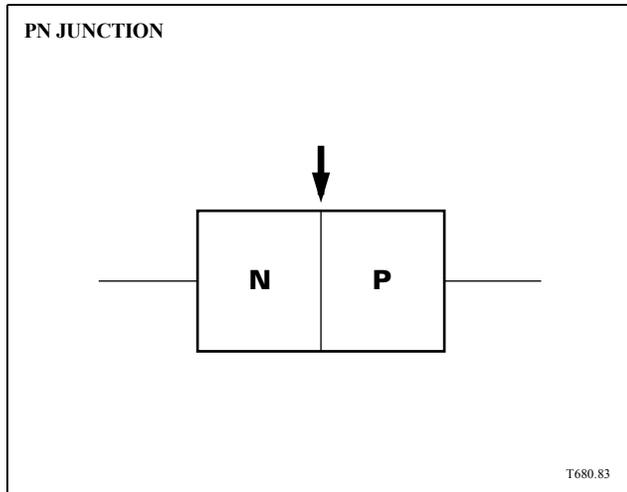
A rheostat is identical to a potentiometer except that terminal 3 is omitted. This arrangement allows the resistance to be varied between terminals 1 and 2.

NOTES



CIRCUIT COMPONENTS

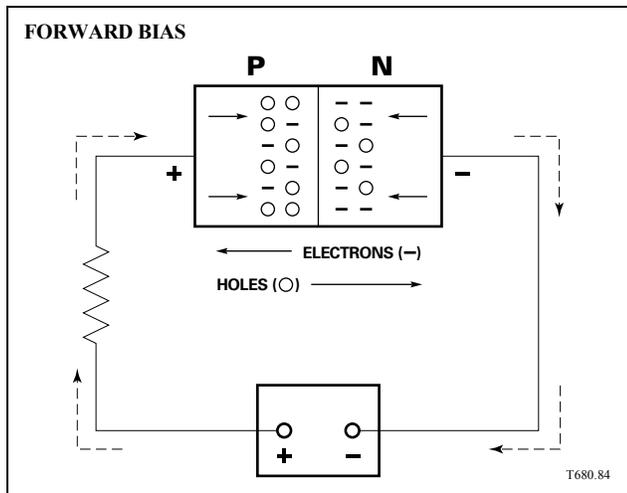
Semiconductor Components



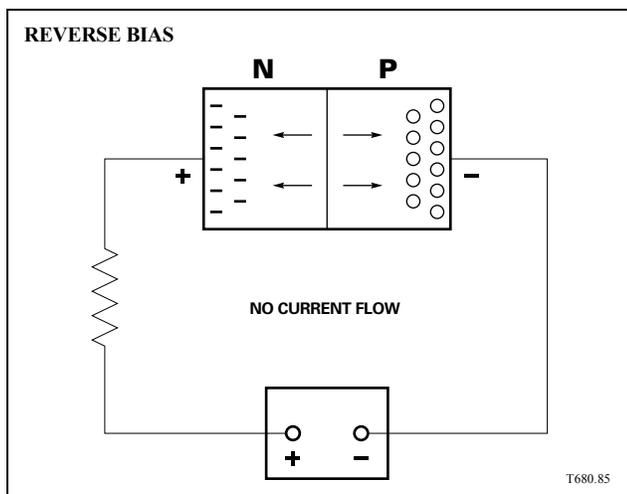
As explained earlier, a semiconductor material is neither a good conductor nor insulator. However, by altering the atomic structure of the semiconductor material the conductivity of the material can be increased. In addition, the material can be restructured in such a way as to create material with additional electrons that are free to move, or with a deficiency of electrons that provide a place (holes) for free electrons to move toward. Materials with additional electrons are N type semiconductors; materials with a deficiency of electrons are P type semiconductors.

Diodes

When N and P type semiconductor materials are grown together to form a single crystal, a solid state diode is created that allows electron flow in one direction only. The area where the N and P type materials join is called the PN junction.



When a battery is connected to the PN junction so that negative voltage is applied to the N type material and positive voltage is applied to the P type material, electrons will cross the junction and combine with “holes” (after a minimal voltage is exceeded) creating a conductor. Current flows through the diode. This condition is called forward bias.



When the battery connection are reversed, electrons and “holes” are attracted by the unlike charges of the battery and move away from the junction. No current can flow through the diode. This condition is called reverse bias.

NOTES

Solid state diode

The PN junction acts as a switch because it conducts only when it is forward biased. The N type material is referred to as the cathode and the P type material as the anode. In most Jaguar circuits, the cathode end is identified by a white wire, the anode end by a blue wire. The arrow head in the symbol points in the opposite direction to electron flow.

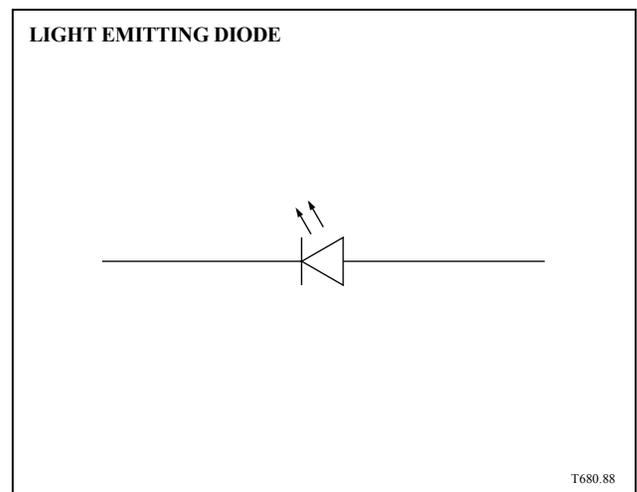
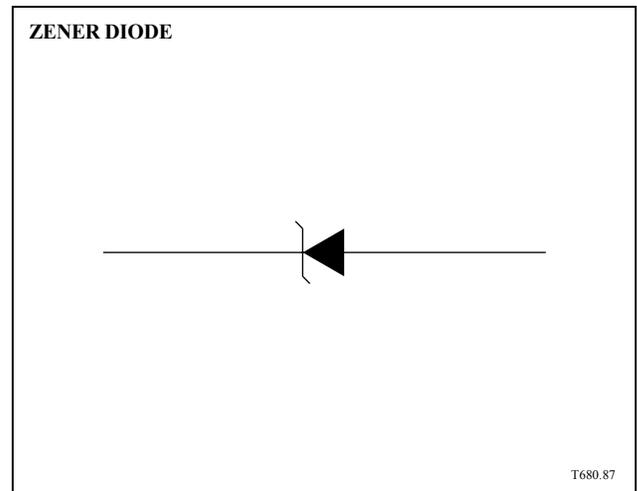
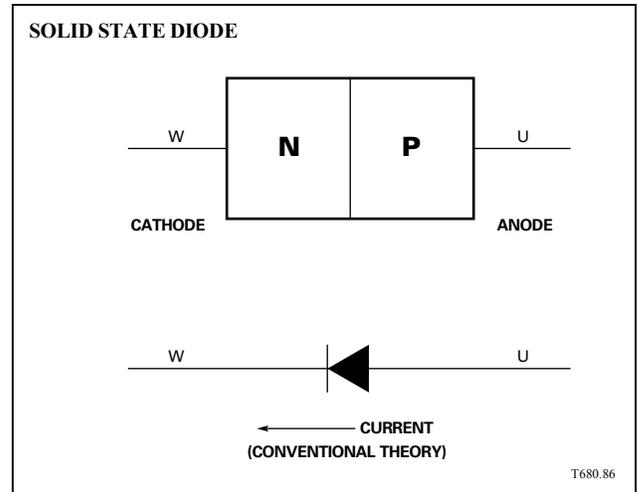
Zener diode

A zener diode is designed to have a specified “reverse breakdown” that allows conduction. By conducting in the reverse direction at a specific voltage, zener diodes can act as voltage sensitive switches. Zener diodes are typically used in voltage regulators and overvoltage protection devices.

Light emitting diode

All diodes emit some electromagnetic radiation when they are forward biased. Certain materials will emit considerably more radiation that becomes visible when forward biased. Light emitting diodes (LED) are typically used for locate and state lighting of controls.

NOTES



CIRCUIT COMPONENTS

Semiconductor Components

Transistors

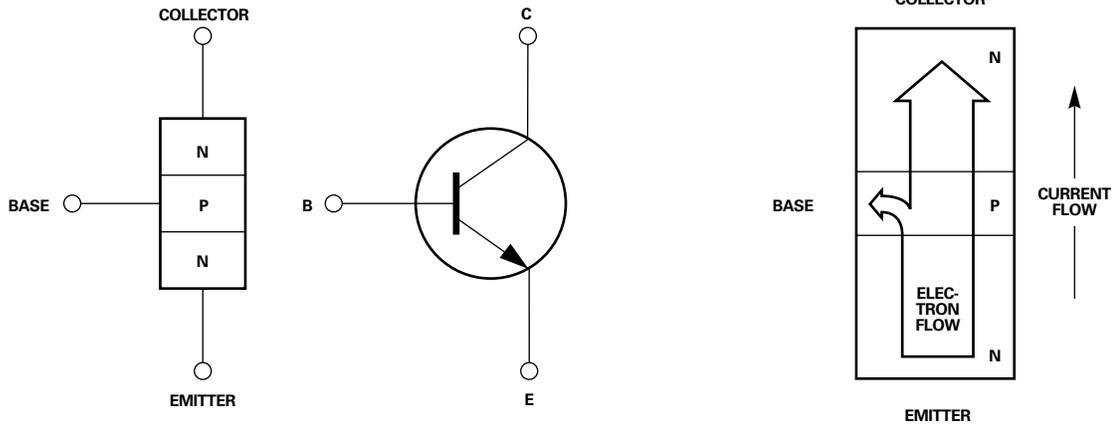
The transistor is an extension of the diode. A transistor is a single semiconductor crystal that contains two PN junctions (a diode has one). The transistor can be constructed in two ways: the P section can be sandwiched between two N sections, or the N section can be sandwiched between two P sections. These are referred to as NPN and PNP transistors.

The three sections of the transistor are called the emitter, the base and the collector. In the symbols, the emitter is identified by an arrow head. The arrow head points in the direction opposite to electron flow. The arrow head also points to the N type material.

When current is applied to the base, current will flow through the transistor. Current flows through the NPN transistor in one direction and through the PNP transistor in the opposite direction. The transistor has three modes of operation: off, switch and amplifier. When no voltage is applied to the base, no current flows through the transistor. When a constant minimal voltage is applied to the base, the transistor will act as a switch and allow current to flow. If the base voltage is varied, the current flow will follow the variation allowing the transistor to act as an amplifier.

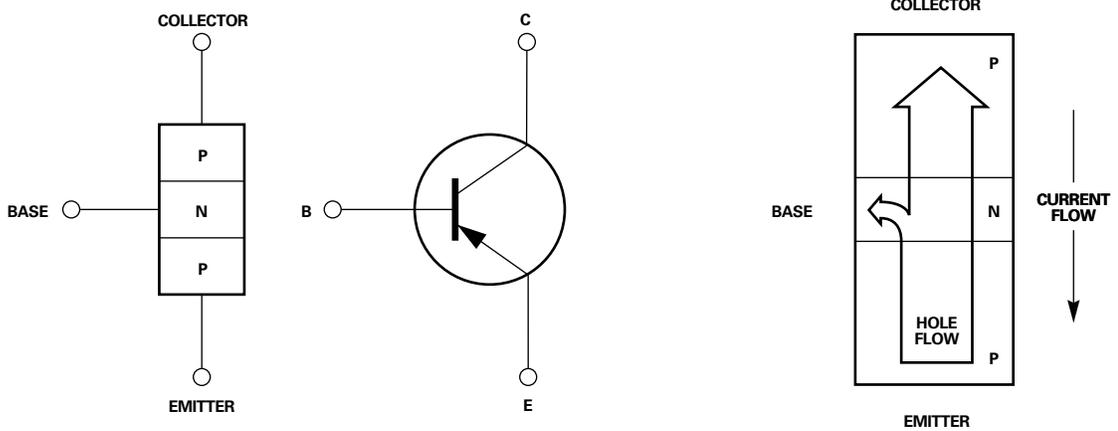
NOTES

NPN TRANSISTOR



T600.89

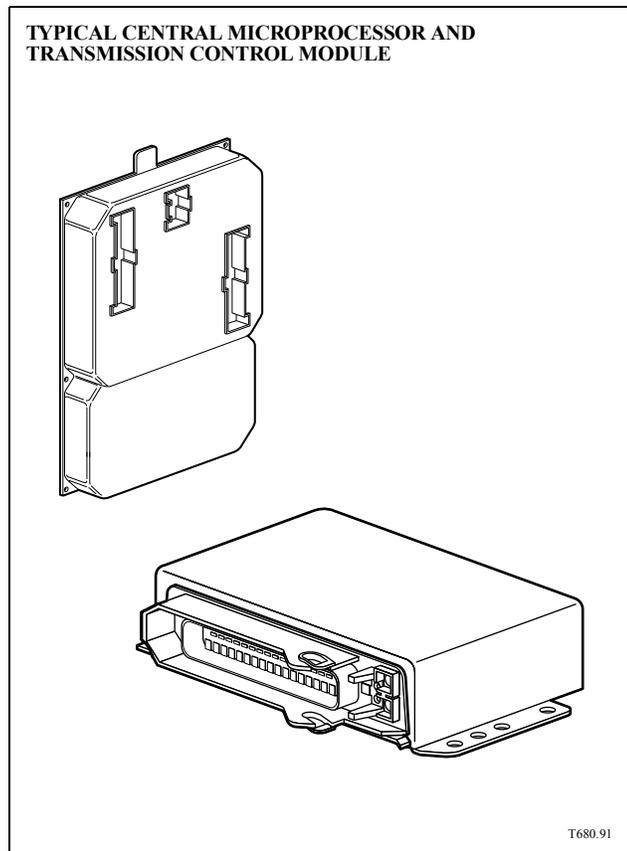
PNP TRANSISTOR



T600.90

CIRCUIT COMPONENTS

Microprocessors



Microprocessors are electronic devices that are used to perform complex, high-speed switching functions. In automotive use, microprocessors are contained in vehicle control modules. They provide sophisticated circuit control necessary for systems such as engine management, anti-lock braking and transmission control.

Microprocessors operate on three different kinds of memory:

ROM (Read Only Memory)

Read only memory is in permanent storage and cannot be altered. The programmed instructions are used by the microprocessor as directed by sensor input. The engine control module uses ROM to control all engine management functions.

PROM (Programmable Read Only Memory)

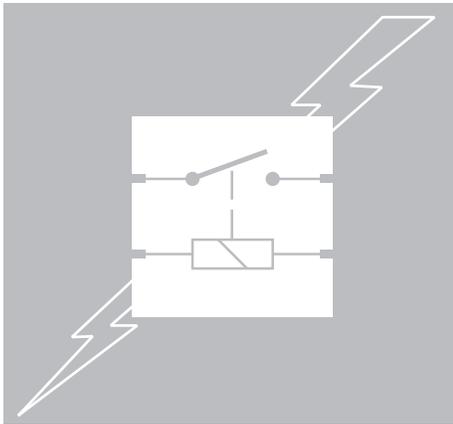
Programmable read only memory is in permanent storage, however, the user can select which functions to enable or disable. The security system control module uses PROM to allow the vehicle operator a choice of security system functions.

RAM (Random Access Memory)

Random access memory is used by a microprocessor to perform the processing functions. As used in a computer, RAM is used to both read and write information, meaning that documents can be created and modified based on programs contained in ROM.

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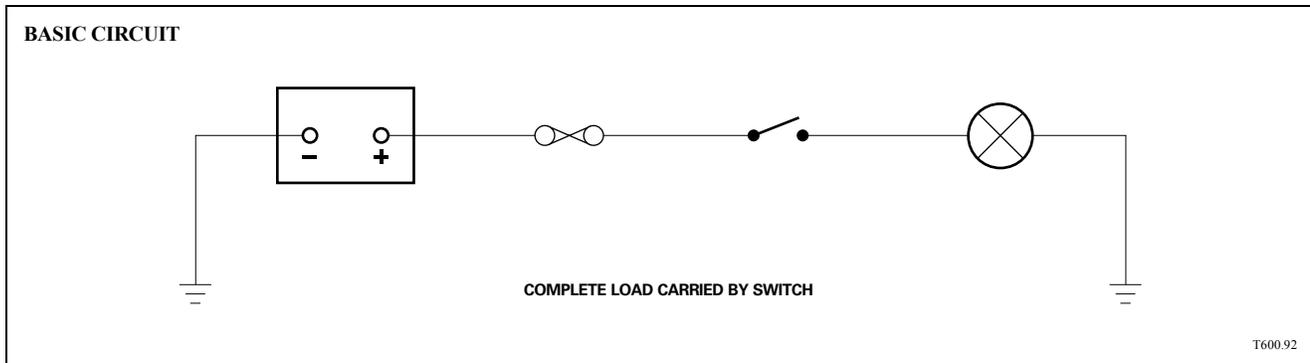


CIRCUIT DESIGN

Conventional Automotive Electrical Circuit

Basic Circuit

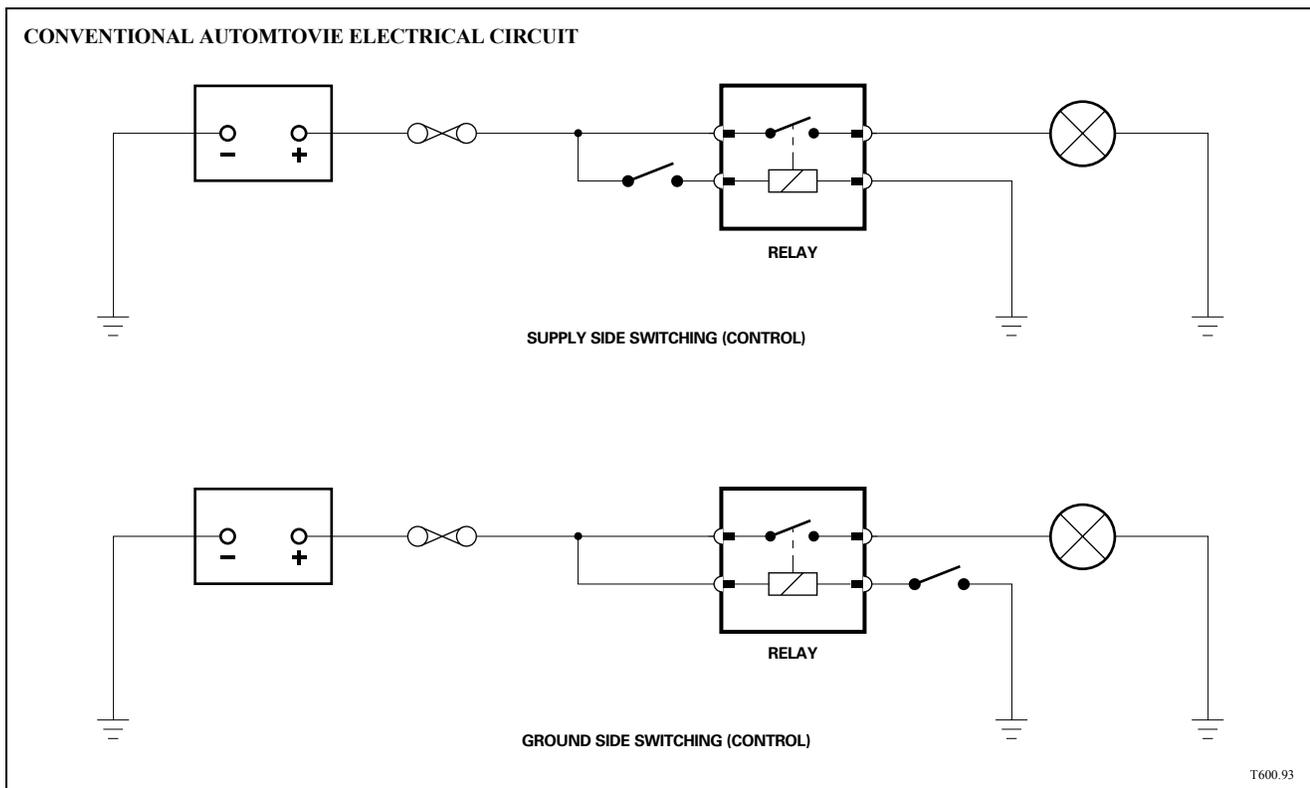
In a basic automotive electrical circuit, switching control for the circuit normally occurs on the supply (hot) side of the circuit. The switch is the obvious weak link in this circuit.



Conventional Automotive Electrical Circuit

To overcome this weakness, relays are used to carry heavy current loads allowing the use of a lighter duty switch to control the relay "coil" circuit. In certain circumstances the switch is located on the ground side of the coil circuit.

The XJS electrical circuit is designed using this conventional layout.

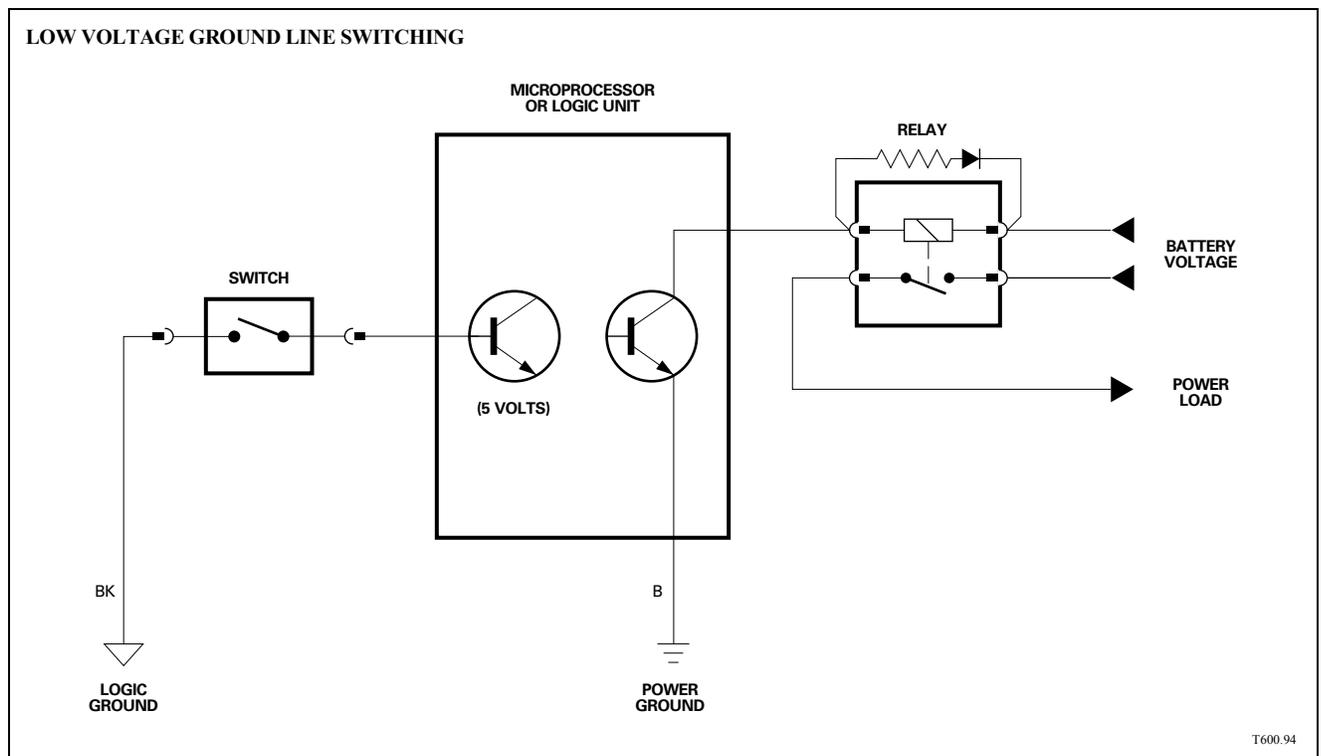


Low Voltage Ground Line Switching

In this circuit, the controlling switch is always located on the ground side of the circuit. Further, the switch now acts only as an input to a microprocessor, logic unit or an integral electronic circuit. The switch is therefore required to carry only very low current. The “ground” signal to a microprocessor, logic unit or electronic circuit is referred to as a LOGIC GROUND. The electronic circuit, in turn, controls a relay coil circuit. After receiving the logic ground input, the electronic circuit switches the ground side of the relay coil circuit to activate the relay. This ground connection is referred to as a POWER GROUND. Logic grounds are identified by the color code BK (black pink). Power grounds are identified by the color code B (black).

The Sedan Range electrical circuit is designed using this “low voltage ground line switching” layout. In the Sedan Range, all logic grounds are spliced together and complete the circuit to the battery negative terminal by a common wire. Power grounds are completed by chassis connection.

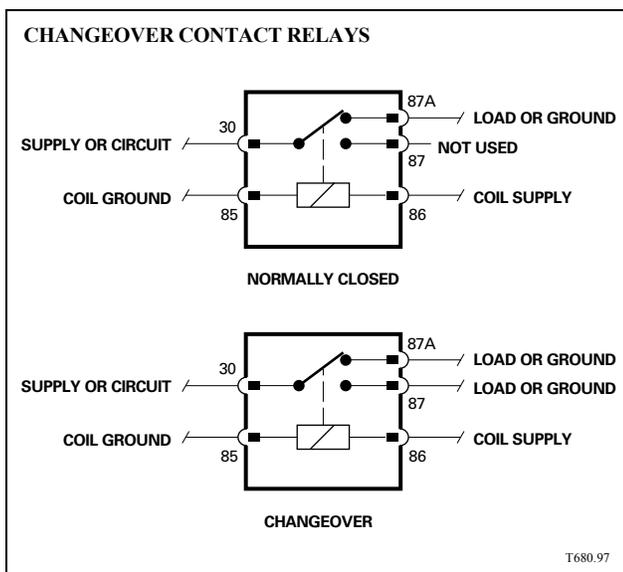
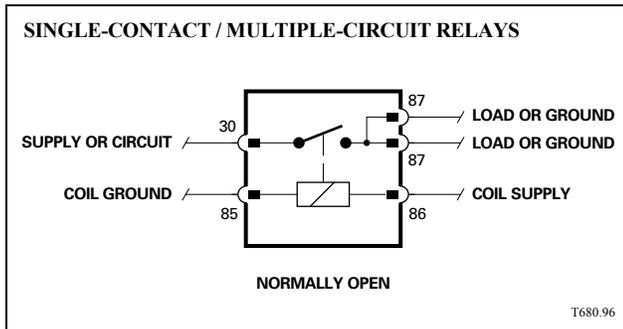
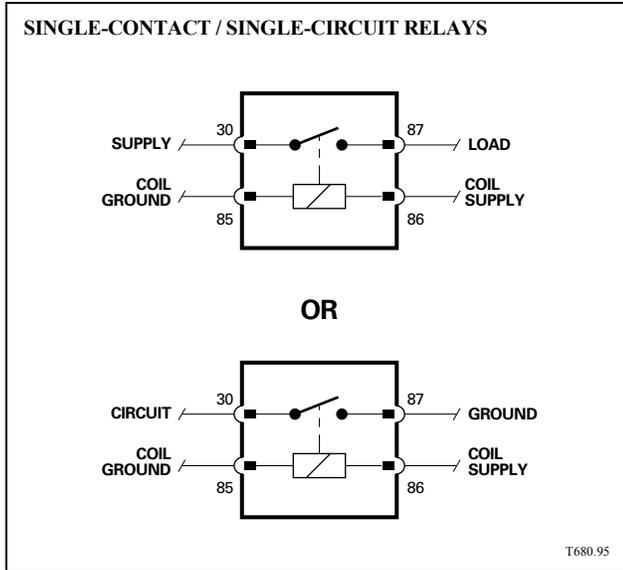
NOTE: The XJS Range electrical system uses a small number of circuits with logic grounds. These, as well as the power grounds, are completed by chassis connection.



NOTES

CIRCUIT DESIGN

Relays



Three basic types of relays are used in Jaguar circuits. Physically, the various relays have the same shape and size. The type is indicated by the case color; the internal circuit is depicted on the case. There are additional special-purpose relays, however, the three explained here make up the majority of those used in the circuits. The relays use a uniform method of identifying the terminals. Terminals 30 and 87 (and 87A) are the controlled circuit with 30 being the input and 87 and or 87A being the output. Terminals 85 and 86 are the controlling (coil) circuit. Terminal 86 is always the supply side of the coil and terminal 85 is always the ground side of the coil.

Single-Contact / Single-Circuit Relays

Single-contact / single-circuit relays are “normally open” and are used to switch on a load or complete a ground circuit.

Single-Contact / Multiple-Circuit Relays

Single-contact / multiple-circuit relays are “normally open” and are used to switch on a load(s) or complete a ground circuit(s). Terminals 87 and 87A are common via an internal splice.

Changeover Contact Relays

Changeover contact relays can be used as normally closed (load or ground connected to terminal 87A) or changeover relays (load or ground connected to terminals 87A and 87). The relay contact always rests on terminal 87A when the relay is not energized.

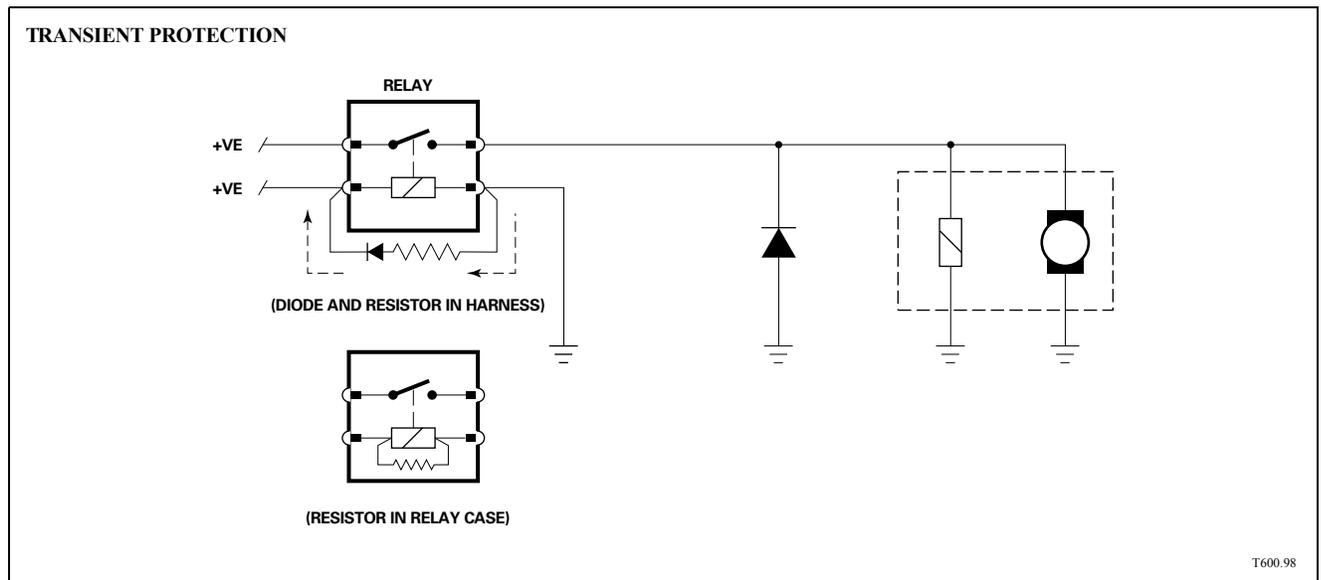
NOTES

Transient Protection

Relays and inductive power (coil type) consumers also have transient protection. Coils produce “high voltage spikes” when they are switched off and the magnetic field collapses.

Some relays have a resistor placed in parallel with the coil. Other relays have a diode and resistor placed in parallel with the coil. The voltage drop across the diode plus the drop across the resistor dissipates voltage as it “winds down”, similar to a flywheel. The majority of current production relays incorporate the protection components within the relay case. Some relays are wired with the protection components in the connecting harness. Relay modules and integral relays have the circuit incorporated into the circuit board.

Inductive power consumers such as the A/C clutch, horns, and radiator fan have a diode placed in the circuit which dissipates voltage when the component is switched off.

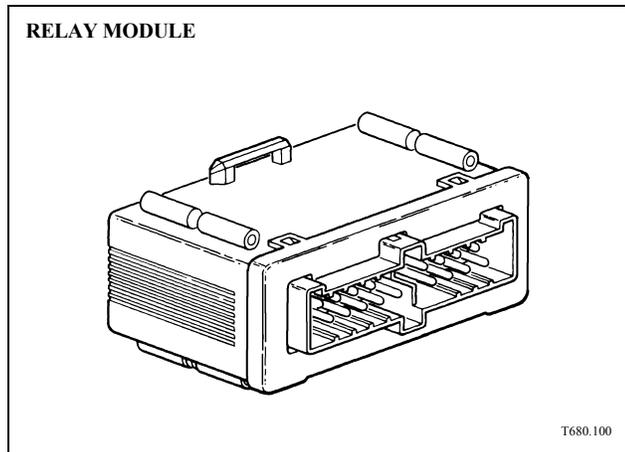


CAUTION: Never disconnect the battery with the engine running. Never use a test light to troubleshoot an electrical fault; use only a digital multimeter (DVOM).

NOTES

CIRCUIT DESIGN

Relays

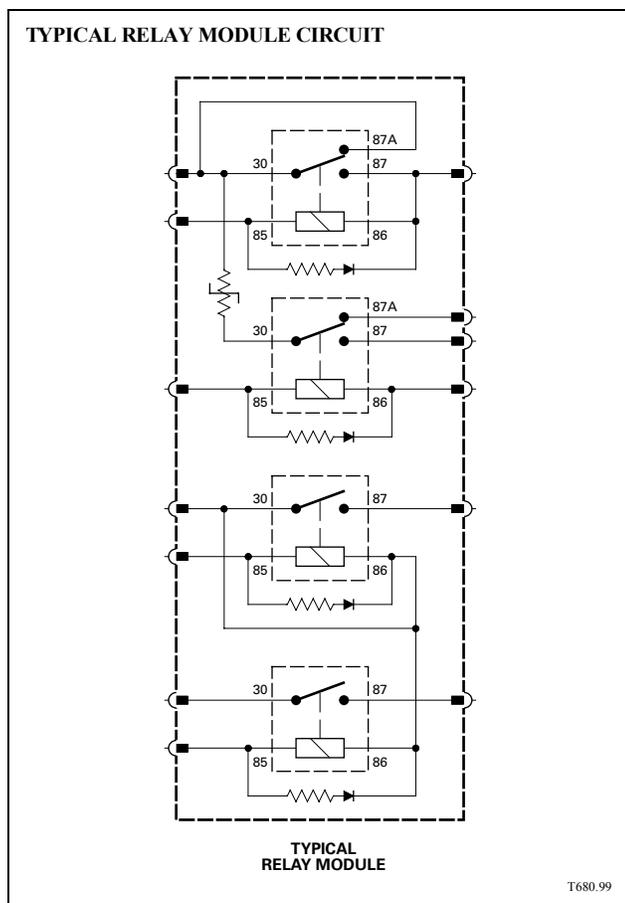


Relay Modules

Relay modules, introduced in the 1993 Model Year, contain four individual relays and additional components and circuitry formerly contained in the wiring harness, thereby simplifying the wiring harness. Each relay module is unique and carries a separate part number. In addition, circuit information is imprinted on the module label.

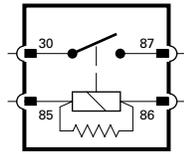
Both normally open and changeover contact relays are used in relay modules. The modules also incorporate internal transient protection.

CAUTION: Each relay module has unique circuitry; relay modules are not interchangeable.

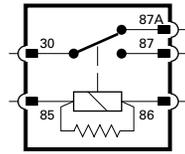


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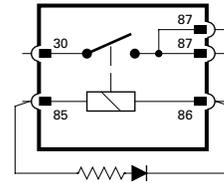
CURRENT PRODUCTION RELAYS



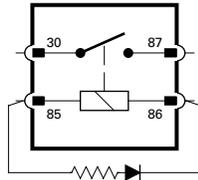
**NORMALLY OPEN
(LIGHT BLUE CASE)**



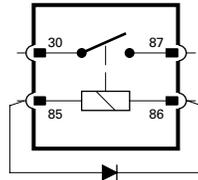
**CHANGE-OVER CONTACT
(VIOLET CASE)**



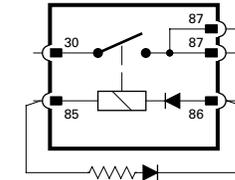
**NORMALLY OPEN
(SILVER CASE)**



**ABS MAIN
(WHITE CASE)**



**ABS PUMP
(YELLOW CASE)**



**NORMALLY OPEN
(SILVER CASE WITH RED STRIPE)**

T600.

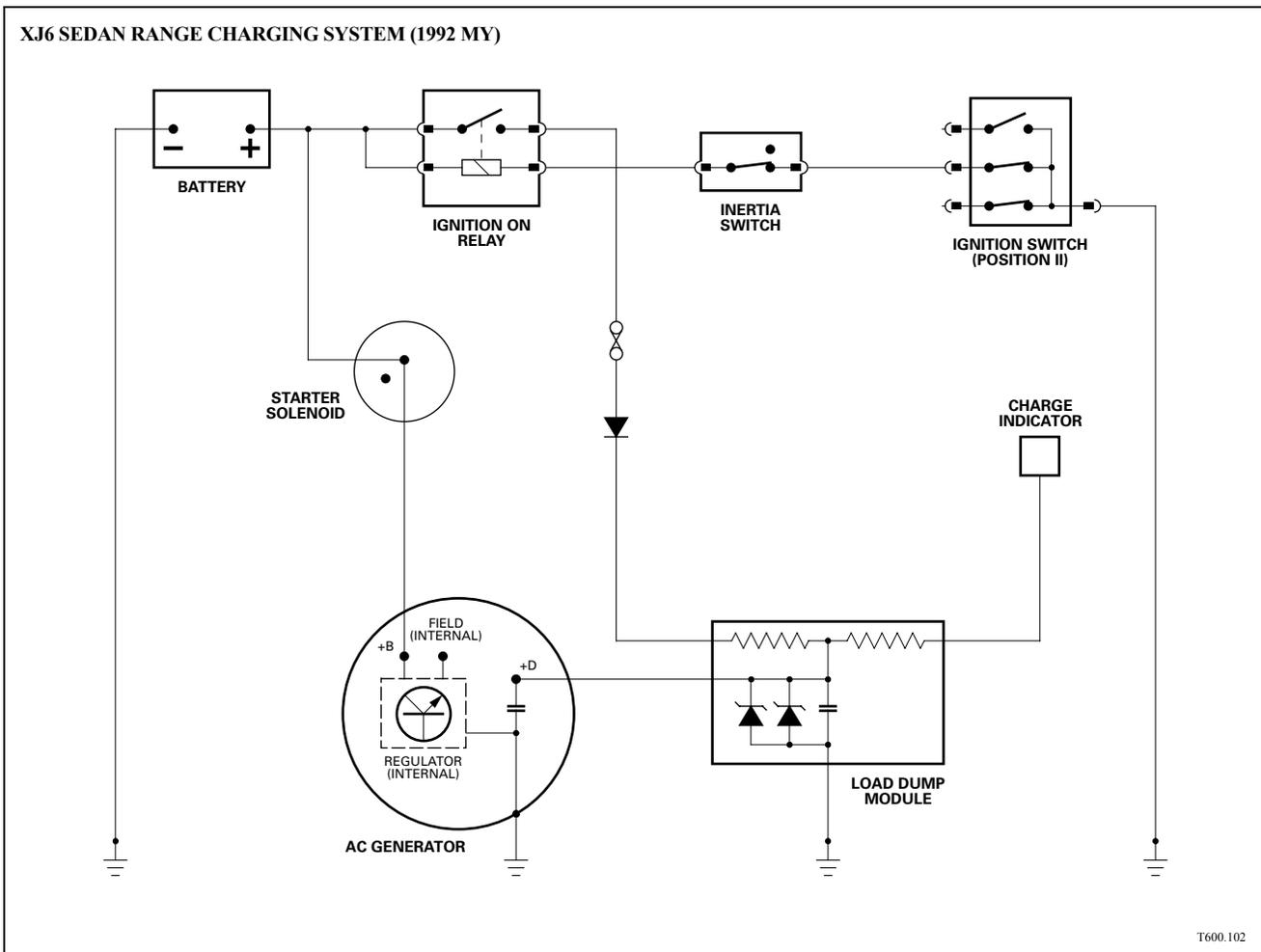
NOTES

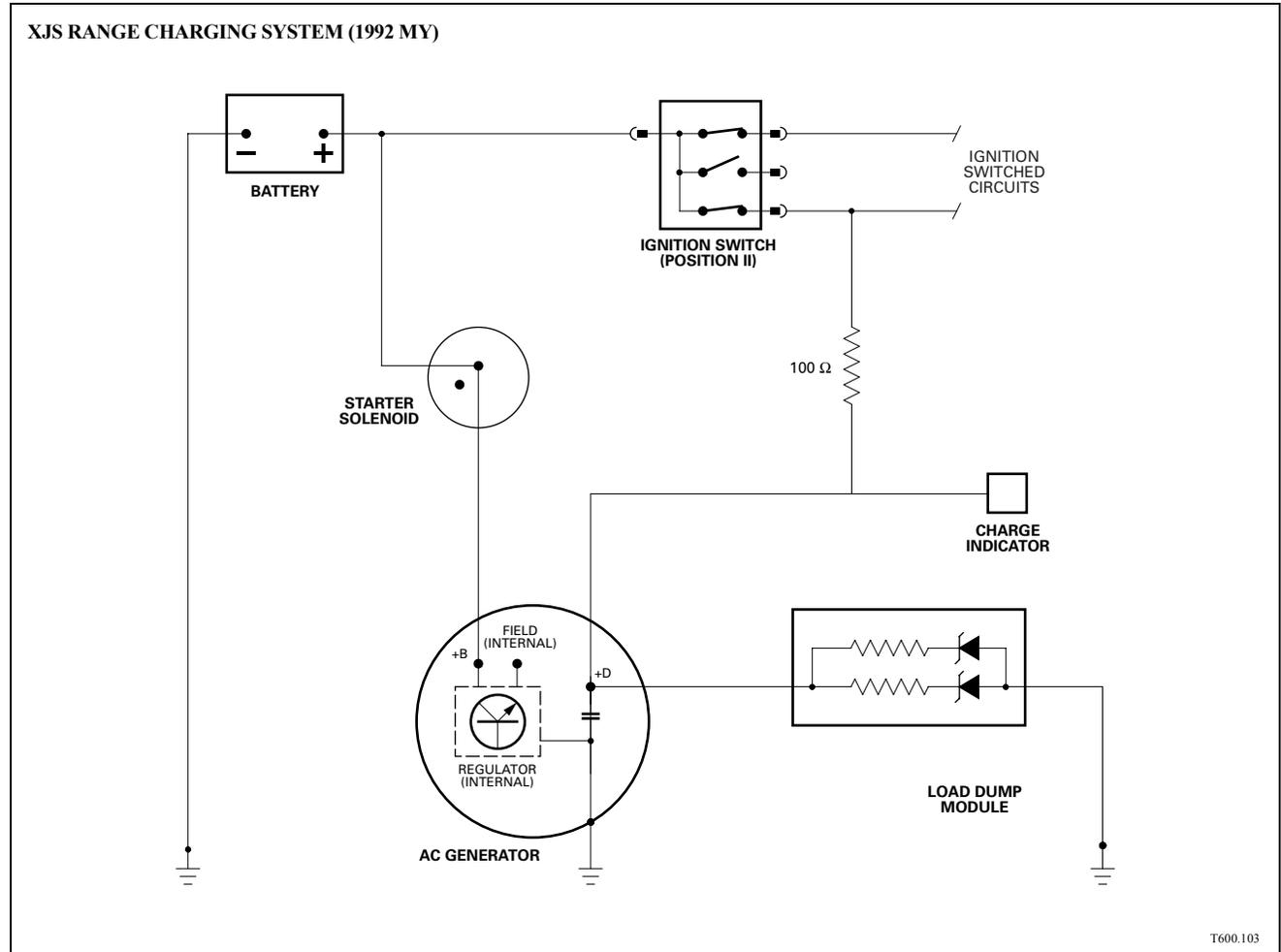
CIRCUIT DESIGN

Circuit Overvoltage Protection

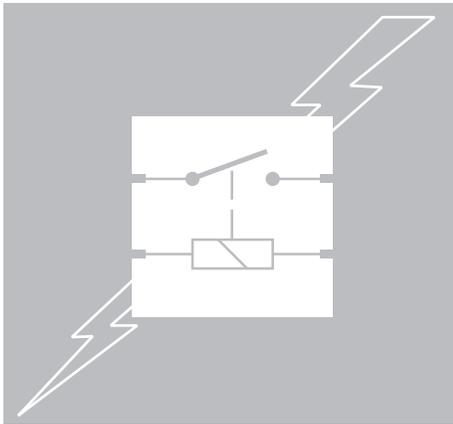
With the use of electronic components, it is necessary to limit the voltage from the charging system to not more than thirty volts to prevent component damage. If the battery is disconnected with the engine running or if loose battery connections exist, the alternator may generate voltage as high as 80 volts, causing extensive electronic component damage. In 1992 model year and earlier vehicles, an AC generator dump module is installed to protect against high system transient voltages. This module will limit system voltage by shunting (dumping) excess voltage to ground.

Vehicles manufactured from 1993 model year on have this feature integral with the voltage regulator.





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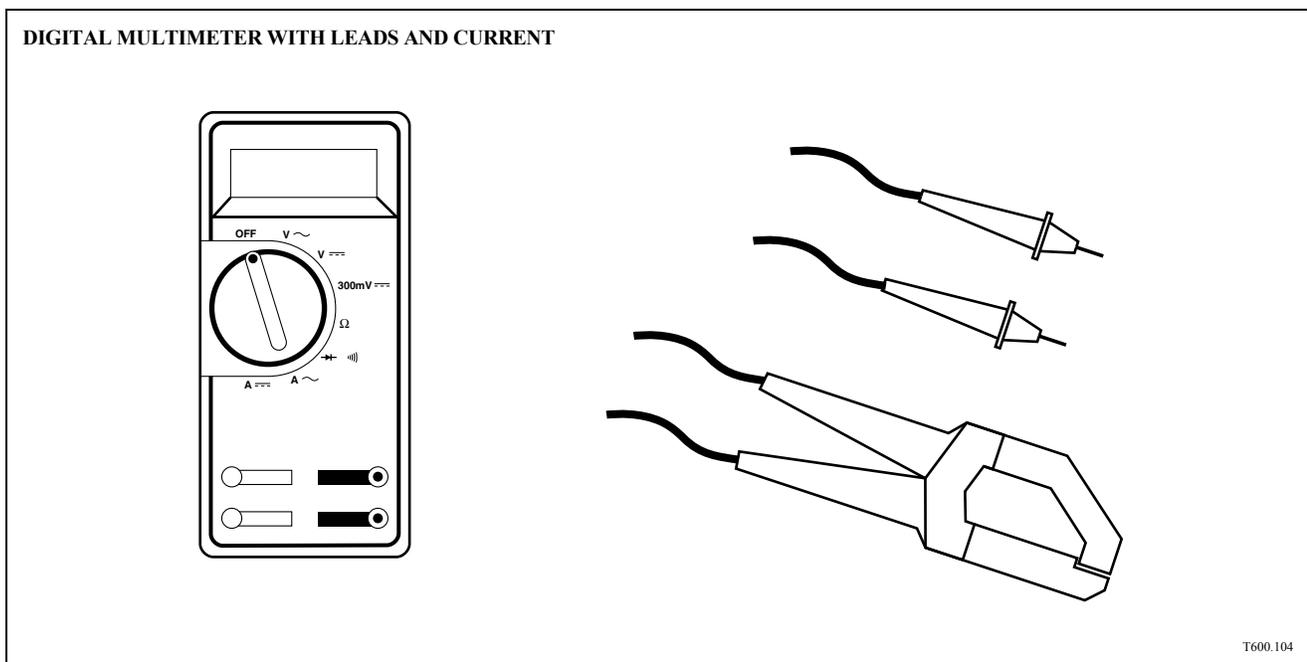
CIRCUIT ANALYSIS

Circuit Analysis with DVOM

Digital Multimeters

Since electronic circuits can be damaged by using analog meters and equipment for circuit testing, only digital multimeters (DVOM) should be used. Analog meters draw too much power from the device they are testing to be used in circuits with sensitive digital components. DVOMs, on the other hand, draw very little power from the device being tested. In addition, DVOMs provide more accurate measurements enabling precise value measurement. By using a DVOM with a combination digital / analog display, it can easily be determined if the measured value is increasing or decreasing.

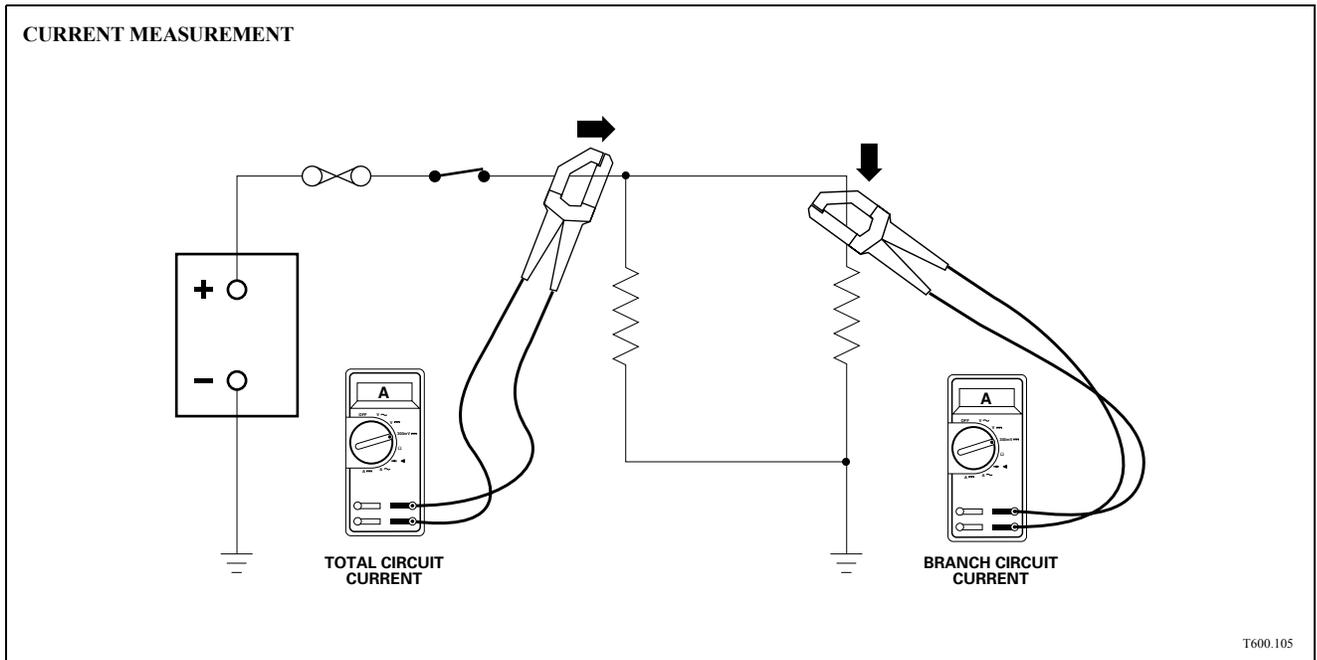
Both JDS (Jaguar Diagnostic System) and PDU (Portable Diagnostic Unit) have digital multimeter capability and can be used for normal circuit analysis.



NOTES

Ammeter

An ammeter measures current flow in a circuit. Conventional meters were connected into the circuit in series to accomplish measurement. Modern meters employ a clamp-on current probe that fits around the circuit wire and senses the strength of the induced magnetic field when current flows. The direction arrow on the probe must be observed to obtain an accurate reading. Depending on the placement of the current probe, total circuit or branch circuit current can be measured.



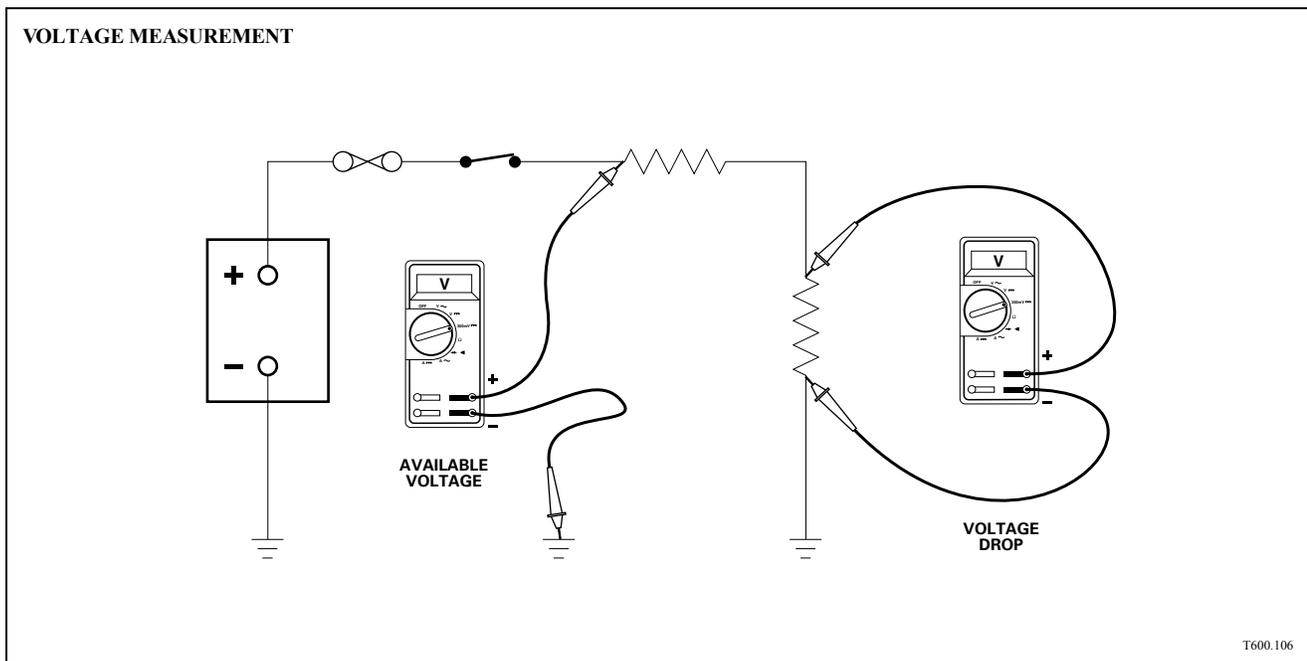
NOTES

CIRCUIT ANALYSIS

Circuit Analysis with DVOM

Voltmeter

A voltmeter measures the difference in voltage between two points in a circuit. The voltmeter uses two leads (positive [+] and negative [-]) to connect to the circuit. A voltmeter is connected in parallel with the current path. The positive lead should be connected closest to the power source (negative ground automotive circuit) in the circuit. The voltmeter can be used to measure voltage at any point in the circuit. It can also be used to measure the voltage drop of components or between components such as connectors and terminals. This measurement is particularly useful for determining the condition of connections as a higher than expected voltage drop will indicate poor connection.

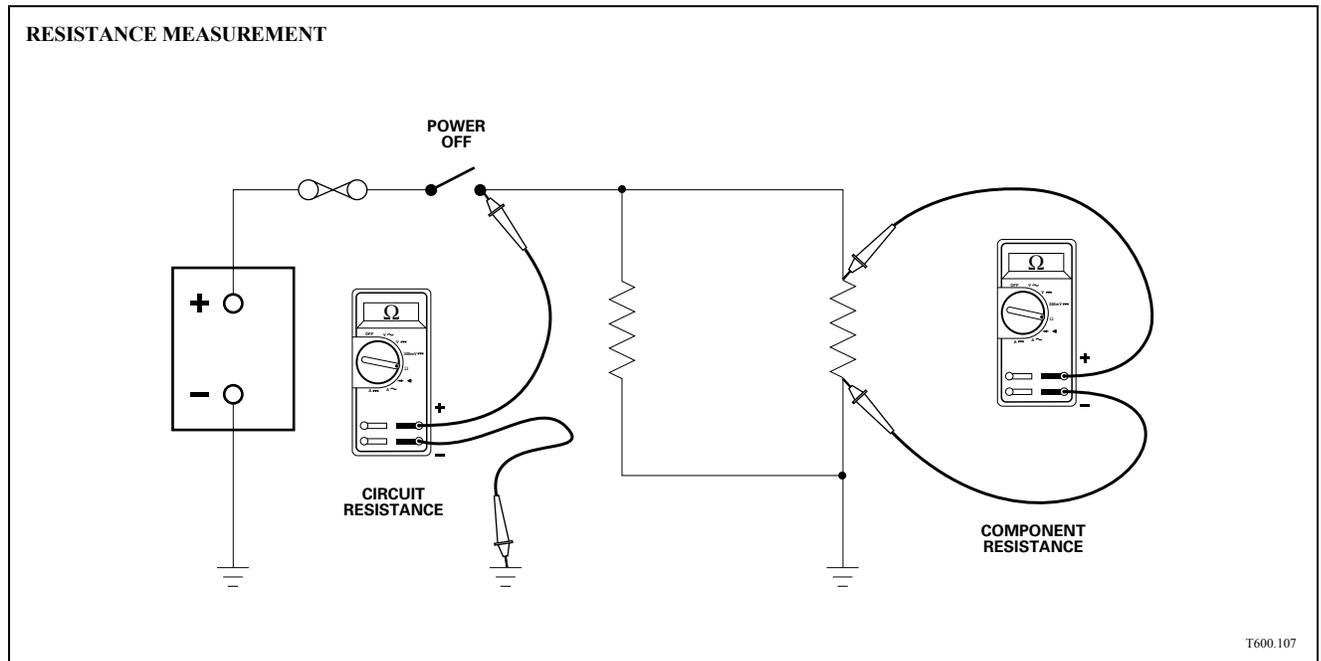


NOTES

Ohmmeter

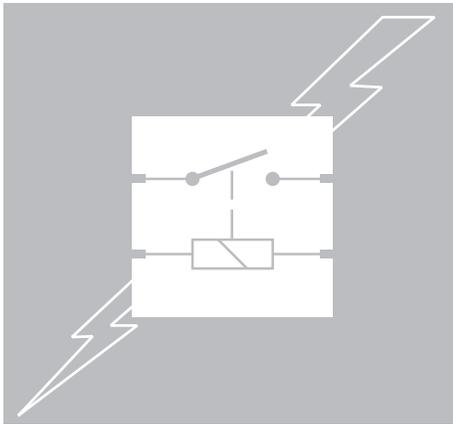
An ohmmeter measures the resistance in a circuit or component. The ohmmeter uses two leads (positive [+] and negative [-]) to connect to the circuit or component. The ohmmeter has its own battery and must be connected in place of the power source to operate properly. The resistance of an entire circuit can be measured. Parts of the circuit and individual components can also be measured after disconnection from the remainder of the circuit.

NOTE: When checking a parallel circuit, the total resistance will be less than the value of the lowest resistance.



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GLOSSARY

Alternating Current (AC)

A current that reverses its direction at regular intervals.

Amperage

The amount of current (amperes) flowing in an electrical circuit.

Ampere (A)

The unit of measurement for the flow of electrons (current) in an electrical circuit. One ampere is the amount of current produced by one volt through a resistance of one Ohm.

Armature

The part of a generator or motor that rotates in a magnetic field. The moveable part of a relay, contact set or solenoid.

Atoms

The small particles that make up all matter.

Capacitor

A device for holding or storing an electrical charge.

Commutator

A device through which current is drawn and rectified from the conductors of a generator armature. A device for reversing the direction of current flow through the conductors of a motor armature.

Conductor

A wire or metallic object made up of atoms with free electrons that are easily dislodged allowing easy electron flow from atom to atom.

Consumer

An electrical component that absorbs or converts electrical power to heat, light, motion or work. (also called LOAD)

Conventional Theory

According to this theory, the flow of electrons in an electrical circuit is from the positive terminal of the power source, through the circuit then back to the negative terminal of the source.

Current

The flow of free electrons through a conductor measured in amperes.

Direct Current (DC)

A current that moves continuously in one direction from a point of high potential (voltage) to a point of lower potential.

Electricity

The controlled movement of electrons in a conductor.

Electrolyte

A mixture of sulfuric acid and water used in “wet” automotive batteries. The chemical reaction between the electrolyte and the battery’s active material provides voltage and current when connected in a complete electrical current.

Electromagnetic Field

The field of force that surrounds a charged conductor or coil.

Electromotive Force

See voltage.

Electron

A particle of an atom that is negatively charged and orbits around the nucleus of the atom.

Electron Theory

The theory that “free” electrons can move from one atom to another, producing electricity.

Free Electron

An electron in the outer orbit of an atom where it is not so strongly attracted to the nucleus of the atom.

Generator

A device that creates electrical current by passing a magnetic field through a stationary conductor.

Ground

The connection made in grounding a circuit to a common conductor for completion of the circuit.

Induction

The process of inducing electricity in a conductor by influencing the conductor with magnetic fields.

Insulator

A material in which the electrons in the outer orbit do not freely leave the atom.

Load

An electrical component that absorbs or converts electrical power to heat, light, motion or work. (also called CONSUMER)

Magnetic Field

The directional field of force produced by a magnet or a magnetic influence.

Ohm (Ω)

The unit of measurement for measuring resistance to current flow. One Ohm of resistance will limit current to one ampere when one volt is applied.

Parallel Circuit

A circuit arranged with separate current paths for each consumer.

Polarity

The condition of having opposite properties or directions (positive [+] negative [-]).

Potential

See voltage.

Resistance

The opposition to the flow of an electrical current.

Semiconductor

A material that is neither a good conductor or a good insulator.

GLOSSARY

Series Circuit

A circuit arranged with only one current path for the entire circuit.

Series / Parallel Circuit

A circuit with some components connected in series and some components connected in parallel.

Static Electricity

Electrical charges temporarily contained in material having an excess of electrons.

Volt (V)

The unit of measurement for measuring the electrical pressure that causes current to flow in a circuit. One volt causes one ampere of current to flow through a one ohm resistance.

Voltage

The total number of volts that causes current to flow in a circuit. Also called electromotive force or electrical potential.

Voltage Drop

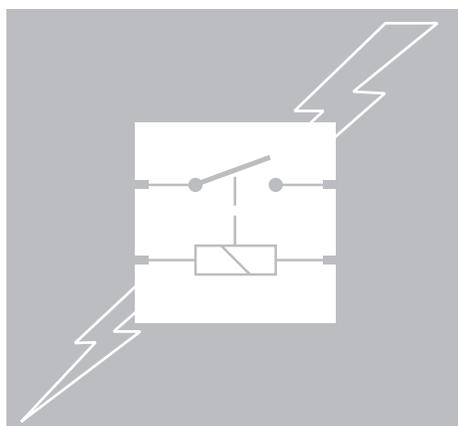
The difference in voltage between one point in a circuit and another.

Watt

The unit of measurement for measuring the electrical power in a circuit. Watts are calculated by multiplying the current (amperes) by the available voltage: $\text{Watts} = \text{volts} \times \text{amperes}$. (746 watts = 1 Hp)

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