MLR: Electrical Study Guide

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UNIT 1: ELECTRICAL THEORY

Chapter 1: Electromagnetism

Safety Warnings and Cautions

Safety in the workplace is of great concern to all of us. The Concepts you learn in each of the modules of this online training program will be applied using real test equipment on live electrical circuits in related projects. It is imperative that you understand that electrical safety is extremely important. The words "caution," "warning" and "danger" are related and mean this: If you do not heed the safety message, you can damage components, equipment, or injure or kill yourself or someone else. The last thing you want to do is become a statistic. Every year, people are injured or killed and property is damaged due to not following electrical safety rules and common sense. Do yourself and others a favor. Pay attention and use safe practices.

Warning! To avoid possible personal injury:

- Always follow all general safety guidelines for servicing motor vehicles with regards to electrical connections, flammable or corrosive materials, adequate ventilation, jacking and supporting, working around hot or moving parts, proper use of parking brake, gear selector, wheel blocks, and disabling fuel or ignition systems. **Refer to the equipment User's Manual and vehicle Service Manual for the operation you are performing.**
- When making electrical measurements, never exceed voltage or current limits as indicated for the equipment.
- Use extreme caution when working with circuits that have greater than 60 volts DC or 24 volts AC.
- Do not operate damaged equipment.
- **Automotive batteries can explode, and have enough power to arc weld**. Always respect the power of a battery, even a "dead" battery. **The sulfuric acid in electrolyte is extremely corrosive, and can cause severe chemical burns to the skin and eyes**. It will also damage painted surfaces and many other materials, including clothing. Always wear approved **safety glasses** when working around batteries and the use of **rubber gloves** is recommended when working with electrolyte. Batteries release hydrogen and oxygen gasses. When a battery explodes, it can rupture the case and spray acid in all directions. Avoid creating sparks around a battery.
- The ground terminal of a battery should always be disconnected **first** and reconnected **last**.
- Connect battery chargers to a battery before plugging in the charger.
- When jump-starting a vehicle, follow the proper procedure. **Do not** connect the jumper cable to the negative battery terminal of the vehicle you are jump-starting.
- **Do not** attempt to charge, jump-start, or load test a battery with a broken or loose post, a cracked case, or one in which the electrolyte is frozen.

- **Never hammer on a battery terminal or cable end, or attempt to remove a cable by prying**. To avoid damage to the battery or terminals, and possible personal injury, use a clamp-spreading tool if the clamp doesn't seat at the bottom of the post, and use a cable clamp puller to remove stubborn clamps. Avoid contact with the white, flaky or powdery corrosion that builds up around battery terminals and trays. This substance is sulfate and/or sulfide; it is corrosive and can cause chemical burns.
- **Accidental shorting of the positive battery terminal or any system voltage source to ground with a tool or metal object can cause severe burns**. Metal jewelry can be heated to its melting point in seconds. Even a brief short of this nature can damage the PCM and other electronic components.

You should know the locations of fire extinguishers and the first aid kit. First aid kits should contain a bottle of sterile, acid-neutralizing eyewash. Larger facilities often have an emergency shower and eyewash station located in the battery storage and service area.

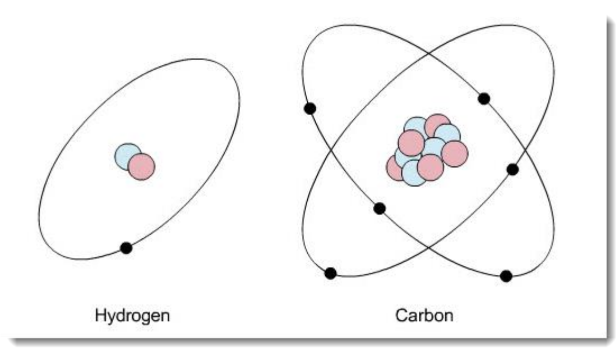
What is Electricity?

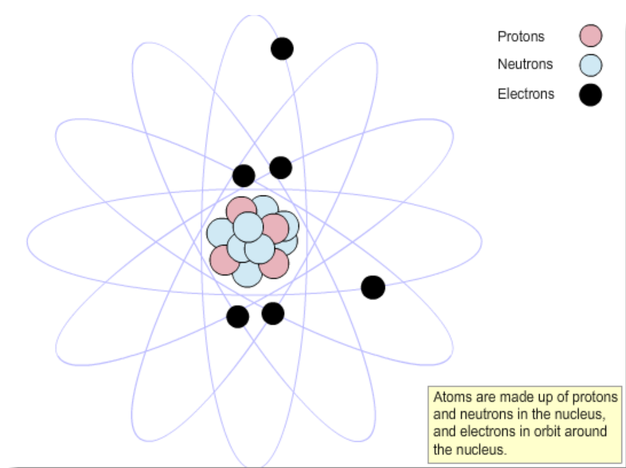
In order to properly diagnose and repair automotive electrical systems, a technician must first have an understanding of how those systems operate. In this section, we will look at electrical fundamentals and how they determine the construction and application of all automotive circuits.

For the purposes of an automotive technician, electricity is best defined as: "**The movement of electrons through a conductor having the ability to do work**". In order to understand how these electrons move, one must understand how matter and energy interact at an atomic level.

Atoms

We have all studied the atom and how it is composed of a nucleus including Protons (which have a positive charge) and Neutrons (which have no charge) with Electrons revolving around it (which have a negative charge). We also know that each type of atom has a different number of electrons around its perimeter.





Atoms are made up of protons and neutrons in the nucleus, and electrons in orbit around the nucleus.

Atomic Structure

The copper atom has 29 electrons around its nucleus located in different layers or shells around the nucleus, two in the first shell, eight in the second and 18 in the third shell for a total of 28. That leaves just one electron in the outer shell or "Valence shell", and this single electron is the one that does all of the electrical work. Atoms that have one or two electrons in the valence shell are called conductors. They include copper, gold, silver, aluminum, nickel, zinc, and others. That is why they are used to make wire.

Atom Info:
1 or 2 valence electrons are conductors
3, 4, or 5 valence electrons are semiconductors
6, 7, or 8 valence electrons are insulators

Valence Electrons:
Electrical force is applied to valence electrons, which causes them to move through wires.

Atoms with a large number of electrons in the outer shell are called insulators and include rubber, plastics, etc. Those atoms that have around four electrons in the valence shell are called semiconductors. Semiconductors are used to make electronic components such as transistors, which will be discussed in later modules. At this point you may be asking, "So what does this have to do with electricity?" Very simple really…

Magnetism

Another electrical characteristic we'll use in a later section is Magnetism. Magnetism, or Electromagnetism, is also caused by the movement of electrons in a wire, and is the property that makes generators, starters, blower motors, EGR valves, and many other "actuators" work.

Electromagnets:
An electromagnet is created when a current is run through a wound wire.

Magnetism:
Magnetism is used to convert electrical energy to mechanical energy or mechanical energy to electrical energy.

Magnetism is used extensively in automotive applications to convert electrical energy to mechanical energy, or conversely, to change mechanical energy to electrical energy. For instance, if we apply electrical current to certain devices we can create lateral (straight line) motion such as in the starter solenoid (to engage the starter drive), or to open fuel injectors. Still other components will use applied electricity to produce rotary (spinning) motion, as is the case with fuel pumps and starter motors. Generators, however, use magnetism to change motion (belt driven) to electrical output. In the automotive field there are two types of magnets used. They are:

- Permanent magnets
- Electromagnets

Permanent Magnets

We are all familiar with permanent magnets, those gray colored devices usually made in bar or horseshoe shapes. It's likely most of us have a number of permanent magnets attached to our refrigerators holding up out-of-date notes and drawings. In cars and trucks we will find permanent magnets in Crank Position Sensors (distributor and distributorless types), Cam Position Sensors, ABS sensors, some fuel pumps, Vehicle Speed sensors, and new style starters.

Electromagnets

Electromagnetism occurs when an electrical current is passed through a conductor and creates a surrounding magnetic field.

Electromagnets usually consist of a wire wound around a metal core and powered by an electrical source. Some students may have done an experiment in school where a wire was wrapped around a nail with both wire ends attached to a battery to form an electromagnet. The device could then be used to pick up paper clips.

Examples of electromagnetic automotive applications include starter solenoids and fuel injectors, as mentioned earlier, as well as some EGR valves, relay contacts, transmission shift and pressure-control solenoids, numerous vacuum control valves, blower motors, cooling fans, wiper motors, fuel pumps, generators and, of course, old style starter motors.

Magnetic Fields

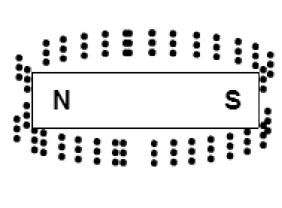
All magnets, whether permanent or electromagnet, have two poles: North and South. Like poles (N-N or S-S) repel and unlike poles (N-S) attract.

Magnetic Field:

The stronger a magnet is, the greater its "flux density".

Automotive applications all operate by magnetic attraction rather than magnetic repulsion. Between these two poles are invisible lines of force called the "flux lines" which make up the magnetic field. A magnet with many flux lines (or high flux density) is strong whereas a weak magnet has few flux lines or low "flux density".

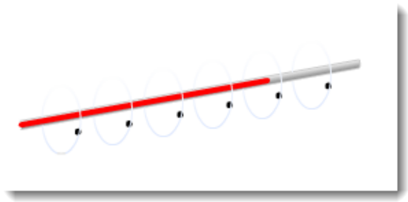
Students may be familiar with instances where magnets have become weak and caused operational problems such as a Crank Position Sensor that causes the engine to cut out at higher rpm's or an ABS sensor that drops to zero while the vehicle is still moving.

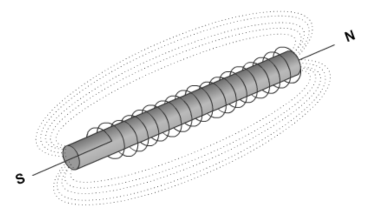


These problems are most often caused by a drop in the flux density of the magnet itself but will not be seen in a resistance check of the wire winding.

Magnetic Force

As electric current is passed through a wire, it creates magnetic lines of force around the wire. If that wire is wound into a coil, it creates North and South Poles much like a permanent magnet except that it can be turned on and off and made stronger or weaker. Because many metals are good magnetic conductors, a core is often used in the center of the coil to enhance the strength of the electromagnet. Most often, the core is part of the design like the plunger in a starter solenoid or the pintle in a fuel injector. If a number of different magnetic devices were cut open, it would be apparent that the size of the wire and the number of turns around the core are not the same. For various applications, designers will change the wire size, the number of turns, the diameter of the coil, the length of the coil, and the applied current to get just the right amount of magnetic force needed for a particular use.





Electromagnetic Induction

We have already seen that we can create a magnetic field with an applied current, but now we will find that we can also produce a current from a magnetic field. The process is called "electromagnetic induction". When a magnetic field and a wire are moved near each other, a voltage is produced in the wire that causes a current to flow. This is called an "Induced Voltage". As long as the movement continues, the current will continue, but if the motion stops, the current will stop.

Electromagnetic Induction:

Electromagnetic induction occurs when a varying magnetic field creates a current in a second winding.

Applications of electromagnetic induction are typically in generators or alternators and in transformers or ignition coils. Generators and alternators are designed similarly to motors in that they have a field winding and an armature winding. How they differ in terms of their induction is this: generators have a coil that turns and a magnetic field that is stationary whereas alternators have a magnetic field turning inside of a stationary coil.

The amount of induced voltage (and therefore current) depends on several factors:

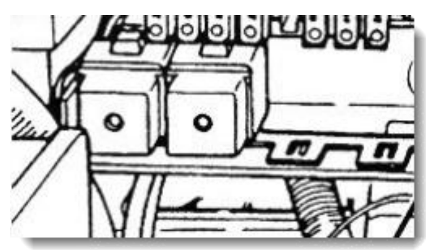
- Strength of the magnetic field
- Speed of motion between the coil and the magnetic field
- Number of conductors in the coil

Chapter 2: Magnetic Components

Let's take a few moments to cover some specific applications of electromagnetism: relays, solenoids, motors, and transformers.

Relays

A relay is an electromagnetic device that operates as an on-off switch using a small coil current to control a larger contact current. Inside a relay, there is a coil of wire and one or more sets of contacts. Applying a small current to the coil creates a magnetic field which "pulls in" the contact(s) and closes the circuit sending the larger "controlled" current to the load device (eg. fuel pump, ECM, etc.).

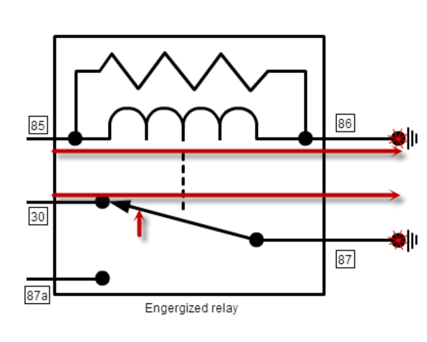


Because a relay uses a small amount of control circuit current to control the flow of a larger current, it allows for the reduction of wire size throughout a vehicle and a corresponding decrease in weight.

Relay

Primarily there are two types of relays on today's vehicles. They are known as Micro relays and Mini relays. They have normally 4 pins or 5 pins. But don't let the number of pins scare you. They all work in the same way!

The control side of the relay are pins 85 and 86. When power and ground are applied to these two terminals an electromagnetic field is created and a contact is pulled down. When this contact is made it allows power waiting at pin 30 to go though the contact and out pin 87 to its destination. There are variables but remember that pins 85 and 86 are married as the control side and pins 87 and 30 are the load or work side of the relay. Pin 87A is normally used to control another portion of a system such as the park control in windshield wipers.

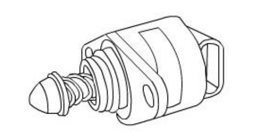


Solenoids (fuel injector)

A solenoid is an electromagnetic device that uses applied current to produce lateral (back and forth) motion. Solenoids such as fuel injectors and transmission shift valves have a movable metal core inside the coil. As current is applied to a coil, the electromagnetic field it produces either pushes or pulls the core and opens or closes a valve, or engages a starter drive. The terms relay and solenoid are sometimes used interchangeably but in fact, they are two different things.

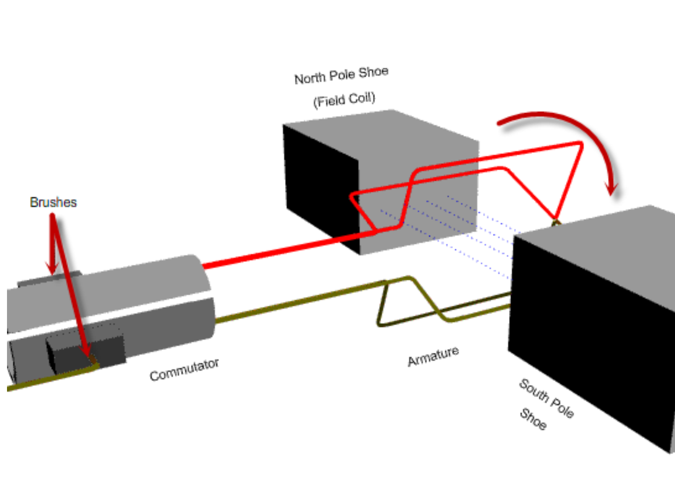
Motors

Electric motors also work on the principles of electromagnetism, but unlike relays or solenoids, their function is to produce rotary (spinning) motion. Motors have two primary components: an Armature or rotating element and a stationary Field Coil. Motors can have permanent magnet armatures with wound field coils, permanent magnet field coils with wound armatures, or have both the armatures and field coils wound. Permanent magnet armature motors are used in Alternating Current applications and are not common in automotive applications.

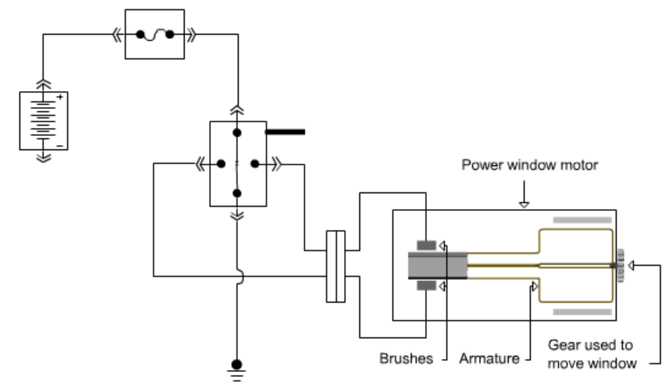


In a DC electric motor, voltage is applied to the armature winding through a pair of carbon brushes and a split ring called a commutator. The commutator has the effect of alternately changing the poles of the armature coil from north to south and back again for each half revolution of the armature. For example, let's assume that a point on the outer Field Coil has a north orientation. The half of the armature that has a south polarity would be attracted to that point and would cause the unit to rotate as they pulled closer. However, just as the two points align, the commutator switches the armature polarity and the new south point is now on the opposite side of the armature winding which causes it to attract the north point on the field coil and the rotation continues.

To build a simple motor, you need a loop of wire/armature, two permanent magnets used to form a north and south pole, a commutator power source, and set of brushes.



DC motors can rotate clockwise or counter-clockwise depending on current flow. This allows one DC motor to control the up and down motion of the power windows or back and forth motion of power seats.

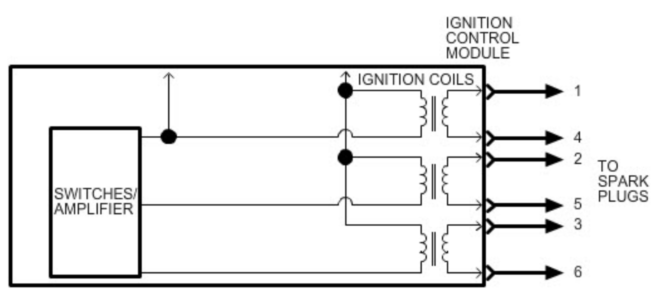


Transformers

Transformers are another type of device that works by electromagnetic induction. A transformer is constructed with two separate windings (a primary and a secondary) wrapped around a common metal core. When alternating current or pulsating DC current is applied to the primary winding a voltage is created, or induced, into the secondary winding.

> **Transformers**:
>
> Transformers use electromagnetic induction to increase or decrease an applied voltage or current.

Transformers are classified as either Step-up or Step-down. A Step-up transformer will create a higher voltage in the secondary winding while a Step-down will cause a lower voltage. Your local electrical sub-station has a series of Step-down transformers to reduce the voltage before it enters your house.



Transformers

The Step-up or Step-down ratio is determined by the number of turns of the wire used in both the primary and secondary windings. One other thing to keep in mind is that the primary and secondary currents will also change except they go up as voltages drop and decrease as voltages increase.

As an example, let's use the most common transformer in automotive use - the ignition coil. In a typical ignition coil the ignition module will apply 12 Volts pulsating DC with a current of between 4-10 Amps. We'll use 6A as an example. The voltage that comes from the secondary to fire the spark plugs is typically between 5,000 Volts and 20,000 Volts (some can go as high as 80,000 Volts). Our example will use 12,000 V. If the input voltage is 12 Volts and the output voltage is 12,000 Volts, then the step-up ratio is 1000:1 (12,000/12), while at the same time the current will drop by the same ratio from 6A to .006 Amps (6/1000). A Step-down transformer will likewise increase the output current by the same ratio that the voltage was decreased. It's also interesting to note that the input power and the output power for a transformer are basically identical.

Chapter 3: Electrical Properties

In our study of electricity, we will apply, measure, and calculate four different units: Voltage, Current, Resistance, and Power.

Voltage

Voltage can easily be described as electrical pressure. A comparison to a household water hose will be useful in discussing voltage. If you have a water hose with a closed nozzle on the end and the spigot has been opened, there is water pressure in the hose even though no water is able to escape through the nozzle.

> **Voltage**:
>
> Voltage is defined as electrical pressure.

What actually causes voltage can be understood by recalling the earlier discussion about "free electrons." When there are more free electrons in one place as compared to another (such as between the positive and negative plates of a car battery), there is said to be a "difference of potential" or Voltage. The greater the difference between the number of electrons on one battery plate and the number on the other plate, the higher the voltage. A dead battery has the same number of electrons on the positive plates as on the negative plates.

As we deal with electricity we will see that this "electrical pressure" has a number of different names which all mean the same. They are:

- Voltage or "V"
- Electrical Potential
- Potential Difference
- Electromotive Force or "EMF" or "E"

For the purposes of this course we will use the term Voltage and either the V or E designation. Also remember that voltage is merely a "pushing" force and does not perform the real work in an electrical circuit.

Source Voltage

Source voltage is a term used to refer to the amount of voltage available to move electrons through a circuit. For most automotive applications, source voltage should be in the 12-14 volt range. However, many of today's sensors operate on a 5V supply while some actuators will use 7, 8, or 10 volts and electronic computer components may use less than one volt. It is most important for the electrical technician to be aware of the amount of voltage that should be applied to a circuit to insure that misdiagnosis does not occur.

Source Voltage:

Source voltage is the voltage applied to a circuit when there is no current flow.

Current

Current is the movement of electrons in a circuit. Like our voltage and water pressure analogy from before, current would be compared to the actual water moving through the hose. It is current, rather than voltage or power, which causes the lights to shine, the motors to turn, and the fuses to blow.

Current:

Current is the movement of electrons through a conductor.

Conventional current flow views current as flowing from positive to negative. Electron current flow views current as flowing from negative to positive.

Unlike voltage, which is the presence of electrons, current is the movement of electrons through some sort of conductor. The greater the number of electrons past a certain point, the greater the current, or amperage.

Automotive systems vary from very high to very low current. For instance, the starter system typically is high current, being in excess of 100 Amps, whereas spark plug current is very low (many confuse high voltage with high current in ignition coils) at much less than one amp.

Current is generally referred to in one of two terms:

- Amperes, Amperage, Amps, or "A"
- Intensity or "I"

For our purposes, "A" and "I" will be used interchangeably.

Conventional Current Flow vs. Electron Current Flow

There are two different ways to look at current flow in a complete circuit; one is called "Electron Flow" and the other is "Conventional Flow." An understanding of the difference will help the technician in the use of electrical diagrams.

The Electron flow theory says that since electrons do the work in a circuit and since electrons have a negative charge, then current must flow from the negative (-) battery terminal through the circuit and into the positive (+) terminal. This is used mostly by electrical engineers.

Conventional flow theory says that since positive is greater than negative, then current must travel from + to -. Conventional flow is used by the automotive and other industries.

DC and AC

The current in any circuit will be one of two types: Direct Current (DC) or Alternating Current (AC).

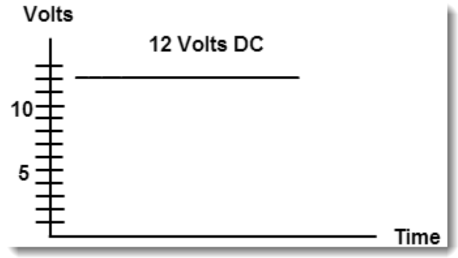
Direct current always flows in the same direction in a circuit, whereas alternating current flows in one direction, then reverses itself and moves in the opposite direction.

Types of Current:

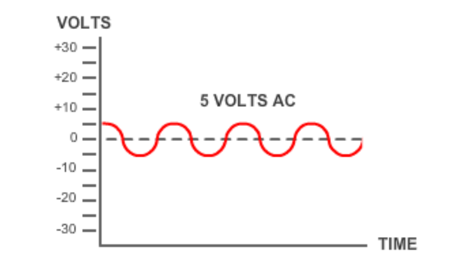
Direct current always flows in the same direction.

Alternating current must change direction.

Batteries and other steady state devices produce DC. We will also see what is referred to as Pulsating DC. Pulsating DC is often incorrectly called AC although it is merely DC with a varying voltage.
Technicians will find that the vast majority of automotive circuits operate on DC.



Alternators and wheel speed sensors produce AC current. In order for a current to be AC, the current flow in a circuit must actually change direction.



Resistance

Resistance is anything that opposes the flow of electrons. As the resistance in a circuit is decreased, the amount of current increases and as the resistance increases, the current decreases. Comparing this once again to our water hose analogy, we find that if we use a larger diameter hose (less resistance) we will carry more water (more current). Conversely, a smaller hose (higher resistance) carries less water (lower current).

Resistance:

Resistance is anything that opposes the flow of electrons.

Some resistance is necessary in any electrical application, as it is used to convert electrical energy to other forms such as heat (defogger grids) or light, and to limit circuit current. Those materials with low resistances, such as copper wire, we use as conductors, while those with high resistances, such as rubber, we use as insulators.

Several things determine a material's resistance:

- Number of free electrons in the outer shell of the atom.
- Length of the conductor – a longer wire will have a higher resistance

- Cross Sectional Area: The larger the circumference of a conductor is, the less its resistance. Example: A 1.0 mm wire (16 Ga.) has less resistance than a .35 mm wire (22 Ga.).
- Temperature – generally, as a material is heated, its resistance increases (exceptions to this rule will be seen later).

Other factors also affect the resistance in a circuit such as: loose connections, corrosion, broken wire strands, etc. In contrast to the useful applications of resistance mentioned before, these will cause a circuit to operate inadequately or not at all. In later sections, we will also become familiar with devices called "resistors," whose function it is to limit the current or voltage to another part of a circuit, and thus control its operation.

Ohms:

Resistance is measured in Ohms and is given the Greek letter Omega: Ω

The standard unit of measure for resistance is known as the "Ohm" and is given the Greek symbol Omega (Ω). An Ohm is defined as the amount of resistance that, when applied to a one-volt circuit, will limit the current to one amp. Thus, one volt through one ohm equals one amp. Students may choose to use either the Ohm symbol or a capital R to signify resistance. We will return to resistance and ohms later.

Power

When studying power there are a few terms that you should be familiar with:

Power is the rate of doing work. Electrical power>is a rate of work done at 1 joule per second. Mechanical power is work done at a rate of 550 foot pounds per second.

Joule: A unit of energy. One joule is the amount of energy required to move one coulomb of charge between 2 points with a potential difference of 1 volt. Also, 3x106 joule equals 1kw.

Coulomb: The basic unit of charge. The amount of electricity represented by 6.25x1018 electrons.

Power:

Power is rated in watts and is a measurement of work output. The formula for measuring power is:

- **P = I x E**

There are alternative formulas for calculating power:

- **$P = I^2 \times R$**
- **$P = E^2 / R$**

For purpose of this course we will focus on electrical power.
Unlike Voltage, Current, and Resistance, Power is not a direct measurement for an electrical property. Power is the output or rate of work performed by a machine or electrical/electronic circuit.

Gasoline, diesel engines, and electric motors are rated as to the number of horsepower they produce. However, many other electrical devices (e.g. light bulbs) are rated by the amount of power they consume rather than by output. Generally, those things that are rated in watts consumed have a different form of output. For instance, light bulbs are rated in watts but have an output in lumens. Audio speakers have an output based on how much air they move, and resistors, also rated in watts, put out heat. Electric motors, as mentioned before, are an exception in that they are rated in horsepower output rather than watts consumed.

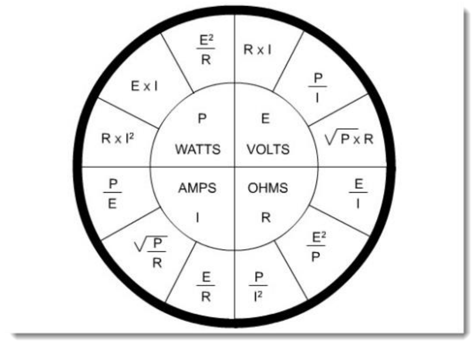
Power (symbol "P") is expressed in Watts but can be converted to horsepower using the equation:

1 Horsepower = 746 Watts

It is not as important for automotive technicians to calculate power, as compared to voltage drop or amperage draw. However, there are circumstances when the amount of power consumed or produced is a concern.

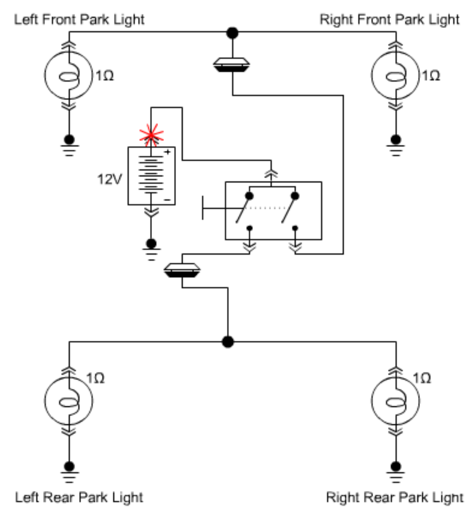
Power Formula

As mentioned earlier, Power is not a direct measurement but rather the product of the voltage, current and resistance. To calculate the power consumed the following pie chart may be helpful. Just like with Ohms law, if any two variables are known you will be able to determine the other two.



P = I x E
or
Watts = Amps x Volts

From this formula we can see that one Watt is equal to one Volt multiplied by one Amp. We can also see that if either the voltage or current is increased, then the power (wattage) also increases. Likewise, a decrease in either voltage or current causes a corresponding reduction in power.



As an example, let's assume we have a device with 120 Volts applied and a Current of 10 Amps. Using the formula we obtain:

- **P = I x E**
- **P = 10A x 120V**
- **P = 1200 Watts**

General Rules of Electricity

Using our study of Ohm's law we can see that the relationships between voltage, current, and resistance follow general rules:

Resistance:

If the **resistance** remains the same:

- As voltage increases, current increases
- As voltage decreases, current decreases

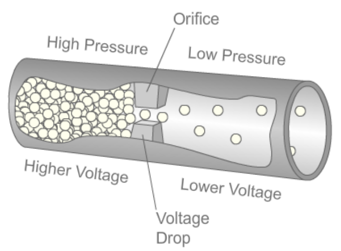
Voltage:

If the **voltage** remains the same:

- As resistance increases, current decreases
- As resistance decreases, current increases

Voltage Drop

Voltage drop is a term that may be unfamiliar to new technicians, but it will be very important in the diagnosis of electrical circuits. To explain voltage drop, let's return to our water hose analogy once again. At one time or another, we've all folded a hose in half to stop the water flow so we could relocate a sprinkler or as a joke to someone trying to wash their car. When that happens, the water pressure remains the same between the kink in the hose and the faucet, while the pressure on the other side of the kink is zero or almost zero. This difference is called the pressure drop and it is principally the same as in electrical applications. Voltage drop is then defined as the difference between the voltage on the inlet side of a device compared to the voltage on the outlet side. Comparing that value to a written specification will assist the technician in determining the fault with the system.



Voltage Drop:

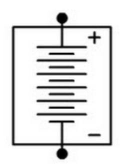
Voltage drop is the difference in electrical pressure between the two sides of a device.

UNIT 2: ELECTRICAL DEVICES AND CIRCUITS

Chapter 1: Circuit Components and Symbols

Batteries

An automotive battery stores chemical energy that can be turned into electrical and mechanical energy. This energy is used to operate automotive electrical systems. The battery supplies power to the starter and ignition systems to start the engine. The battery also supplies the extra power necessary for the electrical system when the vehicle's electrical load exceeds the supply from the charging system, and acts as a voltage stabilizer in the electrical system.



Battery Symbol

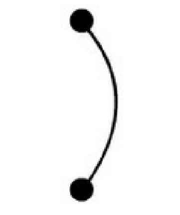
Battery

In automotive circuits, as with any electrical circuit, current flows from the power source (battery). Therefore, the battery is the first component in any electrical circuit.

Circuit Breakers

A circuit breaker is a protection device designed to open when electrical current exceeds a calibrated amperage.

An electromechanical circuit breaker contains a metal strip made of two different metals bonded together called a bimetal strip. When excesses current/heat is applied, the metal strip will separate, opening the circuit and preventing current flow. Some circuit breakers must be reset manually. Other circuit breakers reset automatically; these are referred to as cycling circuit breakers.



Circuit Breaker Symbol

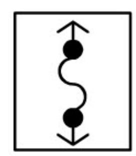
An electronic circuit breaker will open and close automatically when the rated amperage is exceeded. Electronic circuit breakers can be used to control power window circuits and other similar circuits.

Mechanical Circuit Breaker

Electronic Circuit Breaker

Fuses

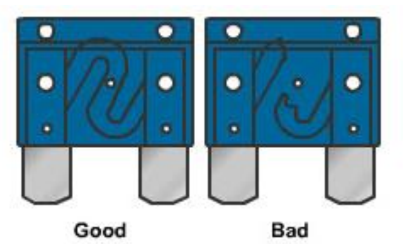
A fuse is another protection device. Fuses are rated in amps, and the rating is determined according to the maximum amount of current the circuit is designed to safely handle. Fuses are always placed in series with the load device they are protecting. A fuse is designed to open internally (blow) whenever current flow exceeds its rated value.



Fuse Symbol

CAUTION: Never replace a fuse with one of a higher amperage rating for the circuit or serious circuit damage or electrical fire could result.

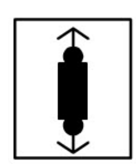
Fuses



Good and Bad Fuses

Fusible Links

Another type of electrical protection device is fusible link wire. Fusible link wire works similarly to a fuse. Most fusible link wire is used with circuits that requires 30 amps or more.



Fusible Link

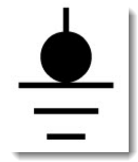
CAUTION: Never replace fusible link wire with regular electrical wire. Fusible link wire will open internally without burning the outer insulation.

Symbol

Fusible Link

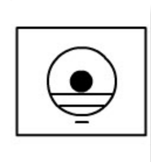
Grounds

Ground reference is a common reference point for electrical/electronic circuits where electrical measurements can be taken.



Ground Symbol

Ground is a common point in an electrical circuit connected to the negative side of the power supply. It's not uncommon for more than one component to share a ground connection. The ground provides the return path to the power source for the circuit – all circuits must have a ground. A ground return can be either hard-wired to the battery negative, or chassis grounded through the metal pieces of the vehicle. Case-grounded components have an internal connection to their metal casing and become chassis grounded when installed in the vehicle.



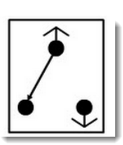
Case Ground Symbol

Typical Ground

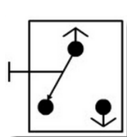
Switches

Electrical switches are used to control current flow in an electrical circuit. An electrical switch can be either normally open or normally closed, depending on the type of circuit it's controlling. Switches can be controlled by hydraulic pressure, heat, vacuum and even light. Switches come in several different shapes and sizes. When replacing an electrical switch, you must ensure you are using one that can handle the circuit amperage. The symbols and diagrams pictured here are common with most manufacturers. Switches can appear in several different shapes and sizes. Another type of switch is a momentary switch, such as a horn or brake light switch.

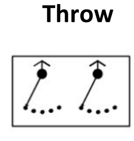
Single Pole Single Throw

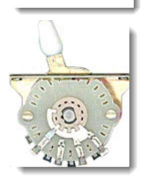


Single Pole Double Throw

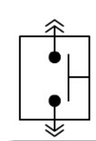


Multiple PoleMultiple Throw



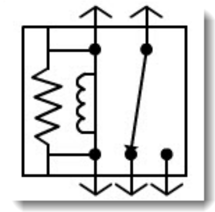


Momentary



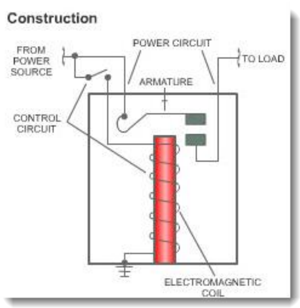
Relays

Another type of switch is a **relay**. As was discussed earlier, a relay uses a small amount of current to control a larger amount of current flow. Relays can be either normally open or normally closed. Relays are constructed using an iron core, an electromagnetic coil, and an armature (moveable contact set). Relays that are controlled electronically, such as those controlled by the PCM (Powertrain Control Module) are usually ground-controlled. Relays that are controlled by the operator, such as the headlight relay, are normally power-controlled. Relays normally follow a common wiring scheme. The main difference between a relay and solenoid is that a relay controls an electrical output, whereas a solenoid controls a mechanical output.

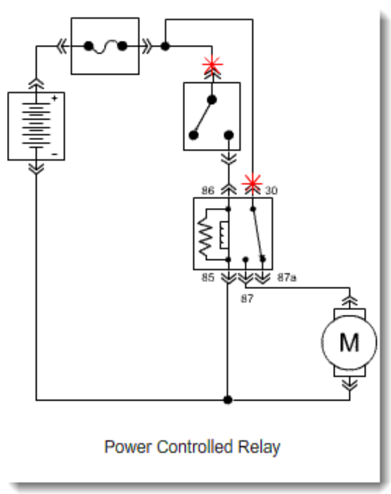


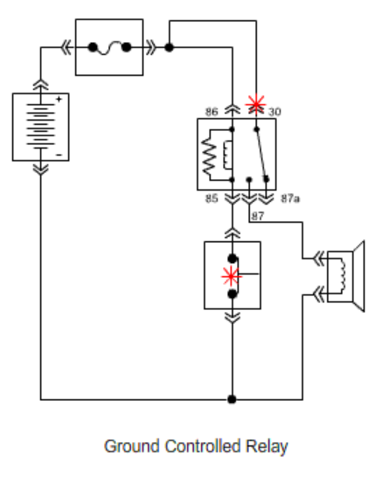
Relay Symbol

Relay Diagram



Relay





Other Components

Here are a few additional common components and their symbols.

Bulbs

Automotive bulbs are used for internal and external illumination and are often used as warning lights. Automotive bulbs are often similar in design; however, due to varying resistances of bulb elements, it's important to use the correct replacement bulb.

Single Element Bulb

Dual Element Bulb

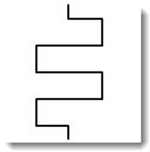
Typical Headlight Bulb

Heater Element

Heater elements are used in several different places on modern automobiles. Some of the more common places are:

- Seats (heated seats)
- Rear window defrosters
- Cigar lighters
- Oxygen sensors

Heater Element

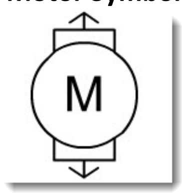


Heated Seat

DC Motor

In modern automobiles, DC motors are used to move seats, raise and lower windows, control engine idle speed, and perform many other functions throughout the vehicle.

Motor Symbol

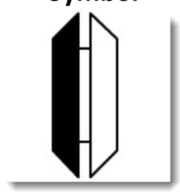


Motor

Rubber Grommet

Rubber grommets are used to protect electrical wires going through the bulkhead or other places where there is a possibility of insulation damage that could cause a short circuit. A rubber grommet can be helpful when using a wiring diagram for location purposes. The darker black section of the grommet indicates the area going away from the passenger compartment. The lighter area of the grommet is inside the passenger compartment.

Rubber Grommet Symbol

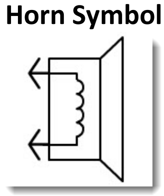


Rubber Grommet

Horn

A horn is a safety/warning device. Most modern vehicles are equipped with two horns: one high note and one low note.

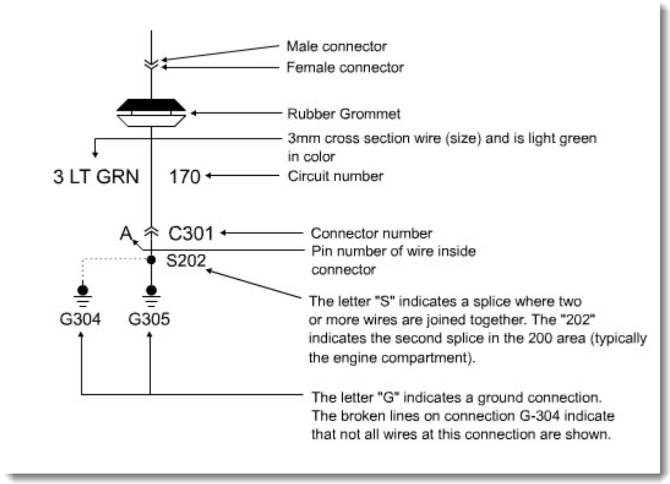
Horn Symbol



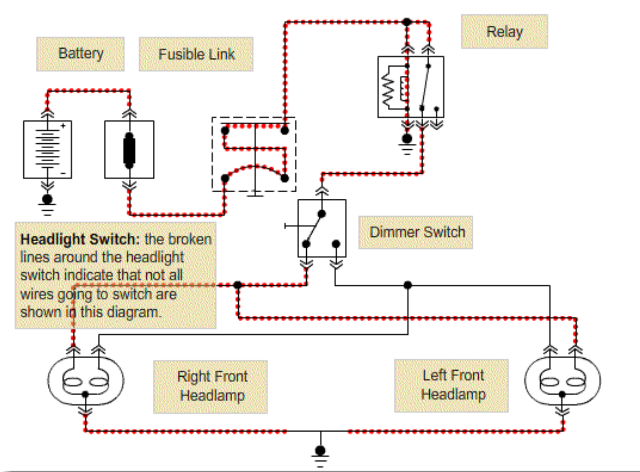
Horn

Wiring Diagrams

In an electrical diagram, it's important to become familiar with connectors, splices, and ground locations. The following is a typical section of a wiring diagram. Please take the time to become familiar with these symbols. When working with an electrical system, it's sometimes necessary to perform voltage drop or continuity tests. Modern wiring diagrams use numbers and letters to help identify circuit connector locations.



How many electrical symbols can you name in the diagram below? Most electrical diagrams may contain additional information such as component location and wire size. Most modern wiring diagrams are drawn from the top of the page to bottom. Often, any component that is not drawn showing all electrical wires will have a page reference number beside it.



Chapter 2: Ohm's Law and Circuits

Ohm's Law

In the early 19th century, George Simon Ohm proved by experiment the relationship between **voltage**, **amperage**, and **resistance**. The mathematical equation used to determine the relationship between voltage amperage and resistance is called Ohm's law.

In electrical circuitry, if any one of the three variables (V, A, Ω) changes, it will affect at least one of the other two. In Ohm's Law equations:

- "E" = Electromotive Force (Voltage)
- "I" = Intensity (Amperage)
- "R" = Resistance (Ohms)

A value for any one of these variables can be found as long as the other two are known.

Formulas and Relationships

Formulas

Ohm's Law Formulas

- Voltage E = I x R
- Current I = E / R
- Resistance R = E / I

The primary formula for Ohm's Law is:

E = I x R

or

Volts = Amps x Ohms.

This tells us that if we multiply the current (in amps) times the resistance (in ohms), we can find the applied voltage or voltage drop.

To find an ***unknown current*** we use:

I = E/R or **A = V/Ω**

Divide the voltage by the resistance to find the current.

Resistance is found with:

R = E/I or **Ω = V/A**

Divide the voltage by the current to find resistance.

Relationships

To better understand the relationships between voltage, amperage and resistance, consider the following rules:

Directly Proportional: means that as one variable increases, another variable will increase in proportion.

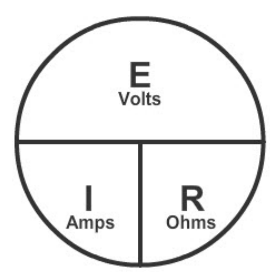
- If voltage increases and resistance remains the same, current will increase.
- If current decreases and resistance remains the same, voltage will decrease.

Indirectly Proportional: means that as one variable increases, another variable will decrease in proportion.

- As resistance increases and voltage remains the same, current will decrease.
- If resistance decreases and voltage remains the same, current will increase.

Ohm's Law Solving Circle

If memorizing formulas isn't your favorite thing to do, then memorize and use the solving circle below. All you need to do is cover the letter for the value you don't know, and the formula to use will be shown by the remaining two.



For example: If you want to know the voltage drop in a circuit, just cover the letter E which will leave IxR. Covering the "I" will give E÷R, and if "R" is covered, then E÷I remains.

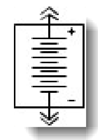
If you don't have the solving circle handy and can't remember the positions, just remember the old mnemonic device, "Eagles flying over Indians chasing Rabbits." It's a little silly, but hard to forget. Another is "Victory over Automotive Repair," (Volts over Amps and Resistance).

Circuit Elements

Before we can learn how to apply Ohm's law in a practical setting, we must first have an understanding of some basic circuit elements.

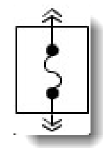
Source

The first requirement for any circuit is a source of power. Automotive applications generally have two primary power sources: the battery and the generator.



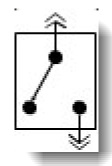
Protection

A fuse, circuit breaker, or fusible link is needed to prevent wiring damage from excessive circuit current.



Control

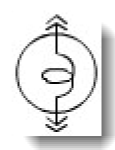
A control device can either turn a load on and off, or it can vary if a changing output is required.



Loads such as headlights or fan motors will be either on or off and will use switches or relays as controlling devices. However, applications such as instrument panel dimming, fuel injection, and transmission valves have variable outputs and are controlled by potentiometers, transistors, and Pulse Width Modulation computer signals.

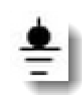
Load

A load is any part or component in a circuit that causes resistance to the current flow in the circuit. All circuit loads will have a corresponding voltage drop. Loads can be devices such as bulbs, motors, and actuators as well as unintentional items including bad connections and corrosion.



Ground

All circuits must have a complete path to operate. Automotive applications all terminate at ground or battery negative. A ground return can be either hard-wired to the battery negative or chassis grounded through the metal pieces of the vehicle. Recall from Module 2 that case-grounded components have an internal connection to their metal casing and become chassis grounded when installed in the vehicle.



Series and Parallel Circuits

There are 3 basic types of electrical circuits. It is important to explore these types in a basic manner at this point in order that we may be able to understand how to apply Ohm's law to a circuit.

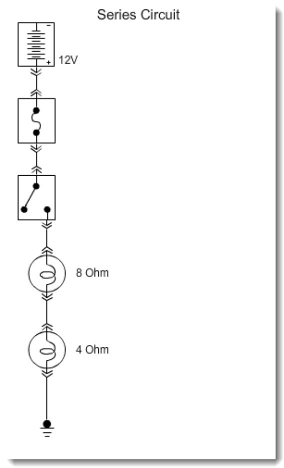
- Series circuit
- Parallel Circuit
- Series/parallel circuit.

A series circuit is a circuit that only provides one path for current to flow. A parallel circuit provides more than one path for current to flow, and a series/parallel circuit is a combination of both types of circuits.

When using Ohm's law there are a few simple rules to remember:

When working with a **series circuit**:

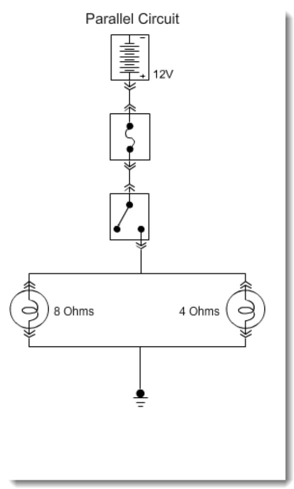
- Two or more electrical devices are required for a series circuit
- Voltage changes (the point of highest resistance will be the point of greatest voltage drop)
- Amperage remains the same
- Total circuit resistance will equal the sum of all resistors or loads in the circuit
- Any opening will disable the entire circuit



When working with a **parallel circuit**:

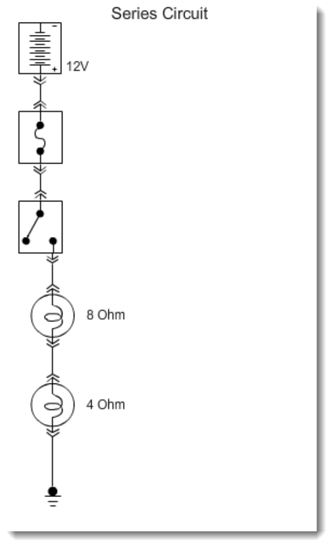
- Voltage remains the same at the input of each branch's first load device.
- Amperage changes, the higher the branch resistance the less current flow in that branch.
- Total resistance will be less than any individual branch resistance.
- Any opening in an individual branch will not disable the entire circuit.

Two or more load devices are required for a parallel circuit.



Calculations for Circuits

In the series circuit to the right, we have:



R_T = 12 ohms (lamp 1 resistance 8 ohms + lamp 2 resistance 4 ohms)

I_T = 1 amp (12 volts / 12 ohms)

E_T = 12 volts (source voltage)

($_T$ = total)

Here is where things get tricky:

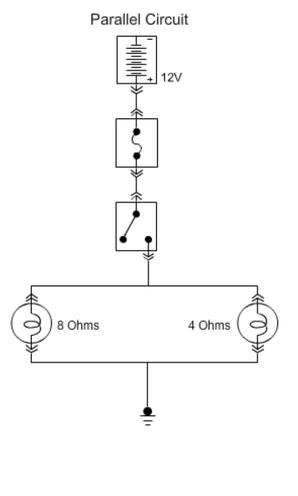
What is the voltage drop at Lamp 1?
1 amp x 8 ohms = ***8 volts***

What is the voltage drop at Lamp 2?
1 amp x 4 ohms = ***4 volts***

Remember!

In a series circuit, amperage remains the same throughout the circuit.

In the parallel circuit to the right (using the same lamps as the series circuit above), we have:



4 ohms x 8 ohms

R_T = 4 ohms + 8 ohms = 2.6 ohms

I_T = 12 volts / 2.6 ohms = 4.5 amps

E_T = 12 volts (source voltage)

($_T$ = total)

Can you determine the following?

What is the current flow through Lamp 1?
12 volts / 8 ohms = ***1.5 amps***

What is the current flow through Lamp 2?
12 volts/ 4 ohms = ***3 amps***

Remember!

In a parallel circuit, voltage remains the same across each branch.

From the equations used above, you can see that current flow through Lamp 1 and Lamp 2 equaled total amperage.

You can also see amperage is different through each lamp. Current is less in Lamp 1 because its resistance is greater than that of Lamp 2.

Chapter 3: Digital Multimeters

Digital Multimeters

In order for a technician to diagnose an electrical problem, he must first test the system to determine which part is malfunctioning. Part of system testing requires the use of a Digital Multimeter, sometimes also called a Digital Volt-Ohm-Meter (DVOM). A DMM is a versatile tool that allows for the measurement of Voltage, Current, Resistance, Capacitance, Frequency, Pulse Width, and other aspects of electricity.

Choosing a Good Digital Multimeter:

A good digital multi-meter must have a high input impedance

Fluke 87

The Fluke 87 is a multi-meter that operates on a base 4 principle. Measurement ranges will be 4, 40, 400, 4000, etc. For instance, on a voltage setting, the maximum value that can be measured will be 4V, 40V, 400V, or 4000V depending on the scale selected. Some other brands of meters are base 2 (2, 20, 200, 2000, etc.) or base 10 (1, 10, 100, 1000, etc.). Either type will work equally well as long as the technician learns to read the meter properly and accurately. As with all things, meters come with different levels of features, quality, and prices. A technician considering the purchase of a meter should keep two things in mind:

- Does it have all the functions I need?
- What is its input impedance?

Impedance is the input resistance a meter has. It prevents the meter from becoming a component of the circuit and affecting the circuit operation. Some lower quality meters have a tendency to "load" the circuit being tested and thus affect not only the operation of the devices itself, but also cause incorrect readings to be displayed. To prevent this "loading", look for a meter with high Input Impedance, generally the higher the better. This becomes even more critical when measuring electronic components, as some low impedance meters can actually cause damage to those circuits. Our Fluke 87 has an input impedance of 10,000,000 Ohms (10MΩ).

Digital Display - The Fluke 87 Display is a digital and analog LCD readout screen for all meter functions. Turning the meter on while holding any button will allow the user to see all of the possible display segments on the screen. Each screen function is self-tested when the meter is turned on and, so to save battery power, the meter will turn itself off if not used for a certain amount of time.

Fluke 87 Main Navigation

Pushbuttons - Eight pushbuttons are used on the Fluke 87 to change display readouts and some rotary dial functions.

Rotary Dial - The rotary dial has eight positions for selecting the desired measurement.

Input Terminals - There are four input terminals at the bottom of the meter for inserting test probes. The Fluke 87 is also equipped with a feature called Input Alert ™. This feature will emit a constant chirp if a lead is inserted into either the A or the mA/µA terminal input and the rotary dial is not turned to the mA/µA or µA position. This prevents damage to fuses or the meter by using and incorrect configuration. Check the fuses using the alert by putting the rotary dial in a non-amperage position (V or W) and inserting a lead into each of the amperage input terminals. Listen for the chirp indicating error. Check both inputs as there are two fuses. Make sure leads are not connected to other sources before inserting the leads, this can prevent damage.

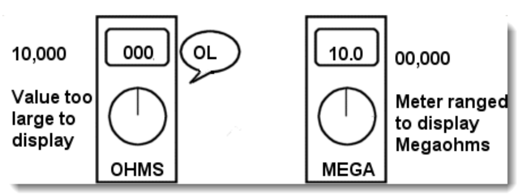
Scaling

If a technician is trying to measure 10,000,000 ohms with the meter set on a 400 Ω range, the display will read OL since the maximum readable value is 400 ohms. After switching the meter to the 40 mega Ω range, the display will show 10.00. Do not confuse this with 10 ohms! That is why it is so important to be aware of the scale currently being used, especially if Auto Ranging is active.

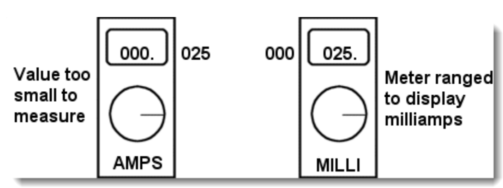
Scaling:

Always use the correct range to prevent reading errors.

The opposite condition can also be confusing in dealing with small values. Imagine you are trying to measure 25 mA on a 40 A scale. The meter would basically display zero (00.03). However, by switching to a 4A (4000mA) scale, the readout now shows 0025 mA which is accurate.

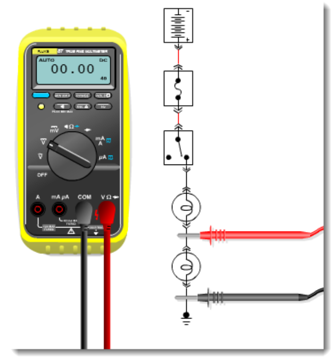


A technician who is careful to use the correct unit setting (Volt, Amp, Ohm) and the right scale, can consistently rely on the meter information to assist in proper diagnosis.



Measurements

Voltage Measurement:

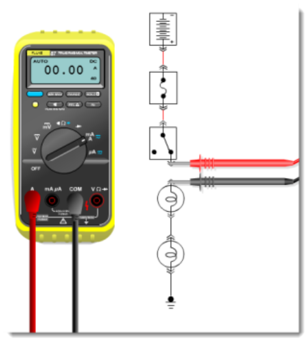


To properly configure a meter for voltage measurements, follow these steps and refer to figure shown here.

1. Insert the meter leads into the COM and VΩ inputs
2. Turn the rotary dial to the AC or DC Volt position
3. Place the leads across the component to be tested (voltage drop
4. Apply power to the circuit

Current Measurement:

Caution:
- To prevent blown fuses, check your meter installation thoroughly before applying power. Remember, in this mode, all of the current in the circuit will pass through the meter.
- Never place leads across a component when measuring amperage.



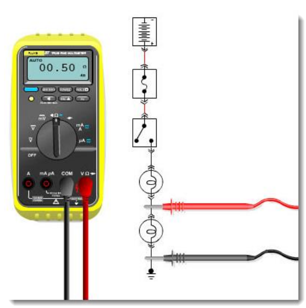
To measure current, follow this procedure and refer to figure shown.

1. Insert the meter leads into the A and COM inputs
2. Turn the rotary dial to the mA/A position
3. Make an open in the circuit
4. Place the meter leads to complete the circuit (leads must be inserted so that all current flows through meter)
5. Apply power to the circuit

When measuring circuit current, always begin with the red lead in the A (10 amp) input terminal. The lead may be moved to the mA input only after you have determined that the current is below the maximum (1A) rating for that terminal.

Resistance measurement:

Note: When measuring resistance, it is important to make sure the power is off. This is done not because it will damage the meter, but because it will give false readings.



Resistance measurements are made according to these steps and shown in the figure.

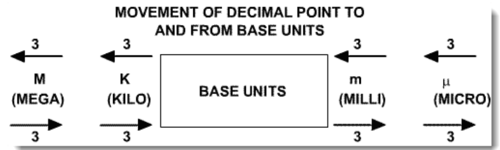
1. Power must be off
2. Insert the meter leads in the COM and VΩ inputs
3. Turn the rotary dial to the Ω position
4. Place the leads across the component
5. Do not allow your fingers to touch the ends of the leads since it will change the reading!

Converting Values

When working with meters, it may be necessary to convert the meter reading to a higher or lower unit of measurement. When converting units, remember the following rules:

- When converting from a larger unit to smaller unit, multiply:
  - ***Example***: 1 volt is converted to millivolts by multiplying 1 x 1000 = 1000mV
- When converting from smaller units to the larger, divide:
  - ***Example***: 500 mV is converted to volts by dividing 500/1000= .5V

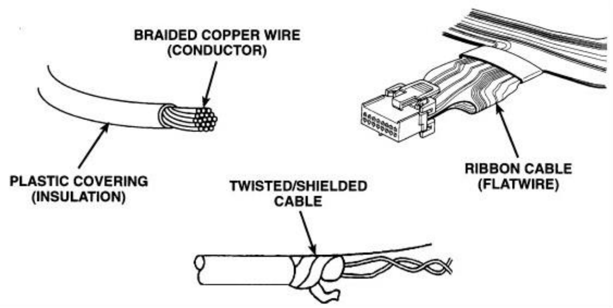
Below is a diagram that may come in handy when doing conversions. Using the table below, the base unit represents the number you are starting with. By moving the decimal right or left, you can easily convert from your base unit to the appropriate measurement.



Automotive Wire Applications

Wires in automotive applications typically come in one of three different configurations: braided, twisted/shielded, and ribbon cable. Braided, or multi-strand wires are made of copper or aluminum and are the most widely used because of their current carrying capacity and flexibility. Twisted or shielded wires are used in places where electric noise may be present and the wires need to be protected. The third type, ribbon cable, is used between electronic printed circuits or computers.

Automotive Wire Applications



Shielding

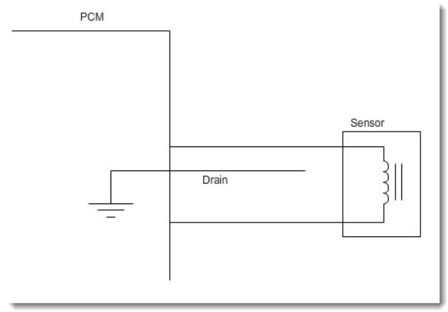
There are three forms of shielding used in most vehicles to protect the wires from receiving erroneous signals or other electric noise. They are twisted wires, Mylar tape, and drain lines.

A twisted pair is simply two wires that have been wrapped around each other a certain number of times for each foot of cable length. Any time a current is passed through a wire, a magnetic field is created around the wire. By twisting the wires together, we can cause the magnetic fields to cancel each other out.

The second type of shield is Mylar tape. Mylar is the same material used to make the shiny balloons, and it has electrically conductive properties. A shield made of Mylar can be either a reflector, to prevent noise from reaching the wires, or it can be connected to a negative point to absorb noise and send it to ground. Any time a repair is made, Mylar shields must be re-wrapped and secured to maintain the noise protection.

Drain lines are less commonly used than the previous two, but they are gaining popularity. A Drain line is a bare (non-insulated) wire that travels the length of a cable with other circuit wires, but is connected to ground only on the module end. Drains act like antennas that receive spurious electrical noise and transfer it to ground. It is important for technicians to remember to not cut the drain wire or connect it to any other wire.

Drain Line Diagram



Wire Sizes

In the automotive industry, there are two scales used to measure the sizes of wires: American Wire Gauge (AWG) and metric.

American Wire Gauge is a system that has been in use for decades but is quickly losing out to the metric standard. The AWG scale uses a series of even numbers to denote the non-insulated diameter of a wire. In the AWG system, the larger the rating number, the smaller the wire and the lower its current carrying capability.

The metric scale for measuring wire is based on the cross-sectional area of a non-insulated wire expressed in square millimeters. Unlike the AWG system, however, a larger number in the metric scale translates into a larger wire and a greater current capacity. Both scales and their respective sizes are shown in the following chart.

Metric Wire Sizes	AWG Wire Sizes	Actual Conductor Size
.22	24	•
.35	22	•
.5	20	•
.8	18	•
1.0	16	•
2.0	14	•
3.0	12	•
5.0	10	•
8.0	8	•
13.0	6	•
19.0	4	•
32.0	2	•

Length vs. Resistance

All wires exhibit increased resistance as their length is increased. Therefore, the longer a wire needs to be, the larger its diameter must be to ensure that the additional resistance does not affect its current carrying capability. Refer to the chart, which shows a comparison of the wire length to wire size requirement for a given amperage. These figures are typical for 12-volt systems.

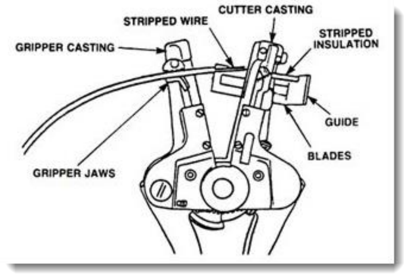
Wire Length versus Current Capacity

Required Amperes	Wire length					
	3 Feet	6 Feet	9 Feet	12 Feet	15 Feet	20 Feet	25 Feet
0-5	20	20	20	20	20	18	18
6-7	20	20	18	18	18	16	16
8	20	20	18	18	18	16	16
10	18	18	18	16	16	14	14
12	18	18	18	16	16	14	14
15	18	18	16	16	14	14	12
18	18	16	16	14	14	12	12
20	16	16	14	14	12	12	10
25	16	14	14	12	12	10	10
30	14	14	12	12	10	10	8

Stripping

Every technician knows that in order to join two wires together, or to install a new terminal on a wire, some insulation must first be removed from the wire. It sounds simple enough; unfortunately, too often bad stripping technique causes the connection to be less than ideal and possibly inoperative.

Typical Wire Strippers



The first thing to remember is to remove only as much insulation as necessary to do the job. Too little bare wire may cause a bad connection and too much may expose the circuit to inadvertent contact with another circuit or to ground.

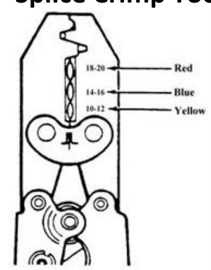
Secondly, always use a proper stripping tool in good condition. Do not use a knife, a pair of side cutters, or any other type of sharp instrument as these will nick or cut some of the strands (called ringing the wire) and reduce the amount of amperage the circuit can carry. Using a good pair of wire strippers also reduces the chance of stretching and weakening the strands.

Splicing

Using Splice Sleeves

Whenever two wires need to be joined, it is advisable to crimp the wires into a splice sleeve. Splice sleeves are connectors that have both a metal insert to make the electrical connection, and a special glue that, when heated, will hold the wires together by the insulation. The glue will also protect the connection against exposure to weather that could corrode or break the wires. Splice sleeves come in three sizes: small, medium, and large, and in the colors red, blue, and yellow, respectively. Refer to this figure for an illustration of the proper procedure for splice sleeve installation.

Splice Crimp Tool



Splice Sleeve Installation

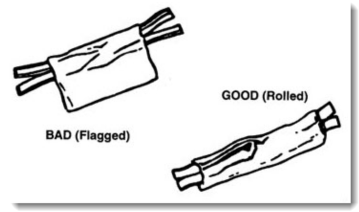
Splice Sleeve Crimping Steps

- Strip each wire just enough that the bare wire is exposed outside of the metal insert. The notch in the middle of the connector will prevent the wire from entering the sleeve too far. Do not twist the wires as that will cause less contact area with the metal insert and reduce its capacity.
- After both wires are inserted, apply a firm crimp just once on each side of the notch. Multiple crimpings will actually weaken the connection. Crimping tools will either be color coded or labeled by wire size to ensure the correct jaws are used on the tool. Do not use pliers, vise grips, or other improper tools for crimping as these will damage the sleeve.
- Use a proper heating tool, such as a shielded butane torch, to melt the splice, always working from the center of the sleeve outward. A proper seal will allow a small amount of glue to seep out of each end. Cigarette lighters, propane torches, and soldering irons are not adequate for heating splice sleeves since they are too hot and will make the connection brittle.

Soldering

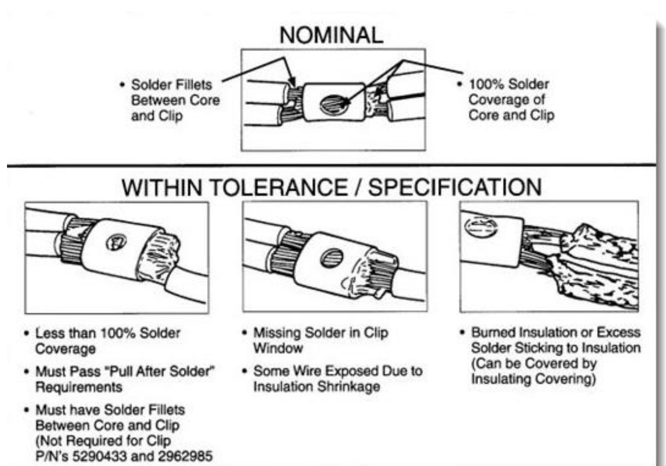
Soldering can be used if two or more wires need to be joined without terminals (a splice), or to insure a better electrical connection between wires and terminals. When properly applied, solder will fill all of the air cavities in wires and permit better metal-to-metal connection. Soldering done improperly, however, results in bad connections, melted insulation, and improper circuit operation. Some recommendations for soldering:

Taping Standards



- Choose a soldering iron or torch with enough heat to do the job but not enough to damage smaller wires. Soldering irons are usually rated in watts.
- Apply some solder to the tip and wipe it clean. This is called "tinning" and helps to transfer heat to your work.
- Apply heat directly to the terminal or "splice clip" and feed the solder into the connection as the heat transfers to the wires.
- Do not use an excessive amount of solder. Too much may not allow pins to fit into the connector cavities and it also just looks messy.
- Do not allow the soldering iron to burn the connection or insulation; too much heat for too long a period of time can cause a bad connection.
- Insure that your solder is smooth and doesn't have any "points" that might stick through the tape.
- Never solder a powered circuit, especially with an electric soldering iron.
- Do not wiggle the wires or terminals until the solder has cooled completely. To do so may result in a "cold" solder joint that could adversely affect the connection.
- After the solder has cooled, apply electrical tape to splices to prevent inadvertent contact with other metal surfaces. Insure that your tape wrap is smooth and does not leave any "flags", which may cause the tape to come loose. Although tape wrap sealing is acceptable, the seal of choice is heat shrink tube. It is similar to the splice cap but is a different style of repair. You manually solder the connection first then slide the shrink tube over the repair and then shrink the tube with a heat source to collapse the tube.

Refer to this chart for acceptable standards for soldering:



Terminals

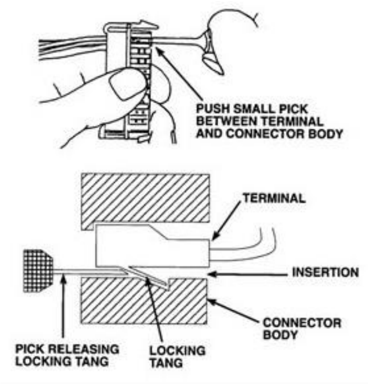
From time to time, it will be necessary to replace terminal pins for loose connections, corrosion, or breakage. It is important that technicians follow a correct procedure in replacing terminals to reduce the possibility of a repeat failure. Some of the problems to be avoided include stripping too much insulation, stripping too little insulation, excessive crimping force that bends and weakens the terminal, and too little crimping force that causes a bad connection.

Releasing Terminals

There are many types of connector terminals used throughout the automotive industry, and there are numerous methods for the removal and replacement of those terminals. Most terminals will have a "tang" or finger that holds the terminal once it is "clicked" into place. Others use some form of cap or wedge that is inserted to hold several terminals all at once. Some use a rubber insulator that seals numerous wires, while others have individual insulators for each wire.

Most of the terminals, however, will have a tang and can be removed by inserting a small pick between the connector and terminal, and compressing the tang (see illustration). Technicians need to be aware that there are two types of these terminals, one with the tang facing rearward (toward the wires) and one with the tang facing forward. It's important to note that those terminals with the tang facing rearward (sometimes called push-to-seat) are inserted from the back of the connector while those terminals with the tang facing forward (pull-to-seat) are inserted from the front of the connector. Attempting to remove a terminal in the wrong direction will obviously cause damage to the terminal and possibly the connector. Pull-to-seat terminals must also have their wires pushed completely through the connector before a terminal is attached. In short, a great deal of frustration can be avoided by verifying the type of terminal being used before attempting to remove it.

Using a Pick for Terminal Removal



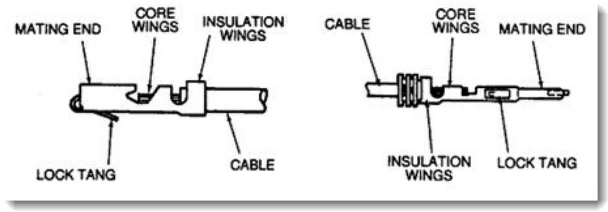
Terminal Crimping

Let's cover some good crimping techniques:

- Strip an amount of insulation such that the bare wire shows on both sides of the "core" crimp but does not extend into the insulation crimp area. The core should also not be long enough to interfere with the mating end of the terminal (see illustration). If it is a "pull-to-seat" terminal, the wire must be inserted through the connector first. Do not twist the wire ends, as that will result in less wire-to-terminal contact.
- Select the proper anvil on the crimping tool and crimp the core first, using firm, but not excessive force. Too much force will bend the terminal. Pliers are never to be used for terminal crimping. It is also necessary to crimp the core first, since crimping the insulation first will cause the strands to spread and make core crimping more difficult.

- Next, select the correct anvil to crimp the insulation wings (if the terminal uses an individual insulator, slide it into place first). This crimp is used to hold the terminal in place, rather than for electrical contact, and therefore will not need to be quite as firm as the core crimp.
- After crimping, gently tug on the wire and terminal, to check for proper tension, and apply solder if required. Reinsert wire into connector.

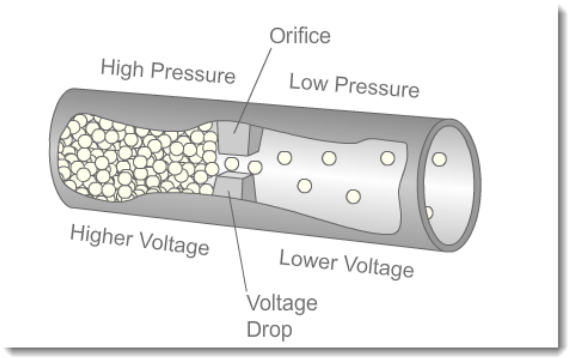
Proper Crimping Position



Chapter 5: Testing Series and Parallel Circuits

Voltage Drop

As explained earlier in this course, voltage drop is like the pressure decrease in a hose with a crimp in it; it is defined as the difference between the voltage on the inlet side of a device compared to the voltage on the outlet side. Comparing that value to a written specification will assist the technician in determining the fault with the system.



Voltage Drop:

Voltage drop is the difference in electrical pressure between the two sides of a device.

Parallel Circuit Formulas

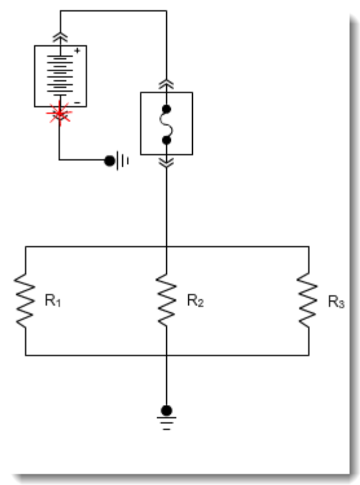
Parallel Circuit Resistance

To calculate total resistance in a series circuit, we can simply add the values of the individual resistances. In a parallel circuit, it is a little more involved. For example, in a circuit with three branches having 10, 20, and 30 ohms respectively, we know the total resistance must be less than 10 ohms (the value of the smallest branch) rather than the 60 ohms we would have in a series circuit.

Parallel Circuit Resistance

Parallel circuit total resistance must be less than the resistance of the smallest branch resistance.

The sum of the reciprocals can also be expressed as:
$1/\mathbf{R}_T=1/\mathbf{R}_1 + 1/\mathbf{R}_2 + 1/\mathbf{R}_3 + 1/\mathbf{R}_4 +...$



Applying our values we have:
$1/\mathbf{R}_T = .1\Omega + .05\Omega + .033\Omega$

$1/\mathbf{R}_T = .183\Omega$

$\mathbf{R}_T = 1/.183\Omega$

$\mathbf{R}_T = 5.46\Omega$

The Windows calculator on your computer can be used to make these calculations. You can open the Windows calculator by clicking on Start, and then Run. Type the word "calc" without the quotes in the space provided and then click the OK button. Try both of these methods using our example numbers of 10, 20, and 30Ω

If your calculator has a 1/x (inverse) key, the formula can be entered by pressing the calculator keys (shown in parentheses) in order as follows:

$\mathbf{R}_1$ (1/x) (+)

$\mathbf{R}_2$ (1/x) (+)

$\mathbf{R}_3$ (1/x) (+)

(1/x) answer

If no inverse key is available, then figure the resistances by pressing the calculator keys (shown in parentheses) in order as follows:

1(÷) $\mathbf{R}_1$ (=) (M+)

1(÷) $\mathbf{R}_2$ (=) (M+)

1(÷) $\mathbf{R}_3$ (=) (M+)

1(÷) (MRC or MR) (=) answer

(1/x is the inverse key, + is the addition key, M+ is the Memory Add key, MRC or MR is the Memory Recall key, is the Division key, and = is the Equals key).

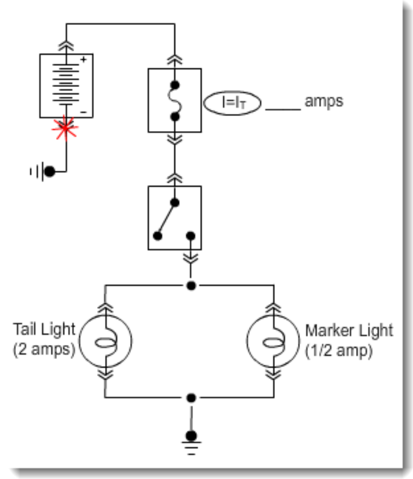
Parallel Circuit Current

Unlike series circuits, where current is always the same, parallel circuits can have a different amperage value for each branch in the circuit. You will recall that the voltage drop is the same for parallel branches, but if each branch has a different resistance, then Ohm's Law can be used to determine that the branches have different currents. The total circuit current can then be found simply by adding the branch currents.

Parallel Circuit Current

The sum of the branch currents adds up to the total current.

What is the total current for this circuit?



We know that since the two bulbs are in parallel, their voltages are equal at 12V each.

The bulb on the left has a resistance of 6Ω and applying Ohm's Law we have:

$\mathbf{I_1 = E_1/R_1}$

or

$I_1 = 12V/6\Omega$

so

$I_1 = 2$ Amps

Similarly, the 24W right bulb has a current given by:

$\mathbf{I_2 = E_2/R_2}$

or

$I_2 = 12V/24\Omega$

so

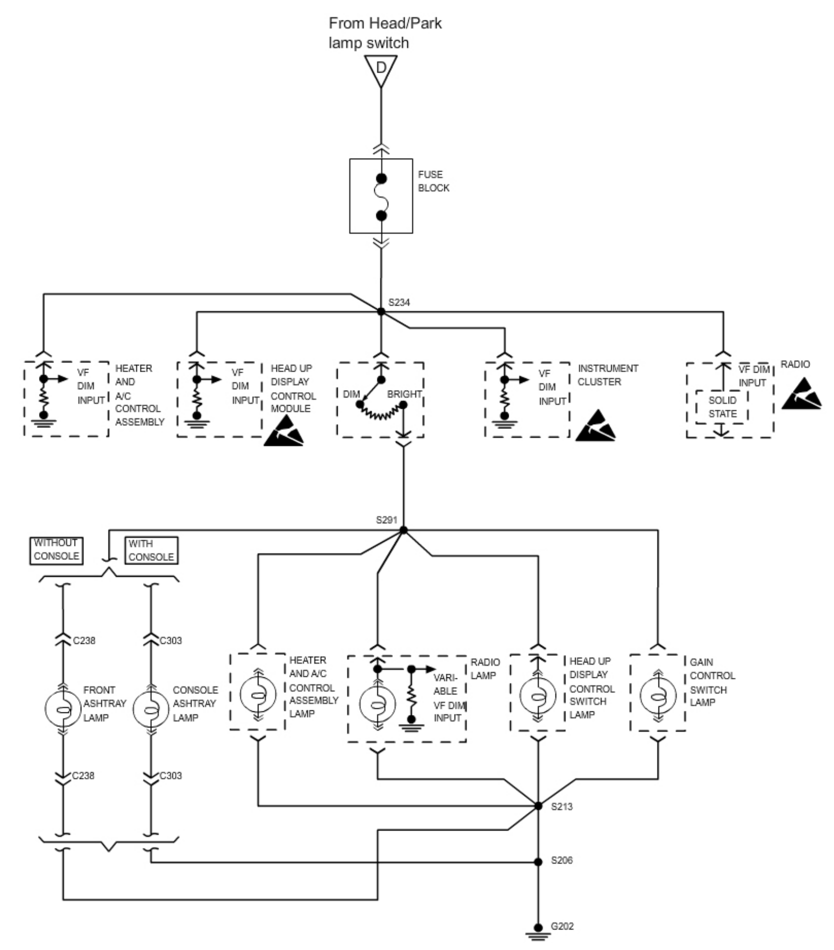
$I_2 = .5$ Amps

Total current is therefore: $\mathbf{I_T} = \mathbf{I_1} + \mathbf{I_2} = 2A + .5A = 2.5$ Amps

Now, calculate the total current if the left bulb is 2Ω and the right bulb is 12Ω.

Series-Parallel Circuits

Sometimes it is necessary to reduce the amount of voltage drop across the branches of a parallel circuit to less than source voltage. To accomplish this we use a circuit called Series-Parallel. A Series-Parallel circuit works by inserting a resistor in series with a parallel network. The series resistor will cause a voltage drop that leaves less voltage available to the branch loads and therefore reduces their currents.



This illustration of a Dash-Light circuit shows how changing the resistance of the rheostat (dimmer control) varies its voltage drop and, in turn, changes the voltage available to the dash bulbs, which controls their brightness.

Question:

How would you calculate the total resistance of a Series-Parallel circuit?

Calculate the parallel portion of the series-parallel circuit just as you would for and parallel network and then add the series resistance to that total.

Question:

How would you calculate the total current?

Use the Ohm's Law formula I=E/R just as you would for any circuit. In this case, the voltage is the 12 volt source and the resistance is the series-parallel value determined in the last step.

Chapter 6: Diagnosing Using Wiring Diagrams

With an understanding of Voltage, Current, and Resistance, we can now turn our attention back to the devices that determine those values.

Circuit Protectors

As introduced in Module 2, three types of circuit protectors are used in modern automotive applications: fuses, circuit breakers, and fusible links. The primary function of these devices is to protect the wiring from damage should a circuit failure cause excessive current. Although circuit protectors are rated in amps, it is actually the heat caused by too much current that causes the device to open the circuit.

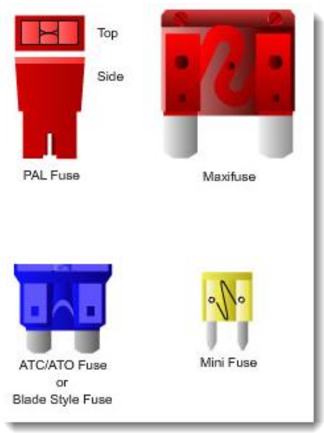
Circuit Protectors

Circuit protectors are used to prevent wiring damage from excessive current.

Fuses

Fuses are the most common circuit protectors in automotive use and are rated from 5 A to 80 A. They are one-use devices with a metal strip inside that melts from the heat caused by exceeding the current rating of the strip. The most common fuse types are the ATC/ATO (Auto Fuse or blade style), Mini Fuse, and Maxi Fuse. As shown in the graph here, different colors are used to identify the amperage values of the various fuses.

Assorted Automotive Fuses



Fuse Colors

Current Rating in Amperes	Fuse Color
Auto Fuse, Mini Fuse	
2	Gray
3	Violet
5	Tan
7.5	Brown
10	Red
15	Blue
20	Yellow
25	White or Natural
30	Green
Maxi Fuse	
20	Yellow
30	Light Green
40	Orange or Amber
50	Red
60	Blue

Circuit Breakers

Unlike fuses, circuit breakers can be reset, either manually or automatically, and reused. Circuit breakers are either "cycling" or "non-cycling."

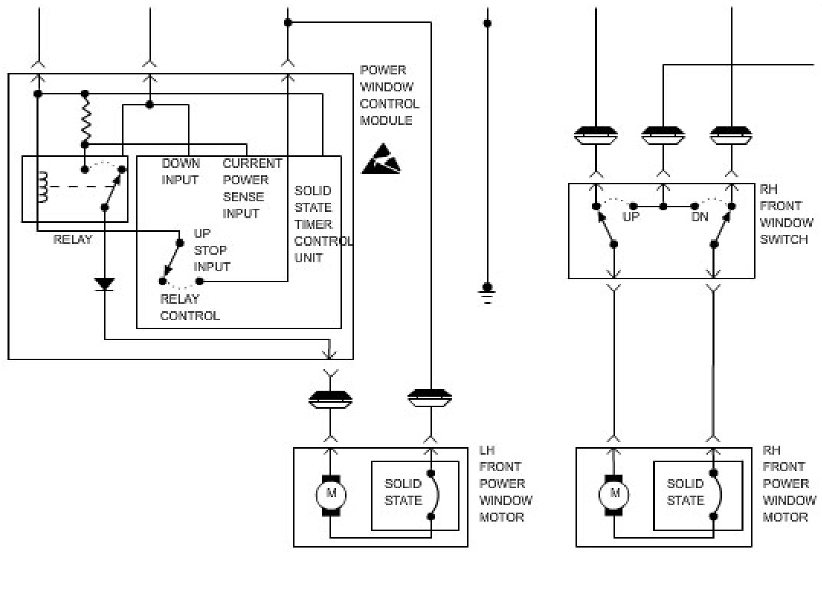
Circuit Breakers

Circuit breakers can be either cycling or non-cycling

A circuit breaker is made with a bi-metallic strip that operates much like the thermostat in many homes. As current passes through the strip it creates heat, which causes the two metals to expand, but at different rates. When one expands faster than the other, the strip bends and opens a contact which stops current flow through the circuit. In a "cycling" type of breaker, the bi-metallic strip will cool, after the current stops, and return to its original shape, which closes the circuit to current flow once again. A mechanical turn signal flasher works this way also.

A "non-cycling" type of breaker will open from excessive current as well but must be manually reset. Another type of circuit breaker is the solid state device called a PTC (Positive Temperature Coefficient). PTCs have no moving parts and are commonly used in window motors and door lock actuators to protect the circuit from damage should a control switch become stuck or in case a limit switch fails. They can also be used as end-of-travel stops without a limit switch.

Power Window Schematic with PTCs



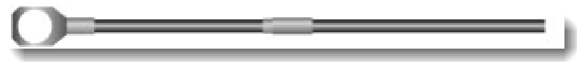
A PTC is a thermistor that works by greatly increasing its resistance when too much current generates excessive heat in the device. As the resistance increases, the current in the circuit is reduced which protects the wiring from damage.

Fusible Links

Like fuses, fusible links are single use devices that melt internally from heat caused by too much current. Although they look like typical wires, fusible links have an insulation designed to withstand a greater amount of heat than regular wire insulation. This prevents inadvertent shorting to ground during a failure caused by excessive current. Fusible links are being used less in modern applications as fuses with higher amperage ratings have become available.

> **Fusible Links**
>
> Fusible links should be 4 sizes smaller than the wire they protect

When replacing an open fusible link, never exceed nine inches in length and use a link that is four sizes smaller than the circuit wire. For example, a 14 gauge wire would be protected with an 18 gauge fusible link. This will ensure that the link burns before the circuit wire. An open fuse link can also be verified by pulling its ends to see if it stretches, which shows failure.



Switches

Switches are simply on-off devices used to open or close an electrical circuit. You are already familiar with some types of switches from the first two modules of this course. There are various types of switches that are categorized by the number of positions they have, as well as the number of circuits they control. Some of the most common types are given below:

Single Pole Single Throw (SPST) - Controls one circuit with two positions (ON-OFF)

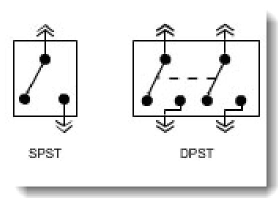
Single Pole Double Throw (SPDT) - One circuit with three positions (two ON positions with a center OFF position)

Double Pole Single Throw (DPST) - Two circuits with two positions

Double Pole Double Throw (DPDT) - Two circuits with three positions

Switches are rated by the amount of current the contacts can carry.

Switch Type Examples

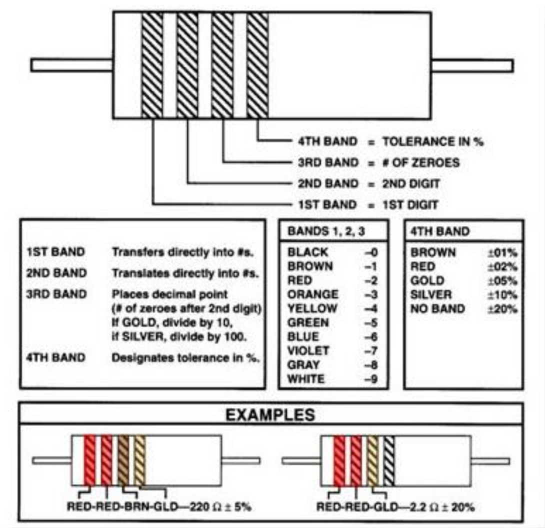


Resistors

Resistors are devices, made of carbon or ceramic, which are used to limit the voltage or current in a circuit. They can be either "fixed" or "variable" and will be rated both in terms of value (ohms) and power (watts).

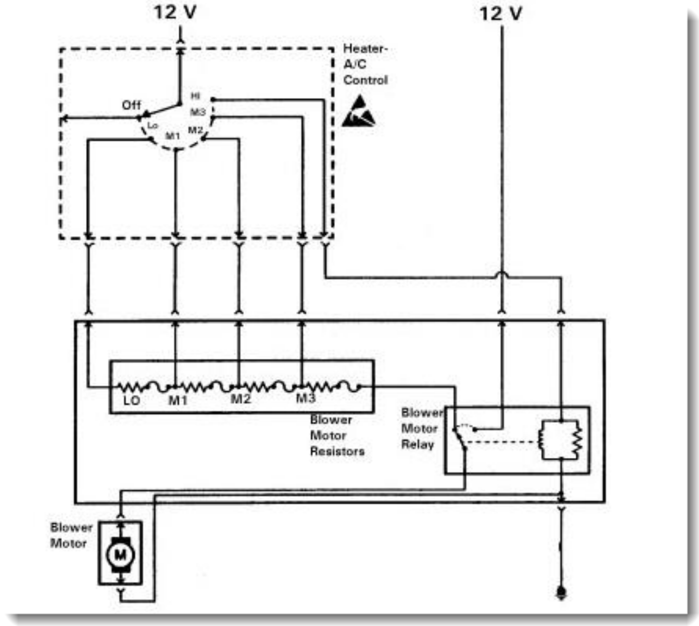
The value of a "fixed" resistor can be read from its color bands. Each resistor has several color bands that should be offset to one end. Hold the resistor so that the color bands are on your left, note the colors, and compare them to the chart.

Resistor Color Coding



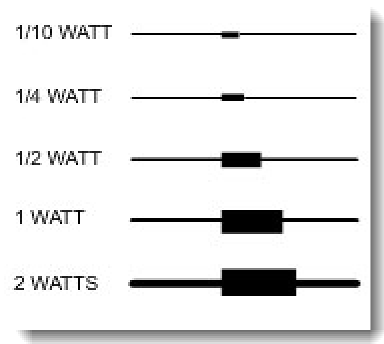
Some resistors, such as those found in blower motor circuits, are wire-wound and have no color bands, as shown here. Resistive values for those should be printed in service manuals.

Blower Motor Resistors



Just as they have an Ohms value, resistors also have a wattage value. Recall from Module 2 that wattage (Power) is the product of Voltage and Current given by P=IxE. As such, resistors are not rated in either voltage or current but rather in watts to limit their heat exposure. For example, if a resistor is rated at 10 Watts and is used in a 12 Volt circuit, then the maximum allowable amperage is .833 Amps [I=P/E]. If we decrease the voltage by half to 6 volts then the current can double without damaging the resistor [P=IxE or P=1.66 amps x 6 volts or P=10 watts]. Most often the wattage rating of a resistor is determined by its size. Some of the most common sizes are shown in the illustration.

Common Sizes

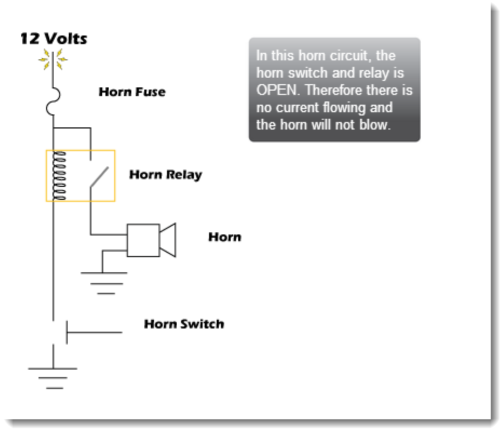


Circuit Failure: Opens, Shorts, and Grounds

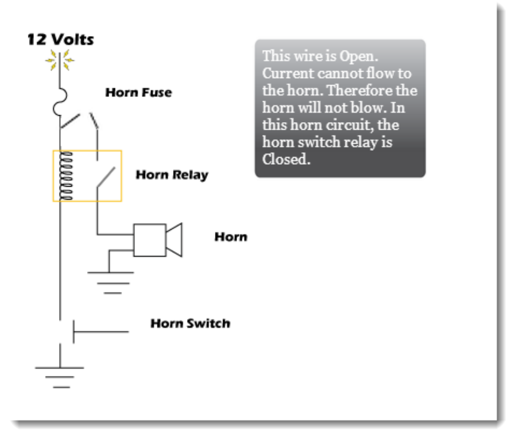
Electrical circuits can fail in several different ways. The most common types of failures are open circuits, short circuits, and grounded circuits.

Open Circuits: An open circuit does not always indicate a fault. For example, a horn circuit is normally open until the horn button is depressed. An open circuit that results in circuit failure is an unintentional opening in the circuit, such as severed wiring or a faulty switch.

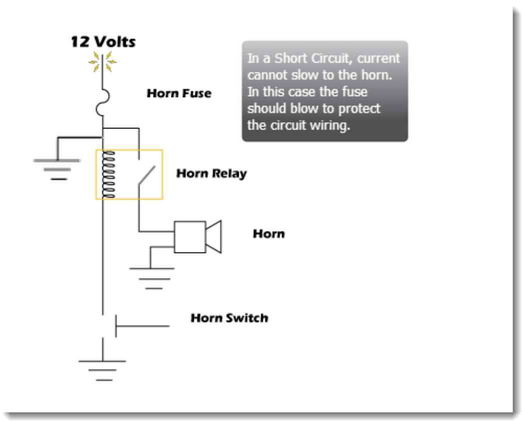
Normal Operation



Open Circuit

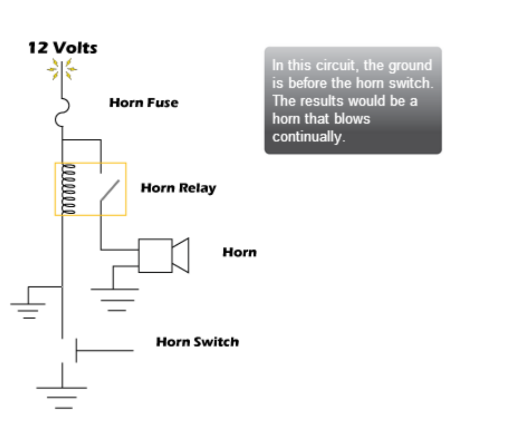


Short Circuit



Short Circuit: A short circuit will allow current to flow out of a circuit by providing a path out of the circuit that has less resistance than the circuit itself. As a result, shorted circuits have low resistance; as we learned when we covered Ohm's law, this results in high current flow. Fuses and circuit breakers were designed specifically to protect against the severe consequences this high current flow can have, and the normal result of a short circuit is a blown fuse or a tripped breaker. However, short circuits can still result in major circuit meltdowns and fires.

Grounded Circuit



Grounded Circuit: In an unintentionally grounded circuit, there is an unintended current path to ground after the load. A component that is grounded in this way will operate continually until either the ground or the source of power are removed.

When diagnosing opens, shorts, and grounds, always use a wiring diagram to determine voltage drops throughout the circuit.

Headlight Circuits

Headlight system operation and service precautions

On several modern vehicle headlights are used for both day and night driving. During the day headlights operate as daytime running lights. Some manufactures use the same lamps for both day and night driving. While others use separate lamps for day and night operation. Systems that use the same headlamps for day operation will normally wire the front lamps in series dropping 6 volts at each headlamp. There are several precautions that should be used when servicing headlamps.

1. Avoid touching the glass of any headlamp. A thin film of oil from your hands and fingers will cause the lamp to operate at a higher temperature. The higher operating temperature will shorten the life of the lamp.
2. Take great care when servicing or changing headlamps. Handle all lamps new or old with great care. Headlamps are under pressure breaking them can cause an explosion sending sharp pieces of glass flying.
3. Install new lamps immediately after removing from packaging. Allowing them to lay on a workbench to long will allow them to attract dust and moisture.
4. Always replace a lamp with one correct part number. Never install a lamp that is not the correct wattage and voltage rating.
5. Always ensure the headlamp socket is installed and sealed properly after replacing a headlamp. Not doing so will allow the lens to become cloudy or the headlamp assemble cover may fill with water, shorting the life of the lamp.

Headlight circuits on most vehicles are protected by a circuit breaker. This is a safety precaution that will allow headlight to operate momentarily **ON** and **OFF** in case there is a short circuit in the headlight circuit. If this condition should occur do not operated the vehicle until repaired.

HID Headlights

CAUTION: On **HID** (**High Intensity Discharge**) headlamps never test using a DMM or test light. On HID headlamps, a voltage of approximately 30000 is momentarily applied to the bulbs. Never touch the high voltage sockets on any vehicle equipped with HID headlights or a serious personal injury could occur.

On HID headlamps the test and inspection procedure can be performed as follows:

1. Turn headlamps off and allow them to cool completely.
2. After they have cooled turn them on for 15 minutes.
3. After 15 minutes turn them off and on quickly 10 times in about a 15 second period.

4. If one headlamp does not obtain full brightness or burn dim the HID headlamp is nearing the end of its useful life.

It is recommended by manufacture that HID headlight be replaced in pairs. Over time HID headlight will not illuminate as they once did when they were new.

Using an electrical wiring diagram

A wiring diagram is an extremely valuable tool when diagnosing an electrical concern in any type of equipment or vehicle. The proper use of a wiring diagram will reduce diagnostic time. There are several different methods advanced by different automotive manufactures and textbook authors. Some recommend always starting at the power source when testing an electrical circuit. Other manufactures teach starting at the malfunctioning component and backwards testing the circuit. Still other recommends starting at the fuse box or relay, (if the circuit is relay controlled). Before beginning diagnostic on an electrical circuit it is recommended that a technician review circuit operation. Some manufacture used slightly different schematic symbols to identify components.

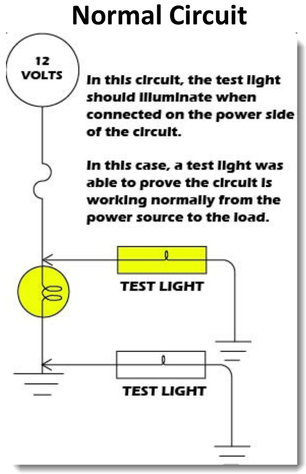
Note: Always follow manufacture diagnostic procedure when diagnosing electrical systems. Failure to do so could result in personal injury or death, damage to electrical system, or improper diagnostic.

Using a Test Light to Test Electrical Circuits

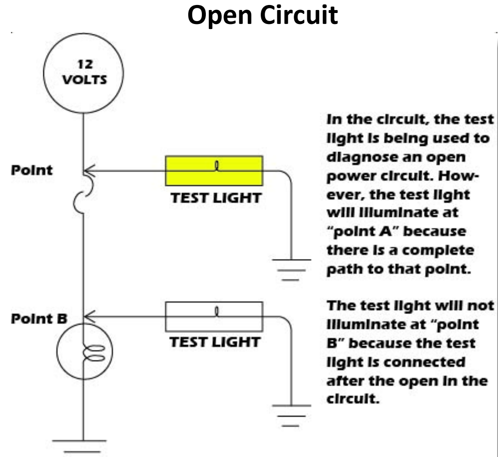
CAUTION: Never use a test light to test low voltage circuit. Doing so may damage or destroy expensive electronic components. On vehicles equipped with electronic control modules only use a test light when directed by a manufacture diagnostics test procedure.

A test light is a useful and reliable tool when used correctly. A test list can be used to test for open circuit, closed circuits, and short circuits. In a closed circuit, the test light will illuminate when connected to a circuit that has a current flowing on the power side. On an open circuit, a test light will not illuminate if there is no current flowing when connected after the opening in the circuit. A test light can be used to test for a short circuit if connected in series with the short circuit.

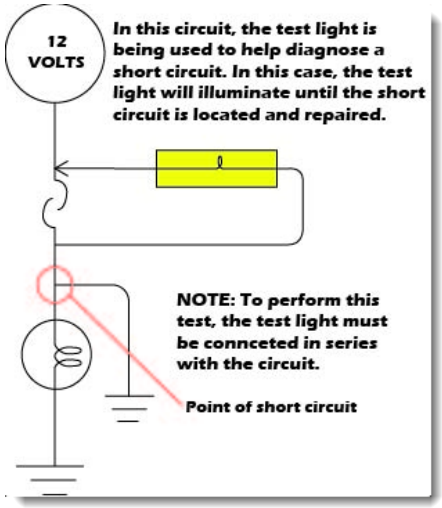
Normal Circuit



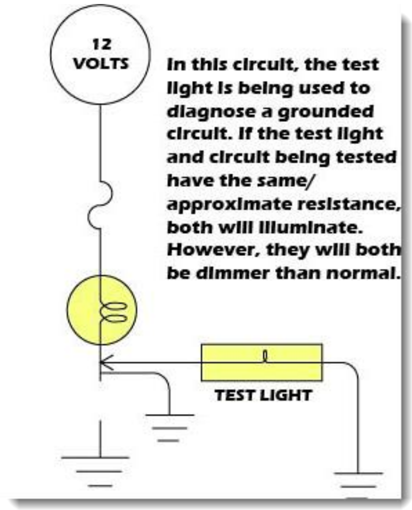
Open Circuit



Short Circuit



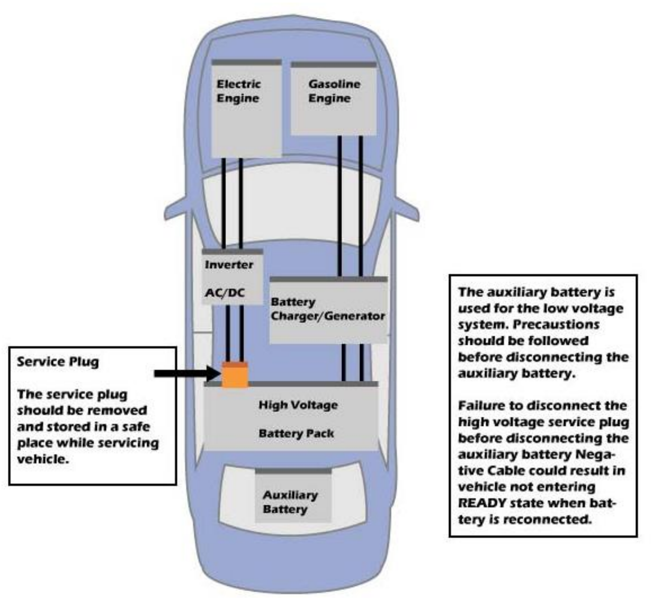
Grounded Circuit



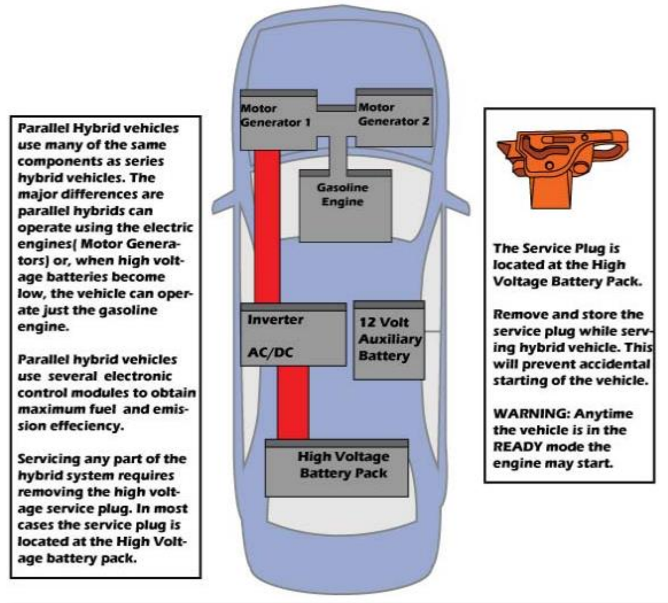
Hybrid System Identification, Inspection and Precautions

All hybrid vehicles have two power sources. One is usually a gasoline power engine however; some manufactures are planning to replace the gasoline engine with a small diesel engine. Hybrid vehicle are also equipped with an electric engine. Manufactures have developed several different configurations for hybrid vehicles. Most can be classified as either series hybrid or parallel hybrid. Both series and parallel hybrid vehicles operated using high voltage batteries and charging systems. For that reason precaution must be taken when servicing or repairing hybrid vehicles. High voltage wiring is bright orange in color. Precautions must be taken when servicing hybrid electrical systems. Not following the proper service procedures when servicing hybrid electrical systems can cause can cause personal injury and/or damage to a hybrid electrical.

Series Hybrid: A series hybrid vehicle uses both an electrical engine and a gasoline engine. The system will operate on electrical power. When the battery pack that operates the electrical engine runs low the gasoline engine will start to recharge the batteries.



Parallel Hybrid: Vehicles can operate on battery power or gasoline. When the battery pack is fully charged and driving condition permit the vehicle operates on battery power alone. When the battery pack becomes discharged the gasoline engine starts to provide power to drive the vehicle and recharge the vehicle. Under heavy acceleration both the electrical and gasoline operate.



Both series and parallel hybrid system use two electrical systems. A low voltage system is used to operate the tradition electrical system such as the lighting, power window, wipers and entertainment system. The high voltage system is used to drive the vehicle. Servicing the battery pack on hybrid vehicles must be done with caution. Hybrid vehicle use device called an inverter to convert high voltage DC to High voltage AC. Many late model hybrid electrical operate at voltage over 600 volts. Because of the high voltages involved. Basic safety precautions must be followed when servicing or inspecting any hybrid electrical system.

- Always wear rubber gloves rated to handle high voltage
- Wear safety goggles
- Wear rubber-soled shoes safety shoes
- Wear a clean uniform
- Read and follow all manufacture service procedures before starting a repair on any hybrid vehicle.

Before servicing or testing the high-voltage electrical system or disconnecting any low voltage connectors at the inverter take safety all recommended safety precautions. Some manufacture requires removing the high voltage service plug from the battery pack and waiting at least 10 minutes before disconnecting negative battery cable from the axillary 12 volt battery. After disconnecting the 12 volt axillary battery it can be tested by following normal charging and testing procedure.

WARNING: Failure to follow manufacture procedure can result in damage to the hybrid system or personal injury.

Unit 3: AUTOMOTIVE BATTERIES

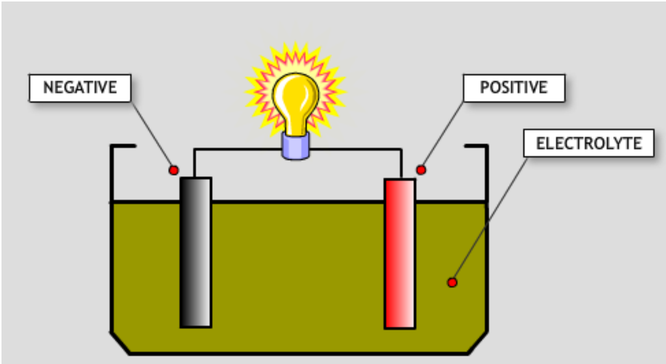
Chapter 1: Batteries Overview

Battery Function

An automotive battery is an electrochemical device that converts electrical energy into chemical energy and stores it until needed. When called upon, the battery converts the stored chemical energy back into electrical energy.

The battery serves four purposes in an automobile:

- It supplies electricity to the accessories when the engine is not running
- It supplies high current to the starter, and system voltage to the ignition system during cranking
- It provides current to the electrical systems when the demand exceeds the output of the generator
- It acts as a voltage stabilizer in the electrical system



Electrical current flow is produced chemically by dissimilar plates in electrolyte solution.

Automobiles generally use what is classified as a wet cell, lead-acid battery. Batteries produce current through a chemical reaction between the active materials of the plates and sulfuric acid in the electrolyte.

Throughout the life of a battery, it is either charging or discharging. When a battery is supplying current to accessories or to the starter, it is said to be discharging. When the engine is running at sufficient speed, the generator carries the electrical load and charges the battery, and both are said to be charging.

> Complete Discharge
>
> While completely discharging an automotive battery does not ruin a battery that is in good condition, it may shorten the life of the battery.

A battery is discharging when:

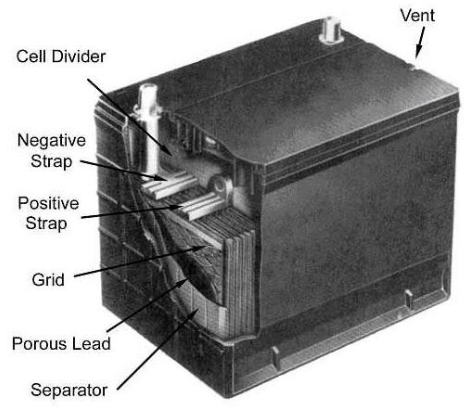
- The engine is not running (parasitic loads or self-discharging)
- The engine is running at a low rpm with conditions of high electrical demand
- There is a fault in the charging system

A battery that is nearly or completely discharged is commonly said to be "dead," "flat," or "run down." A battery in this condition should be recharged to full capacity to provide proper service. Although a generator will charge a battery, it is not designed as a "battery charger." Requiring a generator to recharge a completely dead battery may cause overheating and damage to the generator.

Unlike "**deep cycle**" batteries used in some RV and marine applications, an automotive battery is designed to remain at or near a full state of charge, and not to be completely discharged.

Battery Construction

A battery is made up of individual cells, electrically connected in series for a cumulative voltage effect. Each battery cell contains an element made up of positive and negative plates, separators, and connecting straps.



Each plate consists of a stiff mesh grid of a lead alloy, coated with porous lead on the negative plates, and lead peroxide or lead dioxide on the positive plates. A strap of lead connects the negative plates to form a group, and another strap connects the positive plate group. On each end of the battery, the straps are extended to form battery terminals or posts. The plates are submerged in an electrolyte solution.

Battery cells are housed in a durable, vented, plastic case, and have terminals on the top ("top post") or side (side terminal). Many aftermarket batteries are equipped with both types of terminal arrangements.

> **Terminal Covers**:
>
> When installing batteries equipped for both top and side terminal arrangements, leave the plastic covers in place on the unused terminals to prevent corrosion or accidental shorting.

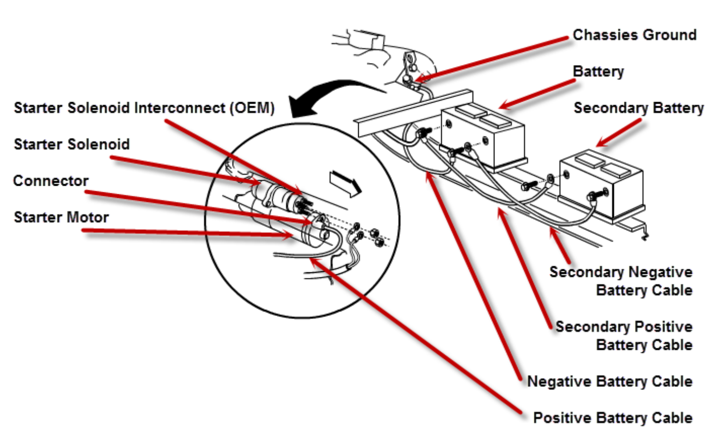
Negative battery cables are usually grounded to the engine block. On some applications, a small pigtail wire also connects the negative terminal to the vehicle body. The pigtail connects the body ground to the engine ground, and it must be connected for the starting and charging system to work properly.

Acid fumes and water vapor are formed and released during the chemical reactions of charging. This **gassing** causes the loss of electrolyte. Conventional batteries have removable vent caps, permitting the electrolyte levels to be checked and topped off, as well as to allow chemical testing. "Maintenance free" batteries are designed to minimize gassing.

Each battery cell is a separate unit that produces 2.1 volts. A "12 volt" automotive battery contains six cells connected in series for a total of 12.6 volts.

Dual Batteries in Parallel

Many diesel applications use two 12 volt batteries, connected in parallel, to provide the high current required to crank a diesel engine. Batteries connected in this fashion still supply 12 volts, but have twice the current capacity of a single battery.



Other Types of Batteries

Low Maintenance and Maintenance-Free Batteries

Many batteries are marketed as "maintenance-free," meaning water should not need to be added during the life of the battery. The plates in these batteries tend to be slightly shorter to allow them to be submerged deeper in electrolyte.

Removable Caps:

On some batteries, it may not be readily apparent that the cell covers are removable, so check carefully.

Some maintenance-free batteries do not have removable covers or caps. Others do, to allow for the addition of water in case of overcharging or severe conditions, and to permit hydrometer testing. These batteries should not require additional water, but if the electrolyte ***can*** be checked, it ***should*** be checked approximately every six months.

Top Post Battery
With Vent Caps Removed

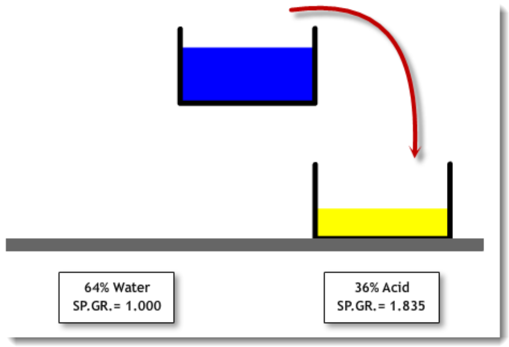
Gel Cell and Absorbent Glass Mat (AGM) Batteries

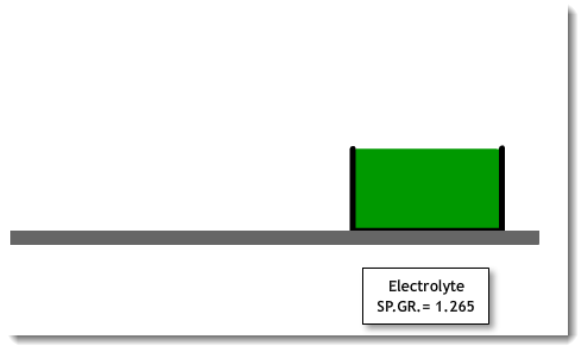
Recent innovations in battery technology include gel cell, and absorbent glass mat designs. These designs do not have free electrolyte. Gel cell batteries were developed for use in mining equipment and have good resistance to shock and vibration.

In AGM batteries, the elements are compressed. The plates are thinner, allowing for more plates per cell. They are heat-resistant, and may last three times longer than wet cell batteries. The gel cell and AGM designs have not yet seen widespread usage, due to their higher cost.

Electrolyte and Specific Gravity

Specific gravity is a measure of the density or weight of a fluid, using water as a baseline. Water has a specific gravity of 1.000, and pure sulfuric acid has a specific gravity of 1.835, meaning it is 1.835 times heavier than water. Electrolyte contains 64% water and 36% acid, which gives it a specific gravity of 1.265 to 1.270 in a fully charged battery (this is often expressed as "twelve seventy," etc.). If the electrolyte is accessible, it can be checked with a **hydrometer**. As a battery is discharged, the electrolyte contains less acid and more water, so a hydrometer float will not rise as high in the hydrometer barrel, or fewer balls will float. Many maintenance free batteries have a hydrometer built into one of the cells. We will cover those, and hydrometer testing, later in the section. For now, keep in mind that the acid is heavier than water, and a discharged battery has more water in its electrolyte.



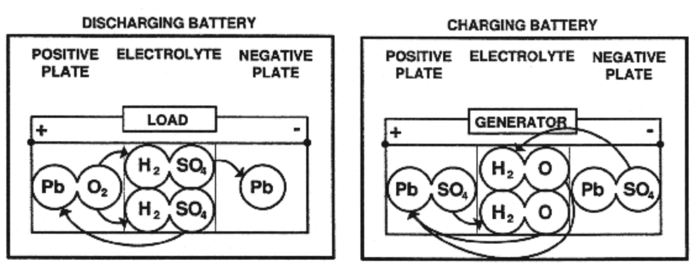


Chemical Reactions while Discharging and Charging

In a fully charged battery, the active materials in the positive and negative plates is distinctly different in chemical composition, and the electrolyte has a high acid content. Positive plates contain a compound of lead and oxygen (PbO2), while negative plates contain lead (Pb). The electrolyte is composed of water (H2O) and sulfuric acid (H2SO4). Sulfuric acid is a compound of hydrogen, sulfur and oxygen.

As a battery begins to discharge, the composition of the plates becomes more similar, and the water content of the electrolyte increases. Lead sulfate (PbSO4) is formed on both the positive and negative plates, trapping the oxygen and sulfur, and leaving water molecules behind (left side of illustration). The voltage potential of a battery is dependent on the dissimilarity of the active materials in the positive and negative plates. As the lead sulfate content in the plates increases, the voltage and available current decreases.

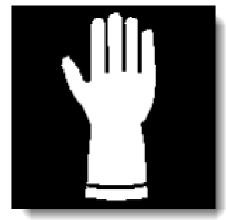
This process is reversed to charge the battery. Current applied to the battery causes the lead sulfate residing on the plates to release its oxygen into the electrolyte. This release increases the acid content of the electrolyte, and returns the plates to their original compositions (right side of illustration).



Battery Safety

There are important safety concerns to keep in mind when working on or around automotive batteries. **Batteries can explode, and have enough power to arc weld**. Always respect the power of a battery, even a "dead" battery. **The sulfuric acid in electrolyte is extremely corrosive, and can cause severe chemical burns to the skin and eyes**. It will also damage painted surfaces and many other materials, including clothing. Always wear approved **safety glasses** when working around batteries and the use of **rubber gloves** is recommended when working with electrolyte.



You should know the locations of fire extinguishers and the first aid kit. First aid kits should contain a bottle of sterile, acid-neutralizing eyewash. Larger facilities often have an emergency shower and eyewash station located in the battery storage and service area.

Batteries release explosive hydrogen and oxygen gasses. A battery can explode with a sound like a shotgun discharging, rupturing the case and spraying acid in all directions. Avoid creating sparks around a battery. The following guidelines will help to reduce the chance of arcing or sparks:

- The ground terminal of a battery should always be disconnected **first** and reconnected **last**.
- Connect battery chargers to a battery **before** plugging in the charger.
- When jump-starting a vehicle, follow the proper procedure. **Do not** connect the jumper cable to the negative battery terminal of the vehicle you are jump-starting. The procedure to follow will be presented later in this section.
- **Do not** attempt to charge, jump-start, or load test a battery with a broken or loose post, a cracked case, or one in which the electrolyte is frozen.

Accidental shorting of the positive battery terminal or any system voltage source to ground with a tool or metal object can cause severe burns. Metal jewelry can be heated to its melting point in seconds. Even a brief short of this nature can damage the PCM and other electronic components.

Never hammer on a battery terminal or cable end, or attempt to remove a cable by prying. To avoid damage to the battery or terminals, and possible personal injury, use a clamp spreading tool if the clamp doesn't seat at the bottom of the post, and use a cable clamp puller to remove stubborn clamps. Avoid contact with the white, flaky or powdery corrosion that builds up around battery terminals and trays. This substance is sulfate and/or sulfide; it is corrosive and can cause chemical burns.

Always follow all general safetey guidelines for servicing motor vehicles with regards to adequate venilation, working around hot or moving parts, proper use of parking brake, gear selector, wheel blocks, and disabling fuel or ignition systems. Refer to equipment User's Manual and vehicle Service Manual.

Temperature, Efficiency, and Ratings

Battery Temperature and Efficiency

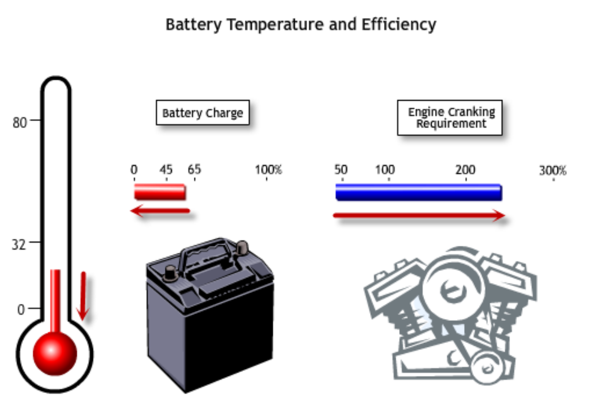
As temperatures fall, chemical reactions in the battery are slowed, and available power is reduced. At the same time, the current required by the starter to crank the engine increases, due to thickening of the motor oil.

> **Cold and Batteries:**
>
> Cold temperatures reduce a battery's available power.

- At 80° F, 100 percent of the battery's starting power is available
- At 32° F, 65 percent of the battery's power is available, but current draw may be increased to 200 percent of normal
- At 0° F, 45 percent of the battery's power is available, but the starting power required may be 300 percent of normal
- At -20° F, only about 20 percent of the battery's power is available, while the starting power required can be over 300 percent of normal

At this point, it is obvious that it is especially important to have clean, tight connections and a fully charged battery in cold weather. Keep in mind that cold temperatures have the same effect on charging rates, that is, it takes longer to recharge a battery in cold temperatures.

Excessive heat can also have an adverse effect on batteries. Batteries will self-discharge faster in a hot environment. In addition, higher-compression engines require more current to start when they are hot.



Battery Ratings

Cold Cranking Amps (CCA)

The Cold Cranking Amps rating indicates how much current (in amps) a battery can provide for 30 seconds at 0° F, while maintaining a minimum terminal voltage of at least 7.2 volts.

> **Battery CCA**:
>
> The CCA rating is the most important rating of a battery.

This is the most important rating of a battery and it is used both in application specifications and in battery testing. The cold cranking rating is usually provided on a label or stamped into the battery case. Ratings from 350 CCA to 1000 CCA are common. The higher the number, the more powerful the battery, and the longer it takes to recharge.

Cranking Amps (CA)

The Cranking Amps rating is similar to the Cold Cranking Amps rating, except the rated temperature is 32° F, instead of 0° F. Naturally, this will yield a higher number than the CCA. This rating may be useful in comparisons of cold weather operation between batteries.

Reserve Capacity (RC)

The Reserve Capacity rating is the time (in minutes) required for a fully charged battery to reach a terminal voltage of 10.5 volts, at 80° F, when placed under a constant load of 25 amps. This rating is useful in determining how long a vehicle with a fully charged battery can travel at night with zero generator output. Typical ratings range from 90 to 200 minutes. The battery in a vehicle, with a charging system failure, will become too weak to start the engine before the reserve capacity is reached. It may, however, provide enough voltage to keep the spark plugs firing for a few minutes after this time. Reserve Capacity ratings usually appear on a battery's label.

Ampere-Hour Rating (AH)

This rating has been largely replaced by the other ratings, but is still sometimes used to calculate recharging times. The Ampere-Hour rating is a measurement of how much current a battery can produce for 20 hours at 80° F without the voltage dropping below 10.5 volts.

Chapter 2: Power Loss

How Batteries Lose Power

Several factors contribute to the discharging or weakening of a battery. These factors may include:

- Normal aging
- Overcharging or undercharging
- Parasitic loads and phantom drains
- Self-discharging
- Inoperative or missing hold-downs
- Normal Aging

Any lead-acid battery will eventually wear out, due to normal cycling, overcharging, and undercharging.

A new battery that has never been in service has not yet developed its full power potential, although normal cycling soon brings the battery to its capacity.

Testing New Batteries:

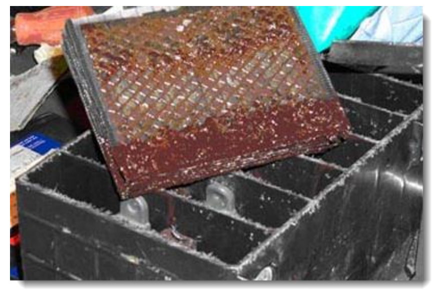
Load testing a new battery at its rated capacity may result in false test failures.

The voltage difference between cells in a new battery is zero or negligible. As a battery ages, the voltage difference increases. When the voltage difference reaches .05 volts, the battery must be replaced. The cell with the lowest voltage will drain the other cells.

Years of cycling will finally take their toll on any battery. Small amounts of the active material on the positive plates are shed during cycling, and fall to the bottom of the battery. If the sediment at the bottom of the battery builds up enough to bridge the positive plates to the negative plates, a shorted cell will result.

Overcharging

Overcharging, either by the vehicle's charging system or an external battery charger, speeds the shedding of plate materials, shortening battery life. Excessive gassing also carries away water from the electrolyte. In a sealed battery, the water cannot be replaced, and the battery will fail prematurely. In a conventional battery, the water can be replaced, but if the level is far enough below the tops of the plates to allow them to become dry, they harden and become chemically inactive.

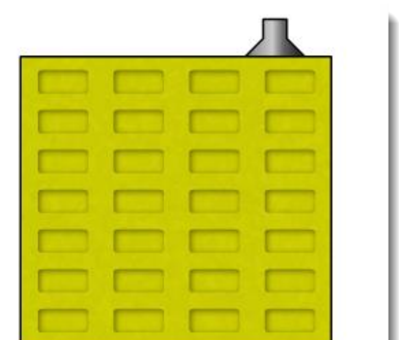


Overcharging promotes corrosion on the plates, and may cause the battery to heat up. Severe overcharging can cause a battery to swell, puffing the ends out noticeably. A strong acidic or sulfurous smell may also be noticed.

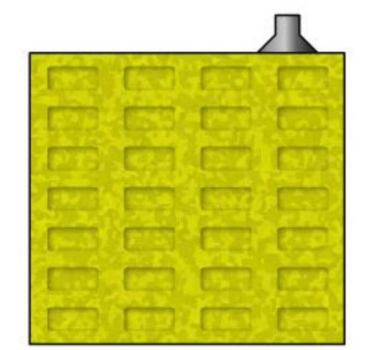
Use care when working around a battery that has been overcharged as an overflow or residue of concentrated electrolyte is likely to be present. The battery tray and hold down should be cleaned and treated to prevent deterioration. A mixture of baking soda and water, or a commercially available treatment, are effective for this purpose.

Undercharging and the Result: A Sulfated Battery

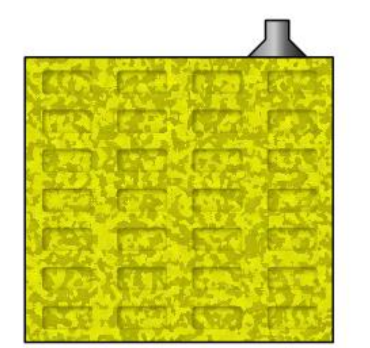
A battery that is less than fully charged is obviously not storing its capacity of energy. More importantly, it will be permanently damaged if left in this condition very long.



Normal Sulfation



Sulfation In Progress



Permanent Sulfation

A battery that remains in a discharged condition for longer than approximately 30 days will begin to sulfate. Sulfating occurs when the lead sulfate on the plates crystallizes, becoming dense and hard, and difficult to break down. If the process has not gone too far, the battery may be restored to a serviceable condition by recharging at a reduced rate. A long, slow charge at half the normal rate may succeed in recharging the battery. A battery in this condition will not accept a normal charging rate and will simply overheat. In the same manner, a battery that remains in service in a partially charged condition, due to poor connections, abnormally high electrical demands, or a low charging rate, will become partially sulfated, and battery performance will be diminished. The result will be premature failure.

Parasitic Loads

In modern vehicles, batteries are constantly being discharged by very small current loads needed to power the memory circuits of electrical devices such as electronic control modules and digital clocks. These are known as parasitic loads, because the circuits involved are always connected to the battery and continue to drain small amounts of current, even when the ignition is turned off. One or more control modules may, at some time, exhibit a failure mode that causes a high parasitic drain. The total parasitic draw for a particular vehicle varies according to the level of electrical equipment on the automobile. For example, a fully equipped luxury car would normally have a much greater parasitic draw than a smaller economy car. The table shows examples of typical parasitic draws, measured in milliamps (mA), for various automotive components.

High Parasitic Draw:

Some special applications may have a high parasitic draw - up to .06 amps.

Component	Typical Milliamp (mA) Draw
Adapative Lamp Motor	0.5
Blower Control Module	1.0
ELC (After 7 Minute Time Out)	0 to 1.0 max
Electronic Brake (& Traction) Control Module After 4 Minute Time Out	1.0
Generator	2.0
Heated Seat Control Module (LH/RH)	0.5
HVAC Programmer	0.5
Instrument Panel Digital Cluster Gages Cluster	4.0
Lamp Control Module	0.5
Oil Level Module	0 to 0.1 max
PCM	5.0
Pull-Down Unit	1.0
RAC Module (Retained Accessory Power) (Illuminated Entry) (Remote Keyless Entry)	0 to 3.8 max
Radio	7.0
CD	1.8

Parasitic draw can be measured by connecting an ammeter in series with the battery, or by using an ammeter with an inductive pickup that closes around a battery cable. All of the leads going to the battery terminal must be enclosed in the probe. The inductive amps probe on starting and charging test equipment is typically accurate to only about .1 amps, so in most cases an ammeter in series, accurate in the milliamps range, is needed. Current draw from 5 to 30 milliamps is usually considered normal parasitic draw; however, some RV applications may have a normal parasitic load of up to 60 milliamps.

To properly test for parasitic loads with an ammeter connected in series requires a special tool. The tool maintains continuity through the system until you are ready to take the reading. This is necessary because current drain may not occur after the battery is disconnected to install an ammeter. Cycling the ignition key to the RUN and then to the OFF position may cause the drain to recur, but there may be drains that will not recur unless the vehicle systems are reactivated in a road test. **The key must not be turned to the START position with an ammeter installed** (except with a high-current shunt installed, such as when checking starter draw). The special tool does enable the vehicle to be driven to assure that all systems are ready for testing.

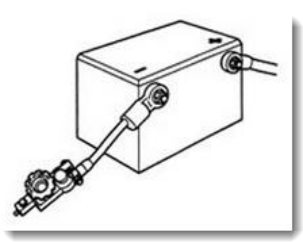
When using a hand-held DVOM, be sure to use the highest amperage range to prevent blowing the meter's fuse in a lower range range. Furthermore, be sure not to cause a current overload by opening a door (courtesy lights) or by any other means with the tool in the OFF position. When testing is complete, turn the special tool to the ON position (continuity through battery cable) to guard against current overload, and **never turn the tool to the OFF position with the vehicle's engine running**. To do so could damage the meter and the vehicle's electrical system.

Any time the battery is disconnected from the system, you may want to use a memory saver. This device plugs into the vehicle cigarette lighter receptacle, and provides voltage to the system when the battery is disconnected. Using a **memory saver** will prevent driver-programmed information from being lost (radio station presets, clock, etc.) as well as possibly avoiding driveability problems associated with the control modules having to relearn information. It can take up to one hundred miles of driving to relearn everything (ideal ignition timing, injector pulse width, etc.) and operate normally.

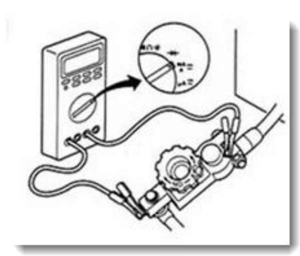
Memory Saver:

Using a memory saver is helpful for retaining programmed information.

The service manual provides the procedure for Battery Electrical Drain/Parasitic Load testing using an ammeter in series, and the special tool. **Follow the procedure exactly** to avoid damage to the vehicle or meter.



Special Tool



Parasitic Draw Test

Follow the Procedure Exactly

Phantom Drains

A phantom drain is an abnormal parasitic load caused by a component such as a trunk or glove box light bulb that stays on all the time. This can be caused by misadjustment, a bad switch, or a short. A phantom drain can draw up to several amps, and will discharge the battery faster than a normal parasitic load.

Once it has been established that there is an excessive parasitic load, the problem can be isolated by pulling fuses or disabling circuits until the circuit causing the drain is identified. The fuse is then replaced and each component on that circuit is checked one at a time until the trouble is isolated. It may be necessary to remove the fuse for the interior lights so the doors can be opened.

Self-Discharging

When a battery is stored, a slow chemical reaction causes the battery to self-discharge. A significant amount of power is lost after one month, and after four months of storage at 80° F, a battery can be 50% discharged. For this reason, stored batteries must be recharged periodically, **before** they become significantly discharged.

Stored Batteries:

Stored batteries self-discharge over time.

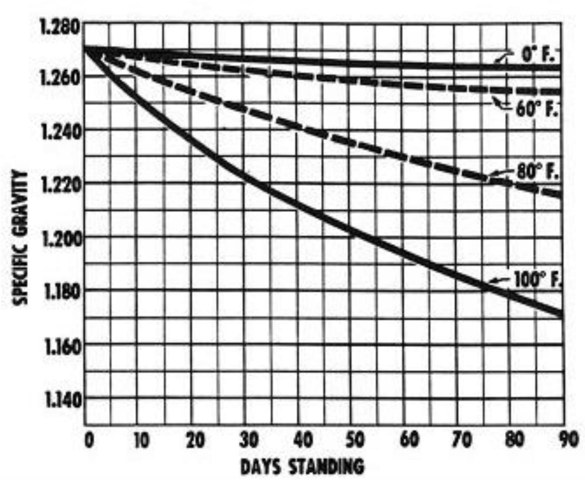
Self-Discharge Rates

Cold temperatures, on the other hand, slow the rate of self-discharge. A battery can be stored at 0° F for an extended period without self-discharging.

Dirt and/or electrolyte residue between the battery terminals can speed self-discharging. Current can track across the residue, to ground, so the area between the terminals should be clean. This is more prevalent with top post batteries.

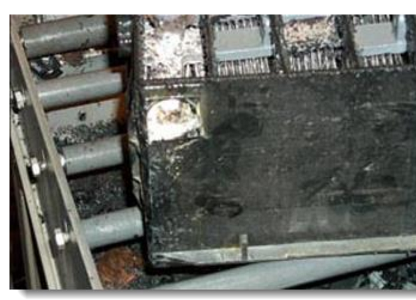
Contrary to popular myth, setting a battery on a cement or concrete floor has no effect on the rate of self-discharge.

Self-Discharge Rates



Corrosion

Corrosion forms on and around the battery cable ends, between the cable ends, on the battery terminals, and inside the battery. The positive terminal is particularly susceptible to corrosion build-up, which can creep down the cable where it is not visible. Look for a swollen cable or discolored insulation. The positive terminal of the battery to the right corroded so badly it became fused to the cable and broke. Note the internal corrosion on the strap and plates.



When corrosion builds up between the points of contact, it creates excessive resistance to current flow and can prevent starting and proper charging. This type of bad connection may allow small amounts of current to pass, but not the larger current needed for starting.

Note: Avoid replacing corroded cable ends with units that splice to the end of the cable. These invite corrosion at the splice. The splice also tends to come loose and cause a poor connection. Replace the cable, if at all practical.

"Universal" Terminals are Not Recommended

Battery Testing and Service

There are several methods for determining the condition of a battery. A battery that fails these tests can often be condemned immediately.

Electronic battery testers that run a series of tests on a battery are available. These testers are simple to use, and can determine the condition of batteries without having to take the time to recharge them. However, these testers may return a result of "Charge and Retest." This means the battery is insufficiently charged to be tested. **A battery must be fully charged in order to be accurately load tested.**

Initial Assessment

Battery testing begins with a visual inspection of the battery, connections, and cables. A battery with a cracked case, broken or loose posts, or a sealed battery with insufficient electrolyte must be replaced. **No testing is necessary**; do not attempt to test such a battery. During your visual inspection, also note the general condition and age of the battery.

Battery Life

Despite marketing claims, many batteries do not last the length of their extended, prorated warranty period. The normal lifetime of most batteries is from three to five years.

The date of manufacture is stamped into the battery case, and/or punched out of the label.

Most manufacturers use a date code with a letter corresponding to the month, and a number corresponding to the last digit of the year. For example, a date code of "A-1" means the battery was produced in January of 2001.

Battery Information

Open Circuit Voltage

Open circuit voltage is the voltage in a battery without any loads connected. Checking the open circuit voltage will give you a quick check of a battery's state of charge.

Remove the surface charge by turning on the headlights for one minute, then connect a voltmeter across the battery. The reading should be 12.6 volts or more for a fully charged battery.

Discharged Batteries May Still be Viable:

Approximately 40% of condemned batteries are fit for recharging and continued service.

A weak or discharged battery is often a symptom of a problem elsewhere in the vehicle. Regardless of the testing method used, be sure the battery is bad, and not merely discharged before recommending a replacement.

Hydrometer Testing

Hydrometers are used to measure the specific gravity of electrolyte. A hydrometer with a single float and a numerically graduated scale is recommended. This type of hydrometer usually has a built-in thermometer to make necessary temperature corrections. Smaller hydrometers that use multiple, colored balls are generally not reliable. The hydrometer pictured is a Snap-on BB4A.

This chart shows the charge level and voltage for specific gravity readings taken with a hydrometer.

Charge Level, Specific Gravity, and Voltage

Charge Level	Specific Gravity	Voltage (12)	Voltage (6)
100%	1.270	12.60	6.3
75%	1.225	12.45	6.2
50%	1.190	12.24	6.1
25%	1.155	12.06	6.0
Discharged	1.120	11.89	6.0

Built-In Hydrometers

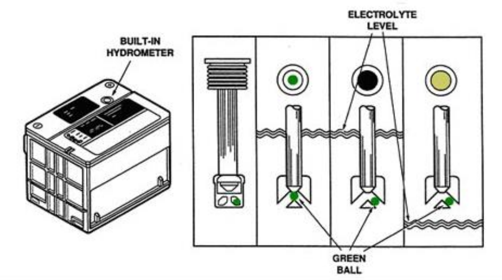
Many maintenance free batteries are equipped with a built-in hydrometer. Hydrometers will indicate the state of charge in only one cell of the battery, and therefore have limited diagnostic value. The built-in hydrometer contains a ball (usually green) and a round sight window or "eye" on top of the battery. Information on interpreting built-in hydrometer readings is printed on the top of most batteries. Wipe the window clean and look straight down at it in sufficient light. The eye will appear green, dark, or yellowish.

Built-In Hydrometer Limitations:

Keep in mind that a built-in hydrometer indicates the state of charge for only one cell.

- **Green eye** – The battery is charged to at least 65% of its specific gravity. Some battery manufacturers consider this sufficient for testing.
- **Dark eye** – The ball is not floating high enough to be seen, indicating the battery is less than 65% charged. This does not necessarily mean the battery is bad, merely discharged. The battery may be tested with an appropriate electronic tester, but results may be inconclusive. The battery must be recharged in order to perform conventional load testing.
- **Yellowish eye** (clear) – The electrolyte level is low; replace the battery. Sometimes a gas bubble will cause a false yellow reading. Tap the hydrometer lightly with a small screwdriver handle or shake the battery gently and check it again. **Do not attempt to charge or load test a battery with a yellow eye**.

Built-In Hydrometer



Battery Explosion Risk:

Load testing, charging, or jump-starting a battery with insufficient electrolyte or a loose post poses an explosion risk!

Conventional Hydrometers

A conventional hydrometer works like an eyedropper or a turkey-baster. The battery caps are removed, and the bulb is squeezed before immersing the pick-up tube in the electrolyte. When the bulb is gently released, electrolyte fills the tube, and the float rises to a certain level, indicating the state of charge of the cell. A reading is taken and noted, and each cell is checked in this manner.

Hydrometer Float:

The float will rise higher in a fully charged battery because the electrolyte is heavier. The float will rise less or not at all in a discharged battery.

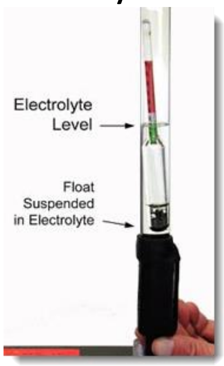
Here are some guidelines for using a hydrometer:

- Remember – electrolyte is acidic. Be careful, and avoid allowing the hydrometer to drip. Release the electrolyte back into the battery slowly.
- The float should be lifted free, and not touch the sides or bottom of the barrel.
- Take the reading with your eye level to the surface of the fluid.
- If there is a difference of .050 between the lowest and highest readings, or if all readings are below 1.225, recharge the battery.
- If, after recharging the battery, there is still a .050 difference between the highest and lowest reading, or there is still a reading below 1.225, replace the battery.
- If the battery passes this test, proceed with a load test.

Conventional Hydrometer

Frequently, five cells will show good readings in the 1.250 to 1.270 range, with one cell showing a very low reading or not moving the float at all. Commonly called a "dead cell," this usually indicates a short. No further testing is necessary; the battery must be replaced.

Drawing Electrolyte into the Hydrometer



Buoyant Float

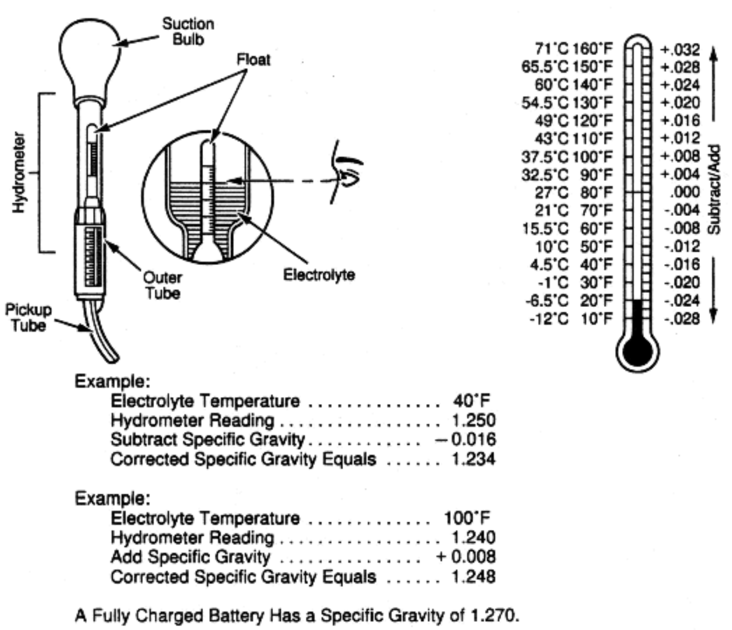
Cell Reading: 1.265

Last Cell Doesn't Float

Reading Below 1.100

Keep in mind that hydrometer testing must be done while correcting for outside temperature.

Hydrometer and Temperature Correction



Chapter 3: Charging and Replacement

Load Testing

Load testing a battery is an effective way to test the battery's actual performance ability. To perform a load test, a specified current load is applied to the battery while its voltage is monitored. If a battery's voltage drops below a specified value, it fails the test and the battery should be replaced. To load test a battery, testing equipment that can apply a load of ½ the battery's CCA is needed. This is usually in the 200 to 500 amp range. The machine should be equipped with a voltmeter, ammeter, heavy gauge clamps, and a load control knob. The load is applied using a carbon pile, and is adjusted with the load control knob. Many different types of battery/starting/charging system testers are available, and most are operated in a similar manner. Refer to the manufacturer's instructions for use.

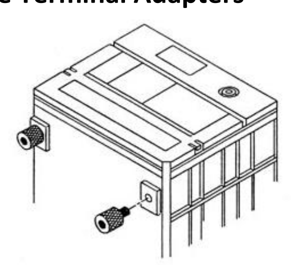
> **Charging Before Testing:**
>
> For a load test to produce an accurate result, the battery must be fully or near fully charged.

Load testing a battery is an effective way to test the battery's actual performance ability. To perform a load test, a specified current load is applied to the battery while its voltage is monitored. If a battery's voltage drops below a specified value, it fails the test and the battery should be replaced. To load test a battery, testing equipment that can apply a load of ½ the battery's CCA is needed. This is usually in the 200 to 500 amp range. The machine should be equipped with a voltmeter, ammeter, heavy gauge clamps, and a load control knob. The load is applied using a carbon pile, and is adjusted with the load control knob. Many different types of battery/starting/charging system testers are available, and most are operated in a similar manner. Refer to the manufacturer's instructions for use.

Adapters

Follow the equipment manufacturer's instructions regarding connection adapters and procedures. Use the side terminal adapters that are provided with the equipment. **Do not** substitute standard bolts for proper adapters, as this may damage the battery terminals. **Do not** use adapters that consist of a post of lead poured around a steel stud that screws into the battery terminal. These adapters may cause high resistance and are a common cause of false test failures.

Side Terminal Adapters



The connection inside the post can become faulty, due to breakage or hidden sulfide build-up between the stud and the lead post. Acceptable adapters are usually brass or steel.

> **Insufficient Electrolyte Warning:**
>
> Do not attempt to load test a battery with insufficient electrolyte. Observe all battery safety precautions.

The Test

To perform a load test:

1. Verify that the battery is sufficiently charged for testing by observing the hydrometer eye or performing a hydrometer check. An alternate method is to perform step 4 and then check for open circuit battery voltage of at least 12.4 volts.
2. Connect the test machine heavy clamps to the battery. If the battery is in a vehicle, connect to the terminals. Rock the clamps back and forth to ensure a good "bite" on the terminals. If not in a vehicle, install adapters (side terminal applications).
3. Follow the equipment instructions for connecting the inductive amp probe. This usually involves installing the probe around the negative tester cable, with the probe arrow pointing in the direction of current flow (towards the machine). The instructions may also direct you to zero the ammeter.
4. Remove the surface charge by applying a 100 amp load for 10 seconds. Wait 15 seconds to let the battery recover before testing.
5. Apply a load of ½ the battery's CCA rating, using the tester's carbon pile.
6. After 15 seconds, note the voltage and remove the load.
7. Measure or estimate the battery temperature and compare the voltage reading to the appropriate value on the chart. At 70° F, the voltage should not drop below 9.6 volts.

Minimum Voltages

VOLTAGE / TEMPERATURE TABLE

Minimum Voltage	Temperature °F	Temperature °C
9.6	70	21
9.5	60	16
9.4	50	10
9.3	40	4
9.1	30	- 1
8.9	20	- 7
8.7	10	- 12
8.5	0	- 18

Useful Quick-Checks

To check for electrical leakage across the surface of the battery, touch the positive probe of a voltmeter to the surface of the battery between the terminals, and the negative probe to the negative battery terminal.

Any voltage reading indicates electrical leakage. This test is most useful with top post batteries.

Checking for Electrical Leakage

To check for a poor connection between the battery post and the cable clamp, measure the voltage drop. Disable the fuel system to prevent starting. Probe the top of the positive post with the positive probe, and probe the body of the clamp with the negative probe while cranking the engine. A reading greater than .2 volts indicates the terminal and cable end need cleaning.

Checking for Poor Connection

Using Battery Chargers

A discharged battery that is otherwise good can be restored to a charged condition with the use of a battery charger. The charger forces current through the battery and replaces the energy that has been drained.

The time required to bring the battery to full capacity depends on several factors:

- The condition of the battery
- State of charge of the battery
- Battery temperature
- Battery size and rating
- Rate of the charger/rate selected

Recharge Rate:

Recharging at a low rate is preferable.

A slow charge at a low rate of about 10 amps provides better results and less wear on the battery than a fast charge at high amperage. This is especially true of batteries that have been in service for an extended period. Generally, the lowest rate that time permits should be used.

Battery Condition

A battery that is sulfated will not accept a high current. Attempting to fast-charge a sulfated battery will cause it to overheat. No battery should be allowed to reach a temperature of over 120° F, or a voltage of over 15.5 volts when charging.

When charging a partially sulfated battery, a lower charging rate may allow the sulfate to break down, permitting the battery to be recharged and returned to service.

Similarly, a battery that is severely discharged will not accept a high current. A completely discharged battery will take more than twice as long to charge as a half-charged battery of the same size. As the state of charge increases, the battery accepts more current, and the remaining time required for recharging is reduced.

A completely discharged battery may not have sufficient voltage to activate the polarity protection circuits on some chargers. These circuits are designed to prevent accidental reversing of the charger leads at the battery, and usually require at least two volts from the battery before they allow the charger to operate. Carefully follow the manufacturer's instructions on bypassing or overriding this circuitry when charging a completely drained battery.

Using a high charging rate to fast-charge a battery will not damage a battery that is in **good condition**; however, it will not bring the battery to as full a state of charge as a slower rate will. To recharge a severely discharged battery in a reasonably short period of time, start with a high charging rate of around 20 to 35 amps. As time permits, switch to a lower charging rate of around 5 to 10 amps to finish. Higher beginning charge rates may be used, but they do not promote extended battery life. Some chargers automatically reduce the charging rate as the battery's state of charge increases.

Battery Temperature

We have said that cold temperatures slow the chemical reactions inside batteries. This increases the time required for recharging. The current accepted by the battery is very low at first. As the battery warms up, it accepts a higher current. A deeply discharged battery may take quite a long time to recharge, if charged in cold temperatures. A temperature of 70° to 80° F is optimal.

Battery Size and Rating

Larger, more powerful batteries will take longer to recharge. A battery with a high CCA rating may take more than twice as long to recharge as one with a low CCA rating. The battery with the higher rating is denser, having more plate material.

Charging Rate

The more amps a charger can supply, the faster it can recharge a battery. Recharge time is often measured in ampere-hours. Look at the comparisons of recharging times for a battery that has been discharged at a rate of 20 amps for one hour (20-ampere hours).

- A charging rate of 20 amps will recharge the battery in one hour
    - 20 amperes x 1 hour = 20 ampere hours
- A charging rate of 10 amps will recharge the battery in two hours
    - 10 amperes x 2 hours = 20 ampere hours
- A charging rate of 5 amps will recharge the battery in 4 hours
    - 5 amperes x 4 hours = 20 ampere hours

When fast charging a battery at a high rate (20 to 50 amps) to bring it to a serviceable level of charge in the fastest possible time, it must be checked frequently. Check to see that the terminal voltage does not exceed 15.5 volts, that electrolyte doesn't spew from the vent holes, and that it does not feel excessively hot.

High Rate Charging:

Carefully monitor batteries when charging at a high rate.

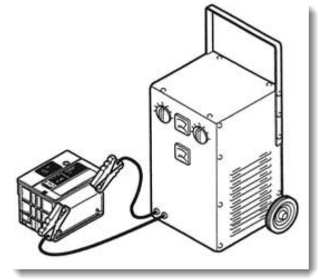
Battery Charging

Charging a Single Battery

Charging a single battery with a fast charger is a simple operation. Ensure that there is sufficient electrolyte before charging the battery. Remove the cell caps on non-sealed batteries and add clean water to bring the electrolyte level to the bottom of the filler neck, then replace the caps. On sealed batteries, check the built-in hydrometer. Do not attempt to charge a battery with a yellow (clear) eye; replace the battery. The eye should be dark. If the eye is green, proceed with a load test.

- If the battery is out of the vehicle, install appropriate side terminal adapters, as described in the section on load testing. If it is installed in the vehicle, ensure that the cable ends and battery terminals are clean and in good condition, and that the ignition is off.
- Considering the above factors, make a judgment about how long and at what rate to charge the battery.
- Ensure that the charger is unplugged or turned off before connecting the charger clamps to the battery.

Charging a Single Battery



- Check the battery at least every hour for excessive heat or spewing of electrolyte, and observe the hydrometer. High charging rates require checking more frequently. After the battery is charged, check the electrolyte level and perform a load test.

Three-Minute Charge Test

The three-minute charge test, or "quick charge" test can be used to determine if a battery will accept a charge. A battery that fails this test usually has sulfated plates.

To perform a three-minute charge test, connect a battery charger as previously outlined. Connect and observe a voltmeter while charging the battery at a rate of 30 to 40 amps. If the voltage rises above 15.5 volts, replace the battery.

Charging Multiple Batteries

Larger service centers may have a battery charger for charging multiple batteries at once. These chargers are usually maintained at a low charging rate of three to 10 amps per battery, and are used for slow, "trickle" charging. The charger and batteries are collectively referred to as the "charging line," or "charging rack." The charging line should be carefully monitored throughout the day.

Two different types of chargers can be used for group charging batteries. These are:

- Current-Limiting (constant current or series chargers)
- Voltage-Limiting (constant voltage or parallel chargers)

With series chargers, the batteries are connected in series, so that each battery receives the same amount of current. As such, the charging procedures are different from parallel chargers.

With parallel chargers, the batteries are connected in parallel, so that the charging current is divided among the batteries. Each battery receives only the charging current it can accept at the charger's voltage.

Regardless of which type of charger is used, the procedures outlined here must be followed closely to prevent undercharging or overcharging and battery damage on the charging line.

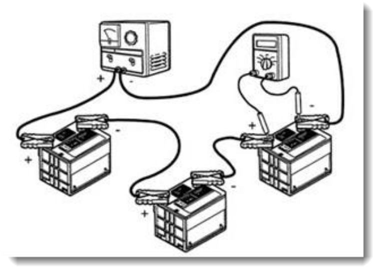
Series Charging

Batteries on a charging line may vary in age, capacity or size, state of charge, and type. **For this reason and other considerations, series charging is not recommended**. The procedure has been included for your information, and in case you should be required to use a series charger.

Batteries on a series charger should be closely monitored for spewing, gassing, high temperature, or voltage of over 15.5 volts.
To charge batteries in series:

- Connect all the batteries, negative terminal to positive terminal, using single jumper cables
- Connect the charger to the remaining positive terminal on one battery and the remaining negative terminal on the other battery to complete the series circuit, as shown in the illustration.

Series Charging



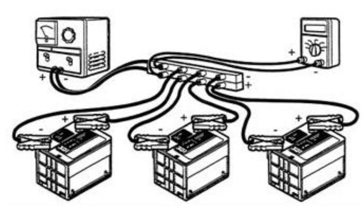
- Connect the charger to a power source
- Set the charger to maintain a charging rate of 5 to 10 amps
- Monitor each battery and the charging rate every 30 minutes
- Turn off the charger and disconnect any recharged battery

Parallel Charging

When charging batteries in parallel, the current rate is dependent on the voltage setting. Most parallel chargers have a number of switches that adjust the charging rate. The switches are adjusted to obtain the desired voltage, and the ammeter reading indicates the amount of current being accepted by the charging line. To charge batteries in parallel:

- Connect all the batteries to the buss bars, positive terminals to the positive bar, and negative terminals to the negative bar, as shown.
- Connect the charger to a power source and turn it on
- Adjust the voltage to the desired setting (between 14.2 and 15.5 volts)
- Monitor each battery every hour or two
- Disconnect any recharged battery. It is not necessary to turn off the charger as long as there is at least one battery on the line, but the line voltage will increase as batteries are removed, so it may need to be reduced

Parallel Charging



Keep in mind that even if the charger is turned off, any batteries connected to the bus bars are connected electrically, and the line contains the amperage potential of all of the batteries combined!

> **Bus Bar Clamps Storage and Precautions:**
>
> If the bus bar clamps are normally clamped to their bus bar when not in use, double-check for proper polarity before returning them to the bus bar. Crossing the polarity of the clamps will cause a fire and possible explosion.

Jump-Starting

Observe all safety precautions when jump-starting. To jump-start a vehicle:

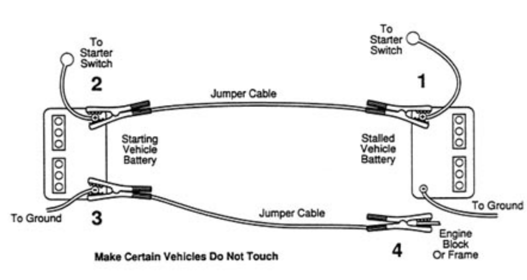
1. Set the parking brake in both vehicles and place the transmission in Park, if the vehicle has an automatic transmission, or Neutral for vehicles with manual transmissions. Start the engine of the vehicle providing the jump.
2. Turn off the lights, heater, or other electrical loads.

3. Attach one end of one jumper cable to the positive terminal of the stalled vehicle battery, and the other end of the same cable to the positive terminal of the donor (good) vehicle battery as shown.
4. Attach one end of the remaining jumper cable to the negative terminal of the donor vehicle battery, and the other end of that cable to a ground at least 12 inches from the battery of the stalled vehicle.

This procedure is used in order to reduce the chance of a battery explosion. There is likely to be a spark when making the final connection, due to the difference in voltage between the two systems. If the spark occurs near a battery, it could ignite explosive gasses. Do not make the final connection to the negative battery terminal, to metal tubing, or anywhere gasoline fumes may be present.

> **Battery Safety:**
>
> Keep your face away from batteries. Wear safety glasses.

Jumper Cable Hookup



Replacing a Battery

Replacing a battery is typically a simple job. There are some things to keep in mind, however.

After installing a new battery, the vehicle's starting and charging system should be checked to ensure satisfactory performance from the battery.

Battery terminals are made of lead, a very soft metal. Below are the **torque specifications** for battery connections.

Terminal Type	Torque Measured in: Pound / Inch	Pound / Foot	Newton Meters
Tapered terminal posts (SAE)	50 - 70 lb-in	4 - 6 lb-ft	5.4 - 8.1 N•m
Side terminals	90 - 180 lb-in	7.5 - 15 lb-ft	10.0 - 20.0 N•m
Stud terminals	120 - 180 lb-in	10 - 15 lb-ft	13.5 - 20.0 N•m

Unit 4: STARTING SYSTEMS

Chapter 1: Starting System Components

Starting System

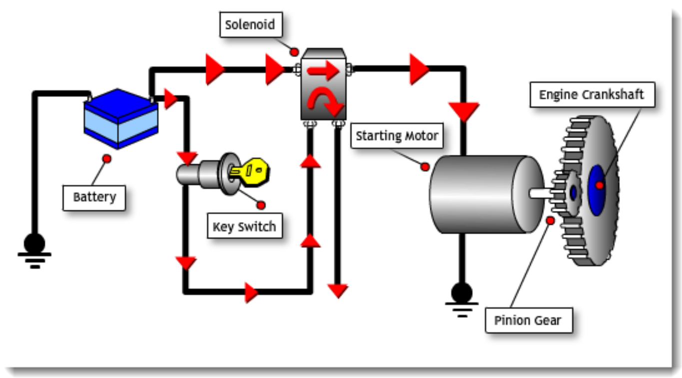
The starting system uses power from one or more batteries to spin a cranking motor (starter). When the starting circuit is energized, a **pinion gear** mounted to the shaft of the cranking motor engages with teeth on the flywheel, and the engine is cranked for starting. The components involved in the starting system include:

- **Battery** – provides power to the cranking motor and ignition system
- **Ignition switch** – permits operator to control starting system operation

- **Solenoid** – high-current relay that permits connecting the battery to the cranking motor at a convenient physical location in the circuit. Provides the movement for engaging the pinion gear to the flywheel
- **Starter** – high-torque electric motor for cranking the engine. Includes the drive mechanism for engaging the pinion gear with the flywheel
- **Battery cables**, wiring, starter relay, fusible links, etc.

When the ignition key is turned to the START position, a circuit to the solenoid is completed to ground. The circuit current causes the solenoid contact points to close, completing the cranking motor's circuit to ground, and the battery is connected to the starter. The starting system circuit will be covered in more detail, but first let's examine some starter engagement components.

Note that in the system pictured here, used on many Fords, the solenoid does not engage the pinion with the flywheel; it is merely a high-current relay. This is not a true solenoid, because it does not produce linear movement, but it is often referred to as a solenoid.

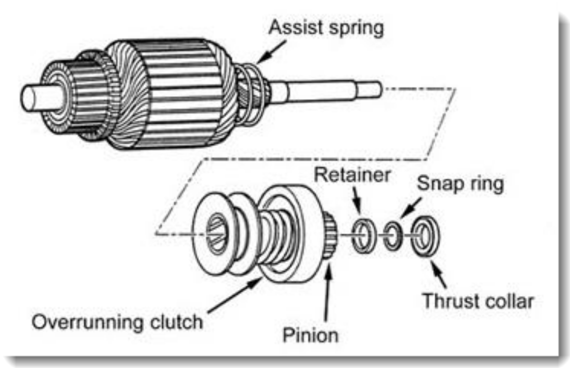


Motor Drive Mechanism

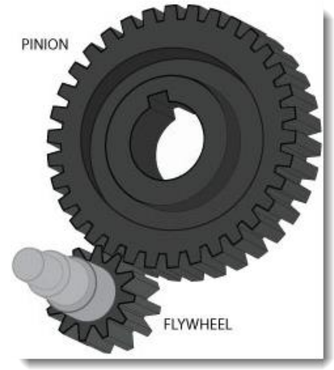
The motor drive mechanism is the component through which power is transmitted from the starter armature to the engine flywheel during cranking. The main components of the drive mechanism are the **pinion gear** and the **overrunning clutch**. These components work together with one of the several methods used on various vehicles to engage the pinion with the flywheel.

As the armature spins, it turns the pinion gear. As the vehicle's key is held in the START position, the pinion gear meshes with teeth on the flywheel as voltage is applied to the starter motor. When the key is released from the START position, a return spring disengages the pinion from the flywheel.

Typical Motor Drive Mechanism



Pinion and Gear Reduction

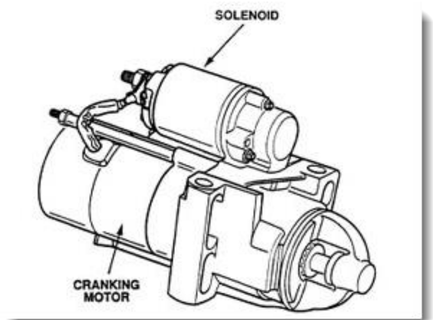


Several different types of drive mechanisms are used on starting motors, but in all cases, gear reduction occurs between the pinion and the flywheel. The amount of gear reduction designed into the application is a balance between the torque required of the starter and the speed required for reliable engine starting.

Proper disengagement of the pinion is critical to cranking motor operation. Because of the gear reduction ratios, if the pinion were to remain engaged after the engine started, the flywheel would drive the armature at speeds that could damage the cranking motor. This is where the overrunning clutch comes into play. When the flywheel begins to drive the pinion, the overrunning (or "one way") clutch freewheels to prevent damage to the starter.

Starter-Mounted Solenoid

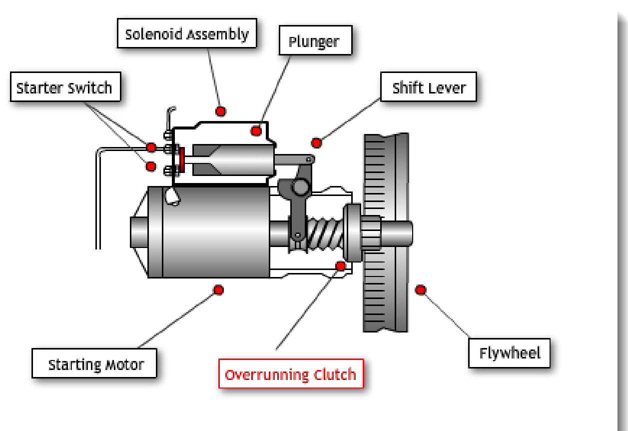
Solenoid and Starter Motor



The starter-mounted solenoid is a powerful electromagnetic coil that is energized with a relatively low amount of current when the ignition switch is turned to the START position. When energized, the solenoid draws a plunger into a coil and holds it there.

As the magnetic field created by the coil pulls the plunger in, a shift lever moves the pinion toward the flywheel. When the plunger reaches the end of its throw, a contact disk is pushed into firm contact with two terminals. One terminal is connected to the battery and the other is connected to the starter, thus completing the circuit. By this time, the pinion is fully engaged with the starter, and cranking begins.

Observe the shift lever and its link to the solenoid in this illustration.

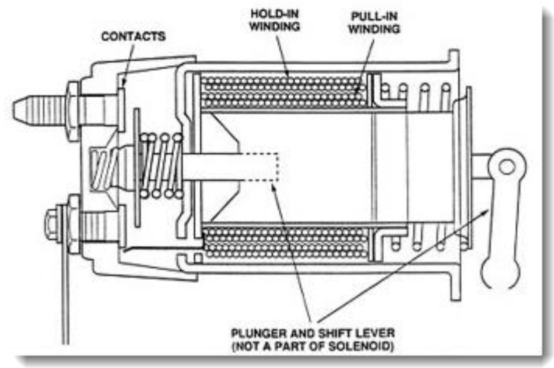


Solenoid and Drive Operation

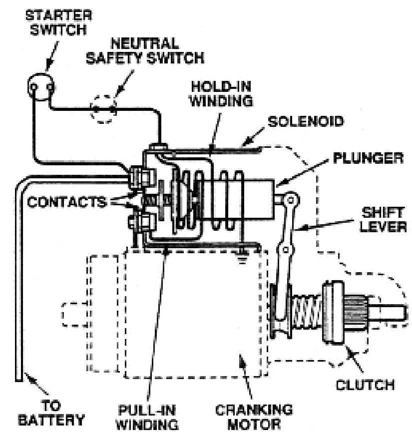
Solenoid Pull-in Winding and Hold-in Winding

Some solenoids have two separate windings: a pull-in winding, and a hold-in winding. The pull-in winding has many turns of wire, and the hold-in winding has the same number of turns of smaller wire. The illustration shows both windings.

Solenoid Windings



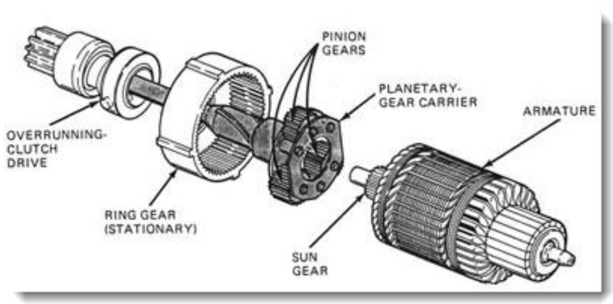
As the ignition is turned to START, current flows from the battery to the S terminal on the solenoid, and through the hold-in winding to ground. Current also flows through the pull-in winding to the solenoid M terminal, and through the motor windings to ground. When the solenoid contacts are connected, there is equal voltage on both sides of the pull-in coil; thus, no current flows through that branch of the circuit.

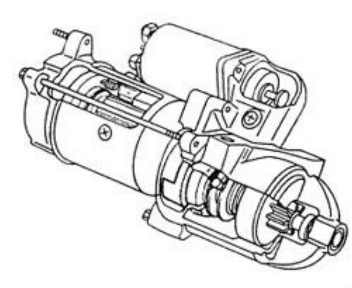


Diagnostically, if a hold-in winding fails, the pinion will engage repeatedly but it will not remain engaged. Likewise, a pull-in winding failure will prevent the pinion from engaging at all. On some starters, a pull-in winding failure will allow the motor to run, even if the pinion is not engaged.

Reduction Starters

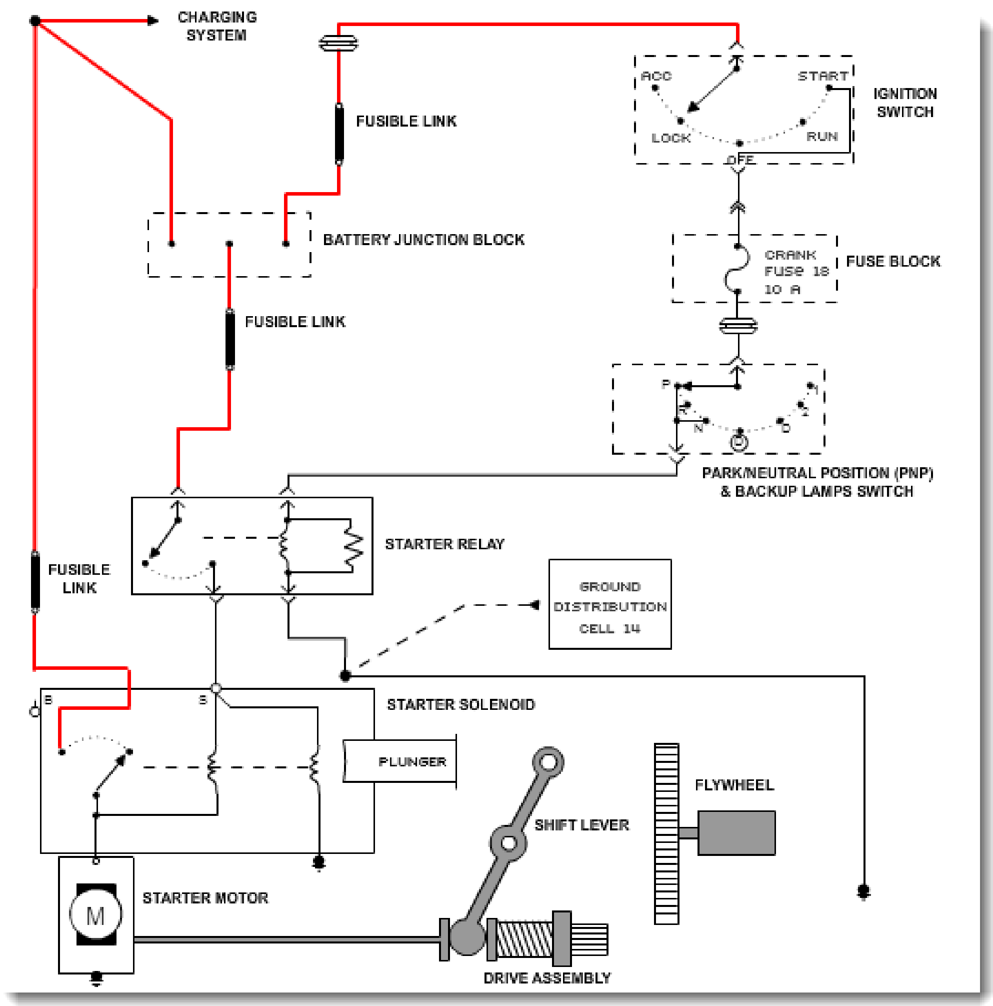
On some starters, called reduction starters, extra gears are used to achieve even more reduction and develop higher torque. A planetary gearset or an idler gear arrangement provides the additional gear reduction.





Starting Circuit

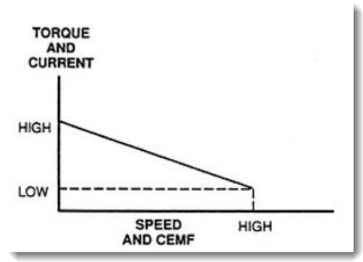
In a typical starting circuit the ignition switch is powered from a battery junction block and protected by a fusible link. When the ignition switch is turned to the start position, a current of less than 10 amps travels through a fuse. The current then flows through the park neutral position and back-up lamp switch PNP. Proved the switch is in the park or neutral position. The PNP is a safety feature to prevent cranking with the vehicle in gear. Manual transmission equipped vehicles have a clutch/petal position or CPP switch. From the PNP switch, current flows through the starter relay coil and to ground. Energizing the relay coil causes the contacts to close, supplying current from the junction block to the solenoid. The hot at all times portions of the relay and solenoid circuits are protected with fusible links. Energizing the solenoid causes the plunger to move engaging the pinion gear with the flywheel and the contact disc connects the solenoid's battery and starter terminals. High current then flows from the battery cable, through the solenoid to the starter motor. The starter motor case completes the circuit to ground and starting begins.



Current Draw and Torque

A direct relationship exists between the current draw of the starter motor and the torque it produces. Torque and current flow are both greatest when the armature is stalled. Electric motor stall occurs at that point when voltage has first been applied but the motor has not yet begun to turn.

CMEF



Chapter 2: Starting System Diagnosis and Service

Starting System Diagnosis

Diagnosis of starting system failures is straightforward. Common causes of starting system problems are:

- Dead battery
- Poor battery cable connections
- Burned solenoid contacts
- Burned fuse or fusible link
- Loose starter or solenoid mounting bolts
- Loose starter cable connection(s)
- Bad or misadjust PNP or CPP switch
- Ignition switch problems (tumbler, actuator, or contacts)
- Theft deterrent system active
- Bad cranking motor

The service manual provides detailed diagnostic flow charts, procedures, and specifications. We will present some general testing guidelines here.

Common Starting System Problems

This chart addresses some common starting system problems.

Result	Possible Cause	Problem Source
1. Engine cranks slowly but does not start.	Battery discharged.	Check Battery
	Very low temperature.	Battery must be fully charged; engine wiring and starting motor in good condition. Install proper cables.
	Undersized battery cables.	Install proper cables.
	Cranking motor defective.	Test cranking motor.
	Mechanical trouble in engine.	Check engine.

Result	Possible Cause	Problem Source
2. Solenoid plunger chatters.	Low battery, loose or corroded terminals.	Check battery, clean and tighten terminals.
	Hold-in winding of solenoid open.	Replace solenoid.
3. Pinion disengages slowly after starting.	Sticky solenoid plunger.	Clean and free plunger.
	Overrunning clutch sticks on armature shaft.	Clean armature shaft and clutch sleeve.
	Overrunning clutch defective.	Replace clutch.
	Shift-lever return spring weak.	Install a new spring.
	Tight alignment between flywheel and pinion.	Realign cranking motor to flywheel.
4. Cranking motor turns but engine doesn't.	Pinion not engaged.	Realign cranking motor to flywheel.
	Pinion slips.	Replace defective drive.

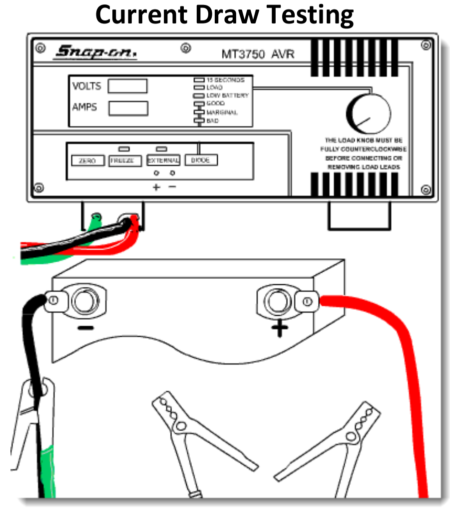
Some medium duty diesel applications are equipped with starter overcrank protection. These starter motors have a built-in thermostat that opens the circuit to the solenoid if the starter gets too hot. The thermostat closes the circuit when the starter cools. An open in the thermostat will cause a "no start" condition. The thermostat terminals are on the front of the starter, and should show continuity when with checked an ohmmeter.

Testing

Current Draw Testing

A starter current draw test can quickly tell you the condition of the starter motor and other system components. Current draw should not be higher or much lower than specifications.

Current Draw Testing



To perform a current draw test:

1. **Disable fuel delivery system** to prevent the engine from starting. Refer to the service manual to find the procedure for the application on which you are working.
2. **Connect an ammeter** in series between the negative battery terminal and cable end, or clamp the ammeter's inductive pickup around the negative battery cable. A meter rated to 500 or 600 amps is recommended. Do not exceed the meter's range. If using a hand-held DVOM, be sure to use the correct high-current shunt to avoid damage to the meter.

Headlights Quick Check

Attempting to crank the engine with the headlights or dome light on while observing what happens may quickly point you in the right direction. This chart lists possible conditions, related causes, and problem sources.

Result	Possible Cause	Problem Source
1. No cranking, lights stay bright.	Open circuit in switch.	Check switch contacts and connections.
	Cranking motor.	Check commutator, brushes, and connections.
	High resistance at battery connection.	Clean and tighten terminal connections.
	Theft deterrent system active.	Check theft deterrent system for proper operation.
2. No cranking, lights dim significantly.	Battery discharged or malfunctioning.	Recharge and test battery.
	Very low temperature.	Check wiring circuit and battery.
	Pinion jammed.	Poor alignment between cranking motor and flywheel – free pinion, check gear teeth.
	Stuck armature.	Frozen bearings, bent shaft, loose pole shoe.
	Short in cranking motor.	Repair or replace as necessary.
	Engine malfunction.	Check engine for loss of oil, mechanical interference.
3. No cranking, lights dim slightly	Loose or corroded battery terminals.	Remove, clean, and reinstall.
	Pinion not engaging.	Clean drive and armature shafts, replace damaged parts.
	Solenoid engages but no cranking. Excessive resistance or open circuit in cranking motor.	Clean commutator, replace brushes, repair poor connections.
4. No cranking, lights out.	Poor connection, probably at battery.	Clean commutator, replace brushes, repair poor connections.
5. No cranking, no lights.	Open circuit.	Clean and tighten connections, replace wiring.
	Discharged or malfunctioning battery.	Recharge and test battery.

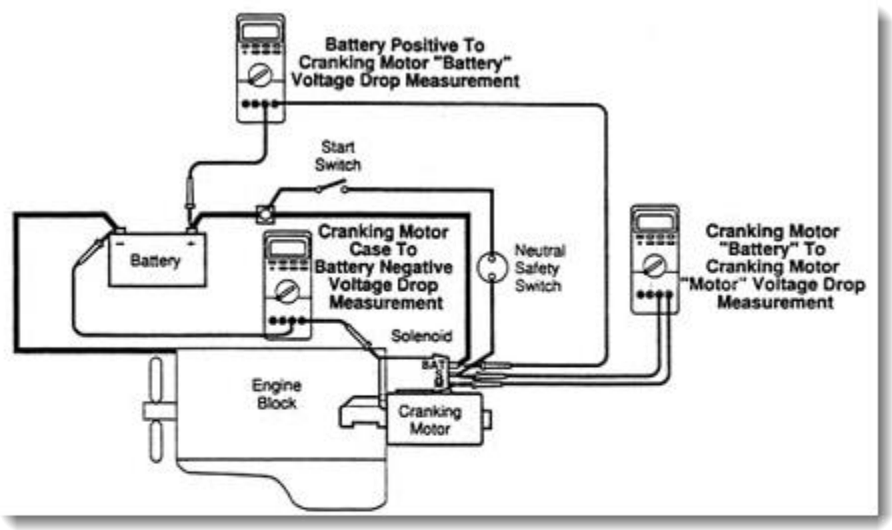
Voltage Drop Testing

Voltage drop tests are useful for quickly finding sources of high resistance in the circuit. Either the positive or the ground side can introduce excessive resistance to the circuit, and both can be checked with a voltmeter. Step 3 of the current draw test is actually a voltage drop test of the entire starting circuit. If the battery is known to be in good condition and excessive voltage drop is indicated, proceed to test the circuit components.

To check the voltage drop of the positive battery cable, measure the drop from the positive battery terminal to the battery terminal on the solenoid while cranking with the fuel system disabled. The reading indicates the voltage drop. The rest of the circuit can be checked in a like manner.

The illustration shows meter connections for all three of the common voltage drop tests. If you use the starting and charging system tester's external volts leads, the load clamps must be connected to the battery to power the meter's display.

Checking Voltage Drop



In general, a .2 voltage drop is acceptable for each cable or the solenoid. If a higher voltage drop is indicated, clean the connections and retest. If the voltage drop is still high, replace the component. Starter relays and other small components are generally allowed a voltage drop of .2 volts. Total starting system voltage drop should not normally exceed .6 volts.

Cranking the Engine:

Do not crank the engine for more than 30 seconds at a time. Five to ten seconds should be adequate to obtain the reading.

No-Load Test

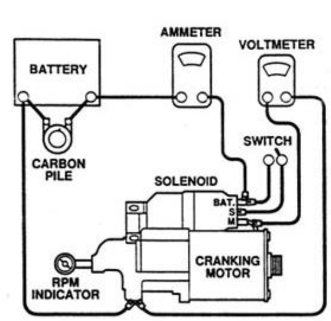
When removed from the vehicle, the starter can be no-load, or "bench tested." First, attempt to turn the pinion with a screwdriver. If the pinion does not turn freely, the motor may have binding bearings, a bent armature shaft, or other internal problems. If the pinion turns freely, the starter can be no-load tested.

Important Safety Precautions:

To minimize the risk of eye injury, wear safety glasses when performing this test.

A no-load test may point to specific defects in the motor, and is also useful for testing new or rebuilt units for proper operation prior to installation on the vehicle. To perform a no-load test, make the connections as shown. When the switch is closed, compare the current and voltage readings with the specifications. A higher voltage will yield higher rpm, with the current remaining essentially unchanged.

No-Load Test



An even simpler form of this test can be used to verify that a unit will operate. This is especially useful for checking new or rebuilt units before installation. The starter motor is held firmly by a suitable means, and connected to a battery with jumper cables and a jumper wire across the solenoid. Connect the positive cable to the solenoid battery terminal **first**, and then connect the negative cable to a suitable ground on the starter (otherwise arcing may damage the threads on the terminal). The solenoid will kick the pinion out, and the motor will spin. With experience, the sound and pitch of the starter at free speed can be used to estimate starter condition.

Wires and Cables

When checking wiring, ensure the following conditions are met:

- Cables are routed to avoid heat, abrasion, and vibration
- Grommets are in place where cable passes through holes in sheet metal
- Insulation is intact
- Cables are supported every 24 inches
- A strain relief or anchor point is provided a short distance from the battery terminal

Connection Points:

When testing an electrical circuit, never pierce an electrical wire with any type of probe. Doing so will allow moisture to enter the circuit, causing corrosion and high resistance. Always test circuits at connection points.

Keep in mind that the longer a cable is, the more voltage drop will occur. Be sure adequate sized cable is used. For example, a cable 22 feet long that is required to carry 150 amps should be 00 AWG, which has a conductor approximately 3/8 of an inch in diameter. Rope stranded core is recommended.

Cable gauge must be sufficient to prevent voltage drop from exceeding the following SAE specifications:

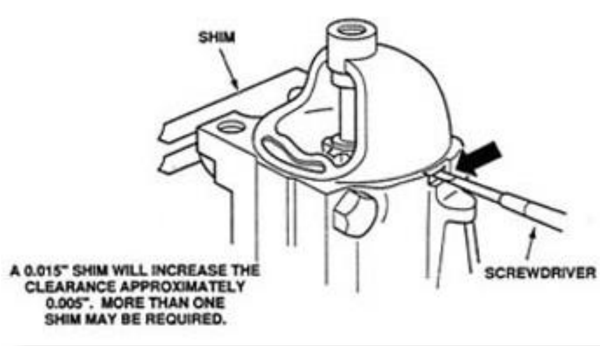
- 6 volt light and medium duty-- .12 volts per 100 amps
- 12 volt heavy duty-- .12 volts per 100 amps
- 12 volt light and medium duty-- .20 volts per 100 amps
- 24 and 32 volt heavy duty-- .20 volts per 100 amps
- 24 volt light and medium duty-- .40 volts per 100 amps
- 12 volt high-output heavy duty-- .075 volts per 100 amps
- 12 volt super heavy duty-- .060 volts per 100 amps

Minimum gauge size for 12 volt, high-output systems must be 00. Dual path circuitry is preferred.

Symptoms	Probable Cause
1. High-pitched "whine" during cranking (before engine fires) but engine cranks and fires okay.	Distance too great between starter pinion and flywheel.
2. High-pitched "whine" after engine fires, as key is being released. Engine cranks and fires okay. This intermittent complaint is often diagnosed as "cranking motor hang-in" or solenoid weak.	Distance too small between starter pinion and flywheel. Flywheel runout contributes to the intermittent nature.
3. A loud "whoop" after the engine fires but while the cranking motor is still held engaged. Sounds like a siren if the engine is revved while cranking motor is engaged.	Most probable cause is a defective clutch. A new clutch will often correct this problem.
4. A "rumble, growl" or (in severe cases) a "knock" as the cranking motor is coasting down to a stop after starting the engine.	Most probable cause is a bent or unbalanced motor armature. A new armature will often correct this problem.

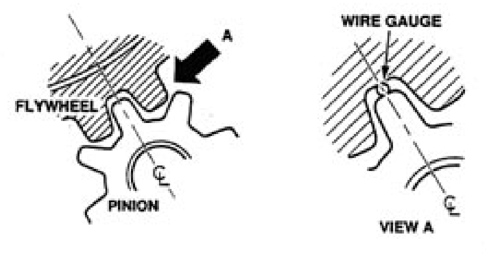
Pinion Clearance

Insufficient clearance between the pinion and flywheel may also cause a grinding sound during cranking. If improper clearance is suspected of causing an abnormal noise:



- **Remove the flywheel housing cover** and check for obvious problems such as broken or damaged teeth on the flywheel and pinion, a bent flywheel, cracked starter housing, or unusual tooth wear.
- **Mark the flywheel** to identify the high point of tooth runout. To do this, start the engine and **carefully** touch the outside diameter of the rotating flywheel with chalk or a crayon.
- Turn off the engine and **disconnect the negative battery terminal** to prevent inadvertent cranking of the engine.
- **Rotate the flywheel** so that the marked teeth are in the cranking motor pinion gear area.
- **Move the pinion** into mesh with the flywheel. Some applications provide a hole in the bottom of the starter housing for inserting a screwdriver to do this (illustration).

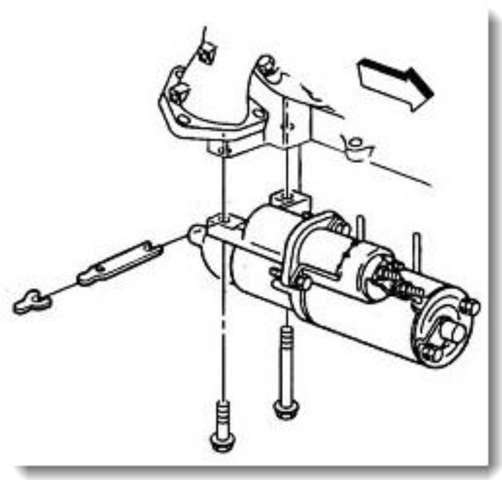
Flywheel to Pinion Clearance

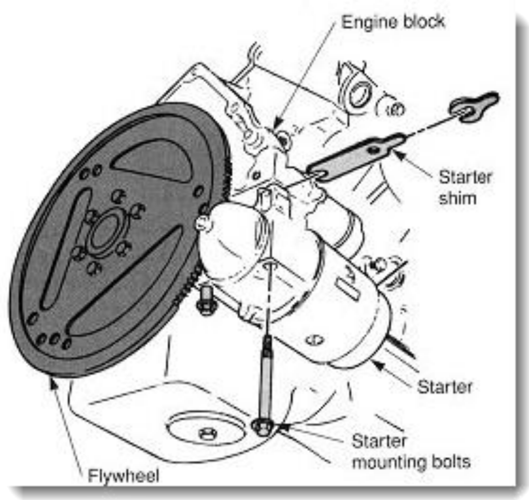


- **Turn the flywheel** if necessary, so that a pinion tooth is centered directly between two flywheel teeth (illustration).
- **Check the clearance** with a wire gauge or an Allen wrench and compare to specs. Clearance is generally between .020 to .125 inches.

On some applications, pinion gear clearance can be corrected with shims. To increase the clearance, install shim(s) to contact both starter motor mounting pads, as shown in the illustrations.

- When replacing a starter motor, always re-install any original shims.
- Shimming is not recommended on diesel applications.





Starter Replacement and Repair

Starter replacement is a straightforward affair. Procedures are in the service manual.

- Be sure to disconnect the negative battery cable before you begin.
- Re-install any heat shields or support brackets.
- Starter mounting bolts are hardened to withstand the repeated torque produced by the starter motor. Do not replace them with standard hardware.
- It is much easier to make the solenoid connections before mounting the starter to the engine.
- Avoid allowing the starter to hang from the cables.

In many cases, it may be more practical for both you and the customer to replace the starter and solenoid as a unit. This is a good preventive-maintenance practice, because trouble with one component may foretell trouble with the other.

Starter Motor Repair

The service manual contains detailed procedures and specifications for repair and rebuilding of starter motors. Again, this requires a judgment call, and may not be practical. With some units, rebuilding is not recommended. Check the service manual.

Unit 5: CHARGING SYSTEMS

Chapter 1: Charging System Components

The charging system uses power from the engine to keep the battery fully charged and supply the vehicle's electrical needs when the engine is running. Major components of the charging system include:

- **Generator** – generates electrical power to recharge the battery. Supplies electrical needs of the vehicle's accessories
- **Voltage regulator** – an electronic device that sets an upper limit on the amount of voltage generated and sent to the battery and accessories, thus protecting them from damage.

- **Battery** – receives electric power from the generator. Supplies initial current to energize the generator. Provides for electrical needs when generator output is insufficient. Helps stabilize generator output
- **Drive belt** – transmits mechanical power from the engine to the generator pulley
- **Charge indicator** – voltmeter or ammeter, and/or generator warning lamp

Generators and Their Functions

Generators are the primary components of charging systems. Just as motors convert electrical energy into motion using conductors and electromagnetic fields, generators use the same principles to convert mechanical rotary energy into electrical energy. In other words, instead of using electrical power to turn a starter, mechanical power is used to turn the generator, which produces electricity. Motors and generators both use the principle of **electromagnetic induction** to perform their respective functions.

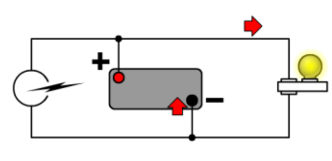
Generator Operation:

Generators use the principle of electromagnetic induction to perform their functions. Induction occurs when a conductor moves through a magnetic field.

The increased output possible with newer AC generator compared to older DC generators is due to a fundamental difference in design. In a DC generator, the conductor windings (armature) rotate within a stationary magnetic field, but in an AC generator, the magnetic field rotates within a stationary conductor winding assembly.

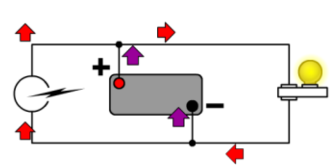
Modern AC generators are commonly called **alternators**, and today the terms "generator" and "alternator" are used interchangeably.

Charging System Modes of Operation



This illustration shows a typical battery, generator, and electrical load configuration. In this mode, the generator is not producing current and the battery is supplying all of the available current. This condition occurs when accessories are operating without the engine running, and or during a charging system failure.
If this situation were allowed to continue for an extended period, the battery would become discharged.

Battery and Generator Supplying Current

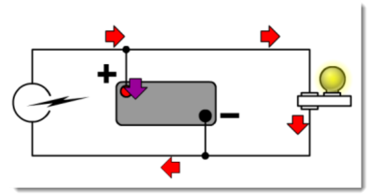


This illustration shows both the battery and generator supplying current. This situation occurs when the generator is not operating at a sufficient speed to meet the electrical demand, and the battery is required to make up the difference. A high electrical demand at idle could cause this condition.

This condition will also cause the battery to become discharged.

Generator Supplying Current

In this illustration, the generator is operating at a sufficient speed to supply both adequate operating current and to recharge the battery. The generator recharges the battery by creating a voltage high enough to send current through the battery in the opposite direction as during discharge. This is the normal, desired operation.



Generator Voltage Output

A generator's output can be varied three ways:

- Alter the number of turns, or windings, in the stator (stationary winding)
- Change the speed of rotor rotation
- Vary the strength of the rotor's magnetic field

The first two ways are determined from a design standpoint, and the third is used by the voltage regulator to control the generator's voltage during operation.

If the **number of windings** in the stator is increased, the magnetic field cuts through more conductors, and **amperage** in the stator is increased.

If the **speed** of the rotor rotation is increased, the magnetic lines of force are cut through with greater frequency, increasing the **voltage** produced in the stator windings. Rotor speed, which increases with engine rpm, is determined by pulley size and design.

Altering the rotor's **magnetic field strength** controls the generator's **voltage** output. The stronger the field, the greater the voltage induced in the stator. Voltage regulators control generator output by varying the amount of current, and thus the magnetic field, which passes through the rotor (rotating winding).

Generator Components

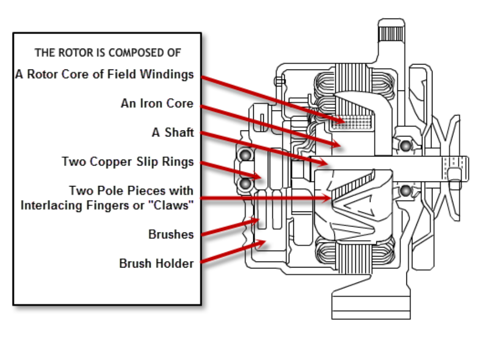
A generator is made up of four primary components:

- Rotor and brushes
- Stator
- Diode bridge
- Voltage regulator

Rotor and Brushes

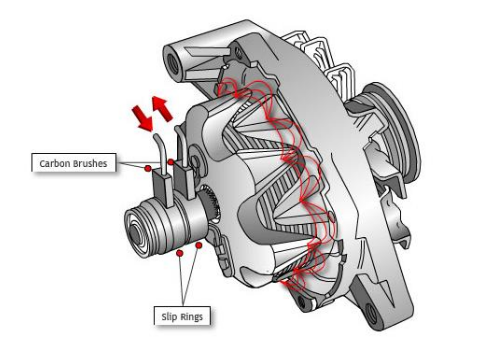
Rotor

A generator rotor is rotating a magnetic field assembly, mounted on a shaft, that rides in bearings located in the front and rear of the generator case.



Brushes

The spring-loaded, carbon brushes are in constant contact with the slip rings. The slip rings are insulated from the rotor shaft and are connected to opposite ends of the rotor windings. One of the brushes is connected to system voltage and the other to an alternating ground. As a result of the applied voltage, a variable current flows through the field windings, and creates a variable magnetic field. Note the alternating N and S fingers of the pole pieces in the illustration.

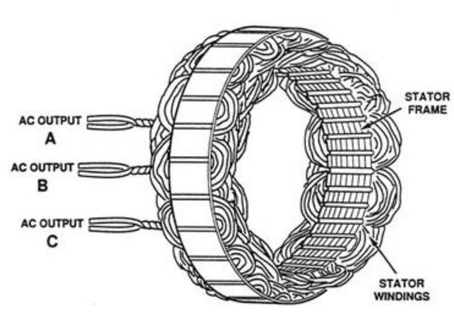


The brushes in an AC generator tend to be much smaller than brushes in starter motors since they carry only field current to the rotating field.

Stator

In an alternator, the stationary winding assembly is called a stator. A stator consists of three windings, called phases, assembled onto an iron frame. The currents that are induced in each winding, by the rotor, are added to produce the alternator's total output current. As the alternating N and S poles of the rotor pass next to the stator coils, three distinct AC voltage cycles are produced.

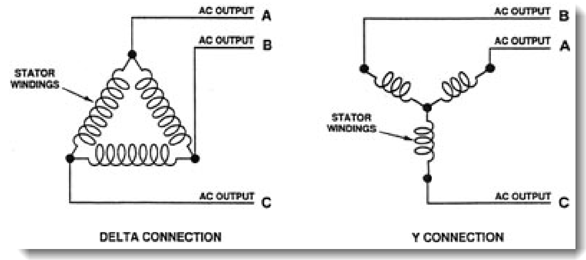
Stator Assembly



Delta and Y

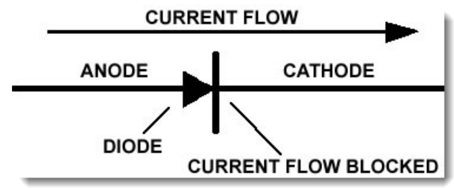
The output from each stator winding is connected in either a delta (D) or a Y configuration. The Y configuration provides good voltage levels with acceptable current output for many applications. The delta configuration produces good current at an acceptable voltage level, and a high maximum output. The delta configuration is the most common in automotive applications.

Delta and Y Connections



Diodes and Diode Bridges

Automotive circuitry operates on direct current (DC), and generators produce alternating current (AC). As a result, we must convert the current from AC to DC before it can be used. To accomplish this we use a series of diodes, or rectifiers, to make the conversion.



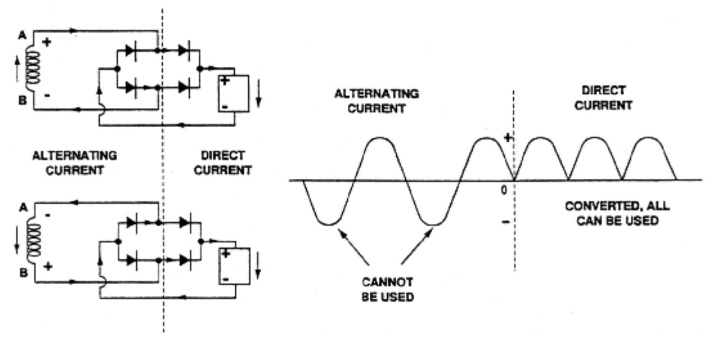
Diodes are electronic devices that only allow current to flow in one direction through the device. By incorporating a series of diodes, called a rectifier bridge, we can convert 3-phase AC to 3-phase DC.

> **Diodes:**
>
> A diode is an electronic component that acts as an electrical check valve allowing current to flow through it in only one direction.

Waveforms

A rectifier bridge, also referred to as a full-wave rectifier, commonly consists of six diodes, which convert all of the AC voltage to DC.

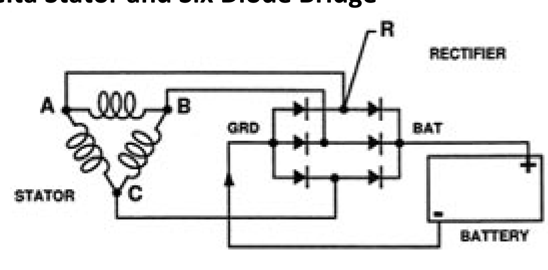
This illustration shows a four-diode bridge and its output waveform pattern.



Delta Stator

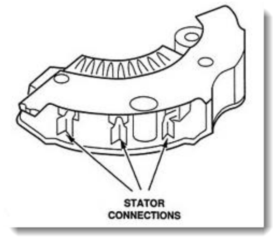
This diagram shows a delta stator wired to a six-diode bridge. Note that the current is blocked from flowing from the stator to the grounded side of the bridge.

Delta Stator and Six Diode Bridge



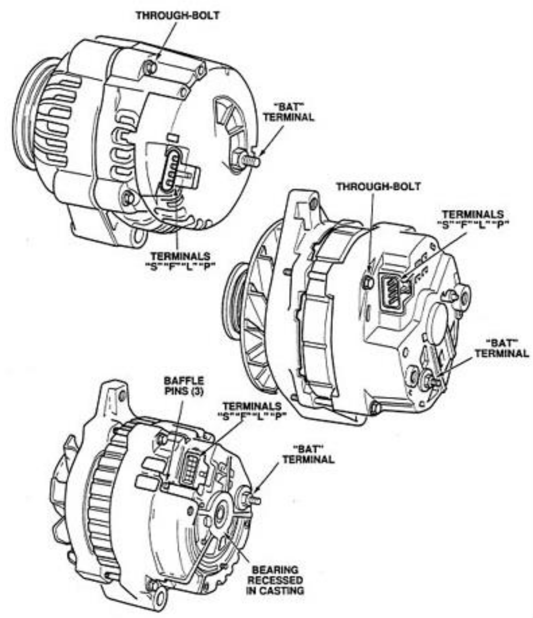
Here, a typical diode bridge is illustrated.

Typical Diode Bridge



Voltage Regulator

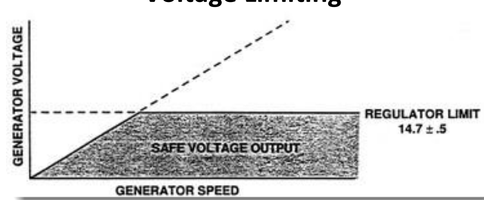
All alternators have a voltage regulator, and most are internally mounted as part of the unit. This illustration shows some typical alternators with internal regulators and with both internal and external cooling fans.



Limiting Voltage

Voltage regulators limit generator output to a level approximately two volts higher than battery voltage. This higher voltage level provides the "push" necessary to force current through the battery, recharging it (when the engine is running at a sufficient speed and without excessive electrical loads). As shown in this illustration, system voltage must be kept to a safe level (14.7 V ±.5) to prevent damage to electrical components.

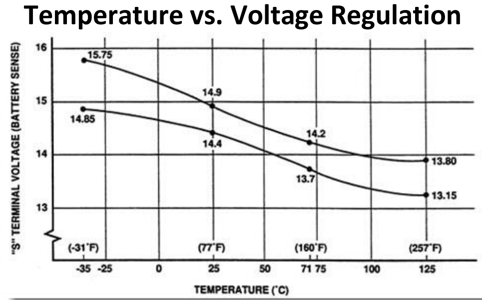
Voltage Limiting



Temperature vs. Voltage

Voltage regulators sense system voltage, and many also sense battery or generator temperature. Regulators will increase the system voltage setting to compensate for cooler temperatures and reduce voltage output for higher temperatures. In this way, overheating of charging components can be avoided. This graph displays the temperature/voltage curve for two typical applications.

Temperature vs. Voltage Regulation

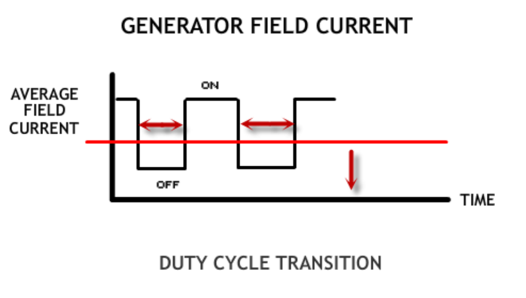


Duty Cycle

In order to achieve a regulated system voltage, a voltage regulator will switch the field (rotor) current on and off at a fixed frequency of about 400 cycles per second. System voltage is then controlled by varying the on/off time of the field current. For example, at low speeds, the field may be turned on 90 percent of the time and off 10 percent of the time. This yields a relatively high average field current which, when combined with the low generator speed or high electrical demand, produces the desired system voltage.

> **Voltage Regulator:**
>
> The voltage regulator controls the magnetic field strength by rapidly turning the field current on and off.

As generator speed increases, less field current may be needed to generate the desired system voltage, and the duty cycle changes to reduce the average field current. At high engine speeds, the regulator may be on for only 10 percent of the time and off 90 percent of the time. The duty cycle will change as operating factors and loads change, to provide just the right amount of field current to produce the necessary system voltage. Observe how the on/off cycle can vary.



High Electrical Demands

Keep in mind that the voltage regulator only limits the maximum voltage output of the generator. When demands on the vehicle electrical system are such that the full output of the generator is insufficient, the regulator will provide continuous (full) field current in order to obtain the maximum possible output from the generator. In other words, the regulator limits the maximum voltage the generator can produce; however, combining many high electrical loads on a vehicle can often cause the actual system voltage to be less than the regulator setting.

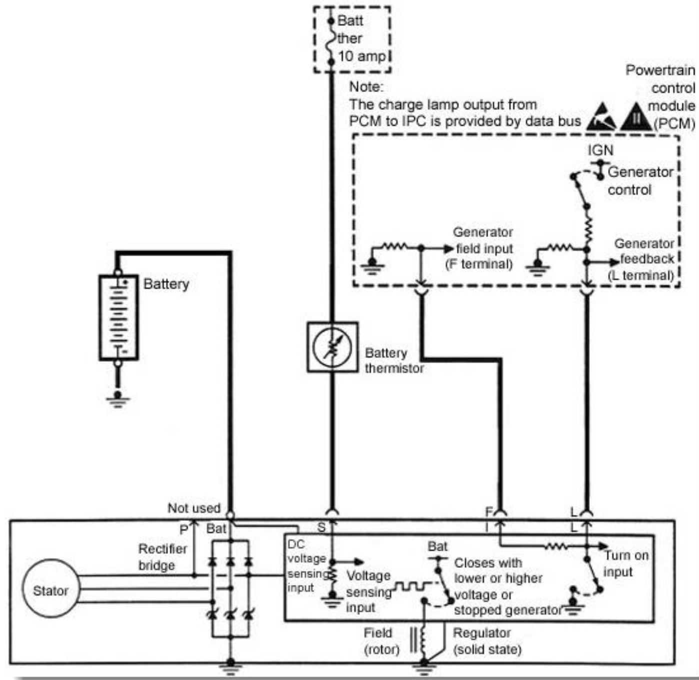
> **High Electrical Demand Causes:**
>
> High electrical demands can cause the actual system voltage to be less than the regulator setting.

Methods of Regulating Voltage

Several different methods of regulating system voltage have been used, and late model vehicles are increasingly using electronic control modules to supplement or replace conventional voltage regulators. Computerized ECM or PCM control of system voltage offers several benefits, such as greater accuracy and consistency. Other advantages include the ability to set diagnostic codes, and to enhance driveability such as turning off the alternator at full throttle to reduce engine load.

This diagram is an example of a system in which voltage is controlled by the PCM. Carefully examine this schematic and the components. Note the battery thermister, which provides battery temperature information to the system for voltage corrections.

PCM Control of System Voltage



Chapter 2: Charging System Diagnosis and Service

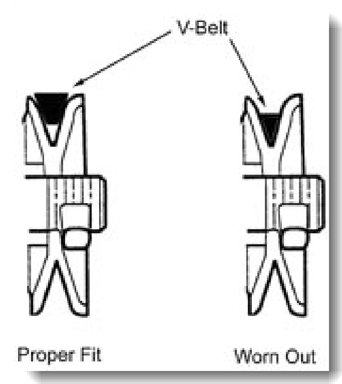
While there are relatively few components involved in the charging system, they are interdependent, and troubleshooting should be systematic and methodical to ensure an accurate diagnosis. Refer to the appropriate service material for diagnostic flow charts, procedures, and specifications.

Visual and Mechanical Inspection

Begin by checking that all battery terminal and alternator connections are clean and tight.

Check the drive belt condition and tension. Look for glazing or oil on the belt, which may cause slippage. **Even a small amount of slippage** may prevent the battery from receiving an adequate charge. On V-belt applications, check for proper fit and alignment. The belt should be driven by the sides of the V and should not ride low in the pulley nor contact the bottom of the pulley, as shown. Any belt that "bottoms out" must be replaced.

V-Belt Fit



One method of checking for slippage is to firmly grasp the generator by the fan blades or pulley and attempt to rotate it. If the pulley can be rotated by hand, excessive slippage is present and must be corrected. **Do not** overtighten a worn-out or oily belt as this can ruin the bearings in the alternator or other accessories.

Listen for unusual noises from the alternator. A buzzing, grinding or rattling can indicate mechanical problems such as a bad bearing or broken internal parts. A loud whining can be caused by bad diodes or overcharging.

Checking for Belt Slippage

The system to the right uses a flat, serpentine belt with an automatic self-tensioner. A spring inside the unit applies the proper tension to the belt.

A Spring Applies Proper Tension

Electrical Testing

For accurate electrical testing, the vehicle must have a known-good sufficiently charged battery. A sulfated, shorted, or dead battery can cause misleading test results.

Connect a voltmeter across the battery with the engine running at about 2000 rpm for a quick functional check of the alternator. A no-load voltage, or open-circuit voltage, of approximately 13.2 to 14.7 volts indicates some output is being generated.

An output lower than 13.2 V indicates battery voltage only. If battery voltage is indicated, check wiring harnesses and generator connections. Jiggle the wires while observing the voltmeter. If the system begins charging, you have located a wiring problem. You may notice a whining as the generator begins to charge, and a brief loading of the engine before the PCM adjusts the idle speed.

Safety Precautions:

- Never short or ground any charging system terminal unless instructed to do so by the service manual.
- Never remove the battery from the circuit with the engine running!

Never remove the battery from the circuit with the engine running! The resulting voltage spike may ruin the PCM or other electronic components. **Never short or ground any charging system terminal unless instructed to do so by the service manual.** On older vehicles, a common diagnostic method was to bypass the regulator and apply full system voltage to the field circuit in order to determine whether the alternator was capable of charging. Bypassing in this manner causes the alternator to begin unregulated charging, which can damage electronic components.

Scan Tools and Scopes

For many vehicles a scan tool can be useful in diagnosing charging systems. Scan tools can display charging rate, battery temperature, and other useful data. Oscilloscopes can be used to display voltage waveforms to diagnose diode failures that voltmeters cannot detect. Study the waveform examples on the following screens, and refer to the scan tool instructions.

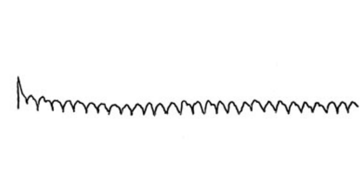
Scan Tool

Digital Oscilloscope

Waveforms

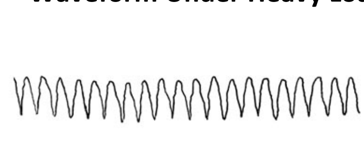
This is a typical normal output waveform. The alternator is charging correctly.

Normal Waveform



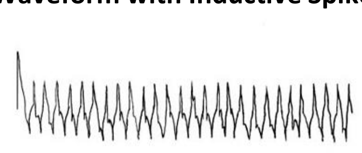
This waveform is also normal, but indicates the alternator is under a heavy load.

Waveform Under Heavy Load



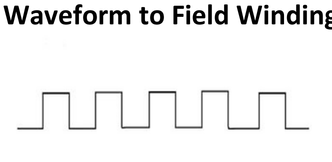
This pattern is seen with some charging systems that use electronic regulators and duty cycles. The higher inductive spike is normal on these systems.

Waveform with Inductive Spikes



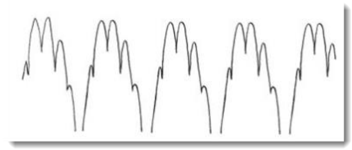
This pattern shows a duty cycle from a control module to the field windings.

Duty-Cycle Waveform to Field Windings



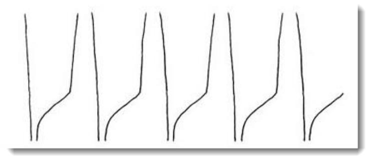
This is an unacceptable waveform. The high spikes in this pattern indicate an open diode.

Open Diode Waveform



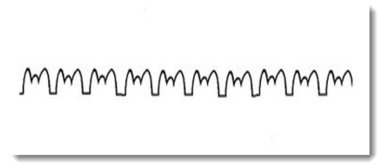
This unacceptable waveform is showing one open diode and one shorted diode.

Waveform of Open and Shorted Diodes



This waveform, also unacceptable, shows shorted diodes or stator windings.

Waveform Showing Shorted Diodes or Stator Windings



Tests

Charging System Output Test

The load-testers used for checking batteries and starting systems also provide an effective means for testing charging systems. They can test for adequate current and voltage output under varying loads up to the rated capacity of the generator. Load-testers also have features for testing alternator diodes and stator windings.

In general, the procedure consists of the following:

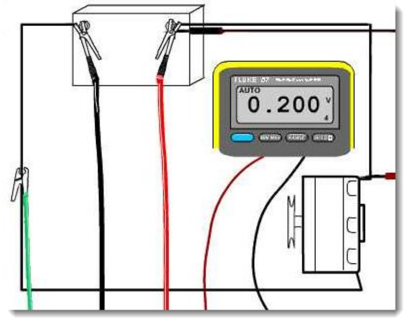
- Connect the tester's heavy clamps to the battery terminals, and clamp the inductive amps probe around the negative battery cables
- Start and run the engine at approximately 2000 rpm.
- Gradually rotate the load control knob until the ammeter indicates the specification for current. Observe that the voltage remains in the acceptable range (13 to 15 volts). Remove the load.
- **Note**: Alternator current output should be within approximately 20 percent of its rated capacity.
- Press the DIODE key (or rotate the tester's function selector knob to the diode/stator test) and observe the reading.

Circuit Resistance Tests

If you suspect poor test results are due to circuit problems, rather than the alternator/regulator, circuit resistance tests can pinpoint problems in the wiring. These are voltage drop tests similar to the starting system tests described in the Starting Systems section. To perform a circuit resistance test on the positive side of the circuit:

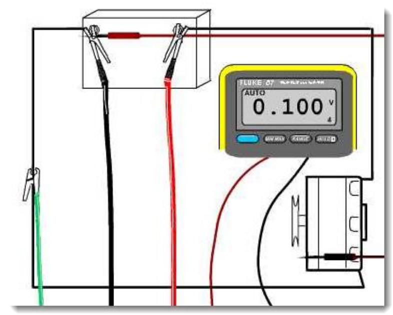
- Connect the positive probe to the alternator output terminal and the negative probe to the positive battery terminal, as shown.
- Start and run the engine at approximately 2000 rpm.
- Adjust the load control knob to approximately half of the alternator's rated output.
- Observe the voltmeter reading. Voltage drop should not exceed .5 volts in most cases.

Positive Side



Circuit resistance test for the ground side is similar to the test for the positive side, but the positive probe is connected to the negative battery terminal and the negative probe is connected to the alternator housing, as shown. If you use the starting and charging system tester's external volts leads, the load clamps must be connected to the battery to power the meter's display. Refer to the service manual for applicable specs and exact procedures. Most applications specify not more than a .6 volt drop for both sides of the circuit.

Negative Side



Generator Repair

Although some generator units are "serviceable", it is recommended that any repair of these units be left to electrical repair facilities with the proper tools and test equipment.