# Batteries, Starting and Charging – Study Guide



## Course Objectives

Upon completion of this course, technicians should understand and be able to apply their knowledge of:

- Electrical Fundamentals, Including Magnetism, Induction, Voltage, Amperage, and Resistance
- Construction, Operation, And Diagnosis of Starting and Charging Systems, including:
- Batteries and Cables
- Generators (Alternators) and Voltage Regulators
- Cranking Motors, Solenoids, and Starter Drives
- load and no-load battery and charging system tests, parasitic tests for excessive key-off current, and starter draw tests for excessive or insufficient current load
- Voltage drop tests

### Using the Job Sheets

As you proceed through the online modules, on some pages you will find links that will open a window with a printable procedure or job sheet containing hands-on lab activities based on the NATEF standards related to the content you are studying. When you come upon a procedure or job sheet link, click on it and print the job sheet for completion in the shop. See your instructor for guidance in completing the job sheets. Some jobs sheets will require supplemental materials such as a vehicle service manual, equipment manual, or other references.

### Electrical Fundamentals

#### Overview

To properly diagnose and repair starting and charging systems, the technician must first have an understanding of the basics underlying how the systems operate. In this section we will provide a brief refresher on electrical fundamentals and how they affect automotive circuits. This is intended only as a review; if you have not been through Melior's *Circuits and Meters* or an equivalent training course, you may need further study on electricity and using a DVOM (digital volt/ohm meter, or "multi-meter").

#### Electrical Properties

Electricity involves three basic properties: **voltage, current, and resistance**. Each of these properties has its own unit of measurement: voltage is measured in volts, current is measured in amperes (or "amps"), and resistance is measured in ohms. Most students have no doubt used these terms and probably measured for them, but often they are used interchangeably even though they are in fact all different. To ensure that we are all talking about the same thing, a brief description of each is in order.

Another electrical characteristic you need to understand is **magnetism**. Magnetism, or electromagnetism, is caused by current flow through a conductor, and is the property that makes generators and starters work.

#### 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.

When there are more 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. Batteries will be discussed in the following section.

The base unit for voltage is the “volt.” Keep in mind that voltage is merely a “pushing” force and does not perform the real work in an electrical circuit.

**Current**
Current is the movement of electrons in a circuit. In 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, which causes the motors to turn, the lights to shine, and the fuses to blow.

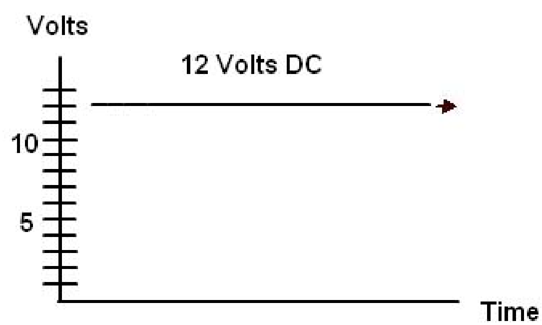
> Voltage is defined as electrical pressure, and current is the flow of electrons through a conductor.

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. The base unit for current is the “amp.”

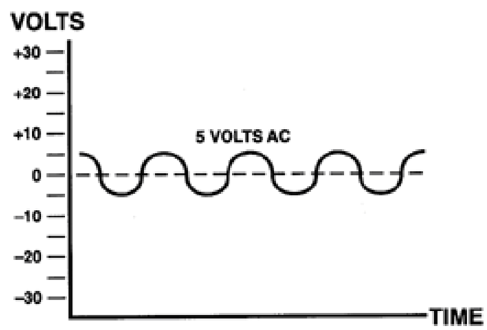
Various automotive electrical systems may use either a very high or a very low current. For instance, the starter system typically is high current, in excess of 100 amps, whereas spark plug current is very low (many confuse high voltage with high current in ignition coils) at much less than one amp.

**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. Alternating current flows in one direction then reverses itself and moves in the opposite direction.

> The automotive industry normally uses conventional flow theory. Most automotive circuits operate on DC. Remember that voltage is measured in volts, and current is measured in amps.




**Direct Current or DC**




**Alternating Current or AC**

**Resistance**
The base 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.

> Resistance is anything that opposes the flow of electrons. Resistance is measured in ohms.

Resistance is anything that opposes the flow of electrons. As the resistance in a circuit is decreased, the amount of current increases. As the resistance increases, the current decreases. Comparing this 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 is affected by a substance’s composition, the length and cross sectional area of the conductor, and temperature. A longer wire will have a higher resistance, and the larger the circumference of a conductor is, the less its resistance. For example, a 1.0 mm wire (16 Ga.) has less resistance than a .35 mm wire (22 Ga.). Also, as a substance is heated, its resistance increases (there are some exceptions to this rule).

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.

**Source Voltage**

Source voltage is a term used to refer to the amount of voltage available to move current through a circuit. For most automotive applications, including starting and charging systems, source voltage should be in the 12-14 volt range. It is most important for the technician to be aware of the amount of voltage that **should** be applied to a circuit to insure that misdiagnosis does not occur.

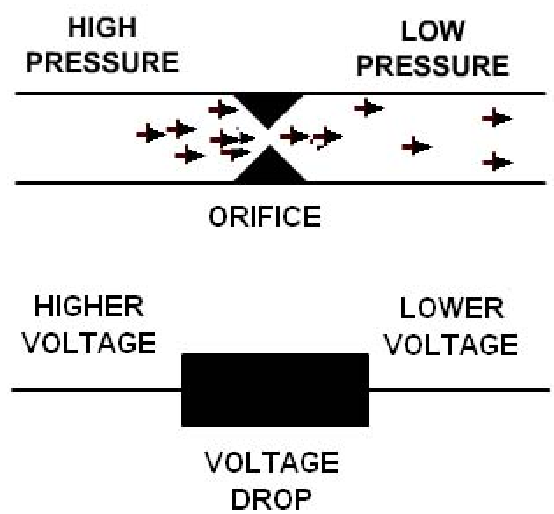
Source voltage is the voltage applied to a circuit when there is no current flow.

**Shorts and Opens**

A short circuit is a circuit that’s “shorter” than it’s supposed to be. Something provides an electrical pathway that shouldn’t be there. A short to ground before a load will prevent the component (load) from operating, and cause the live part of the circuit to have insufficient resistance. This may cause excessive heat in the wiring, or cause fuses to blow. A short circuit across a switch may cause the switched component to operate when it is not supposed to, as will a short to power after a switch.
An open is an unintended break in a circuit. A common cause of an open is a broken wire.

**Voltage Drop**

Voltage drop is 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 on 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 a system.




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

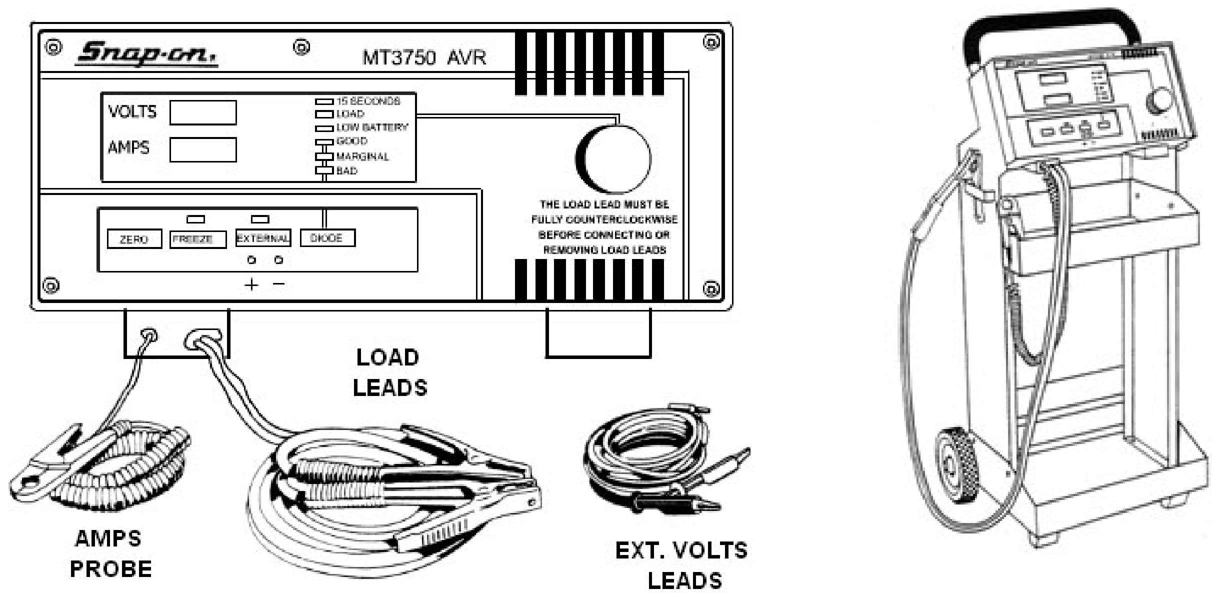
A DVOM can be used to check voltage drop, as well as many other starting and charging system tests. Other equipment also can be used to test batteries, starter current draw, and generator charging rate. These testers use a carbon pile to place a load on the battery or generator.

## Battery and Starting/Charging System Test Equipment

### Typical Starting and Charging Systems Testers

Several manufacturers produce specially designed units dedicated to testing batteries, and starting and charging systems. The carbon pile we have discussed is the distinguishing component of these machines. One popular model and its control panel is illustrated below.

Machines of this type use an inductive amps probe, eliminating the need to break into the circuit for series starting and charging testing. The contacts of the inductive amps probe should be inspected periodically for dirt build-up, and to ensure the jaws close together fully. For best accuracy, place the probe away from strong magnetic fields such as those near generators or motors.




**Starting and Charging Systems Tester**

## Automotive Batteries

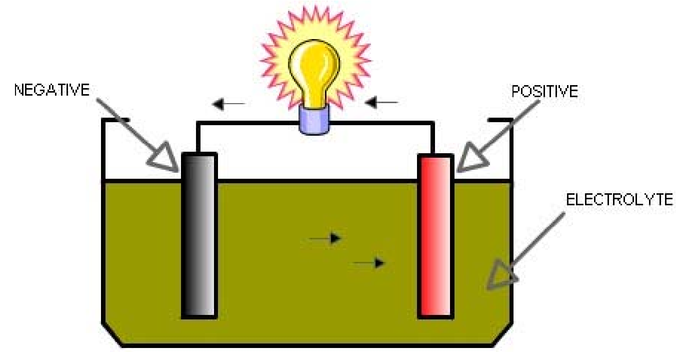
### Battery Function

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

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.



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

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.

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

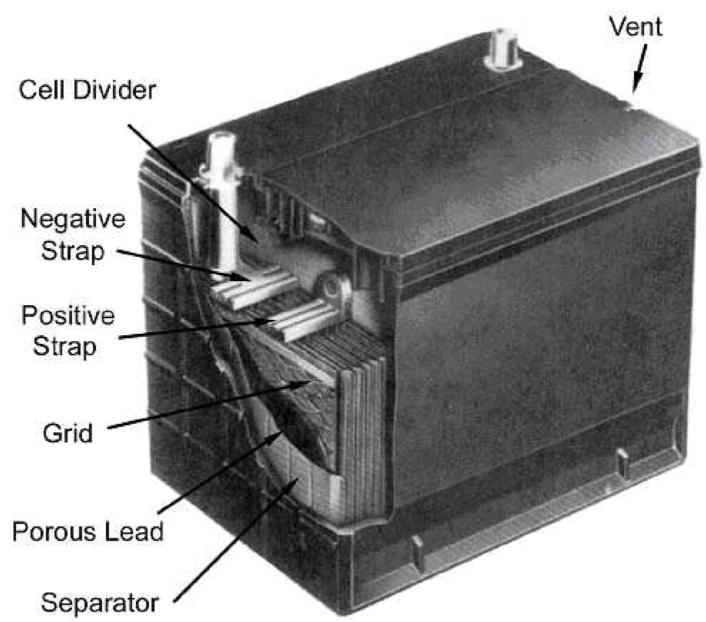
A battery that is nearly or completely discharged is commonly said to be "dead," "flat," or "run down." A battery in this condition should be recharged to full capacity to provide proper service. Although a generator will charge a battery, it is not designed as a "battery charger." Requiring a generator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

Deep cycle batteries are designed to be more deeply discharged many times. While completely discharging an automotive battery does not ruin a battery that is in good condition, it may shorten the life of the battery.

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.



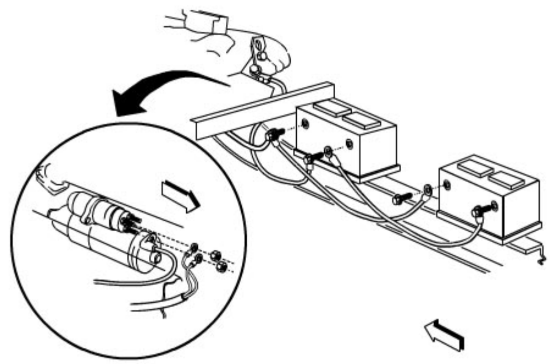

Each plate consists of a stiff mesh grid of a lead alloy, coated with porous lead on the negative plates, and lead peroxide or lead dioxide on the positive plates. A strap of lead connects the negative plates to form a group, and another strap connects the positive plate group. On each end of the battery,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

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.

Between the positive and negative plates are separators, which are constructed to keep the plates from touching each other and shorting. The separators are porous, to allow electrolyte to circulate freely and permit the chemical process to take place.

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. 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.

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.



**Two batteries in parallel on a diesel application**

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.

## 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.

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.

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

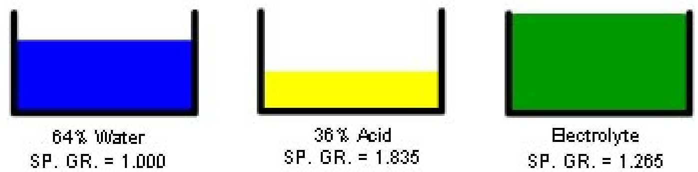
**Conventional, Top Post Battery with Vent Caps Removed**

**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.

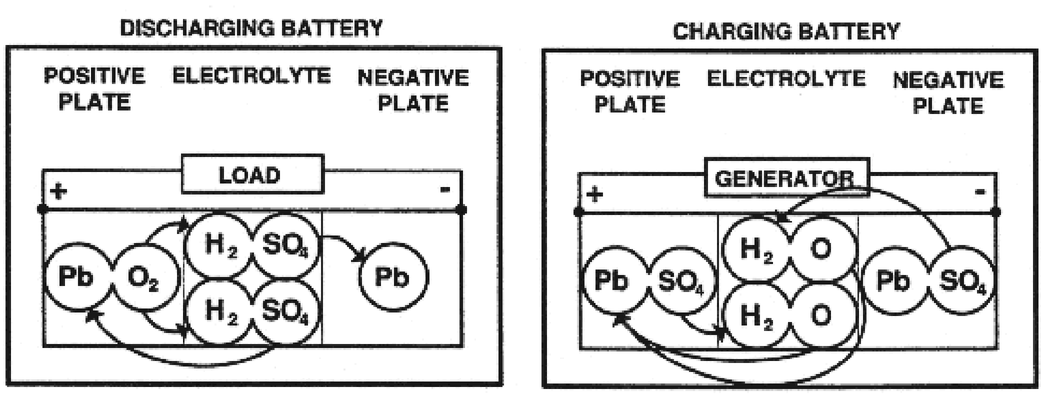



## Chemical Reactions while Discharging and Charging

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.

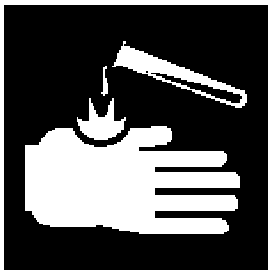
As a battery begins to discharge, the composition of the plates becomes more similar, and the water content of the electrolyte increases. Lead sulfate (PbSO4) is formed on both the positive and negative plates, trapping the oxygen and sulfur, and leaving water molecules behind (left side of illustration). 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.

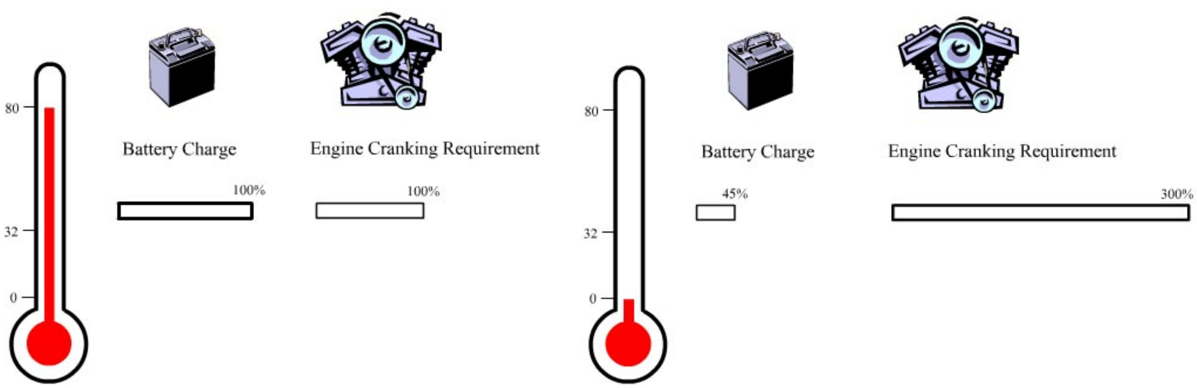
**Never hammer on a battery terminal or cable end, or attempt to remove a cable by prying.** To avoid damage to the battery or terminals, and possible personal injury, use a clamp spreading tool if the clamp doesn't seat at the bottom of the post, and use a cable clamp puller to remove stubborn clamps. 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.

## 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.

- 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.

Cold temperatures reduce a battery's available power.

## 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. 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.

The CCA rating is the most important rating of a battery; it is used in application specifications and in battery testing.

### 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.

## 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.

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

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.

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.

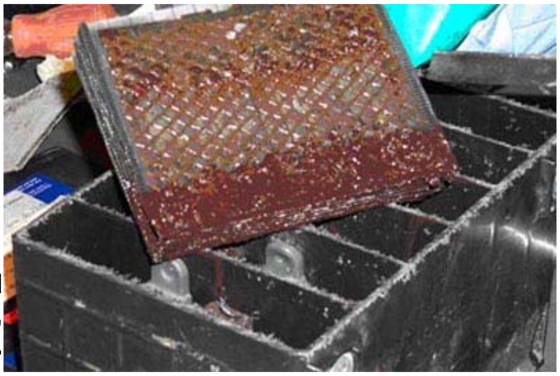
Years of cycling will finally take their toll on any battery. Small amounts of the active material on the positive plates are shed during cycling, and fall to the bottom of the battery. If the sediment at the bottom of the battery builds up enough to bridge the positive plates to the negative plates,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

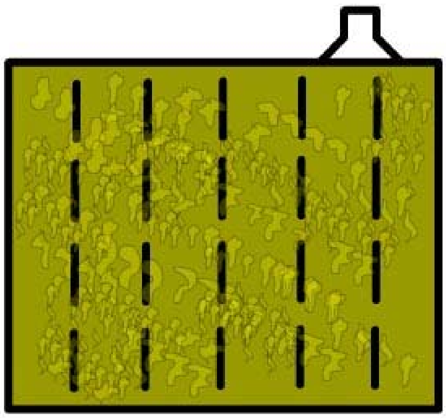


**Shedding of Plate Material -- Overcharging has caused active material (brown) to shed from this plate, reducing capacity and powder. Note the exposed grid.**

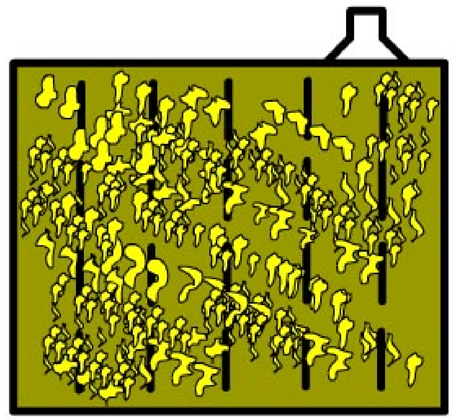
## Undercharging and the Result: A Sulfated Battery

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.

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.



Normal Sulfation



Permanent Sulfation

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

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

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.

| **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 |

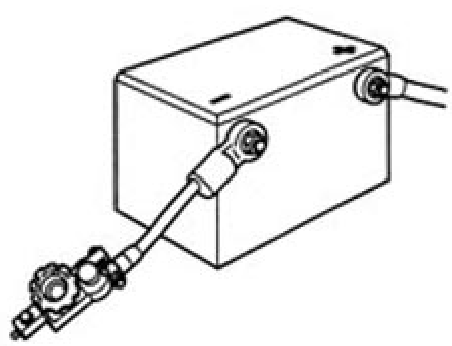
| | |
|---|---|
| HVAC Programmer | 0.5 |
| Instrument Panel<br>Digital Cluster<br>Gages Cluster | <br>4.0<br>4.0 |
| Lamp Control Module | 0.5 |
| Oil Level Module | 0 to 0.1 max |
| PCM | 5.0 |
| Pull-Down Unit | 1.0 |
| RAC Module<br>(Retained Accessory Power)<br>(Illuminated Entry)<br>(Remote Keyless Entry) | 0 to 3.8 max |
| Radio<br>CD | 7.0<br>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.

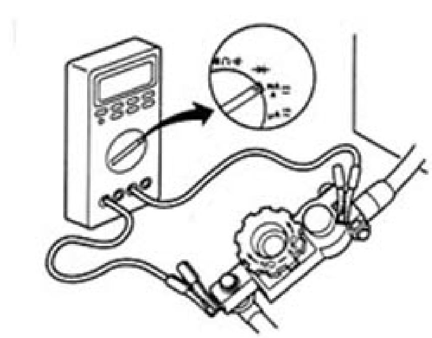
Current draw from 5 to 30 milliamps is usually considered normal parasitic draw; however, some RV applications may have a normal parasitic load of up to 60 milliamps.

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. 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.



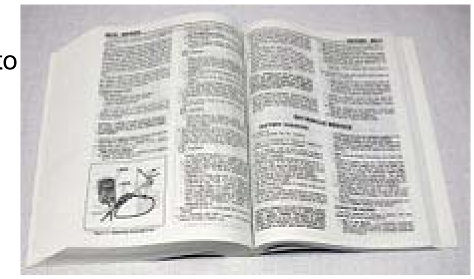
**Special Tool**



**Parasitic Draw Test**

Using a memory saver is helpful for retaining programmed information.

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.



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.

## 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.

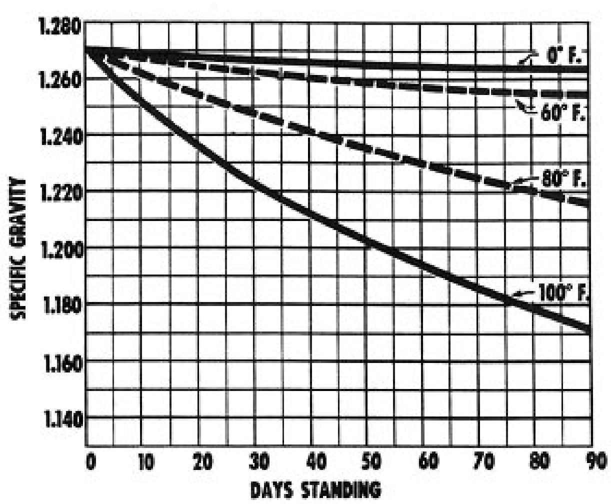
Once it has been established that there is an excessive parasitic load, the problem can be isolated by pulling fuses or disabling circuits until the circuit causing the drain is identified. The fuse is then replaced and each component on that circuit is checked one at a time until the trouble is isolated. 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 self-discharge over time.

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.

## Inoperative or Missing Hold-Down

Many batteries fail prematurely due to an inoperative or missing hold-down. It is very important that the hold-down be securely tightened, and that the tray is intact and holds the battery level. Without the hold-down, the battery can slam into

The battery hold-down must be in place!

other components and suffer internal or external damage. In some cases, the battery can even tip over or contact a metal object and short out. Because of the strong chemical reactions in the battery, the battery tray and nearby components are prone to corrosion. Most applications now use trays and hold-downs made of corrosion-resistant materials.

## Corrosion

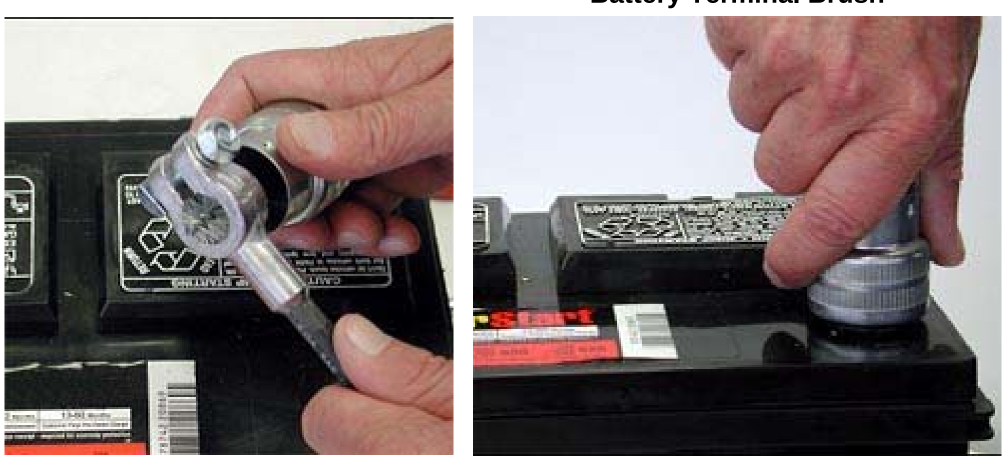
Corrosion forms on and around the battery cable ends, between the cable ends, on the battery terminals, and inside the battery. The positive terminal is particularly susceptible to corrosion build-up, which can creep down the cable where it is not visible. Look for a swollen cable or discolored insulation.

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.

**Corrosion --The positive terminal of this battery corroded so badly it became fused to the cable and broke. Note the internal corrosion on the strap and plates.**

For best battery performance and longest life, the cables should be disconnected, cleaned, and inspected about once a year. Excessive corrosion can be removed and neutralized with a baking soda and water solution. Battery terminals and cable ends should be cleaned with a battery terminal brush. The surface of the cable end that mates to a side terminal battery is prone to a build-up of very hard, bluish-white sulfide. All of this stubborn corrosion must be removed. The use of a small screwdriver or awl may be necessary. After reconnecting, the cable ends can be protected with a light coating of petroleum jelly or wheel bearing grease.

**Battery Terminal Brush**



**Cleaning Terminals with a Terminal Brush**

**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

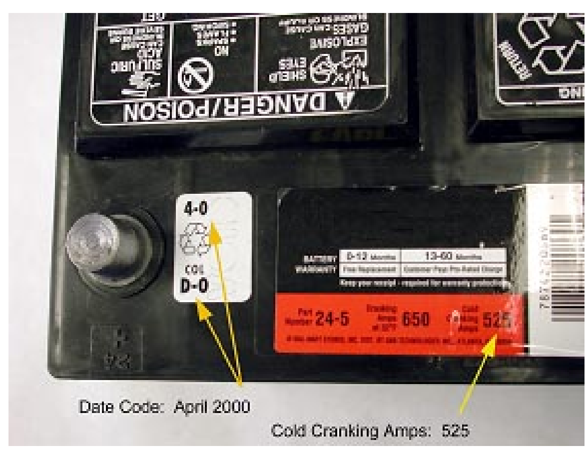
Battery testing begins with a visual inspection of the battery, connections, and cables. A battery with a cracked case, broken or loose posts, or a sealed battery with insufficient electrolyte must be replaced. **No testing is necessary;** do not attempt to test such a battery. During your visual inspection,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

**Battery Condition - This battery is leaking from a loose positive post and should not be tested. The battery is finished.**

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.

### Battery Information

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.




Batteries are labeled with a date code.

## 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.

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.

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

## 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.
**Hydrometer floats and barrels are made of thin glass and are fragile. Handle with care!**

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

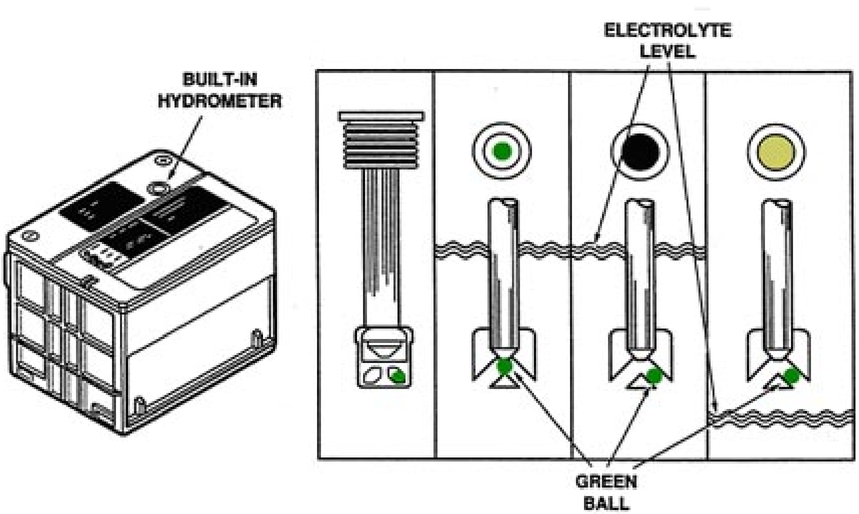
| Charge Level | Specific Gravity | Voltage (12) | Voltage (6) |
|---|---|---|---|
| 100% | 1.270 | 12.60 | 6.3 |
| 75% | 1.225 | 12.45 | 6.2 |
| 50% | 1.190 | 12.24 | 6.1 |
| 25% | 1.155 | 12.06 | 6.0 |
| Discharged | 1.120 | 11.89 | 6.0 |

**Battery Hydrometer**

## 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.

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

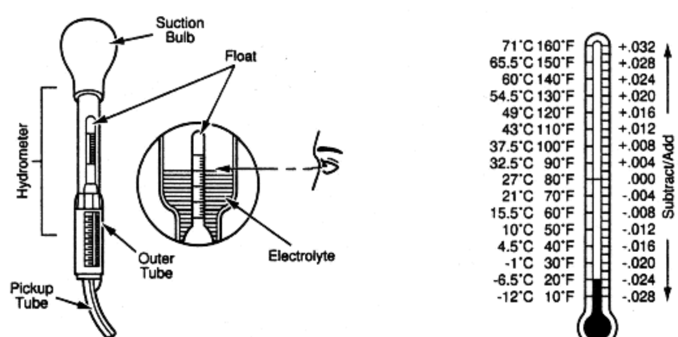



- **Green eye** – The battery is charged to at least 65% of its specific gravity. Some battery manufacturers consider this sufficient for testing.
- **Dark eye** – The ball is not floating high enough to be seen, indicating the battery is less than 65% charged. This does not necessarily mean the battery 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.**

> 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.




Example:

Electrolyte Temperature .............. 40°F
Hydrometer Reading ................. 1.250
Subtract Specific Gravity ............ – 0.016
Corrected Specific Gravity Equals ...... 1.234

Example:

Electrolyte Temperature ............. 100°F
Hydrometer Reading ................. 1.240
Add Specific Gravity ............... + 0.008
Corrected Specific Gravity Equals ...... 1.248

A Fully Charged Battery Has a Specific Gravity of 1.270.

The reading is corrected as shown in the chart to compensate for temperature if necessary.

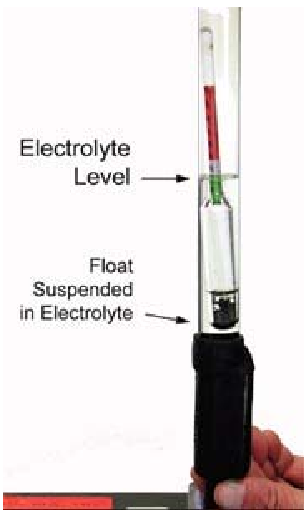
Here are some guidelines for using a hydrometer:

- 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.

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.

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**




**Notice how buoyant the float is in this fully-charged battery.**

**The next cell is checked, and also reads good: 1.265. But...**

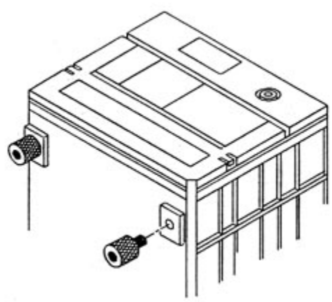
**...the last cell doesn't move the float at all.**

**The reading is below 1.100. When compared to the other readings, this indicates a bad cell.**

## 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.

For a load test to produce an accurate result, the battery must be fully or near fully charged.



**Side Terminal 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** 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.

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.

Do not attempt to load test a battery with insufficient electrolyte. Observe all battery safety cautions.

**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.

**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.

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 Electrical Leakage**

**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

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.

### State of Charge

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 than 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

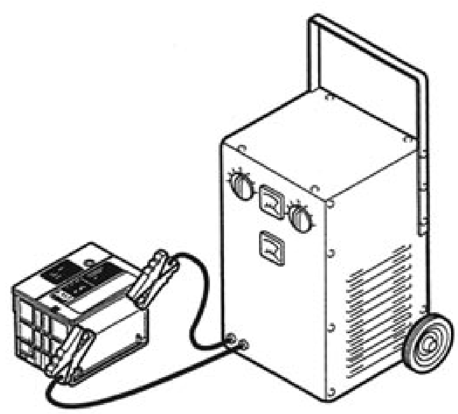
When fast charging a battery at a high rate (20 to 50 amps) to bring it to a serviceable level of charge in the fastest possible time, it must be checked frequently. Check to see that the terminal voltage does not exceed 15.5 volts, that electrolyte doesn't spew from the vent holes, and that it does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

Carefully monitor batteries when charging at a high rate.

## 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.



**Charging a Single Battery**

- 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.
- 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:

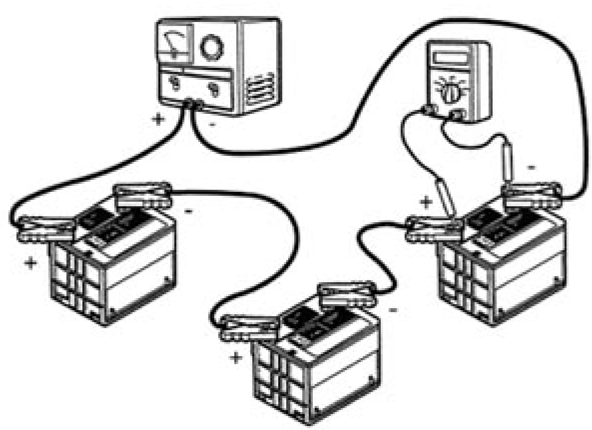
- Current-Limiting (constant current or series chargers)
- Voltage-Limiting (constant voltage or parallel chargers)

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.
- 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



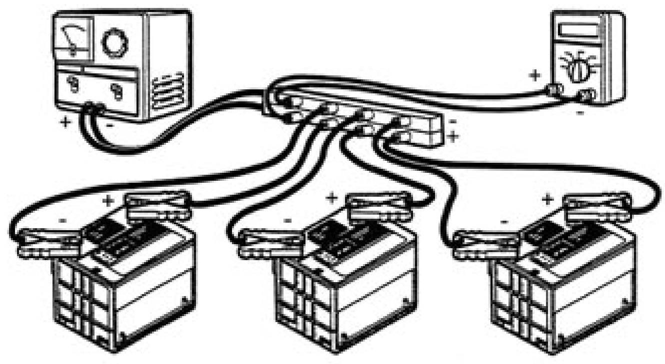

**Series Charging**

**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 chargers rated at 300 amps are common.



**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!

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.

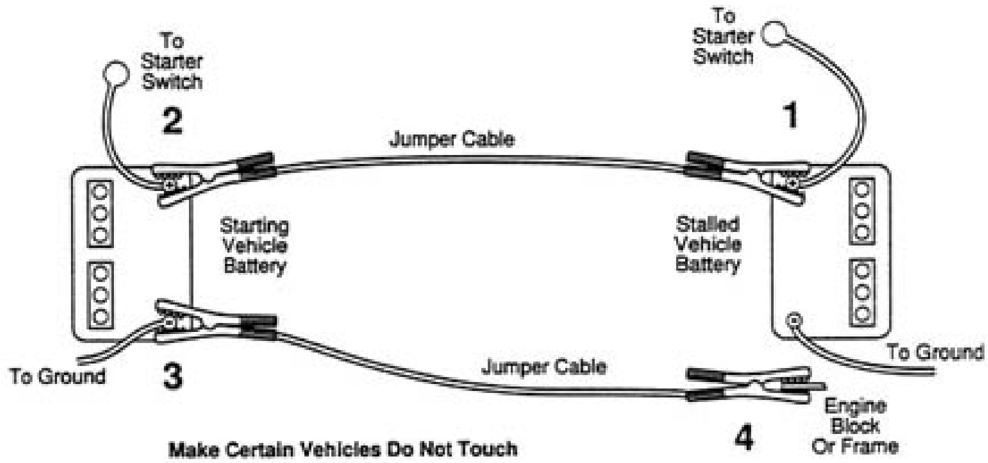
## Jump-Starting

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.

Keep your face away from batteries. Wear safety glasses.

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.




**Jumper Cable Hookup**

## Torque Specifications

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 |

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

## 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.

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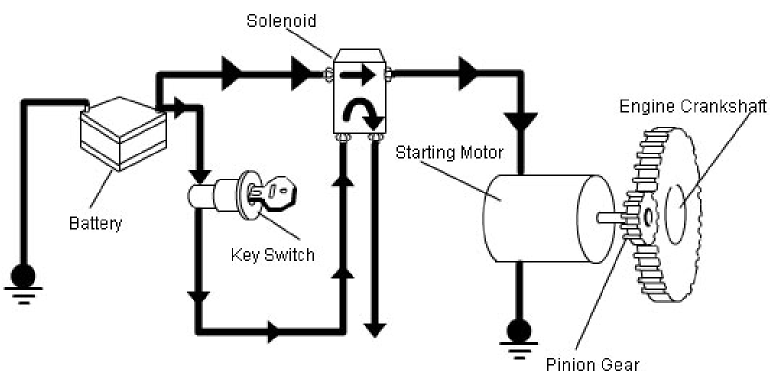
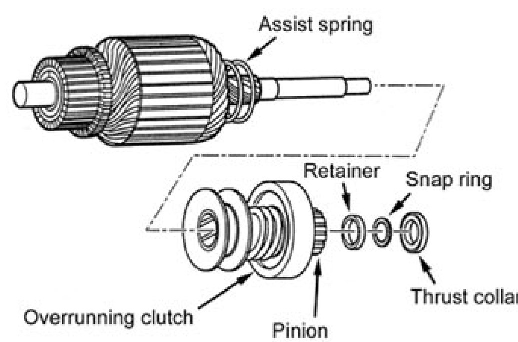
Note that in the system pictured here, used on many Fords, the solenoid does not engage the pinion with the flywheel; it is merely a high-current relay. This is not a true solenoid, because it does not produce linear movement, but it is often referred to as a solenoid.




### 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.



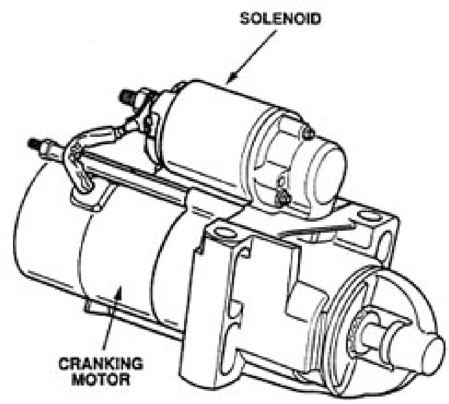

**Typical Motor Drive Mechanism**

### Pinion and Gear Reduction

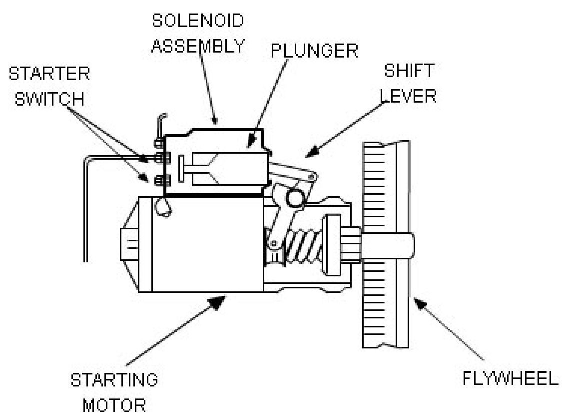
Several different types of drive mechanisms are used on starting motors, but in all cases, gear reduction occurs between the pinion and the flywheel. The amount of gear reduction designed into the application is a balance between the torque required of the starter and the speed required for reliable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

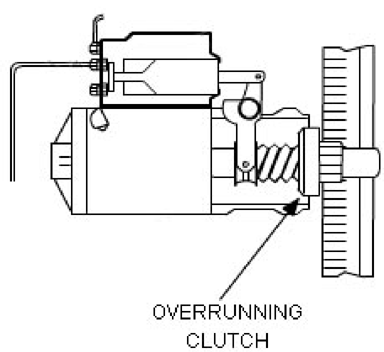
The starter-mounted solenoid is a powerful electromagnetic coil that is energized with a relatively low amount of current when the ignition switch is turned to the START position. When energized, the solenoid draws a plunger into a coil and holds it there.




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.




**Disengaged**

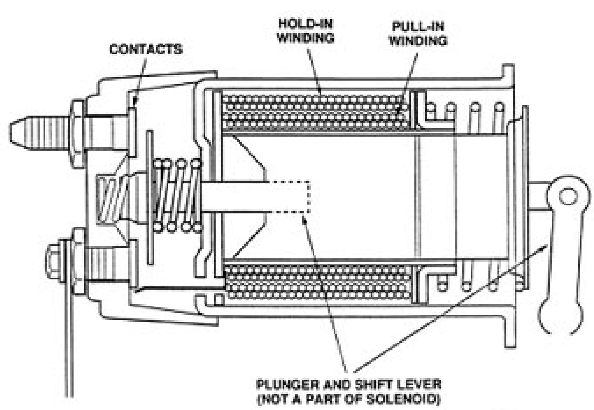



**Engaged**

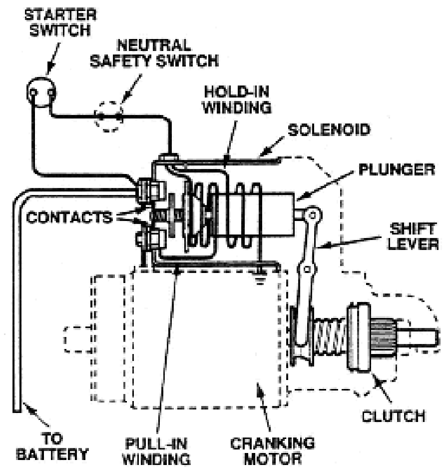
**Solenoid Pull-in Winding and Hold-in Winding**

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.

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.

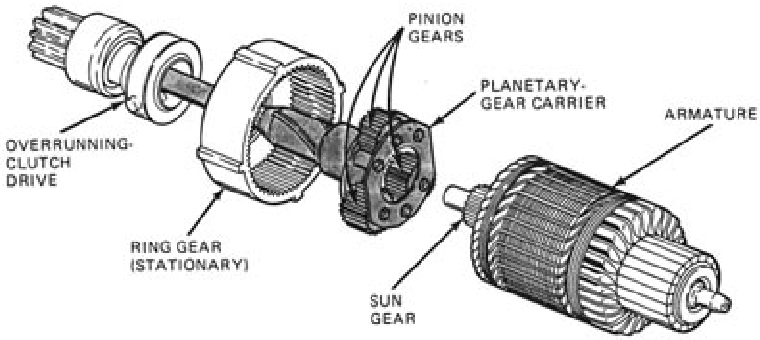


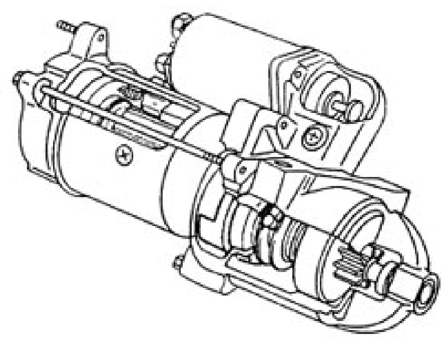
Diagnostically, if a hold-in winding fails, the pinion will engage repeatedly but it will not remain engaged. Likewise, a pull-in winding failure will prevent the pinion from engaging at all. On some starters, a pull-in winding failure will allow the motor to run, even if the pinion is not engaged.




## 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.

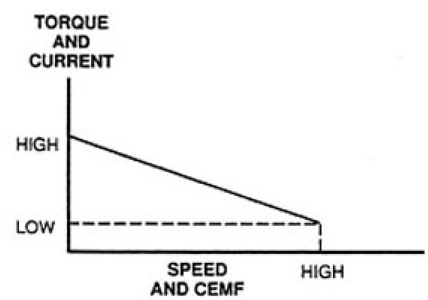


**Reduction Starters**

### Current Draw and Torque

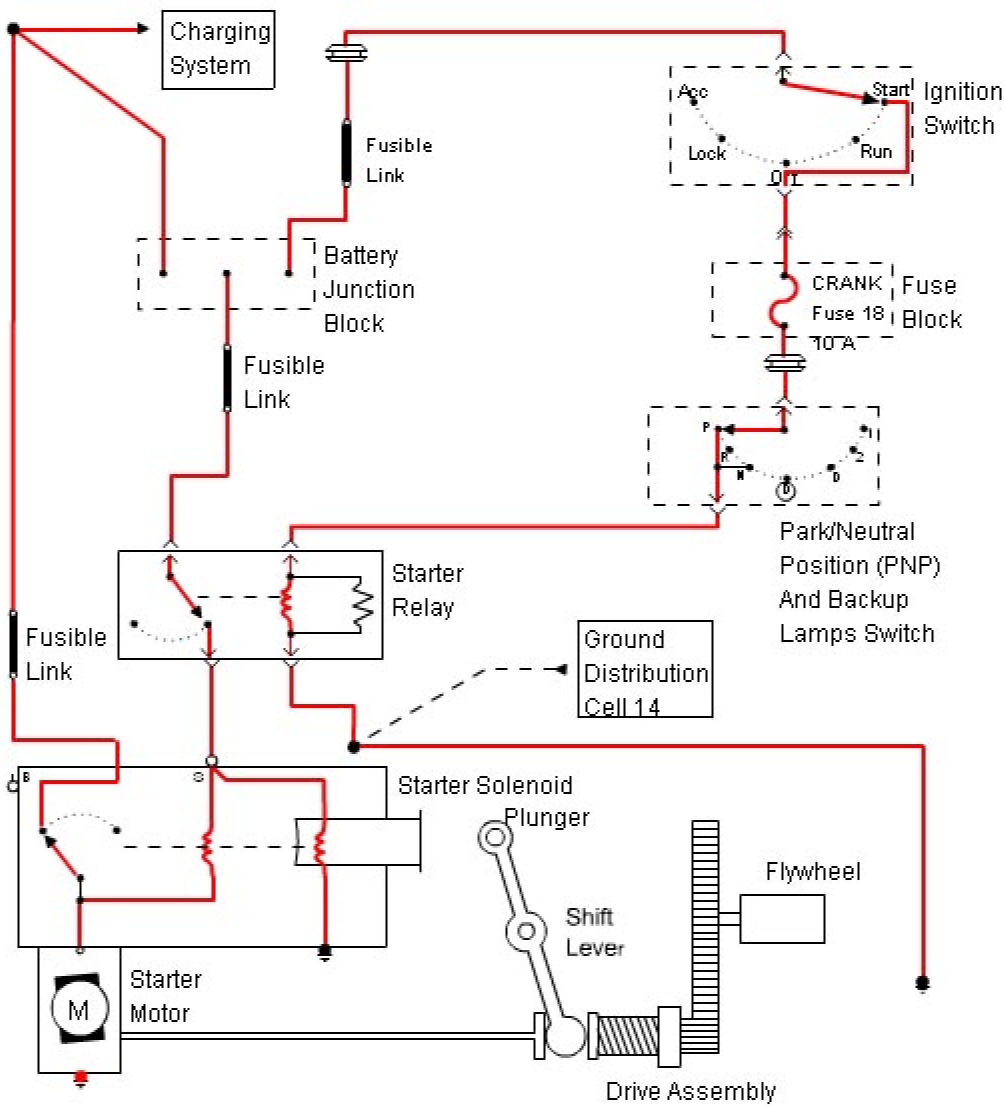
A direct relationship exists between the current draw of the starter motor and the torque it produces. Torque and current flow are both greatest when the armature is stalled. Electric motor stall occurs at that point when voltage has first been applied but the motor has not yet begun to turn.




## 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




**Starting Circuit (Energized)**

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

Attempting to crank the engine with the headlights or dome light on while observing what happens may quickly point you in the right direction. The chart on the following page 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. |
| | • Open in control in circuit | Check solenoid, switch, 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<br>• 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 cable clamp and terminal, tighten clamp. |
| 5. No cranking, no lights. | • Open circuit | Clean and tighten connections, replace wiring. |
| | • Discharged or malfunctioning battery | Recharge and test battery. |

**Headlights Quick Check**

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. |
| 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 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. |

**Common Starting Problems**

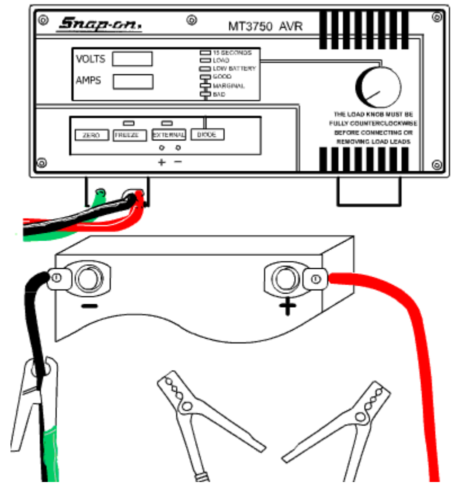
Some medium duty diesel applications are equipped with starter overcrank protection. These starter motors have a built-in thermostat that opens the circuit to the solenoid if the starter gets too hot. The thermostat closes the circuit when the starter cools. An open in the thermostat will cause a “no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

**Current Draw Testing**

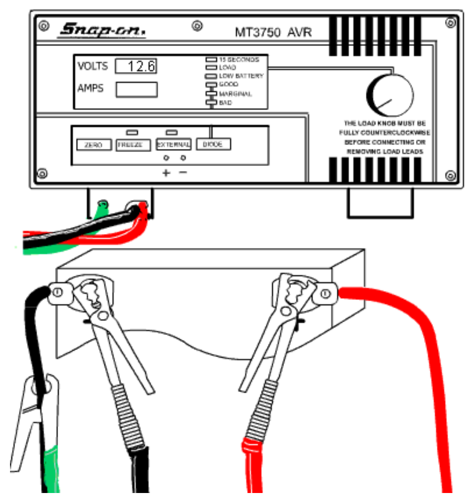
A starter current draw test can quickly tell you the condition of the starter motor and other system components. Current draw should not be higher or much lower than specifications.

To perform a current draw test:

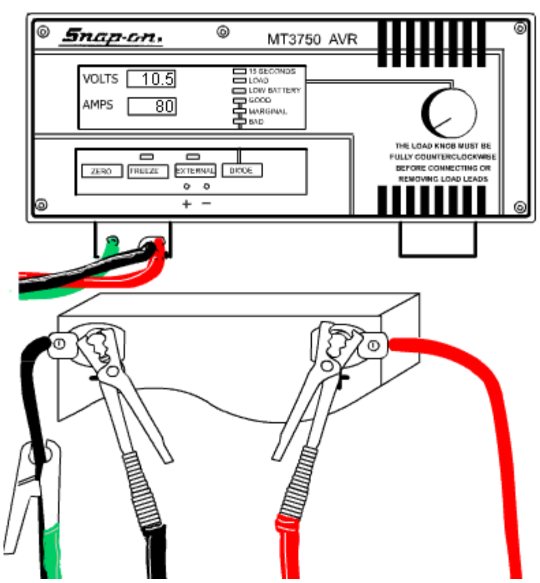
1. **Disable fuel delivery system** to prevent the engine from starting. Refer to the service manual to find the procedure for the application on which you are working.
2. **Connect an ammeter** in series between the negative battery terminal and cable end, or clamp the ammeter’s inductive pickup around 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.




3. **Connect a voltmeter** across the battery. Most starting and charging test machines read the voltage from the heavy test clamps. The voltmeter is used to make sure the battery and connections are not causing the problem. Voltage should not drop below the specified value, which is usually in the range of 9.5 to 10 volts during cranking.




4. **Crank the engine for about 10 seconds**, observing the voltage and amperage on the meter. Crank the engine long enough to allow the current to stabilize (current draw may be high at first). Compare the readings to the specifications.




Do not crank the engine for more than 30 seconds or the starter may overheat.

As a general rule, smaller, four or six cylinder engines will draw from 65 to 150 amps. Larger or high compression eight cylinder engines will draw from 130 to 250 amps. The trend in late model vehicles is toward lower current draw, so check the specs.

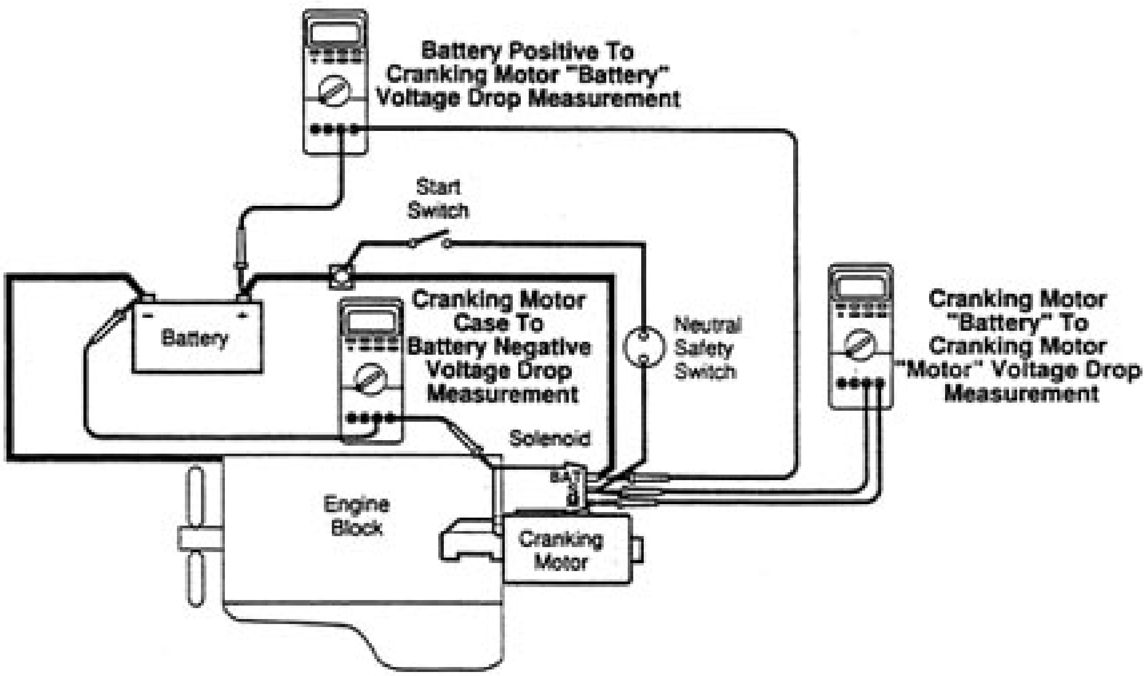
Recall from our discussion that current draw is highest when the motor is not turning. If something is preventing the starter from turning freely (starter "dragging" or engine mechanical problems) current draw will be quite high. This may be accompanied by heating of the battery cables and starter.

**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.

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

### 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

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.

### Abnormal Noises

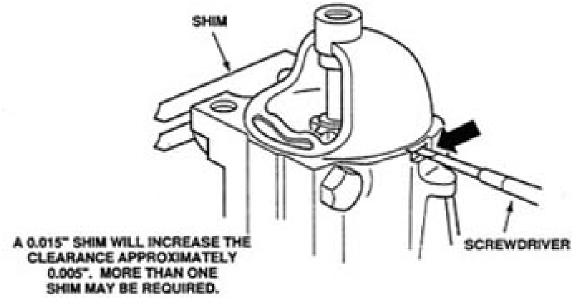
Some conditions may produce abnormal noises during or after cranking. Refer to the chart for symptoms and causes.

| 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. |

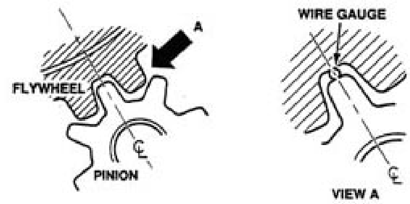
**Abnormal Noises**

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

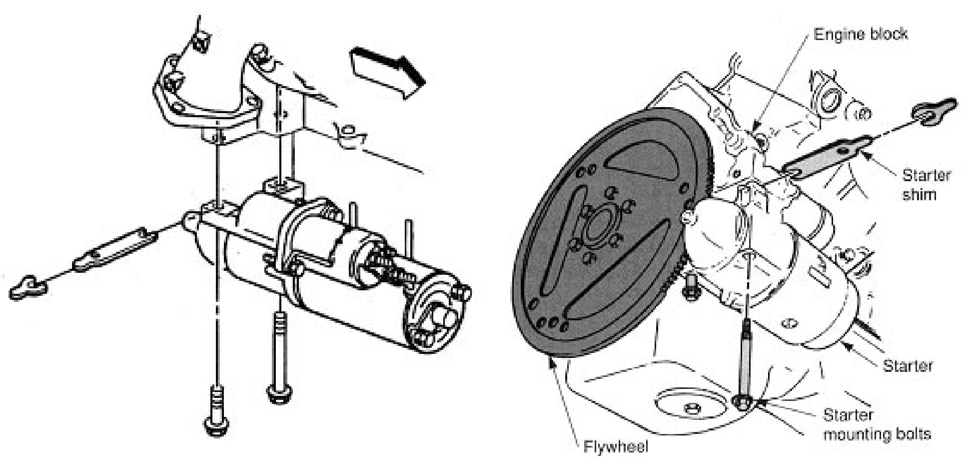


**carefully** touch the outside diameter of the rotating flywheel with chalk or a crayon.
- Turn off the engine and **disconnect the negative battery terminal** to prevent inadvertent cranking of the engine.
- **Rotate the flywheel** so that the marked teeth are in the cranking motor pinion gear area.
- **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).
- **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.




**Flywheel to Pinion Clearance**

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.

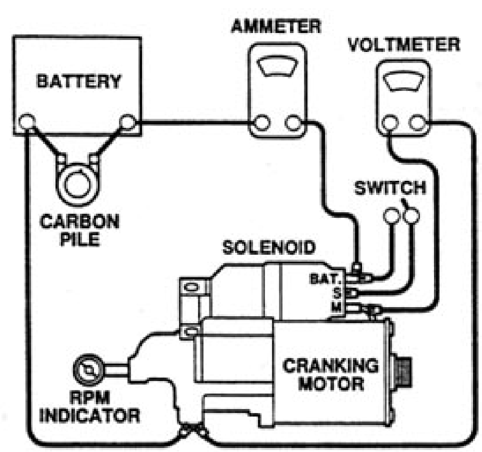



**Shim Placement**

**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.

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.

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.

## 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.

## Charging System

### Overview

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

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.

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

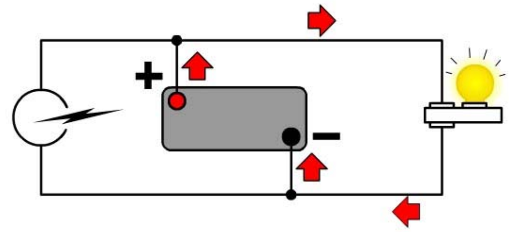
The increased output possible with newer AC generators compared to older DC generators is due to a fundamental difference in design. In a DC generator, the conductor windings (armature) rotate within a stationary magnetic field, but in an AC generator, the magnetic field rotates within a stationary conductor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

> Some AC generators now in use can produce up to 300 amps.

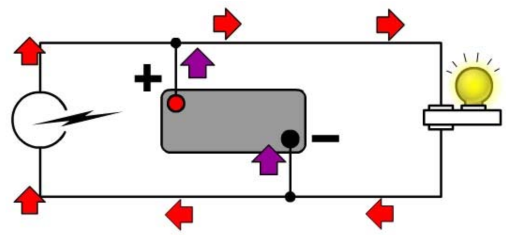
Modern AC generators are commonly called **alternators**, and today the terms "generator" and "alternator" are used interchangeably.

## Charging System Modes of Operation

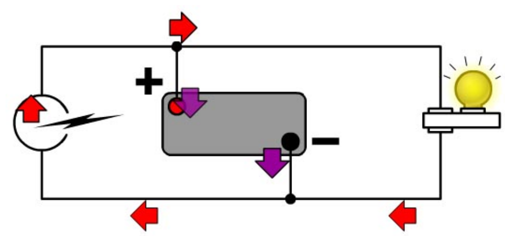
The illustration at right shows a typical battery, generator, and electrical load configuration. In this mode, the generator is not producing current and the battery is supplying all of the available current. This condition occurs when accessories are operating without the engine running, and or during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



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.



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:

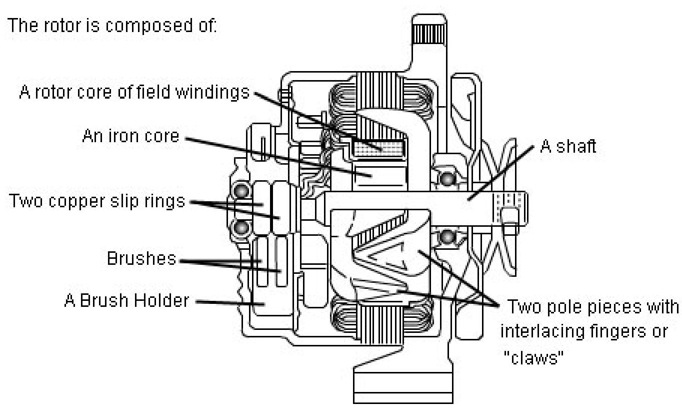
- Rotor and brushes
- Stator
- Diode bridge
- Voltage regulator

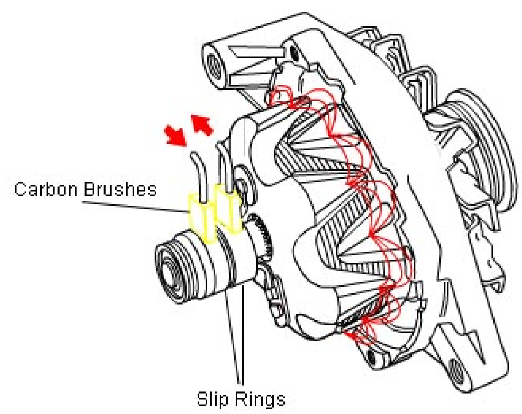
### Rotor and Brushes

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.

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.

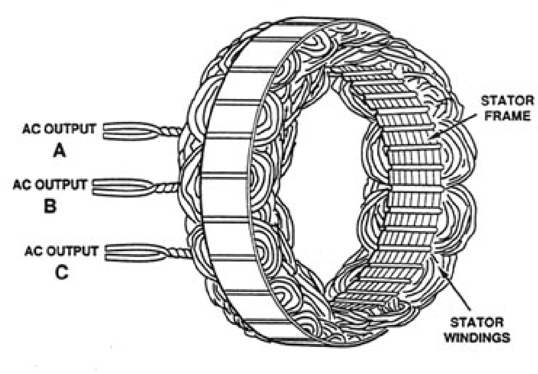
The brushes in an AC generator tend to be much smaller than brushes in starter motors since they carry only field current to the rotating field.



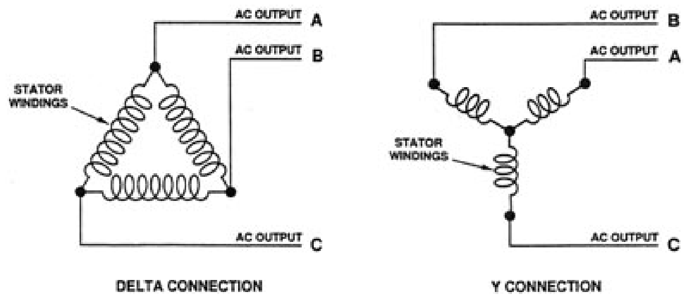

### Stator

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**

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.



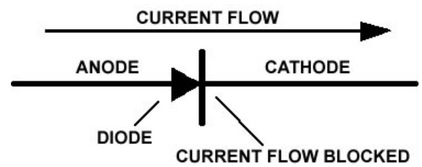

**Delta and Y Connections**

### Diodes and Diode Bridges

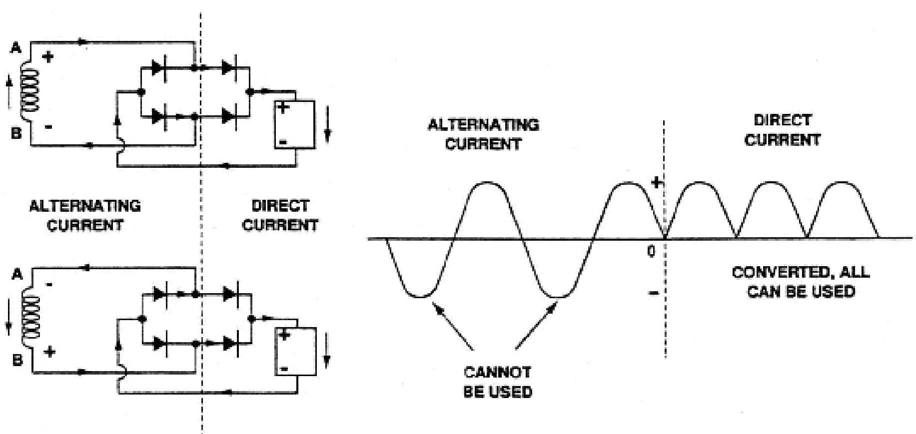
Automotive circuitry operates on direct current (DC), and generators produce alternating current (AC). As a result, we must convert the current from AC to DC before it can be used. To accomplish this we use a series of diodes, or rectifiers, to make the conversion.

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

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.

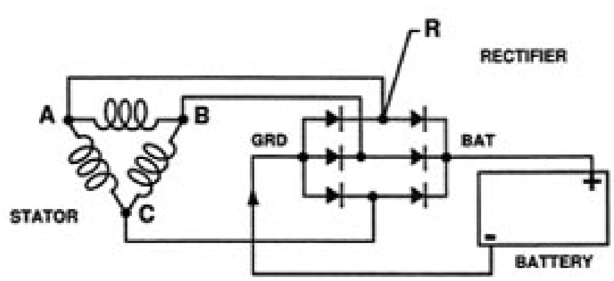



A rectifier bridge, also referred to as a full-wave rectifier, commonly consists of six diodes, which convert all of the AC voltage to DC. This illustration shows a four-diode bridge and its output waveform pattern.

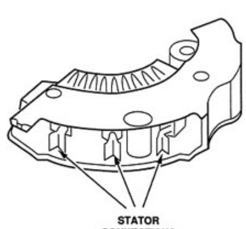



### Delta Stator and Six Diode Bridge

The diagram at right 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.

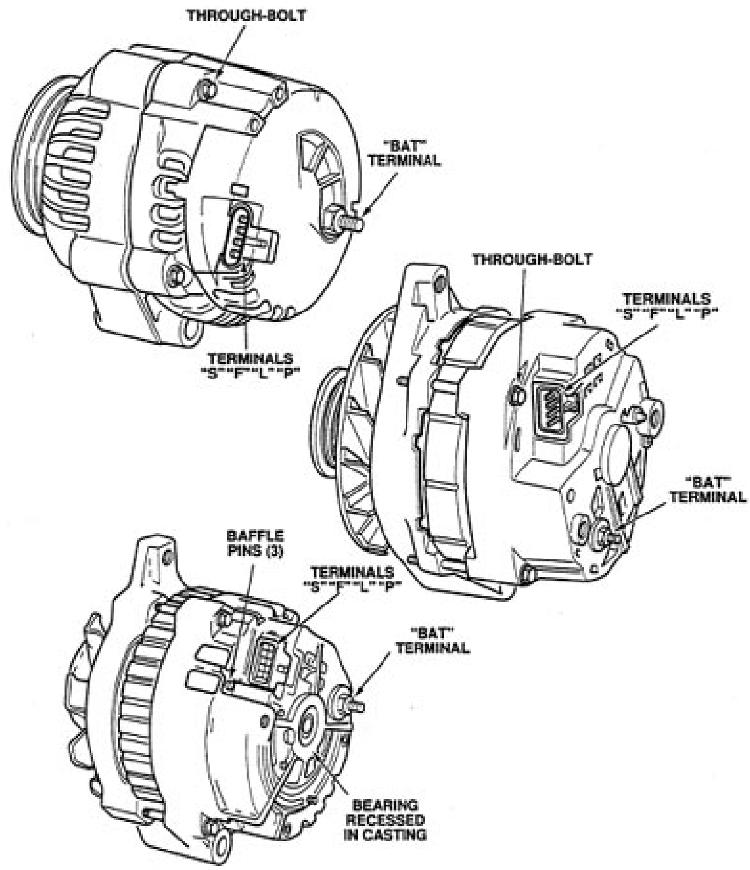



**Typical Diode Bridge**



### Voltage Regulator

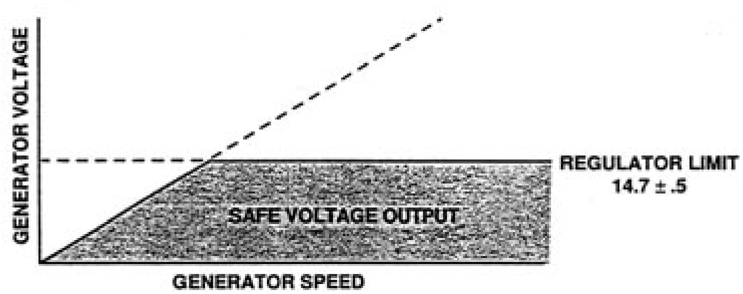
All alternators have a **voltage regulator**, and most are internally mounted as part of the unit. This illustration shows some typical alternators with internal regulators and with both internal and external cooling fans.




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

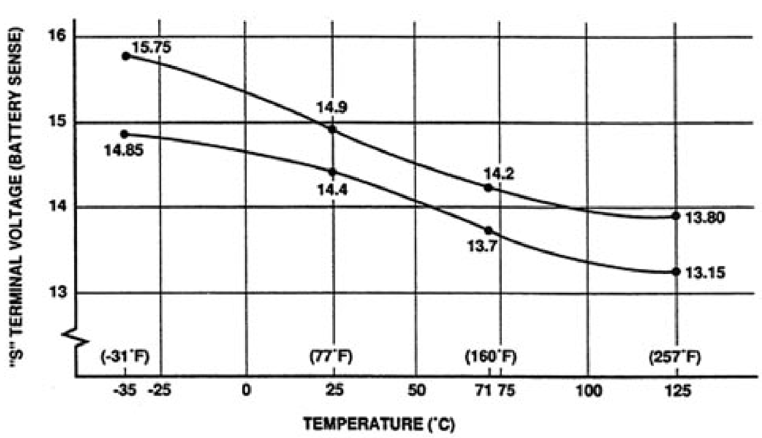
Voltage regulators limit generator output to a level approximately two volts higher than battery voltage. This higher voltage level provides the "push" necessary to force current through the battery, recharging it (when the engine is running at a sufficient speed and without excessive electrical loads).

As shown in this illustration, system voltage must be kept to a safe level (14.7 V ±.5) to prevent damage to electrical components.

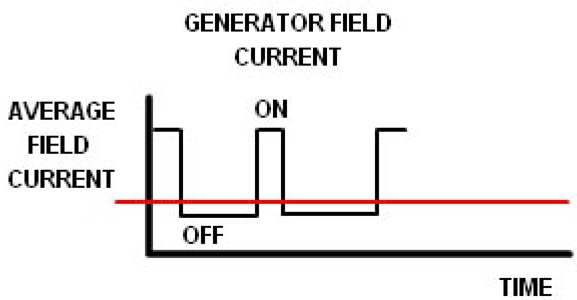


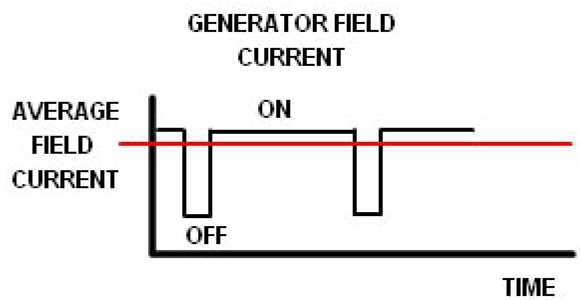

### Voltage Limiting

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.



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. 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.



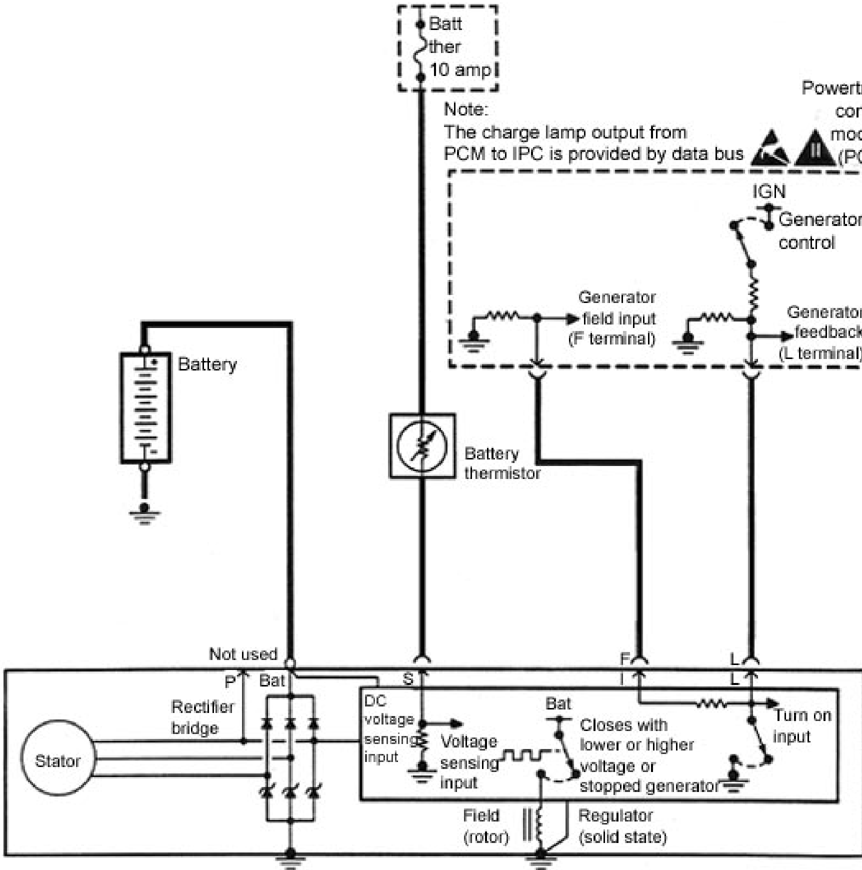




> High electrical demands can cause the actual system voltage to be less than the regulator setting.

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.

**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.

The following 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**

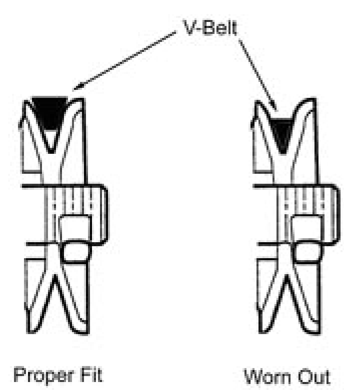
## Charging System Diagnosis and Service

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**

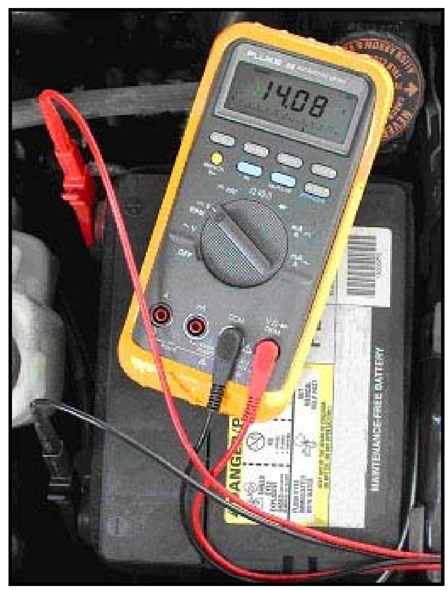
One method of checking for slippage is to firmly grasp the generator by the fan blades or pulley and attempt to rotate it. If the pulley can be rotated by hand, excessive slippage is present and must be corrected. Do **not** overtighten a worn-out or oily belt as this can ruin the bearings in the alternator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

**This system uses a flat, serpentine belt with a self-tensioner. A spring inside the unit applies the proper tension to the belt.**

**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.

**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.

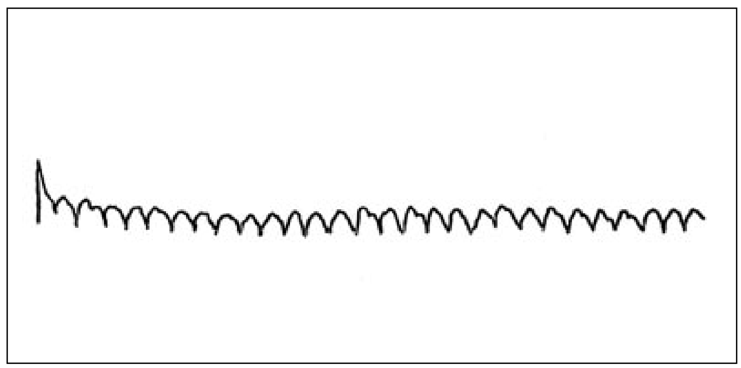
Never short or ground any charging system terminal unless instructed to do so by the service manual. Never remove the battery from the circuit with the engine running!

**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.

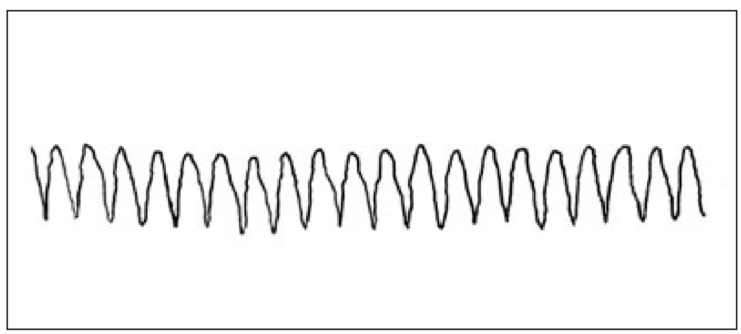
**Scan Tools: The model on the right is a digital oscilloscope**

**Waveforms:**

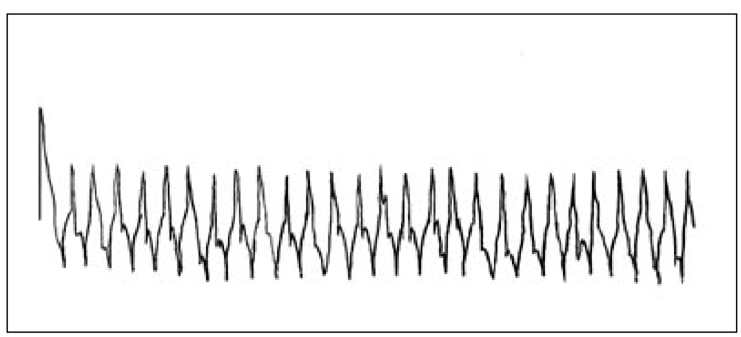
**Normal**
This is a typical normal output waveform. The alternator is charging correctly.



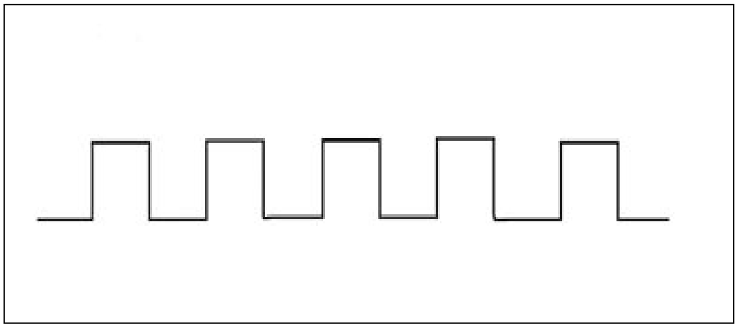
**Waveforms Under Heavy Load**
This waveform is also normal, but indicates the alternator is under a heavy load.



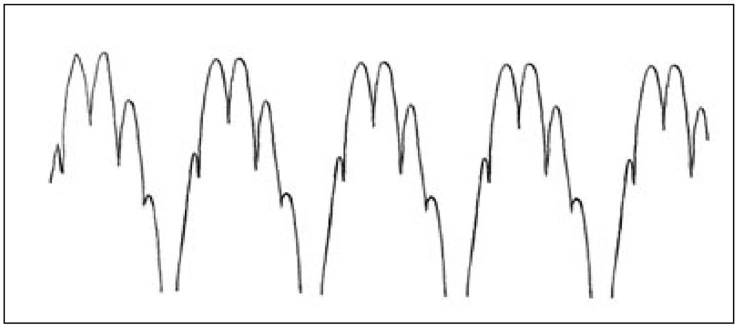
**Waveform with inductive spikes**
This pattern is seen with some charging systems that use electronic regulators and duty cycles. The higher inductive spike is normal on these systems.



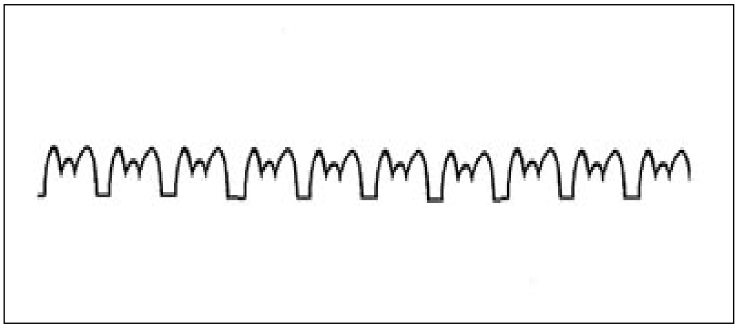
**Duty-cycle waveform to field windings**
This pattern shows a duty cycle from a control module to the field windings.



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



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



**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.

Alternator current output should be within approximately 20 percent of its rated capacity.

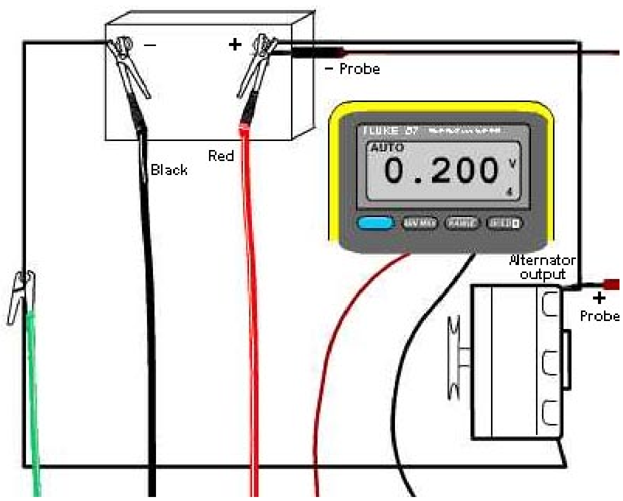
- Press the DIODE key (or rotate the tester's function selector knob to the diode/stator test) and observe the reading.

### Circuit Resistance Tests

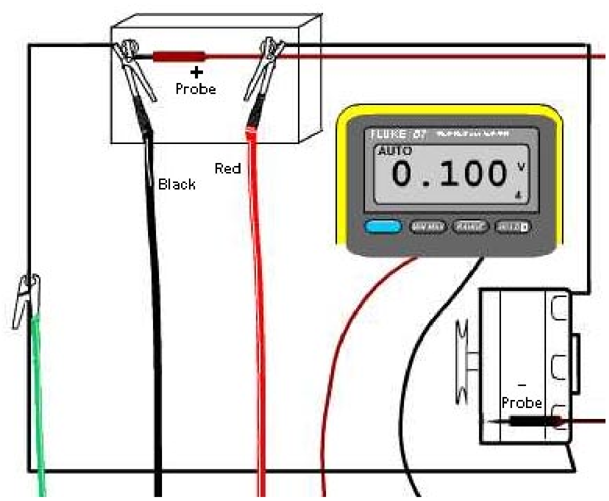
If you suspect poor test results are due to circuit problems, rather than the alternator/regulator, circuit resistance tests can pinpoint problems in the wiring. These are voltage drop tests similar to the starting system tests described in the Starting Systems section. To perform a circuit resistance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

- Connect the load clamps to the battery, then 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.

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.




**Positive Side**




**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.

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