Figure 48-1  N-type material. Silicon (Si) doped with a material (such as phosphorus) with five electrons in the outer shell results in an extra free electron.

Figure 48-2  P-type material. Silicon (Si) doped with a material, such as boron (B), with three electrons in the outer shell results in a hole capable of attracting an electron.
Figure 48-3  Unlike charges attract and the current carriers (electrons and holes) move toward the junction.

HOLES  P  N  FREE ELECTRONS

NEGATIVE CHARGES  JUNCTION  POSITIVE CHARGES

Figure 48-4  A diode is a component with P-type and N-type materials together. The negative electrode is called the cathode and the positive electrode is called the anode.

(+) ANODE  DIODE  CATHODE (−)

FREQUENTLY ASKED QUESTION:

What Are Logic Highs and Lows?

All computer circuits and most electronic circuits (such as gates) use various combinations of high and low voltages. High voltages are typically those above 5 volts, and low is generally considered zero (ground). However, high voltages do not have to begin at 5 volts. High, or the number 1, to a computer is the presence of voltage above a certain level. For example, a circuit could be constructed where any voltage higher than 3.8 volts would be considered high. Low, or the number 0, to a computer is the absence of voltage or a voltage lower than a certain value. For example, a voltage of 0.62 may be considered low. Various associated names and terms can be summarized.

- Logic low = Low voltage = Number 0 = Reference low
- Logic high = Higher voltage = Number 1 = Reference high
Figure 48-5  Diode connected to a battery with correct polarity (battery positive to P-type and battery negative to N-type). Current flows through the diode. This condition is called forward bias.

Figure 48-6  Diode connected with reversed polarity. No current flows across the junction between the P-type and N-type materials. This connection is called reverse bias.

Figure 48-7  Diode symbol and electrode names. The stripe on one end of a diode represents the cathode end of the diode.
FREQUENTLY ASKED QUESTION

What Is the Difference Between Electricity and Electronics?
Electronics usually means that solid-state devices are used in the electrical circuits. Electricity as used in automotive applications usually means electrical current flow through resistance and loads without the use of diodes, transistors, or other electronic devices.

TECH TIP: Burn In to Be Sure
A term commonly heard in the electronic and computer industry is burn in, which means to operate an electronic device, such as a computer, for a period from several hours to several days. Burn in helps to determine the capability and effectiveness of the device. It may be due to the heat of running the device or due to the device being exposed to a high current or voltage. Burn in is a common practice in the electronic and computer industry. This practice helps to determine the effectiveness of the device and to identify any potential issues.

Most electronic devices fail in infancy, or during the first few hours of operation. This early failure occurs if there is a manufacturing defect, especially at the P-N junction of any semiconductor device. The junction will usually fail after only a few operating cycles.
(a) Notice that when the coil is being energized, the diode is reverse biased and the current is blocked from passing through the diode. The current flows through the coil in the normal direction. (b) When the switch is opened, the magnetic field surrounding the coil collapses, producing a high-voltage surge in the reverse polarity of the applied voltage. This voltage surge forward biases the diode, and the surge is dissipated harmlessly back through the windings of the coil.

Figure 48-10 A diode connected to both terminals of the air conditioning compressor clutch used to reduce the high-voltage spike that results when a coil (compressor clutch coil) is de-energized.

Figure 48-11 Spike protection diodes are commonly used in computer-controlled circuits to prevent damaging high-voltage surges that occur any time current flowing through a coil is stopped.
A zener diode is commonly used inside automotive computers to protect delicate electronic circuits from high-voltage spikes. A 35-volt zener diode will conduct any voltage spike higher than 35 volts, reducing the discharge of the fuel injector coil safely into ground through a current-limiting resistor in series with the zener diode.

A despiking resistor is used in many automotive applications to help prevent harmful high-voltage surges from being created when the magnetic field surrounding a coil collapses when the coil circuit is opened.

A typical light-emitting diode (LED). This particular LED is designed with a built-in resistor so that 12 volts DC may be applied directly to the leads without an external resistor. Normally a 330 to 680 ohms, 0.5-watt resistor is required to be attached in series with the LED, to control current flow to about 0.020 A (20 mA) or damage to the P-N junction may occur.
FREQUENTLY ASKED QUESTION: How Does an LED Emit Light?

An LED contains a chip that houses P-type and N-type materials. The junction between these regions acts as a barrier to the flow of electrons between the two materials. When a voltage of 1.5 to 2.2 volts of the correct polarity is applied, current will flow across the junction. As the electrons enter the P-type material, they combine with the holes in the material and release energy in the form of light (called photons). The amount and color the light produces depend on materials used in the creation of the semiconductor material.

LEDs are very efficient compared to conventional incandescent bulbs, which depend on heat to create light. LEDs generate very little heat, with most of the energy consumed converted directly to light. LEDs are reliable and are being used for taillights, brake lights, daytime running lights, and headlights in some vehicles.
Figure 48-17  Either symbol may be used to represent a photoresistor.

Figure 48-18  Symbol and terminal identification of an SCR.

Figure 48-19  Wiring diagram for a center high-mounted stoplight (CHMSL) using SCRs.
Figure 48-20 Symbols used to represent a thermistor.

Chart 48-1 The resistance changes opposite that of a copper wire with changes in temperature.

<table>
<thead>
<tr>
<th>COPPER WIRE</th>
<th>NTC THERMISTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold</td>
<td>Lower resistance Higher resistance</td>
</tr>
<tr>
<td>Hot</td>
<td>Higher resistance Lower resistance</td>
</tr>
</tbody>
</table>

Chart 48-1

Figure 48-21 This rectifier bridge contains six diodes; the three on each side are mounted in an aluminum-finned unit to help keep the diodes cool during alternator operation.
Figure 48-22 Basic transistor operation. A small current flowing through the base and emitter of the transistor turns on the transistor and permits a higher amperage current to flow from the collector and the emitter.

FREQUENTLY ASKED QUESTION

Is a Transistor Similar to a Relay?
Yes, in many cases a transistor is similar to a relay. Both use a low current to control a higher current circuit. ▶ SEE CHART 48-2.

A relay can only be on or off. A transistor can provide a variable output if the base is supplied a variable current input.

Chart 48-2 Comparison between the control (low-current) and high-current circuits of a transistor compared to a mechanical relay.

<table>
<thead>
<tr>
<th>RELAY</th>
<th>TRANSISTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-current circuit 85 and 86</td>
<td>Base and emitter</td>
</tr>
<tr>
<td>High-current circuit Contacts terminals 30 and 87</td>
<td>Collector and emitter</td>
</tr>
</tbody>
</table>

CHART 48-2
FREQUENTLY ASKED QUESTION

What Does the Arrow Mean on a Transistor Symbol?
The arrow on a transistor symbol is always on the emitter and points toward the N-type material. The arrow on a diode also points toward the N-type material. To know which type of transistor is being shown, note which direction the arrow points:
- PNP: pointing in
- NPN: not pointing in

Figure 48-23 Basic transistor operation. A small current flowing through the base and emitter of the transistor causes the transistor to turn on and permits a higher amperage current to flow from the collector and the emitter.

Figure 48-24 The three terminals of a field-effect transistor (FET) are called the source, gate, and drain.
FREQUENTLY ASKED QUESTION
What Is a Darlington Pair?
A Darlington pair consists of two transistors wired together. This arrangement permits a very small current flow to control a large current flow. The Darlington pair is named for Sidney Darlington, an American physicist for Bell Laboratories from 1929 to 1971. Darlington amplifier circuits are commonly used in electronic ignition systems, computer engine control circuits, and many other electronic applications. See Figure 48–25.

Figure 48–25 A Darlington pair consists of two transistors wired together, allowing for a very small current to control a larger current flow circuit.

Figure 48–26 Symbols for a phototransistor. (a) This symbol uses the line for the base; (b) this symbol uses red.
Figure 48-27  A typical automotive computer with the case removed to show all of the various electronic components and integrated circuits (ICs). The CPU is an example of a DIP chip, and the large red and orange devices are ceramic capacitors.

Figure 48-28  Typical transistor AND gate circuit using two transistors. The emitter is always the line with the arrow. Notice that both transistors must be turned on before there will be voltage present at the point labeled “signal out.”

**FREQUENTLY ASKED QUESTION**

What Causes a Transistor or Diode to Blow?

Every automotive diode and transistor is designed to operate within certain voltage and amperage ranges for individual applications. For example, transistors used for switching are designed and constructed differently than transistors used for amplifying signals.

Because each electronic component is designed to operate satisfactorily for its particular application, any severe change in operating current (amperes), voltage, or heat can destroy the junction. This failure can cause either an open circuit (no current flows) or a short (current flows through the component all the time when the component should be blocking the current flow).
FREQUENTLY ASKED QUESTION: What Are Logic Highs and Lows?

All computer circuits and most electronic circuits (such as gates) use various combinations of high and low voltages. High voltages are typically those above 5 volts, and low is generally considered zero (ground). However, high voltages do not have to begin at 5 volts. To a computer, the presence of voltage above a certain level is high. For example, it is possible to construct a circuit where any voltage higher than 3.8 volts would be considered high. Low is the absence of voltage or a voltage lower than a certain value. For example, a voltage of 0.62 may be considered low. Various names and terms can be summarized:

- Logic low = Low voltage = Number 0 = Reference low
- Logic high = Higher voltage = Number 1 = Reference high

TECH TIP: Blinking LED Theft Deterrent

A blinking (flashing) LED consumes only about 5 milliamperes (0.005 ampere or 0.005 A). Most alarm systems use a blinking red LED to indicate that the system is armed. A fake alarm indicator is easy to install. A 470 ohm, 0.5 watt resistor limits current flow to prevent battery drain. The positive terminal (anode) of the diode is connected to a fuse that is hot at all times, such as the cigarette lighter. The negative terminal (cathode) of the LED is connected to any ignition-controlled fuse.

When the ignition is turned off, the power flows through the LED to ground and the LED flashes. To prevent distraction during driving, the LED goes out when the ignition is on. Therefore, this fake theft deterrent is auto setting and no other action is required to activate it when you leave your vehicle except to turn off the ignition and remove the key, as usual.
Figure 48-30  Schematic for a blinking LED theft deterrent.

Figure 48-31  To check a diode, select “diode check” on a digital multimeter. The display will indicate the voltage drop (difference) between the meter leads. The meter itself applies a low-voltage signal (usually about 3 volts) and displays the difference on the display. (a) When the diode is forward biased, the meter should display a voltage between 0.500 and 0.700 V (500 to 700 mV). (b) When the meter leads are reversed, the meter should read OL (over limit) because the diode is reverse biased and blocking current flow.

Figure 48-32  To check a diode using a multimeter set to diode check, the meter should display a low resistance if the red lead is connected to the center and the black lead is connected to either end of the diode. If the meter reads high resistance, reverse the meter leads, putting the black lead on the center lead and the red lead on either end. If the meter indicates low resistance, the diode is a good PNP type. Check all P-N junctions in the same way.
A DC to DC converter is built into most powertrain control modules (PCMs) and is used to create the 5 volt reference called V-ref to many sensors used to control the internal combustion engine.

This DC-DC converter is designed to convert 42 volts to 14 volts, to provide 14 V power to accessories on a hybrid electric vehicle operating with a 42 volt electrical system.

A typical circuit for an inverter designed to change direct current from a battery to alternating current for use by the electric motors used in a hybrid electric vehicle.
WARNING: Always follow the manufacturer's safety precautions for discharging capacitors in DC-DC converter circuits.

Figure 48-36 The switching (pulsing) MOSFETs create a waveform called a modified sine wave (solid lines) compared to a true sine wave (dotted lines).

WARNING: Do not touch the terminals of a battery that are being used to power an inverter. There is always a risk that those battery terminals could deliver a much greater shock than from batteries alone, if a motor or inverter should develop a fault.