

## SEMICONDUCTORS

One of the basic building blocks of all modern electronic devices is the semiconductor. Semiconductors can conduct or block electrical current. Because of this ability, semiconductors serve an important function in everything from relays to the integrated circuits of computers.

This chapter examines diodes as well as some of the other components used to construct electronic devices, such as capacitors and resistors. Diodes allow current to flow through them in only one direction and are used in a variety of ways, including suppression of voltage spikes ("de-spiking") and converting alternating current to direct current in an alternator.

Capacitors store electrical charges and are used for electrical noise and voltage spike suppression. Capacitors are also used in timer circuits to delay turning on or off a device or system.

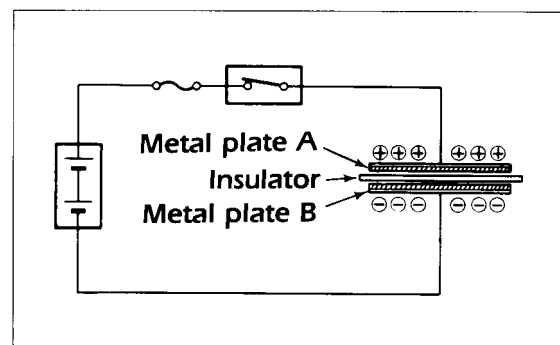
This chapter will examine each of the following areas:

- Capacitors*
- Current Flow Theory*
- Semiconductor Theory*
- Diodes*

## CAPACITORS

Capacitors have the ability to absorb and store an electrical charge and then release it into the circuit. Capacitors are frequently used in timers which will keep a circuit or device in operation for a period of time after the circuit has been shut off. An example of this is a dome light circuit that stays on for a specified length of time after the door has been closed.

A capacitor is constructed from two conducting plates separated by an insulating material called a dielectric. This insulating material can be paper, plastic, film mica, glass, ceramic, air or a vacuum. The plates can be aluminum discs, aluminum foil or a thin film of metal applied to opposite sides of a solid dielectric. These layered materials are either rolled into a cylinder or left flat.

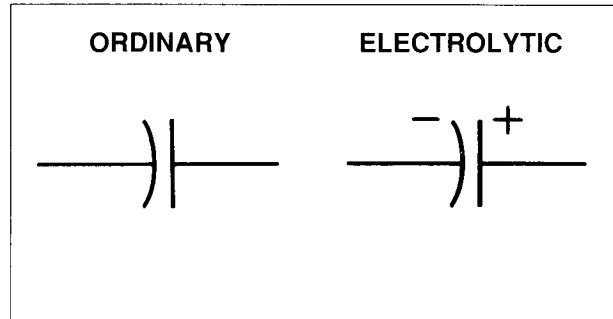
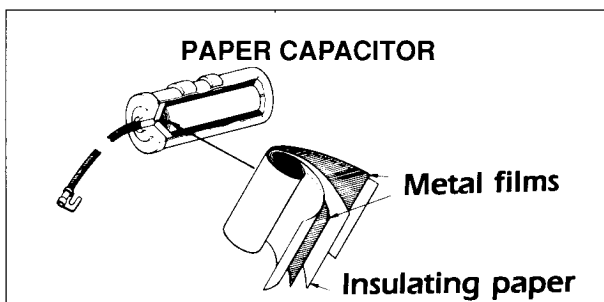
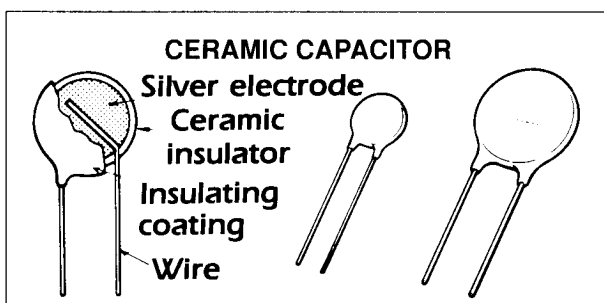
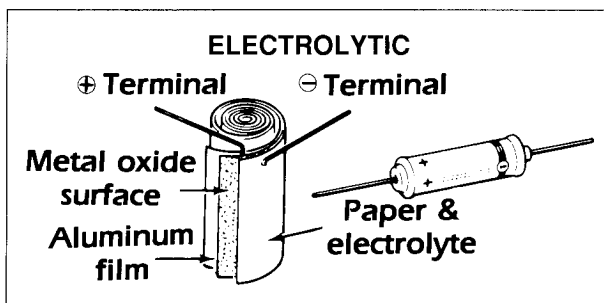


The operation of a capacitor is relatively simple. When the capacitor is placed in a circuit, a charge builds on the plates until the plates are at the same potential as the power source. When the source potential is removed, the capacitor will discharge and cause a current to flow in the circuit. If the potential of the source changes, the capacitor will either charge or discharge to match the source, thereby smoothing voltage fluctuations in the circuit.

Since current can flow into a capacitor only until the charge reaches the potential of the source, a capacitor will block current in a DC circuit. AC currents are not blocked by a capacitor because the polarity of the AC circuit is continually changing.

The unit of measure of capacitance is the "farad." Most capacitors are much less than one farad, and are rated in microfarads or picofarads. When capacitors are connected in series their total capacitance is reduced, like resistors connected in parallel. When capacitors are connected in parallel their total capacitance increases, like total resistance when resistors are connected in series.

There are three types of capacitors: ceramic for electronic circuits, paper and foil for noise suppression in charging and ignition systems, and electrolytic as used in turn signal flashers. Ordinary and electrolytic capacitors are designated by different symbols in wiring diagrams.



As stated, capacitors have three uses:

**Noise suppression**—Noise in an audio system is often caused by AC electrical voltage riding on top of the DC voltage supplying power to a radio or tape player. A capacitor connected to the circuit will filter out the AC voltage by allowing it to pass to ground. Most alternators on Toyota vehicles have a capacitor built in for this purpose.

**Spike suppression**—A capacitor can absorb voltage spikes in a circuit. This application has been used in conventional ignition systems to prevent an arc from jumping the breaker points when they are opened.

**Timers**—A resistor put in series with a capacitor can keep current flowing in a circuit for a specified amount of time after power from the source has been removed. This can be used to keep dome lights on after the vehicle doors are closed. The resistor-capacitor or RC circuit in the example above is used to keep a transistor turned on, so the transistor allows current to remain flowing to the system.

## CURRENT FLOW THEORY

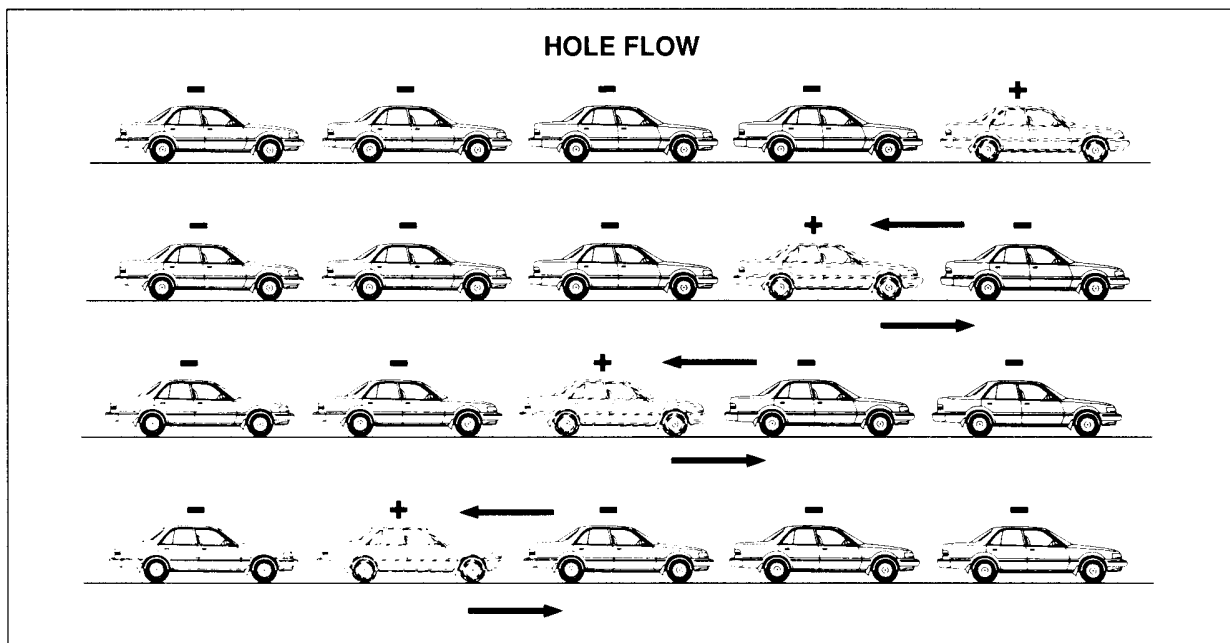
Before we discuss semiconductors and how they operate, it is important to understand current flow theory. There are two different theories of how current flows: electron current flow and conventional current flow (sometimes referred to as "hole flow").

The electron current flow theory says that current flow in a circuit is the movement of electrons through the conductors. Since the electrons have a negative charge and unlike charges attract each other, the electrons move from the negative terminal of the battery to the positive terminal. So the electron theory says that current flows from negative to positive.

The conventional current flow theory, which has been accepted for many years, says that current flows from the positive terminal of the battery to the negative terminal. The conventional current flow theory is sometimes called the hole flow theory because this theory says that when an electron moves, an empty hole is left

behind. The holes are said to travel in the opposite direction from the electrons in the conductor. To understand how this could work think of a line of cars stopped at a stop sign. As one car pulls away from the stop sign a hole is left and the next car in line moves forward to fill the hole. Now the hole has moved back to where the second car was and the third car moves forward to fill it. As each car in turn moves forward to fill the hole, the hole moves to the rear. The cars move one direction and the holes move the other, just like electrons and holes in a circuit.

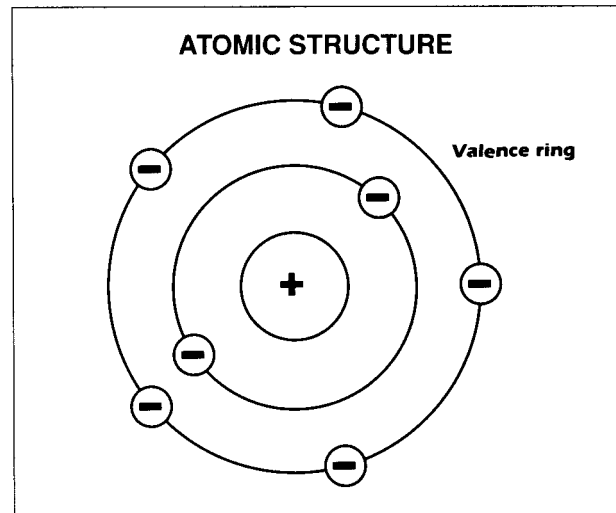
When looking at an electrical circuit, either the electron current flow theory or conventional current flow theory can be applied because the circuit operation and the schematic will be the same. When dealing with diagrams that use electronic symbols, such as diodes and transistors, the arrow in the symbol always points in the direction of conventional current flow. Because the conventional current flow theory is widely accepted in the automotive industry, it is used throughout this book.



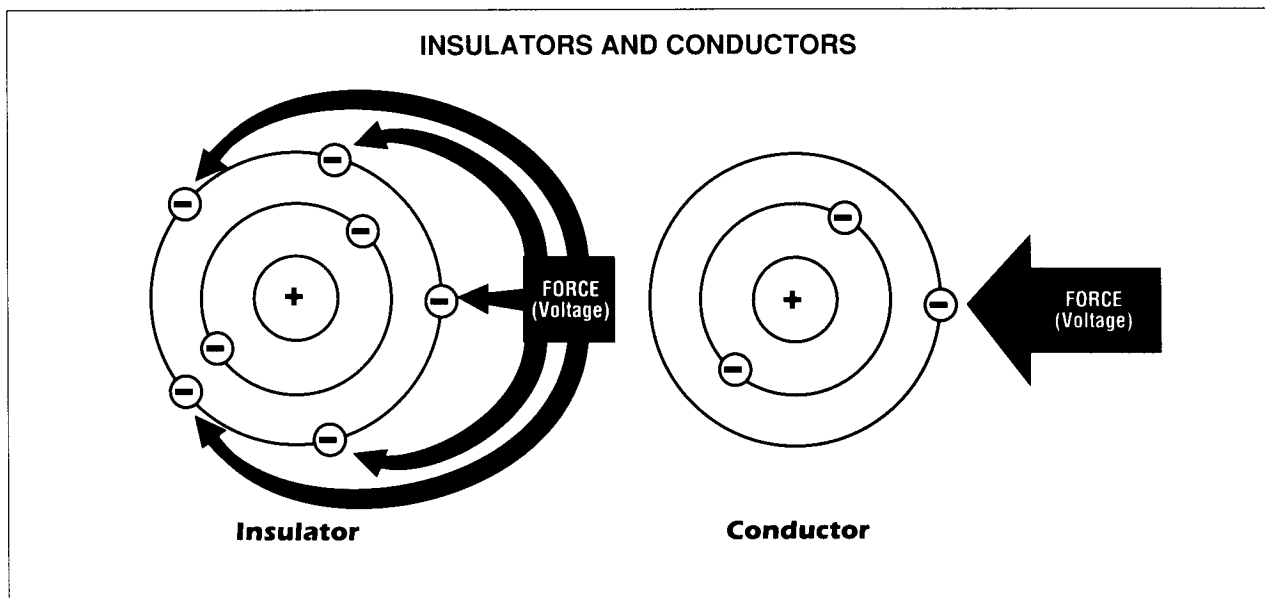
## BASIC THEORY OF SEMICONDUCTOR OPERATION

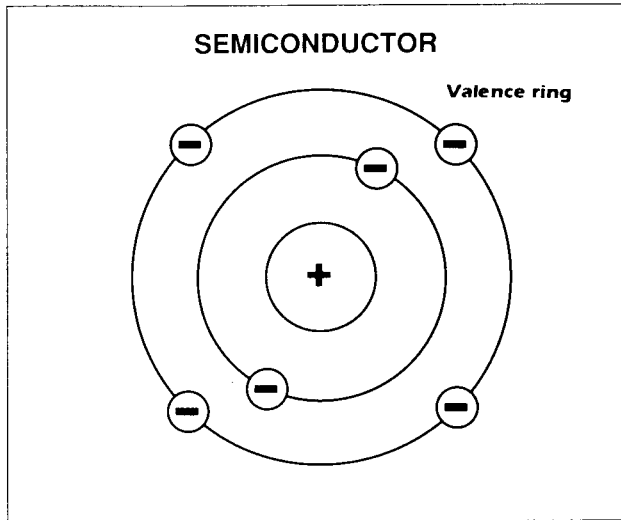
Semiconductors are important to understand because they play such a prominent part in automotive electronics. You will deal with them nearly every time you diagnose a Toyota electronic system.

Some materials conduct electrical current better than others. This is due to the number of electrons in the outermost ring, or shell, of electrons of the atoms that make up the materials. The outer shell is called the "valence shell" or "ring." If the valence ring has five to eight electrons, it takes a large amount of force to cause one of the electrons to break free from the atom, making that material a poor conductor. Such materials are often used as insulators to block current. materials that are made up of atoms with one to three electrons in their valence ring are good conductors because a small force will cause the electrons to break free. Semiconductors fall somewhere in the middle. Since they have four electrons in their valence rings, they are not good insulators or conductors.



Semiconductors are usually made from germanium or silicon which, in their natural states, are pure crystals. Neither have enough free electrons to support significant current flow, but by adding atoms from other materials—a process called doping—the crystals will conduct electricity in a way that is useful in electronic circuits. The semiconductor material, after it has been doped, becomes either N-type material or P-type material.

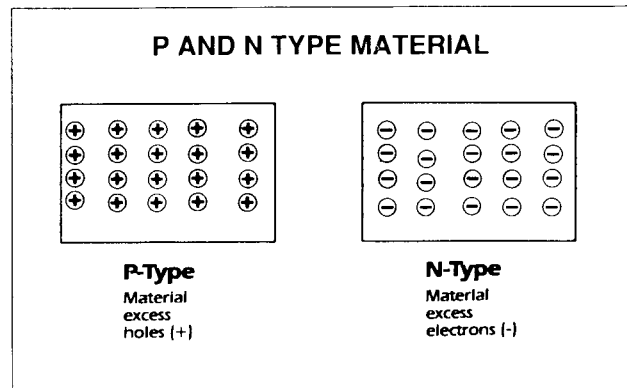




Silicon is the most commonly used semiconductor material. The outer shell of a silicon atom contains four electrons, but it needs eight to be stable. Therefore, the atoms link together to share electrons. In this state, silicon will not conduct current.

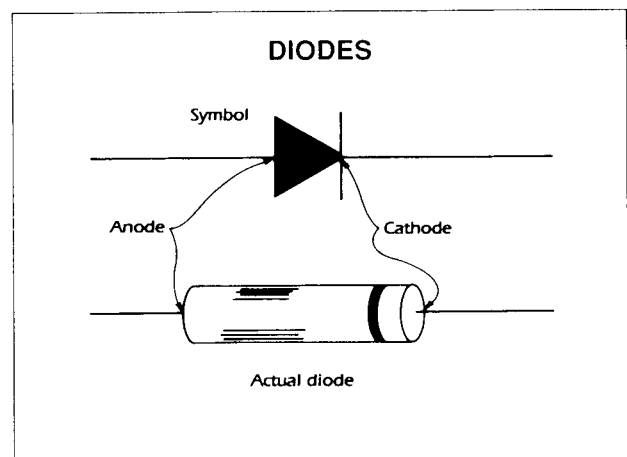
When silicon is doped with a material such as phosphorous, which has five electrons, the resultant material contains free electrons—known as carriers—and therefore conducts electricity. This creates N-type material, named for its negative charge caused by the excess of electrons.

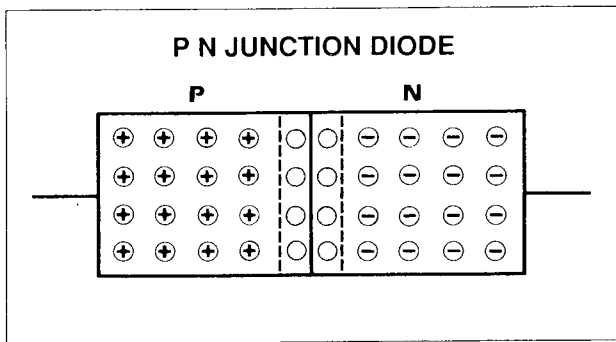
Silicon can also be doped with a material that has fewer than four electrons in its outer shells, as is the case with boron and its three electrons. The resultant structure has "holes" left by the missing electrons. As discussed earlier, an electron can move into these holes and, in effect, the hole moves in the opposite direction. The abundance of holes creates P-type material, named for its positive charge due the lack of electrons or excess of holes. By joining this N-type and P-type material, diodes and transistors can be formed.



## DIODES

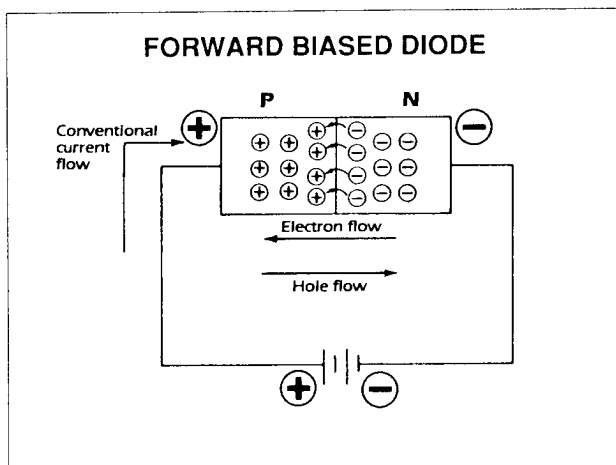
Diodes block current flow in one direction and pass current in the opposite direction. This is accomplished by joining a layer of P type material and a layer of N-type material during manufacturing. Where they meet is called the PN junction. At the PN junction, some of the electrons of the N-type material move into some of the holes in the P-type material and create a neutral area at the junction. Another way of thinking of this is that the positive holes attract the negative electrons leaving no free electrons, so current is unable to flow past that point. This neutral area acts as a barrier, which is called the depletion region.





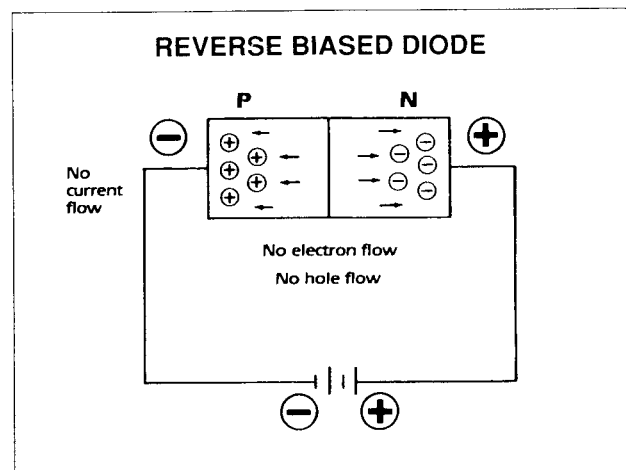
The depletion region is very thin and responds rapidly to voltage changes. It is here that current is either allowed to pass or is blocked.

When the diode is connected in a circuit where the N-type material is connected to the negative terminal of the battery and the P-type material is connected to the positive terminal, the excess electrons in the N-type material are repelled by the negative potential of the battery. At the same time, the positively charged holes in the P-type material are repelled by the positive potential of the battery, resulting in a concentration of holes and electrons at the depletion region. When voltage applied to the diode is great enough (.5 to .7 volts) electrons in the N type material will move across the depletion



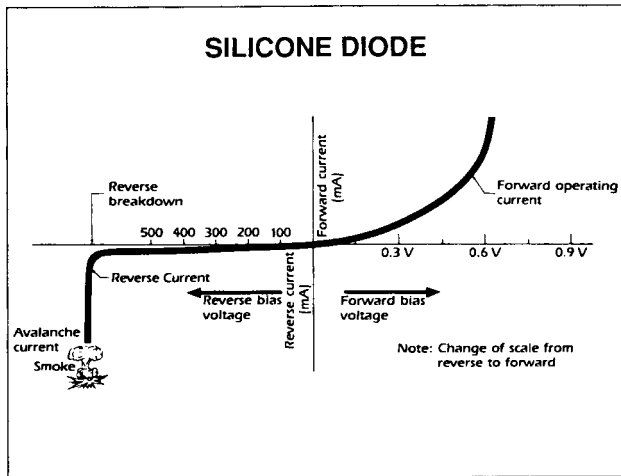
region at the junction, filling holes in the P-type material and leaving holes in the N-type material. Electrons move through the diode to the positive terminal of the battery and holes move through the diode to the negative terminal of the battery. When this happens the diode conducts current and is said to be forward biased.

If the connection of the diode in the circuit is reversed, with the N-type material connected to the positive terminal of the battery and the P-type material connected to the negative terminal, the diode is reverse



biased. In this case, the electrons in the N-type material are attracted to the positive terminal of the battery and the holes in the P-type material are attracted to the negative terminal of the battery. This results in an increase in the depletion region or neutral zone so no current can flow through the diode. Whether the diode conducts or blocks current flow is determined by the voltage polarity applied to it.

If the reverse bias voltage applied to a diode is great enough, the voltage can overcome the depletion region at the junction and the diode will conduct for a short period before burning open. When this happens the diode is destroyed.

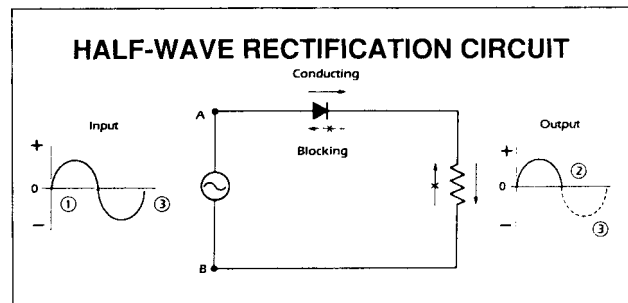


The three main uses for diodes in the automobile are rectification, de-spiking, and isolation.

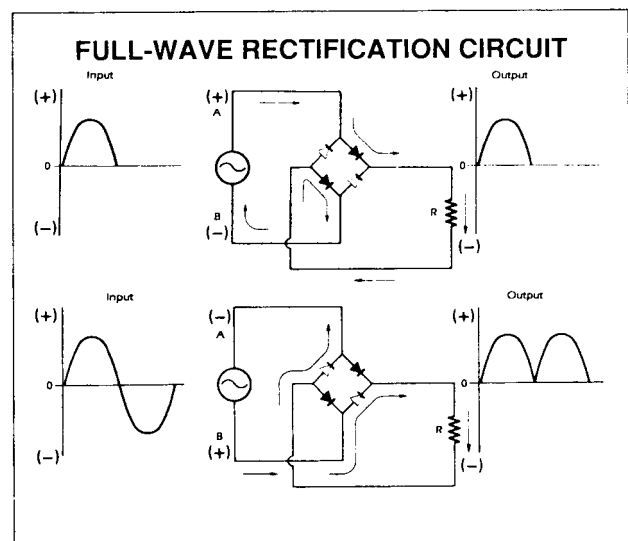
**Rectification**—Since a diode will allow current to flow in one direction and not the other, it can be used to turn alternating current into direct current. This is called rectification. Diodes can provide either full-wave or half-wave rectification, depending on the number of diodes and how they are connected.

A half-wave rectifier consisting of one diode will have an output voltage that is approximately one half of the AC source. Since the output from an AC power source continually changes or alternates from positive to negative, the diode is forward biased for part of the output and reverse biased for the other. The diode will allow current to flow in the circuit when it is forward biased but will block the flow of current when it is reverse

biased. The result is that only half of the wave is output while the other half is blocked by the diode. This type of rectifier is not commonly found in an automotive application since it is not an efficient way to rectify AC to DC to charge a battery.



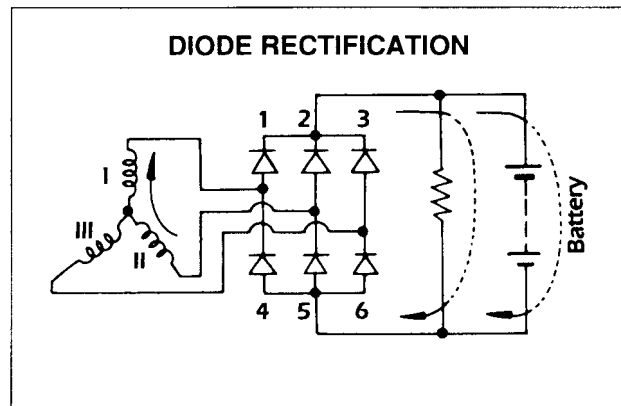
A full-wave rectifier uses a four-diode network to rectify both halves of an AC output. In such a system, current flows from the first half of the phase of the AC power source through the first diode in forward bias, through the external circuit, through the second diode, then completes the circuit. On the second half of the phase, the current flows through the third diode, through the external circuit, through the fourth diode and completes the circuit.



By using four diodes in the full-wave rectifier, all of the current flows to the DC part of the circuit and the current in the DC part always flows the same direction even though the current flow in the AC power source changes directions.

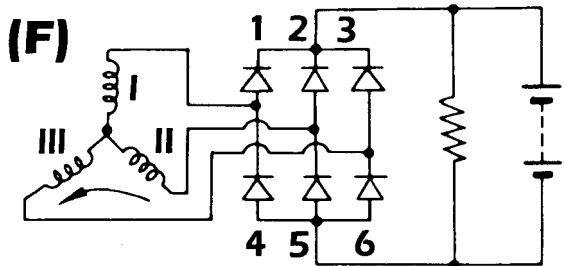
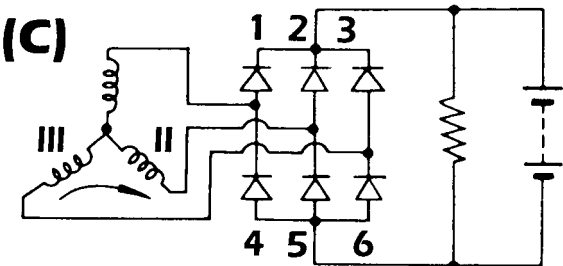
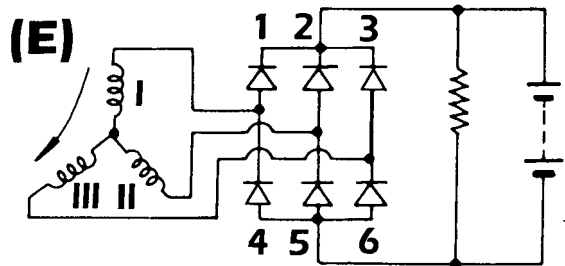
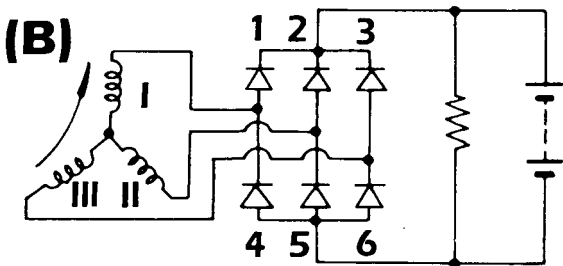
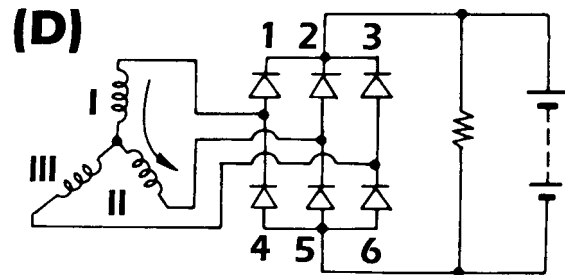
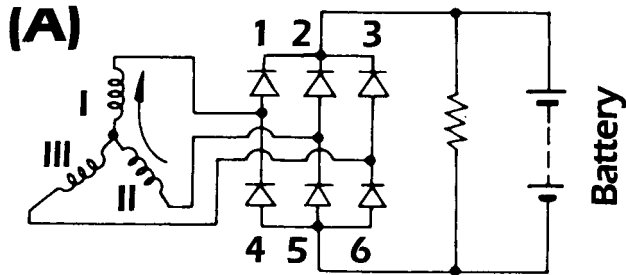
The full-wave, three-phase rectifier found in an automotive alternator goes a step further. Because the alternator uses three coils that produce three overlapping AC sine waves staggered at 120 degree intervals, six diodes are required to achieve full-wave rectification. Each coil uses four of the diodes to rectify the output, achieving full-wave rectification (as in the full-wave, single-phase rectifier discussed earlier). Because the coils and diodes are interconnected, the same diodes are used by different coils at different times. Due to the overlap of the waves, output from each coil in this type of alternator produces a smooth output to the DC system.

The following worksheet shows how the six diodes can rectify the output of all three coils.





DIODE RECTIFICATION WORKSHEET

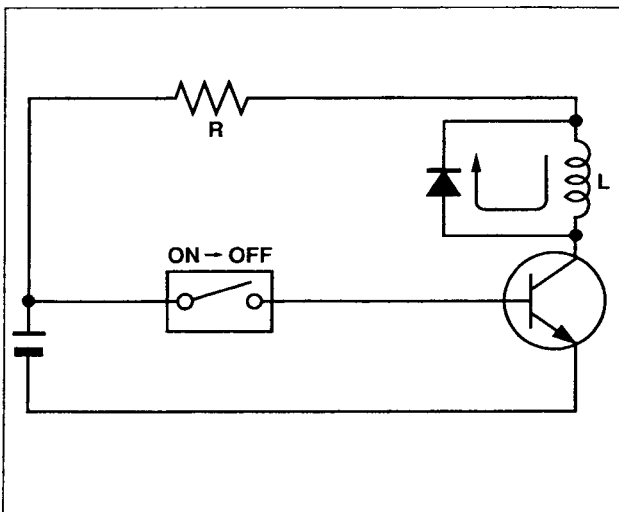


In each of the illustrations above, trace the path of current flow through the stator coils, the corresponding diodes and the DC circuit.

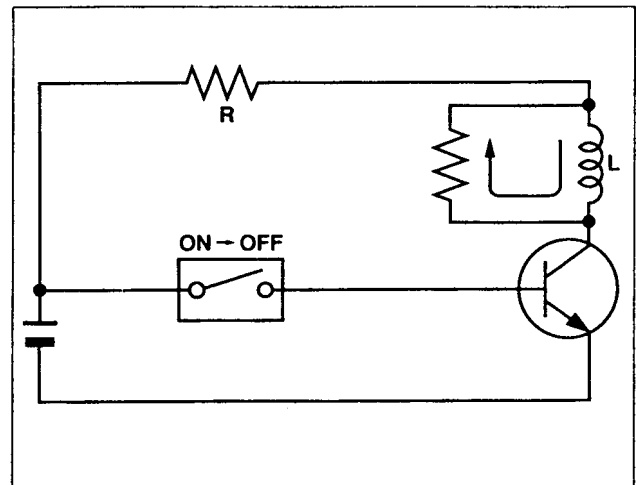
The arrows in the illustrations next to the stator coils show the direction of conventional current flow.

**De-spiking**—Diodes are used on some relay coils to suppress voltage spikes. These spikes can damage components such as transistors in the control circuit of the relay. The voltage spike is produced by the collapsing magnetic field in the relay coil which occurs whenever current flow through the coil is stopped suddenly. The voltage induced in the relay coil is similar to the way an ignition coil operates. The induced voltage in a relay coil can be several times more than the system voltage.

A de-spiking diode is connected in parallel with the relay coil. It is reverse biased when the relay is turned on, therefore no current

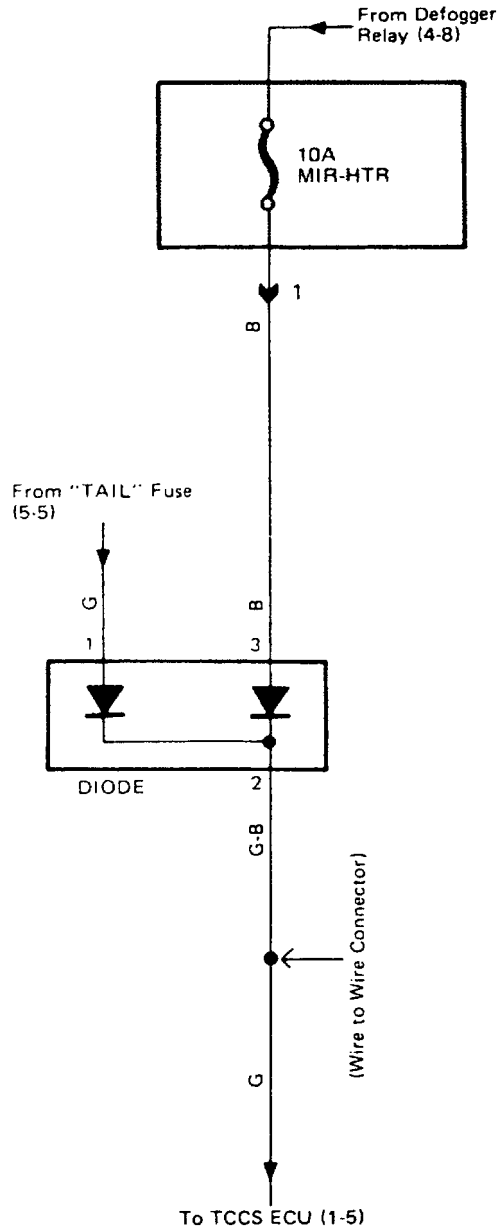


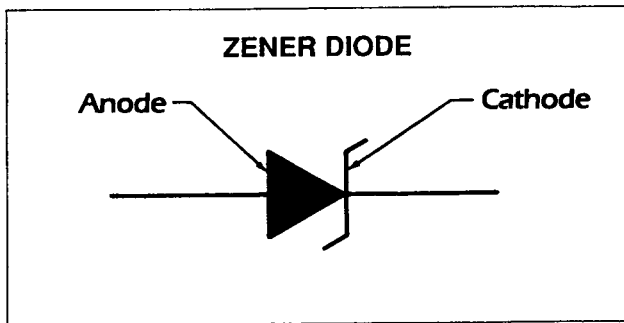
will flow through the diode. When the relay control circuit is opened, current stops flowing through the coil, causing the magnetic field to collapse. The magnetic lines of force cut through the coil and induce a voltage. Since the circuit is open, no current flows. The voltage builds until it reaches about .7 volts, enough to forward bias the diode, completing the circuit to the other end of the coil. The current flows around in the diode and coil circuit until the voltage is dissipated.



Because some relays are located in very hot environments where de-spiking diodes can fail prematurely, resistors are sometimes used instead. The resistor is more durable and can suppress voltage spikes in much the same way as the diode, but the resistor will allow current to flow through it whenever the relay is on. Therefore resistance of the resistor must be fairly high (400 to 600 ohms) to prevent too much current flow in the circuit. Because of resistors' high resistance, they are not quite as efficient at suppressing a voltage spike as diodes.

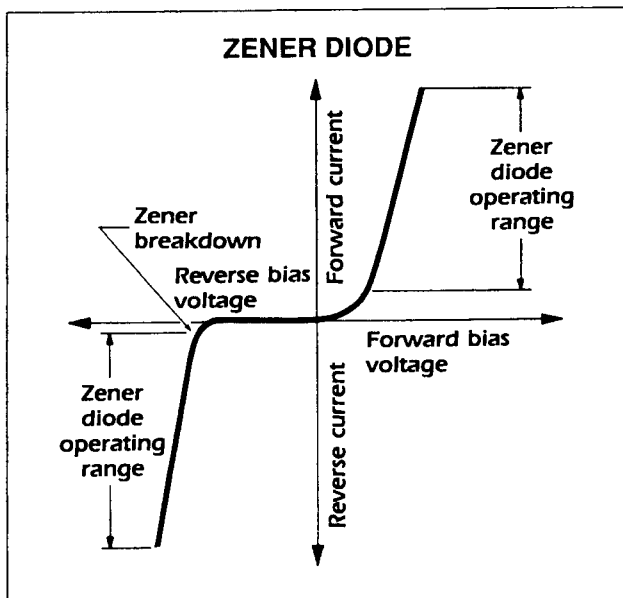
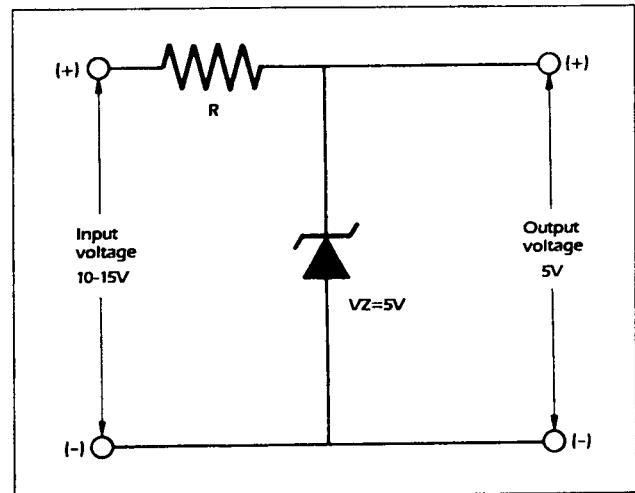
**Isolation**—A diode can be used to separate two circuits. Diodes are used in this way on many Toyota models. The Electronic Load Sense (ELS) circuit used on a Camry is a good example. This system signals the ECU to increase the idle speed when certain electrical loads are turned on. It uses two diodes so two different circuits can provide a voltage signal to the same terminal on the ECU. Without diodes, whenever either of the systems were turned on, voltage would also be applied to the other circuit causing it to operate.



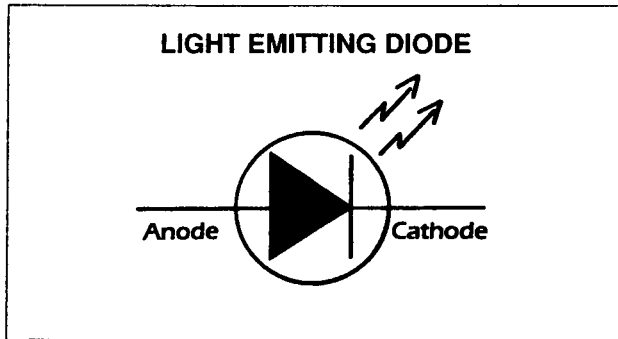


**Zener diode**—A zener diode acts like an ordinary silicon diode when in the forward bias direction, but it has been specially doped to act very differently in reverse bias. A zener diode allows current to flow in reverse bias at a specific voltage without damage over and over again. The reverse bias voltage at which the zener will conduct, sometimes called the zener point, differs from one zener to another as each zener diode is doped to have a zener point at a specific voltage.

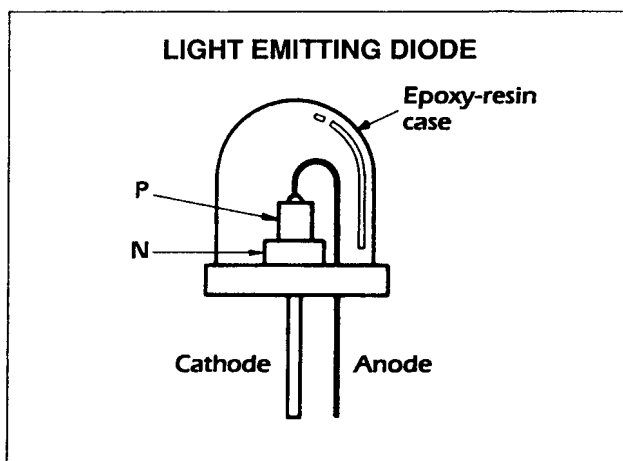
A zener diode can be used to suppress spikes by connecting it between the circuit and ground with the diode reverse biased. When a voltage spike exceeds the zener point of the diode, it completes the circuit to ground and prevents the spike from damaging anything.



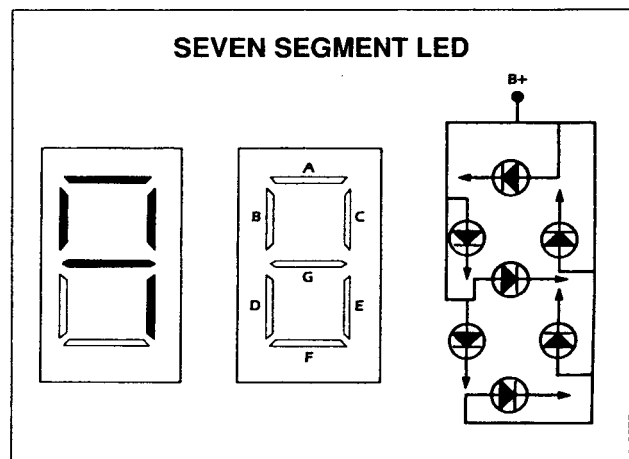
A more common use of a zener diode in an automobile is to sense the charging system voltage. By connecting the zener between the base of a transistor and the positive side of the charging system, the zener can allow current to flow to the base of the transistor when its zener point is reached. If the zener point is 14.5 volts and the transistor to which the zener is connected turns off alternator field current when the transistor is turned on, a constant charging system voltage can be maintained. As soon as the system voltage drops below the zener point, the diode stops conducting and the transistor turns off, allowing field current to flow.



**Light emitting diodes (LEDs)**—An LED is a diode that is specially designed to produce light. LEDs are made with a transparent epoxy case so they can emit the light they produce when forward biased. The color of the light given off by an LED can be red, green or infrared, depending on how the material is doped. An LED, like a standard silicon diode, will conduct current in only one direction. The forward bias voltage drop of an LED (1.5 to 2 volts) is much higher than a silicon diode. The forward bias current through an LED must be controlled, as with any other semiconductor or damage will result. LEDs have advantages over ordinary bulbs, such as longer life, cooler operation, lower voltage requirements and the ability to produce the same amount of light as an incandescent bulb while consuming less power.



In vehicles, LEDs are used in a variety of ways, including displays and indicators. LEDs are also used in conjunction with phototransistors, which convert light to electrical current. A vehicle speed sensor, known as a photo-coupler or light-activated switch, is a good example. In a speed sensor, the speedometer cable is connected to a slotted wheel which separates the LED from the phototransistor. As the wheel turns, it constantly breaks the beam of light emitted from the LED to the phototransistor, thereby turning the phototransistor on and off. The pulsed signal goes to the computer and is used to determine vehicle speed.



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## ASSIGNMENT

NAME: \_\_\_\_\_

1. Describe the construction and operation of a capacitor.
2. Name the three types of capacitors.
3. Describe the three uses of capacitors.
4. Name and explain both current flow theories.
5. Describe how a semiconductor differs from a conductor or an insulator.
6. What are two common types of semiconductor material.
7. Explain what "Doping" is and how N-Type or P-Type material is made.
8. Describe the function and construction of a "Diode".
9. Explain the term PN junction.
10. Describe the depletion region of a diode.
11. What is the voltage drop (the voltmeter reading) of a diode?
12. Explain the terms "Forward" and "Reverse" Bias.
13. Describe Rectification and how diodes are used.
14. Explain the difference between half-wave and full-wave rectification.
15. Describe the function of a De-spiking (Voltage Suppression) diode.
16. Explain the operation of a De-spiking (Voltage Suppression) diode.
17. Describe the function of an Isolation diode.
18. Explain the operation of an Isolation diode.
19. Explain how a "Zener Diode" differs from a conventional diode.
20. Explain the term "Zener Point" (Avalanche Point) and what happens at this point.
21. Explain how a "Light Emitting Diode" (LED) differs from a conventional diode.
22. What is the voltage drop (the voltmeter reading) of an LED?