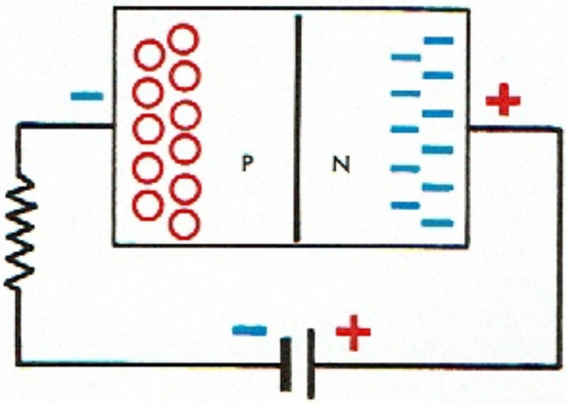
training chart manual

SECTION J

FUNDAMENTALS OF SEMICONDUCTORS

Delco Remy



there will be no current flow. In effect, a very high electrical resistance is created at the junction area. This type of battery connection is referred to as **reverse bias**, which causes the diode to block current flow.

The operating principles of a diode can be summarized in these two statements:

1. The diode will allow current to flow if the voltage across the diode causes electrons and holes to congregate at the junction area. (Forward Bias)
2. The diode will not allow current to flow if the voltage across the diode causes the junction area to be void of electrons and holes. (Reverse Bias)

Let's repeat a statement already made in this chapter. For electrons to move into the "P" material, there must be holes present in the "P" material near the junction **into which the electrons can move.** The reason for the hole theory now becomes more apparent, as this theory provides a convenient means of explaining how a diode blocks or prevents current flow.

diode leakage current

When a reverse bias voltage is connected to a diode, it may be true that a small current will flow through the diode in the reverse direction, but the reverse current is very, very small in magnitude. If the voltage across the diode is increased, a value eventually will be reached called the **maximum reverse voltage** of the diode. At this voltage value, the covalent bond structure will break down and a sharp rise in reverse current will occur. If the reverse current is sufficient in magnitude and duration, the diode will be damaged due to excessive heat. Diodes are selected, of course, with an adequate maximum reverse voltage rating so that damaging reverse currents will not normally occur during operation.

zener diode

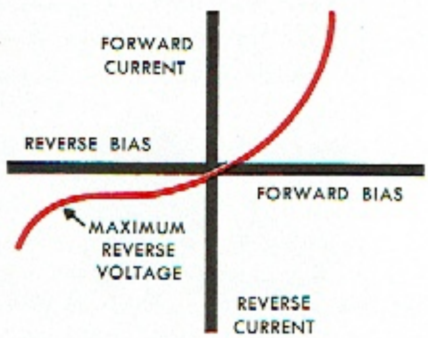
The zener diode is a specially designed type of diode that will satisfactorily conduct current in the reverse direction. The primary feature of this type of diode is that it is very heavily doped during manufacture—the large number of extra current carriers (electrons and holes) allows the zener diode to conduct current in the reverse direction without damage if proper circuit design is used. The zener diode symbol is shown.

ZENER DIODE SYMBOL

The unique operating characteristic of the zener diode is that it will not conduct current in the reverse direction below a certain predetermined value of reverse bias voltage. As an example, a certain zener diode may not conduct current if the reverse bias voltage is below six volts, but when the reverse bias voltage becomes six volts or more, the diode suddenly conducts reverse current. This type of diode is used in control circuits.

performance curves

A performance curve showing current flow for both forward and reverse bias voltages of a typical diode is illustrated. As the forward bias voltage increases, the forward current tends to increase more and more rapidly. This illustrates the fact that the relationship between the voltage and current throughout the voltage range is not linear, that is, a straight line function. This fact is discussed further in the following section entitled "Diode Testing."

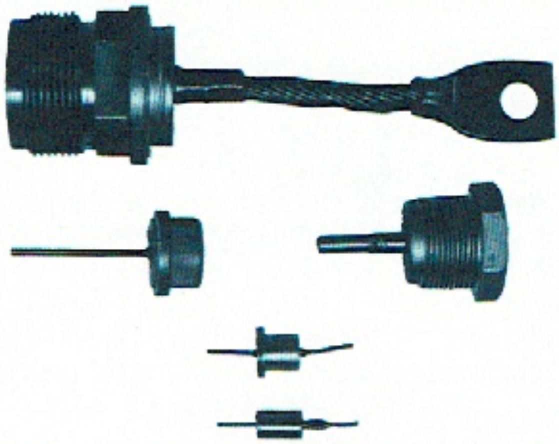


The curve in the lower left portion of the illustration shows that a reverse current will flow when a reverse bias voltage is applied to the diode. The magnitude of the reverse current is very small, and the current increases very little until the breakdown or maximum reverse voltage is reached. At this point, the covalent bond structure breaks down and the reverse current increases very rapidly. As previously mentioned, this breakdown may cause a regular diode to be overheated. The same curve may be used to illustrate the performance of a zener diode, which will safely conduct current when the maximum reverse voltage is reached.

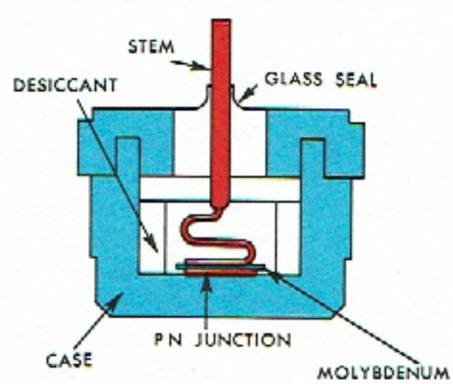
The forward and reverse voltage curves are not drawn to the same scale in order to better illustrate the performance characteristics. Typical current values for one type of diode may be two or three amperes forward current, with less than .001 ampere reverse current.

types, designs and applications

Some of the types of diodes used in Delco-Remy equipment are shown. The smaller diodes are used in control circuits, such as regulators and amplifiers, and the larger diodes are used primarily in Delcotron® generators.



The cross-sectional view illustrates some of the construction details of one of the larger diodes. The die part of the diode assembly, which is the PN junction, rests on the bottom of the copper case, and is connected to the diode stem through a wafer of molybdenum and an "S" shaped connector. The molybdenum expands and contracts slightly due to heat developed within the diode. It reduces the stress on the "N" junction during expansion and contraction of the PN material with heat changes. The molybdenum also serves to dissipate heat from the PN material. It also serves as a good electrical contact between the PN material and the "S" shaped connector. The "S" shaped connector maintains the electrical connection without stressing the PN junction when expansion and contraction oc-



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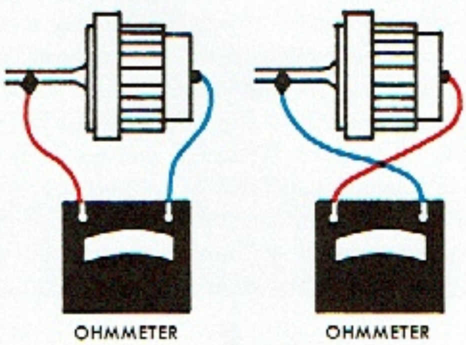
cur. Since moisture adversely affects semiconductor material, a desiccant is located inside the case to absorb any moisture that might enter. Also, a glass seal is used around the diode stem, or lead, to prevent the entry of moisture.

Electrically, the diode case makes up one side of the diode assembly, and the stem is the other side. Diodes of the type shown in the cross-sectional view are pressed into the metal end frame or into a metal heat sink in the generator. This arrangement is necessary in order to dissipate the heat developed in the diode during normal operation. Smaller diodes that are used in control circuits carry very small currents and do not require a heat sink type of mounting.

diode testing

A diode can be checked for defects by connecting an ohmmeter having a 1½ volt cell across the diode first in one direction, and then in the other. If both readings are zero, the diode is shorted; and if both readings are infinite, the diode is open. A good diode will give one very low and one very high reading. Use the lowest range scale on the ohmmeter.



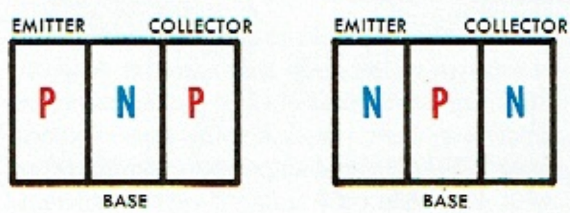
It is important to observe that a diode cannot be condemned because two ohmmeters give different readings on the diode. This occurs due to the different internal resistances of the ohmmeters and the different states of charge of the ohmmeter batteries. Since each ohmmeter will send a different current through the diode, the two resistance values read on the meters will not be the same. This is borne out by the non-linear voltage-current curve illustrated in the previous section entitled "Performance Curves."

A 12-volt d.c. test light may be used to test diodes in place of an ohmmeter. If the lamp lights in both checks, the diode is shorted. If it fails to light in both checks, the diode is open.

transistors

A transistor is an electrical device that is used in circuits to control current flow. Its operation in this section is described by observing the conditions under which it will allow current to flow, and the conditions under which it will not allow current to flow.

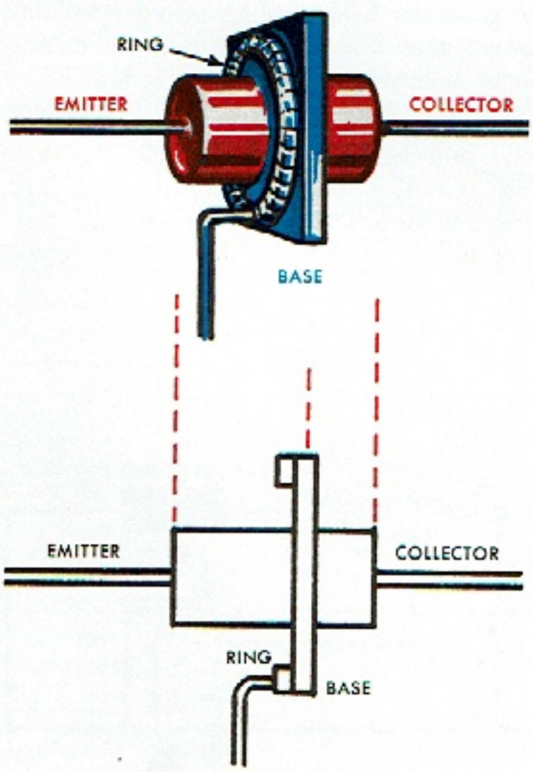
The previous chapter covered the fundamentals and construction of diodes. When a second section of "P" type material is formed on a PN junction, a transistor is formed. The "P" material on the left is called the emitter, the "N" type material in the center is the base, and the "P" material on the right is called the collector. This arrangement results in what is known as a PNP transistor. It is also possible to form an NPN transistor, by using two areas of "N" material and one area of "P" material. The PNP transistor is the type most commonly used in automotive-type electrical systems.



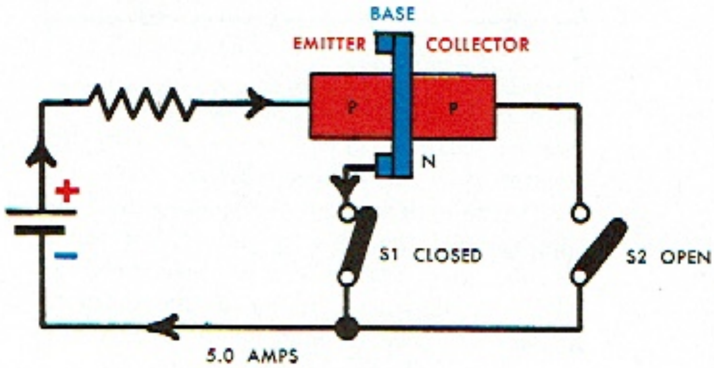
The manufacture of transistors requires rigidly controlled manufacturing techniques, similar to that required during the manufacture of diodes, with purity of material being of the utmost importance. The most commonly used elements in transistors are germanium doped with indium to form "P" material, and germanium doped with antimony to form "N" material.

ELEMENT	ATOMIC NUMBER	NUMBER OF PROTONS	NUMBER OF ELECTRONS	VALENCE RING ELECTRONS
Germanium (Ge)	32	32	32	4
Indium (In)	49	49	49	3
Antimony (Sb)	51	51	51	5

Transistors are constructed with a base of very thin material. A metallic ring is attached to the base at its outer circumference, and a circuit connection is made to this ring. This type of construction results in a shorter distance between the emitter and collector than between the emitter and base ring, and accounts for an unusual operating characteristic of the transistor, as will now be seen.



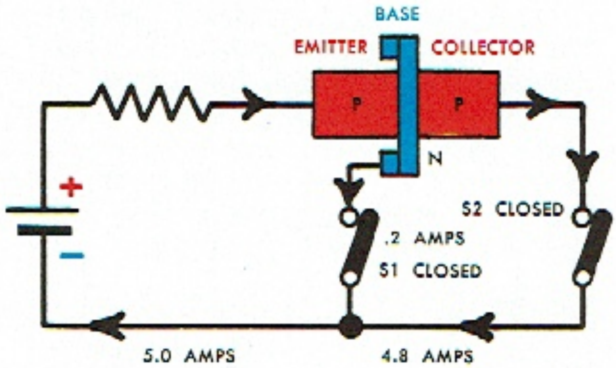
When a battery is connected to a PNP transistor as illustrated, with switches S1 closed and S2 open, current will flow through the emitter-base of the transistor. With switch S2 open, the collector is inoperative, and the circuit arrangement represents a simple PN junction diode (the emitter-base) connected to a battery in the forward bias direction.



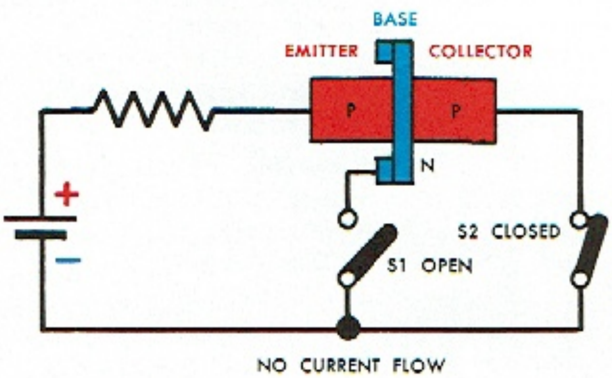
At this point in our discussion, it is well to recall a definition of current flow — the movement of electrons from atom to atom in a conductor. Under this definition, the electrons in this circuit flow from the negative battery terminal through the base-emitter back to the positive side of the battery. However, in order to better understand the operation of a PNP transistor, it is necessary to accept hole movement as a theory of current flow, and to apply this theory to the PNP transistor.

Using the hole movement theory, the current flow in the transistor is considered to be a movement of holes through the "P" material to the "N" material. This movement of holes can be looked upon as current flow, and this theory simplifies the explanation as to how a transistor works. For purposes of discussion, assume that the emitter-base current is five amperes.

When switch S2 is closed, a rather startling thing happens. The total current remains at five amperes, but now most of the current leaves the transistor through the collector circuit. The current through the collector is 4.8 amperes, and the base current has been reduced to .2 ampere. The reasons for this are described in the next paragraph.



Because of the physical arrangement of the emitter, base ring, and collector, with the emitter-collector closer together than the emitter-base ring, most of the holes that are injected into the base by the emitter travel on into the collector **due to their velocity.** Also, the negative potential at the collector attracts the positive holes from the base into the collector. In the example shown, the collector current is 24 times the base current. This factor is called the current gain. These current values serve merely to illustrate the operation of the transistor, as the actual values may vary depending upon the type of transistor and the circuit arrangement used.



An important observation is that with switch S2 closed and switch S1 open, no appreciable current will flow. The reason for this is that with the base circuit open, there are no holes being injected into the base from the emitter, and consequently there are no holes in the base which can be attracted by the negative battery potential into the collector. Furthermore, the negative battery potential at the collector attracts the holes in the collector away from the base-collector junction area and the resistance across the base-collector junction becomes very high. Although there is a physical connection between the emitter and collector, opening switch S1 effectively "shuts off" the transistor so that no appreciable current flows.

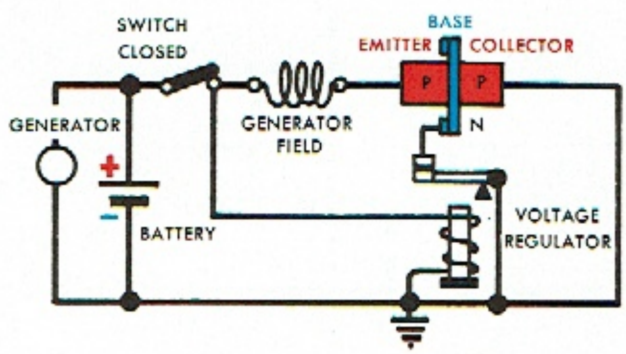
An NPN transistor operates in the same manner as a PNP transistor, with current flow consisting of a movement of electrons from the emitter to the base and collector.

The significant thing about a transistor is that by controlling a small base current, a much larger collector current can also be controlled. This important operating characteristic of the transistor is discussed further in the next section.

basic circuits

A typical circuit showing how a transistor may be used in a transistorized regulator is illustrated. The purpose of the regulator is to intermittently open and close the circuit to the generator field winding in order to limit the generator voltage to a pre-set value. The circuit operation is described as follows.

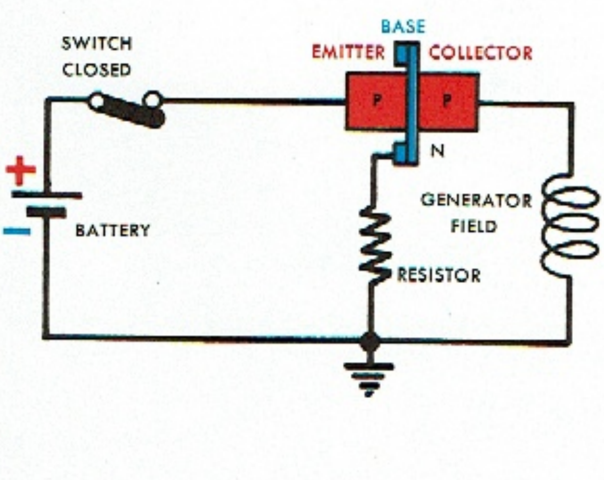
As the generator voltage increases, the magnetic pull in the shunt winding increases. This increased pull attracts the regulator armature toward the core, causing the contacts to separate. With the contacts open,



there is no transistor base current, and no collector current will flow. Consequently, the transistor "shuts off" the generator field current and the generator voltage decreases. This causes a decreased pull in the regulator shunt winding which allows the contacts to reclose and the cycle then repeats many times per second.

In regulators without a transistor, full generator field current flows through the regulator contacts. Since the maximum current for long contact life is approximately two amperes, the generator performance is limited to that obtainable with two-ampere field coils. But in the transistorized regulator, the field current may be five amperes, and the contact current only .2 ampere. This arrangement results in generators with improved performance and regulators whose contacts can be expected to give longer life.

Another typical regulator circuit in which a transistor is used without vibrating contacts is shown. In this type of circuit, other components which are not illustrated operate electronically to alternately impress a forward bias and then a reverse bias across the emitter-base of the transistor. With forward bias the transistor conducts current in the normal manner, but with a reverse bias across the emitter-base, the emitter-base does not conduct current. (This is explained in the section on diodes.) With no holes being injected into the base, there are no holes which the negative potential can attract into the collector, and the transistor "shuts off" generator field current. As the forward bias is restored to the emitter-base of the transistor, the generator field current is turned back on.



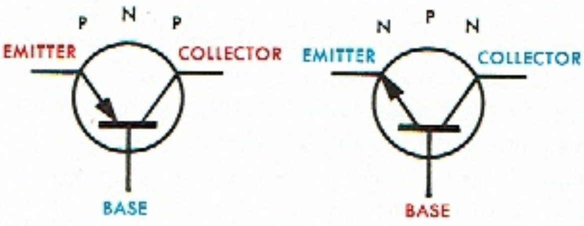
A complete description of the operation of transistors in regulator circuits is covered in other Delco-Remy publications.

types and designs

The most popular type of transistor used in Delco-Remy circuits is illustrated. The two leads on the transistor are the emitter (E) and the base (B), and the transistor case is the collector. In order to provide satisfactory cooling, the transistor is mounted on a metal plate which serves as a heat sink. Since considerable heat is generated in a transistor during operation, it is very important that a transistor having the proper thermal characteristics be selected in order to provide optimum service in the environment involved. Only semiconductors meeting the most stringent requirements are used in Delco-Remy equipment.

symbols

The most common symbol for transistors used in circuits is shown. The line with the arrow is the emitter, the heavy line is the base, and the line without an arrow is the collector. Note that the arrow points in the direction of



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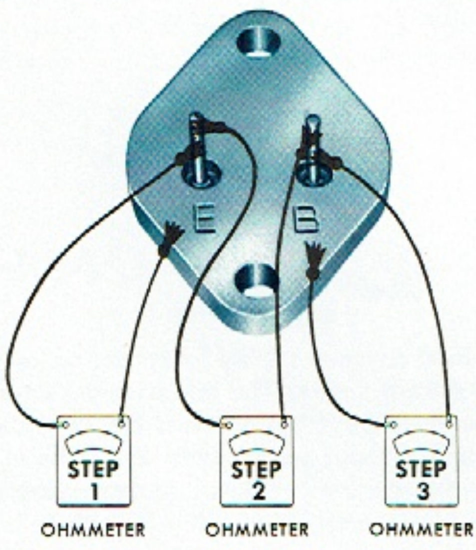
conventional current flow; that is, from positive to negative in the external circuit. As previously described, it is convenient to look upon current flow in the PNP transistor as a movement of holes, and in the NPN transistor as a movement of electrons. Although the electrons move against the arrow in the NPN transistor, this is not contradictory as it is easier to visualize the current carriers (electrons) as being emitted by the emitter into the base and collector.

testing

An ohmmeter may be used to test a transistor for shorts and opens. The lowest range scale on the ohmmeter should be used, and the ohmmeter preferably should have a 1½ volt cell.

To test the transistor, connect the ohmmeter as shown in Step 1, then reverse the lead connections in Step 1. If both readings are



zero, the transistor is shorted. Then connect the ohmmeter as shown in Step 2, and then reverse the connections. If both readings are zero, the diode is shorted. If both readings are infinite, the diode is open. Follow the same procedure for Step 3 as for Step 2.

It is important to observe that a transistor cannot be condemned because two ohmmeters give different readings on the transistor. This occurs because of the different internal resistances of the ohmmeters and the different states of charge of the ohmmeter batteries. Since each ohmmeter will send a different current through the transistor, the two resistance values read on the meters will not be the same because, like a diode, the voltage-current curve for a transistor is not linear.

the Delco-Remy education program

The Delco-Remy Education Program is designed to provide to mechanics and students up-to-date technical information on automotive electrical equipment.

This manual, one of a series, is a part of the program. Used in a classroom in conjunction with training charts, these manuals aid in explaining the theory of operation and construction of electrical units.

Also available to servicemen and students is a series of Maintenance Handbooks. Each handbook is a collection of Delco-Remy service bulletins. They serve as a reference in the maintenance and testing of electrical units.

Test Specification Booklets contain service test data for the electrical units manufactured by Delco-Remy. These booklets are designed for automotive electricians engaged in maintenance and testing.

Strip films with records and film booklets cover the basic operation and maintenance of units in electrical systems. There are many pictures and a wealth of information in diagrams and legends.

Other booklets cover various phases of maintenance and testing procedures for Delco-Remy electrical units and their related circuits.

For complete information on the availability and cost of the above material write to: Technical Literature Department, Delco-Remy Division, General Motors Corporation, Anderson, Indiana.

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