Chapter 7

Basic Automotive Electricity

Topics

To hear audio, click on the box.

Overview

Knowing the basic principles of automotive electricity is essential for the mechanic to understand the operation of all automotive electrical systems and components. Unless you have a clear understanding of these fundamental principles, you will find it difficult to service the various electrical components and systems encountered in the Naval Construction Force. This understanding will enable you to make sound decisions in the troubleshooting process of all electrical systems.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Understand the basic principles of electricity.
2. Understand the theory of electricity.
3. Understand the components of electricity and matter.
4. Identify the elements involved in electrical current flow.
5. Identify the material and devices in use in electrical current flow.
6. Determine voltage, amperage, and resistance.
7. Understand Ohm's Law.
8. Identify the types of electrical circuits used in vehicles.
9. Understand the theory of magnetism.
10. Understand the principles of electromagnetism and electromagnetic induction.

Prerequisites

None

This course map shows all of the chapters in Construction Mechanic Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Automotive Chassis and Body	↑	
Brakes		
Construction Equipment Power Trains		C
Drive Lines, Differentials, Drive Axles, and Power Train Accessories		M
Automotive Clutches, Transmissions, and Transaxles		
Hydraulic and Pneumatic Systems		
Automotive Electrical Circuits and Wiring		B A
Basic Automotive Electricity		S
Cooling and Lubrication Systems		I
Diesel Fuel Systems		C
Gasoline Fuel Systems		
Construction of an Internal Combustion Engine		
Principles of an Internal Combustion Engine		
Technical Administration		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with italicized instructions telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for

review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

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1.0.0 BASIC PRINCIPLES of ELECTRICITY

All activity in any type of electrical circuit depends on the behavior of tiny electrical charges called electrons. To understand the behavior of electrons, we must investigate the composition of matter. The electron is one of the basic electrical components of all matter.

1.1.0 Composition of Matter

All ***matter***, regardless of its state (solids, liquids, and gases), is made up of tiny particles known as atoms. Atoms combine in small groups of two or more to form molecules; however, when atoms are divided, smaller particles are created. These particles have positive or negative electrical charges.

There are just over 100 different basic materials in the universe, and millions of different compounds can be formed from them. These basic materials are called elements. Iron, copper, aluminum, oxygen, hydrogen, and mercury are examples of elements. The basic particles that make up all the elements, and thus the entire universe, are called protons, electrons, and neutrons. A proton is the basic particle having a single positive charge; therefore, a group of protons produces a positive electrical charge. An electron is the basic particle having a single negative charge; therefore, a group of electrons produces a negative electrical charge. A neutron is the basic particle having no charge; therefore, a group of neutrons would have no charge.

The construction of atoms of the various elements can be examined starting with the simplest of all—hydrogen. The atom of hydrogen consists of one proton, around which one electron circles (*Figure 7-1*). There is an attraction between the two particles because negative and positive electrical charges always attract each other. Opposing the attraction between the two particles, and thus preventing the electron from moving into the proton, is the centrifugal force on the electron caused by its circular path around the proton. This same sort of balance is produced if a ball tied to string is whirled in a circle in the air. The centrifugal force exerted tries to move the ball out of its circular path but is balanced by the string (the attractive force). If the string should break, the centrifugal force would cause the ball to fly away. Actually, this is what happens at times with atoms. The attractive force between the electron and proton sometimes is not great enough to hold the electron in its circular path and the electron breaks away.

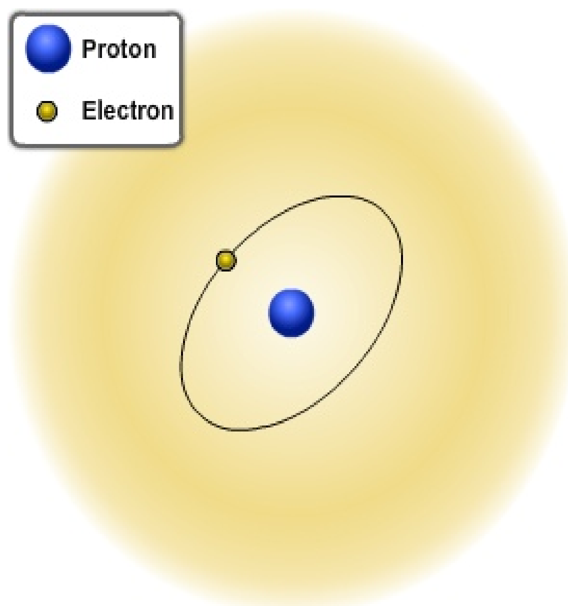


Figure 7-1 — Hydrogen atom.

In an atom, unlike electrical charges attract and like electrical charges repel each other. Electrons repel electrons and protons repel protons, except when neutrons are present. Though neutrons have no electrical charge, they do have the ability to cancel out the repelling forces between protons in an atomic nucleus and thus hold the nucleus together.

1.2.0 Composition of Electricity

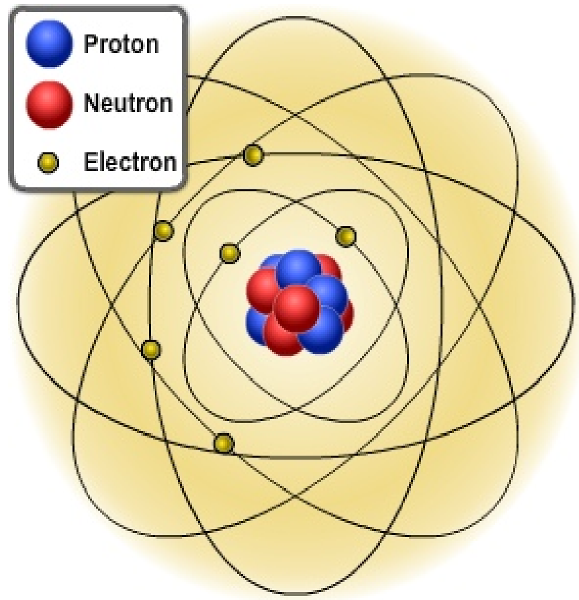


Figure 7-2 — Composition of an atom.

When there are more than two electrons in an atom, they move about the nucleus in different orbits which are referred to as shells (*Figure 7-2*). The innermost shells of the atom contain electrons that are not easily freed and are referred to as bound electrons. The outermost shell contains what is referred to as free electrons. These free electrons differ from bound electrons in that they can be moved readily from their orbit.

If a point that has an excess of electrons (negative) is connected to a point that has a shortage of electrons (positive), a flow of electrons (electrical current) will flow through the connector (conductor) until an equal amount of electrical charge exists between the two points.

1.3.0 Electron Theory of Electricity

A charge of electricity is formed when numerous electrons break free of their atoms and gather in one area. When the electrons begin to move in one direction (as along a wire, for example), the effect is a flow of electricity or an electric current. Actually, electric generators and batteries could be called electron pumps, because they remove electrons from one part of an electric circuit and concentrate them in another part of the circuit. For example, a generator takes electrons away from the positive terminal and concentrates them at the negative terminal. Because the electrons repel each other (like electrical charges repel), the electrons push out through the circuit and flow to the positive terminal (unlike electrical charges attract). Thus we can see that an electric current is actually a flow of electrons from a negative terminal to a positive terminal.

Test your Knowledge (Select the Correct Response)

1. All matter is made up of tiny particles known by what term?

   A. Protons
   B. Electrons
   C. Neutrons
   D. Atoms

2.0.0 ELECTRIC CURRENT

It has been proved that electrons (negative charges) move through a conductor in response to an electric field. “Electric current” is defined as the directed flow of electrons, and the direction of electron movement is from a region of negative potential to a region of positive potential. Therefore, electric current can be said to flow from negative to positive.

2.1.0 Conductors

Any material that will allow an electrical current to flow through it is an electrical conductor. Conductors are used in automotive equipment to carry electric current to all of the electrical equipment. The electrical properties of a substance depend mainly on the number of electrons in the outermost shell of each atom. The maximum number of electrons in an outer shell is eight. When there are less than four electrons in the outer shell of an atom, these electrons will tend to be free. This condition allows the free motion of electrons, making the substance a conductor (*Figure 7-3*).

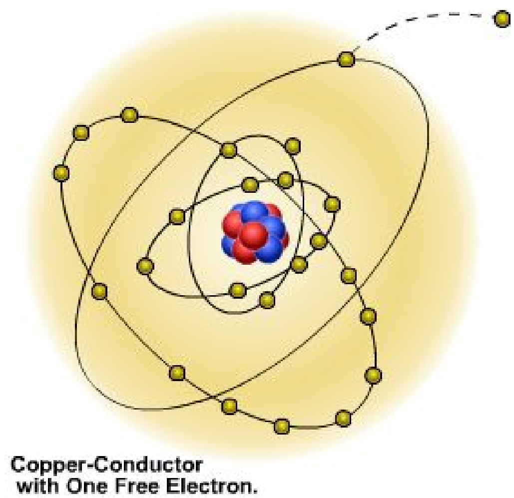


Figure 7-3 — Conductors.

Electrical energy is transferred through conductors by means of the movement of free electrons that migrate from atom to atom within the conductor. Each electron moves a short distance to the neighboring atom where it replaces one or more electrons by forcing them out of their orbits. The replaced electrons repeat this process in nearby atoms until the movement is transmitted throughout the entire length of the conductor, thus creating a current flow. Copper is an example of a good conductor because it has only one free electron. This electron is not held very strongly in its orbit and can break away from the nucleus very easily. Silver is a better conductor of electricity, but it is too expensive to be used in any great quantity. Because of this, copper is the conductor used most widely in automotive applications.

2.2.0 Insulators

Any material that blocks electrical current flow is an electrical insulator. Insulators also are necessary to keep the electric current from taking a shorter route instead of going to the intended component. Whenever there are more than four electrons in the outer orbits of the atoms of a substance, these electrons will tend to be bound, causing restriction of free electron movement, making it an insulator (*Figure 7-4*). Common insulating substances in automotive applications are rubber, plastic, and fiberboard.

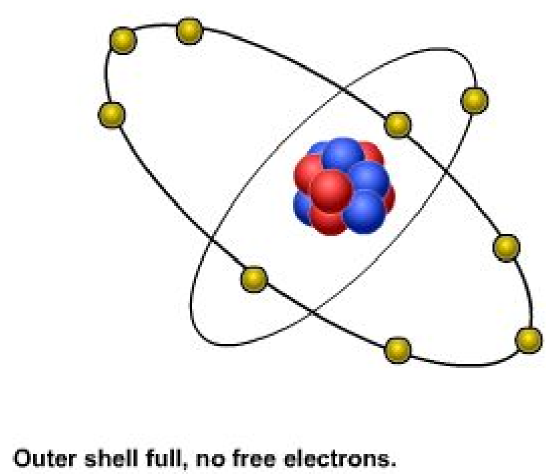


Figure 7-4 — Insulators.

2.3.0 Semiconductors

A semiconductor is an electrical device that acts as a conductor under certain conditions and as a nonconductor under other conditions. The most popular of all semiconductors is silicon. In its pure state, silicon is neither a good conductor nor insulator. But by processing silicon in certain ways, its conductive or insulative properties can be adjusted to suit just about any need. When a number of silicon atoms are jammed together in crystalline (glasslike) form, they form a covalent (sharing) bond. Therefore, the electrons in the outer ring of one silicon atom join with the outer ring of other silicon atoms, resulting in a sharing of outer ring electrons between all of the atoms. *Figure 7-5* shows that covalent sharing gives each atom eight electrons in its

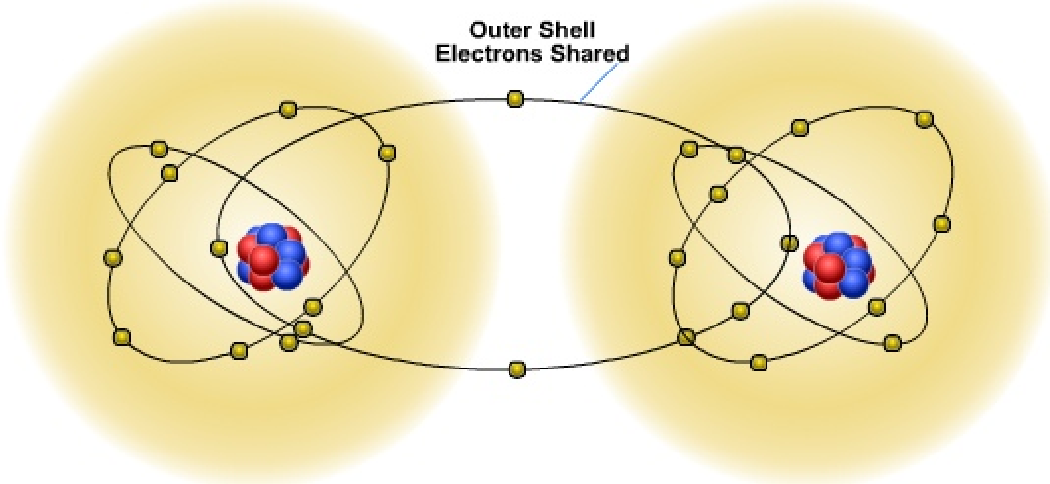


Figure 7-5 — Covalent bonding of silicon.

outer orbit, making the orbit complete. This makes the material an insulator because it contains more than four electrons in its outer orbit. When certain materials, such as phosphorus, are added to the silicon crystal in highly controlled amounts, the resultant mixture becomes a conductor (*Figure 7-6*). This is because phosphorus, which has five electrons in forming a covalent bond with silicon (which has four electrons in its outer shell), will yield one free electron per molecule, thus making the material an electrical conductor. The process of adding impurities to a semiconductor is called doping. Any semiconductor material that is doped to yield free electrons is called N-type material.

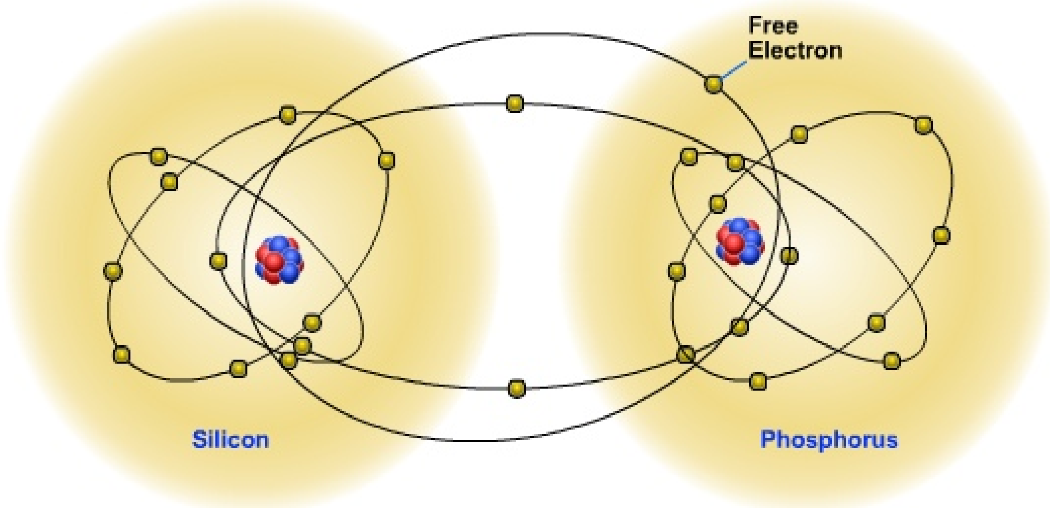


Figure 7-6 — Phosphorus-doped silicon.

When ***boron***, which has three electrons in its outer ring, is used to dope the silicon crystal, the resultant covalent bonding yields seven electrons in the outer shell. This leaves an opening for another electron (*Figure 7-7*). This space is called a hole and can

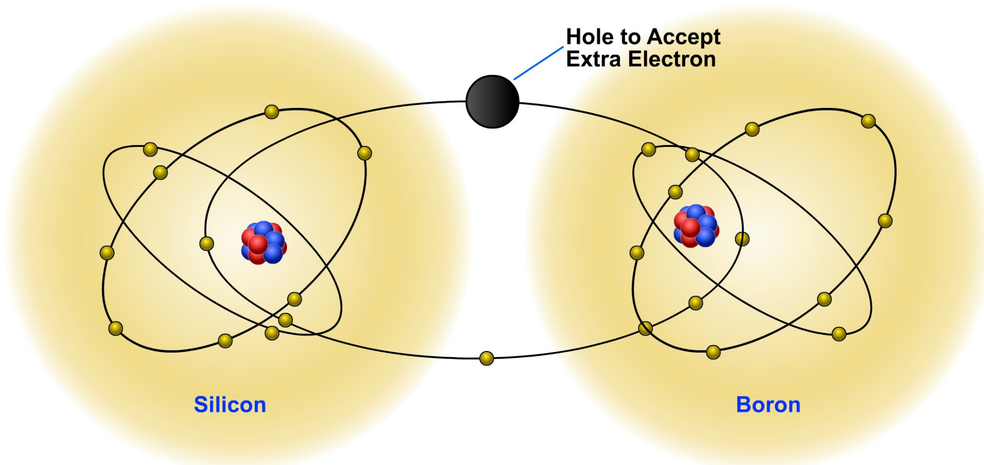


Figure 7-7 — Boron-doped silicon.

be considered a positive charge, just as the extra electrons that exist in N-type semiconductor material are considered a negative charge. Materials that have holes in their outermost electron shells are called positive or P-type materials. To understand the behavior of P-type semiconductors, it is necessary to look upon the hole as a positive current carrier; just as the free electron in N-type semiconductors are considered negative current carriers. Just as electrons move through N-type semiconductors, holes move from atom to atom in P-type semiconductors. Movement of holes through P-type semiconductors, however, is from the positive terminal to the negative terminal. For this reason, any circuit analysis of solid-state circuitry is done on the basis of positive to negative (conventional) current flow.

When a source voltage, such as a battery, is connected to N-type material, an electric current will flow through it (*Figure 7-8*). The current flow in the N-type semiconductor consists of the movement of free electrons, the same as the current flow through a natural conductor, such as copper. When a current source of sufficient voltage is connected across a P-type material, an electric current will also flow through it, but any current flow in a P-type semiconductor is looked upon as the movement of positively charged holes. The holes appear to move toward the negative terminal, as the electrons

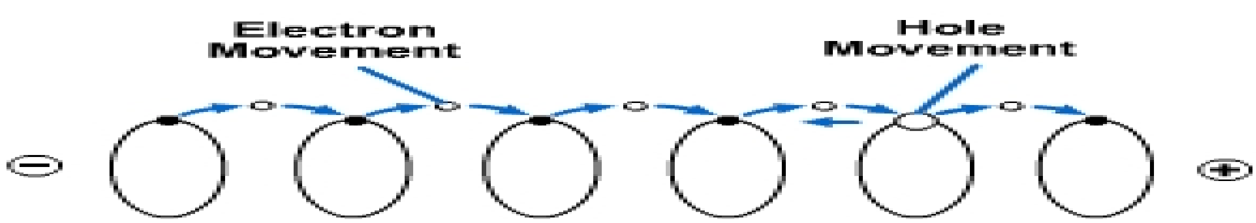


Figure 7-8 — Hole movement theory.

enter the material at the negative terminal, fill the holes, and then move from hole to hole toward the positive terminal. As is the case with the N-type semiconductors, the movement of electrons through P-type semiconductors toward the positive terminal is motivated by the natural attraction of unlike charges.

2.3.1 Diodes

A diode is a device that will allow current to pass through itself in only one direction (*Figure 7-9*). A diode can be thought of as an electrical check valve. Diodes are constructed by joining N-type material and P-type material together. The negative electrical terminal is located on the N-type material and the positive terminal is located on the P-type material.

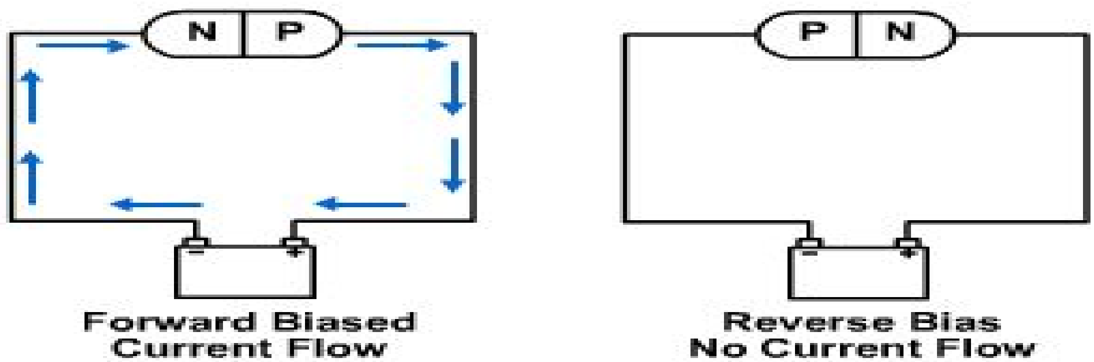


Figure 7-9 — Diode operation.

When a diode is placed in a circuit, the N-material is connected to the negative side of the circuit and the positive side of the circuit is connected to the P-material. In this configuration, which is known as forward bias, the diode is a good conductor. This is because the positively charged holes in the P-type material move toward the junction and fill these holes using them to move across the P-material. If the connections to the diodes are reversed, current flow will be blocked. This design is known as reverse bias. When the diode is connected backwards, the positively charged holes are attracted away from the junction to the negative terminal and the free electrons in the N-material are attracted away from the junction to the positive terminal. Without the presence of holes at the junction, the electrons are not able to cross it.

2.3.2 Zener Diodes

A zener diode is a special type of diode that conducts current in the reverse direction as long as the voltage is above a predetermined value that is built into the device during manufacturing (*Figure 7-10*). For instance, a certain zener diode may not conduct current if the reverse bias voltage is below 6 volts. As the voltage increases to 6 volts or more, the diode suddenly will begin to conduct reverse bias current. This device is used in control circuits, such as voltage regulators.

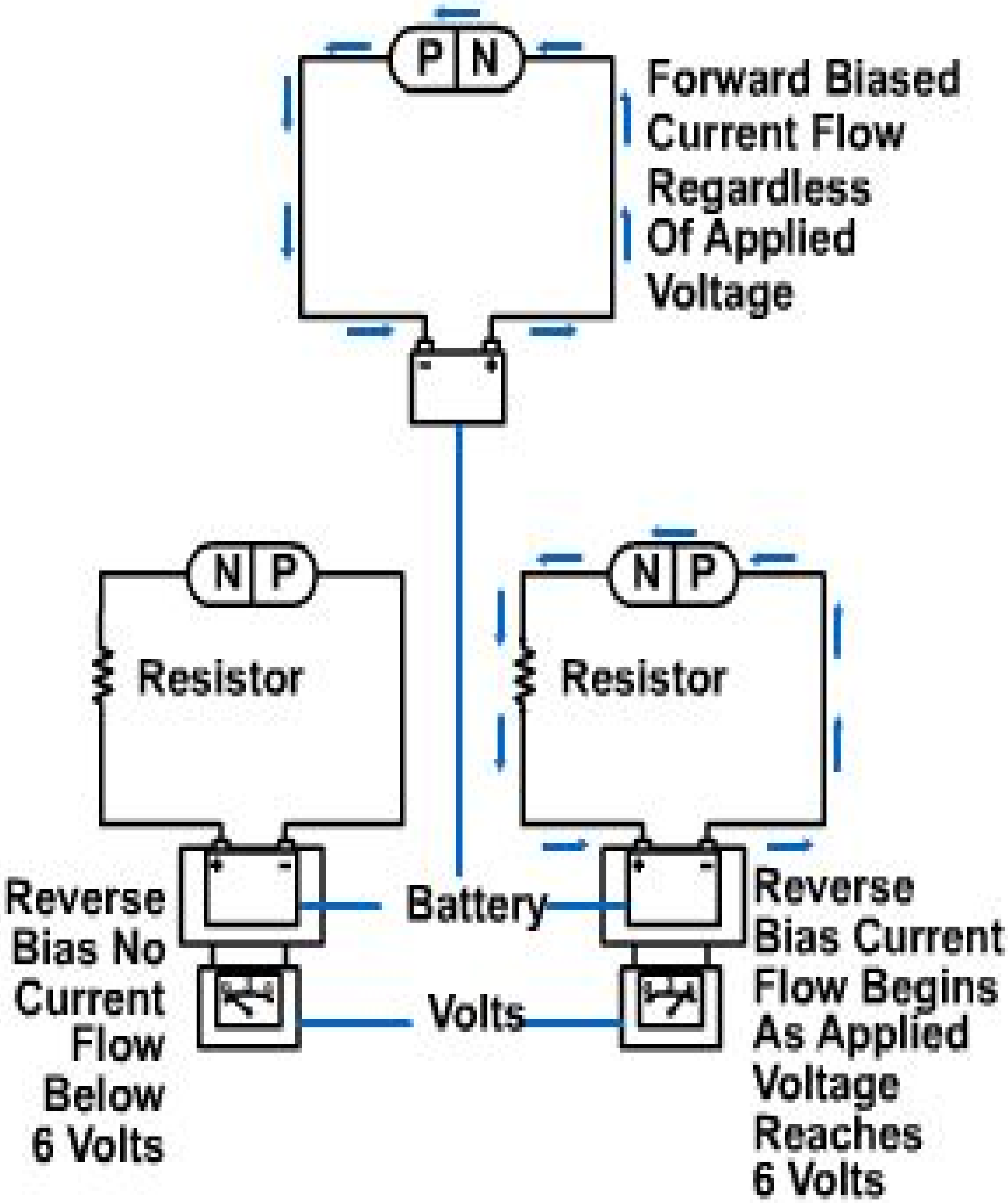


Figure 7-10 — Zener diode operation.

2.3.3 Transistors

A transistor is an electrical device that is used in circuits to control the flow of current (*Figure 7-11*). It operates by either allowing current to flow or not allowing it to flow. Transistors operate electronically and have no moving parts to perform their function. This design allows for a longer operating life of the component. The major automotive applications of transistors are for electronic ignition systems and voltage regulators.

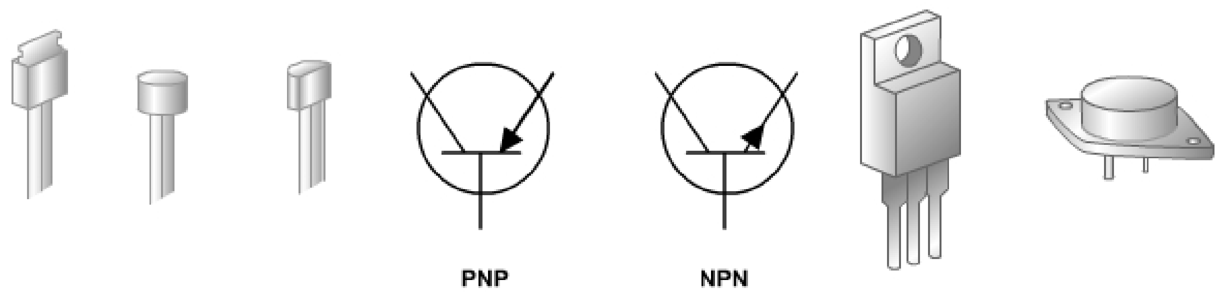


Figure 7-11 — Transistor configurations.

The PNP transistor is the most common design in automotive applications (*Figure 7-12*). It is manufactured by sandwiching an N-type semiconductor element between two P-type semiconductor elements. A positive charge is applied to one of the P-type elements. This element is called the emitter. The other P-type element connects to the electrical component. This element is called the collector. The third element, which is in the middle, is made of N-type material and is called the base. The application of low current negative charge to the base will allow a heavy current to flow between the emitter and the collector. Whenever the current to the base is switched off, the current flow from the emitter to the collector is interrupted also.

The NPN transistor is similar to the PNP transistor (*Figure 7-12*). The difference is that it is used in the negative side of the circuit. As the term NPN implies, the makeup of this transistor is two elements of N-type material (collector and emitter) with an element of P-type material (base) sandwiched in between. The NPN transistor will allow a high current negative charge to flow from the collector to the emitter whenever a relatively low current positive charge is applied to the base.

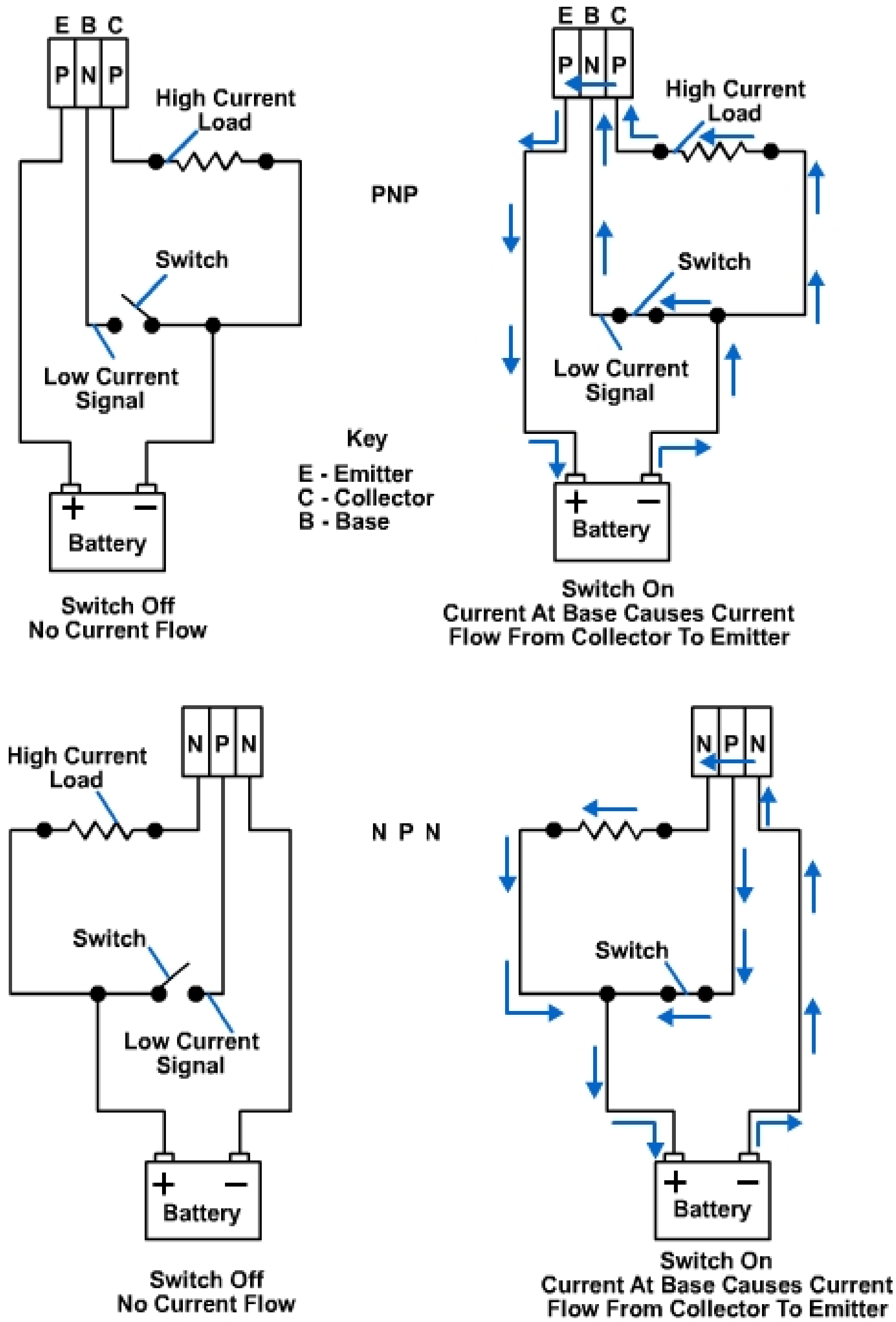


Figure 7-12 — Transistor operation.

Test your Knowledge (Select the Correct Response)

2. In a semiconductor, what type of material is doped to yield free electrons?

   A. O-type
   B. P-type
   C. N-type
   D. Y-type

3. What type of electrical device is used in electrical circuits to control the flow of current and operates by either allowing or not allowing current to flow?

A. Transistor
B. Diode
C. Resistor
D. Thermistor

3.0.0 ELECTRIC MEASUREMENTS

Electricity is measured in two ways—by the amount of current (number of electrons) flowing and by the push, or pressure, that causes current to flow. The push, or pressure, is caused by actions of the electrons. They repel each other. When electrons are concentrated in one place, their negative charges push against each other. If a path is provided for the electrons, they will flow away from the area where they are concentrated.

The pressure to make them move is called voltage. If there are many electrons concentrated in one spot, we say that there is high voltage. With high voltage, many electrons will flow, provided there is a path or conductor through which they can flow- the more electrons that flow, the greater the electric current. Electric current is measured in amperes. Resistance is the movement of electrons through a substance. Resistance is a fact of life in electric circuits. We want resistance in some circuits so that too much current (too many electrons) will not flow. In other circuits, we want as little resistance as possible so that high current can flow.

There is a definite relation between current (electron flow), voltage (current pressure), and resistance. As the electric pressure goes up, more electrons flow. Increasing the voltage increases the amperes of current. However, increasing the resistance decreases the amount of current that flows. These relationships can be summed up in a statement known as Ohm's law.

3.1.0 Ohm’s Law

Ohm’s law is used to figure out the current (I), the voltage (E), and the resistance (R) in a circuit. This law states that voltage is equal to amperage times ohms. Or, it can be stated as the mathematical formula: $E = I \times R$. For the purpose of solving problems, the Ohm’s law formula can be expressed in three ways:

- To find voltage: $E = IR$
- To find amperage: $I = E/R$
- To find ohms: $R = E/I$

The Ohm’s law formula is a useful one to remember because it helps in understanding the many things that occur in an electric circuit. For example, if the voltage remains constant, the current flow goes down if the resistance goes up. This can be better explained by using a truck lighting circuit that is going bad. Suppose the wiring circuit between the battery and the lights has deteriorated due to connections becoming poor, strands in the wire breaking, and switch contacts becoming dirty. All of these conditions reduce the electron path or, in other words, increase resistance. This increased resistance decreases the current flow with the battery voltage constant (for example, 12 volts). If the resistance of the circuit when new was 6 ohms, then 2 amperes will flow. To answer the equation, 12 (volts) must equal 12 (amperes times ohms). But if the resistance goes up to 8 ohms, only 1.5 amperes can flow. The increased resistance cuts down the current flow and, consequently, the amount of light.

If the resistance stays the same but the voltage increases, the amperage also increases. This is a condition that might occur if a generator voltage regulator became defective. In such a case, there would be nothing to hold the generator voltage within limits, and the voltage might increase excessively. This would force excessive amounts of current through various circuits and cause serious damage. If too much current went through the light bulb filaments, for example, the filaments would overheat and burn out. Also, other electrical devices probably would be damaged. However, if the voltage is reduced, the amount of current flowing in a circuit will also be reduced if the resistance stays the same.

For example, with a run-down battery, battery voltage will drop excessively with a heavy discharge. When you are trying to start an engine with a run-down battery, the voltage will drop very low. This voltage is so low that it cannot push enough current through the starter for effective starting of the engine.

3.2.0 Voltage

Electrons are caused to flow by a difference in electron balance in a circuit, that is, when there are more electrons in one part of a circuit than in the other, the electrons move from the area where they are concentrated to the area they are lacking. This difference in electron concentration is called potential difference, or voltage. The higher the voltage goes, the greater the electron imbalance becomes. The greater this electron imbalance, the harder the push on the electrons (more electrons repelling each other) and the greater the current of electrons in the circuit. When there are many electrons concentrated at the negative terminal of a generator (with a corresponding lack of electrons at the positive terminal), there is a much stronger repelling force on the electrons; consequently, many more electrons are moving in the wire. This is exactly the same as saying that the higher the voltage, the more the electric current will flow in a circuit, all other things, such as resistance, being equal.

3.3.0 Amperage

Current flow, or electron flow, is measured in amperes. While we normally consider that one ampere is a rather small current of electricity (approximately what a 100-watt light bulb would draw), it is actually a tremendous flow of electrons. More than 6 billion electrons a second are required to make up one ampere.

3.4.0 Resistance

A copper wire conducts electricity with relative ease; however, it offers resistance to electron flow. This resistance is caused by the energy required to free the outer shell of electrons and the collision between the atoms of the conductor and the free electrons. It takes ***electromotive force*** (emf) or voltage to overcome the resistance met by the flowing electrons. The basic unit of resistance is the ohm. The resistance of a conductor varies with its length, diameter, composition, and temperature. A long wire offers more resistance than a short wire of the same diameter; this is due to the electrons having farther to travel. Some materials can lose electrons more readily than others. Copper loses electrons easily, so there are always many free electrons in a copper wire. Other materials, such as iron, do not lose their electrons as easily, so there are fewer free electrons in an iron wire. However, fewer electrons can push through an iron wire, that is, the iron wire has more resistance than the copper wire. A wire with a small diameter offers more resistance than a wire with a large diameter. In the small diameter wire, there are fewer free electrons, and thus fewer electrons can push through. Most metals show an increase in resistance with an increase in temperature, while most nonmetals show a decrease in resistance with an increase in temperature.

3.5.0 Circuit Configurations

3.5.1 Automotive Circuits

The body and chassis of an automobile are made of steel. This feature is used to eliminate one of the wires from all of the automobile circuits. By attaching one of the battery terminals to the body and chassis, you can connect any electrical component by hooking up one side, by wire, to the car battery and the other side to the body (*Figure 7-13*). This design of connecting one side of the battery to the automobile body is called grounding. The majority of equipment you will encounter has an electrical system with a negative ground. Vehicles with positive ground are very uncommon, but it is always good practice to note what type of grounding system is used on the equipment you are working on.

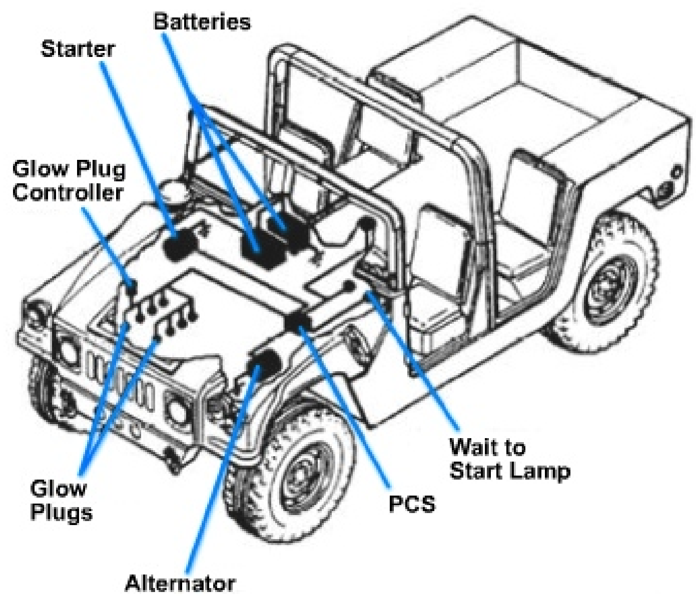


Figure 7-13 — Automotive circuits.

3.5.2 Series Circuits

A series circuit consists of two or more electrical components connected in such a manner that current will flow through all the components. Important characteristics of a series circuit are as follows:

- Any break in the circuit (such as a burned-out light bulb) will render’ the entire circuit inoperative.
- Current (amperage) will be constant throughout the circuit.
- Total resistance of the circuit is equal to the sum of each individual resistance.
- Total voltage of the circuit is equal to the sum of the individual voltage drops across each component.

3.5.3 Parallel Circuits

A parallel circuit consists of two or more electrically operated components connected by parallel wires (*Figure 7-14*). In a parallel circuit, the current divides, part of it flowing into one component and part into the others. The same voltage is applied to each component, and each component can be turned on or off independently of the others. Important characteristics of parallel circuits are as follows:

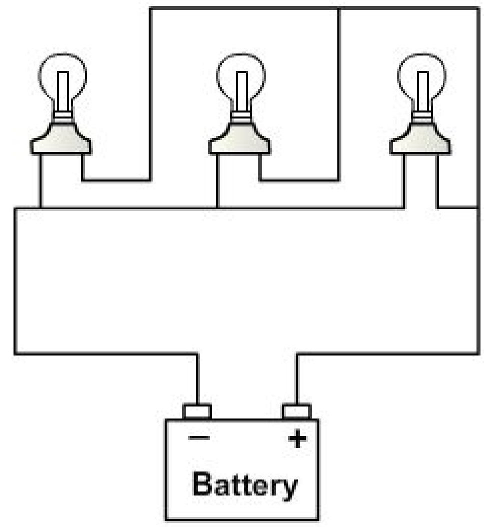


Figure 7-14 — Parallel circuit.

- The total resistance of the circuit will always be less than the resistance of any individual component.
- The disconnection or burning out of any individual component in the circuit will not affect the operation of the others.
- The current will divide itself among the circuit branches according to the resistance of the individual devices. The sum of the individual amperages will be equal to the total circuit current.
- The voltage will be constant throughout the circuit when measured across the individual branches.

3.5.4 Series-parallel Circuits

The series-parallel circuit is a combination of series circuits and parallel circuits (*Figure 7-15*). There must be at least three resistance units to have a series-parallel circuit. Important characteristics of series-parallel circuits are as follows:

- The total circuit voltage will be equal to the sum of the total parallel circuit voltage drop plus the voltage drop of the individual series circuit component.
- The total circuit resistance will be equal to the sum of the total parallel circuit resistance plus the individual resistance of the series circuit components.
- Current flow through the total parallel circuit will be equal to the current flow through any individual series circuit component.
- The disconnection or the burning out of the series components will completely disable the entire circuit, whereas a failure of any of the parallel circuit components will leave the balance of the circuit still functioning.

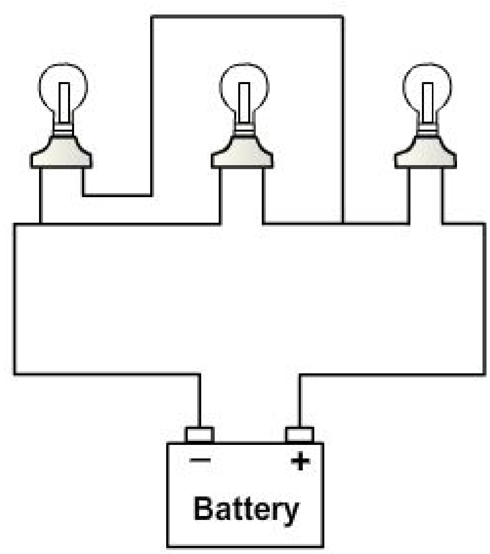


Figure 7-15 — Series-parallel circuit.

3.6.0 Circuit Failures

3.6.1 Open Circuit

An open circuit is a break or interruption in the circuit, such as a wire that has come loose or a slipped connection that is not making contact. But the expression of an open circuit is not only used when wire connections are actually separated as in a switch but also when the resistance in the wiring circuit is such that no current can flow between the battery and the unit it operates. Some good examples of such a condition are rust and corrosion that form and accumulate at a battery cable or terminal, or a fuse failure.

3.6.2 Short Circuit

A short circuit occurs when copper touches copper, such as when wiring insulation between two wires fails and the wiring makes contact. These are undesirable and lead to overheating an electrical circuit. The excessive current flow caused by short circuits overheats the wiring harness and can cause vehicle fire.

3.6.3 Ground Circuit

A ground circuit occurs when any part of the wiring circuit is touching the vehicle frame inadvertently. A ground involves accidental or unintentional contact between copper and the iron frame. This too can lead to excessive current flow and overheating.

Test your Knowledge (Select the Correct Response)

4. To have a series-parallel circuit, you must have what minimum number of resistance units?

   A. One
   B. Two
   C. Three
   D. Four

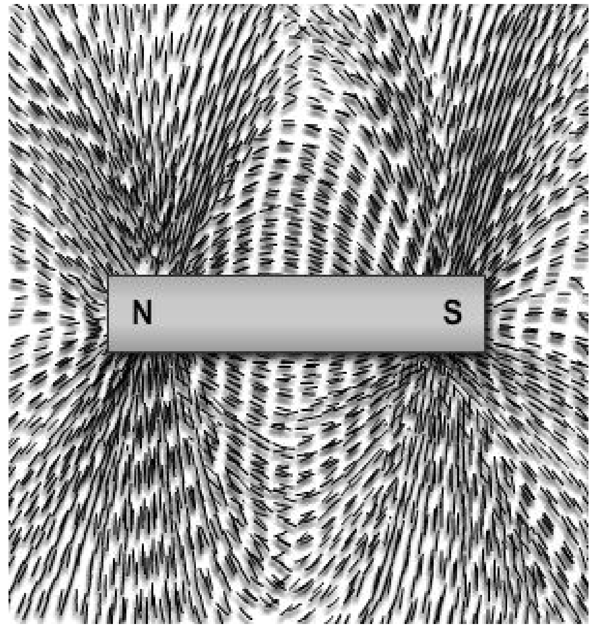
5. What type of circuit failure occurs when the resistance in the wiring circuit is such that current CANNOT flow between the battery and the unit it operates?

   A. Short circuit
   B. Open circuit
   C. Ground circuit
   D. Dead circuit

4.0.0 MAGNETISM

A magnetic field is described as invisible lines of force which come out of the North Pole and enter the South Pole of a magnet. For example, if iron filings were sprinkled on a piece of glass on top of a bar magnet, the filings would form themselves in curved lines (*Figure 7-16*). These curved lines, extending from the two poles of the magnet, follow the magnetic lines of force surrounding the magnet. Lines of force rules are as follows:

- The lines of force (outside the magnet) pass from the North Pole to the South Pole of the magnet.
- The lines of force act somewhat as rubber bands and try to shorten to minimum length.
- The lines of force repel each other along their entire length and try to push each other apart.
- The rubber band characteristic opposes the push-apart characteristic.
- The lines of force never cross each other.
- The magnetic lines of force, taken together, are referred to as the magnetic field of the magnet.



The magnetic fields of a bar and of a horseshoe magnet are shown in *Figure 7-17*. In each, note how the lines of force curve and pass from the North Pole to the South Pole.

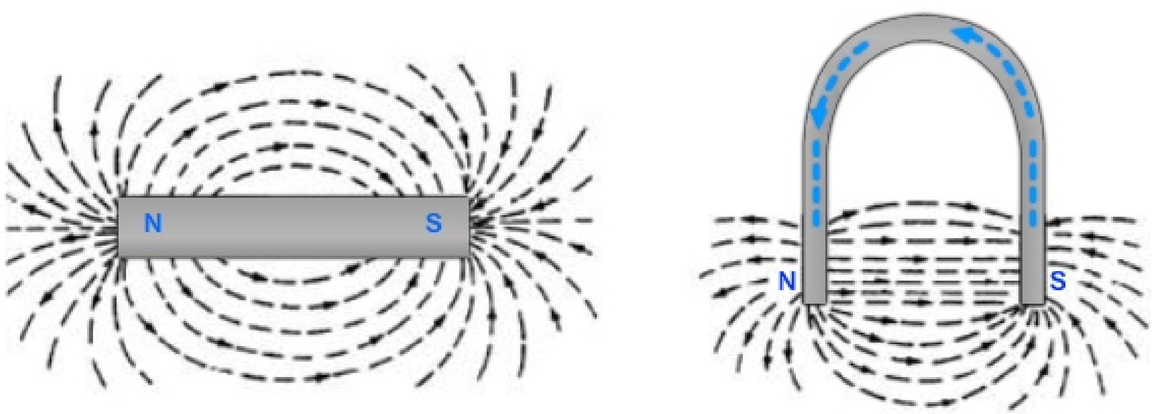


Figure 7-17 — Magnetic fields.

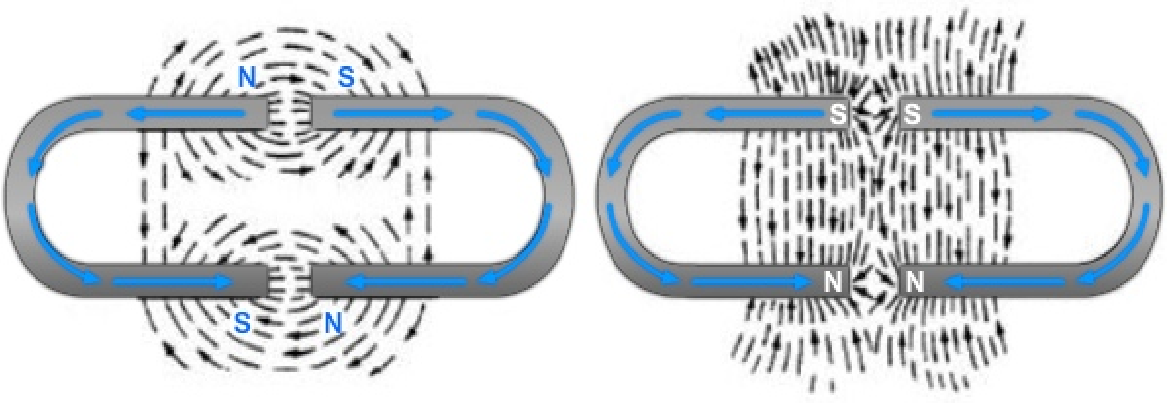


Figure 7-18 — Effects between magnetic poles.

Effects between magnetic poles are depicted in *Figure 7-18*. When two unlike magnetic poles are brought together, they attract. When like magnetic poles are brought together, they repel. These actions can be explained in terms of the rubber band and the push apart characteristics. When unlike poles are brought close to each other, the magnetic lines of force pass from the North Pole to the South Pole. They try to shorten (like rubber bands) and, therefore, try to pull the two poles together. On the other hand, if like poles are brought close to each other, lines of force going in the same direction are brought near each other. Because these lines of force attempt to push apart, a repelling effect results between the like poles.

4.1.0 Electromagnetism

An electric current (flow of electrons) always creates a magnetic field. In the wire shown in *Figure 7-19*, current flow causes lines of force to circle the wire. It is thought that these lines of force result from the movement of the electrons along the wire. As they move, the electrons send out the lines of force. When many electrons move, there are many lines of force (the magnetic field is strong). Few electrons in motion means a weak magnetic field or few lines of force.

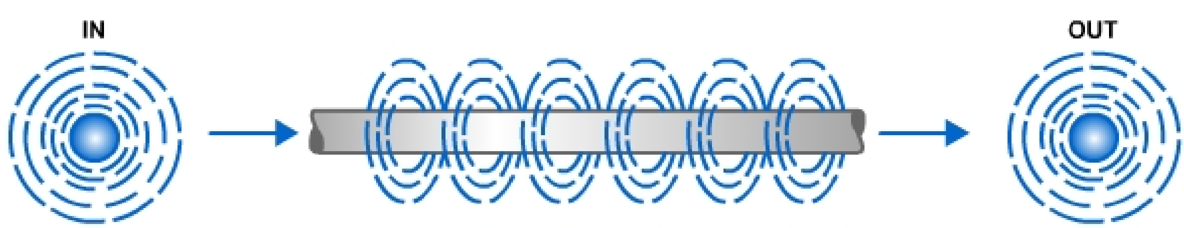


Figure 7-19 — Electromagnetism.

Electron movement as the basis of magnetism in bar and horseshoe magnets can be explained by assuming that the atoms of iron are so lined up in the magnets that the electrons are circling in the same direction and their individual magnetic lines of force add to produce the magnetic field.

The magnetic field is produced by current flowing in a single loop of wire (*Figure 7-20*). The magnetic lines of force circle the wire, but here they must follow the curve of the wire. If two loops are made in the conductor, the lines of force will circle the two loops. In the area between the adjacent loops, the magnetic lines are going in opposite directions. In such a case, because they are of the same strength (from same amount of current traveling in both loops), they cancel each other out. The lines of force, therefore, circle the two loops almost as though they were a single loop. However, the magnetic field will be twice as strong because the lines of force of the two loops combine.

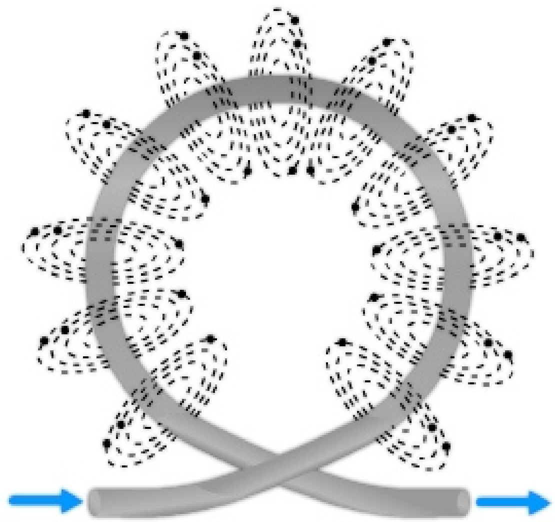


Figure 7-20 — Electromagnetism in a wire loop.

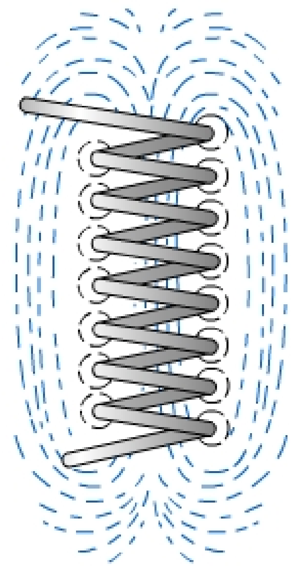


Figure 7-21 — Electromagnetism in a wire coil.

When many loops of wire are formed into a coil, the lines of force of all loops combine into a pattern that greatly resembles the magnetic field surrounding a bar magnet (*Figure 7-21*). A coil of this type is known as an electromagnet or a solenoid. Electromagnets can be in many shapes. The field coils of generators and starters, the primary winding in an ignition coil, the coils in electric gauges, and even the windings in a starter armature can be considered to be electromagnets. All of these components produce magnetism by electrical means.

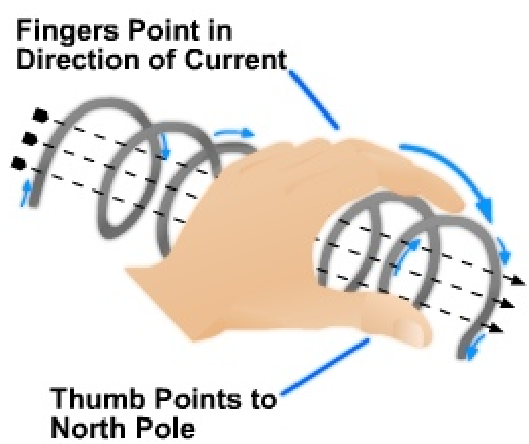


Figure 7-22 — Left-hand rule.

The North Pole of an electromagnet can be determined, if the direction of current flow (from negative to positive) is known, by use of the left-hand rule (*Figure 7-22*). The left hand is wrapped around the coil with the fingers pointing in the direction of current flow. The thumb will point to the North Pole of the electromagnet. This rule is based on current, or electron, flow from negative to positive.

If the direction of current is known, the left-hand rule also can be used to determine the direction that the lines of force circle a wire carrying current. This is done by circling the wire with the left hand with the thumb pointing in the direction of current flow (negative to positive). The fingers will then point in the direction that the magnetic field circles the wire.

The strength of an electromagnet can be increased greatly by wrapping the loops of wire around an iron core. The iron core passes the lines of force with much greater ease than air. This effect of permitting lines of force to pass through easily is called permeability. Wrought iron is 3,000 times more permeable than air. In other words, it allows 3,000 times as many lines of force to get through. With this great increase in the number of lines of force, the magnetic strength of the electromagnet is greatly increased, even though no more current flows through it. Practically all electromagnets use an iron core of some type.

4.2.0 Electromagnetic Induction

Current can be induced to flow in a conductor if it is moved through a magnetic field at 90^0 or perpendicular to the lines of force. In *Figure 7-23*, the wire is moved downward through the magnetic field between the two magnetic poles. As it moves downward cutting into the lines of force, current is induced in it. The reason for this is that the line of force resists cutting and tends to wrap around the wire as shown. With lines of force wrapping around the wire, current is induced. The wire movement through the magnetic field produces a magnetic whirl around the wire, which pushes the electrons along the wire.

If the wire is held stationary and the magnetic field is moved, the effect is the same. All that is required is that there be relative movement between the conductor and the magnetic lines of force to produce enough voltage to move the electrons along the conductor.

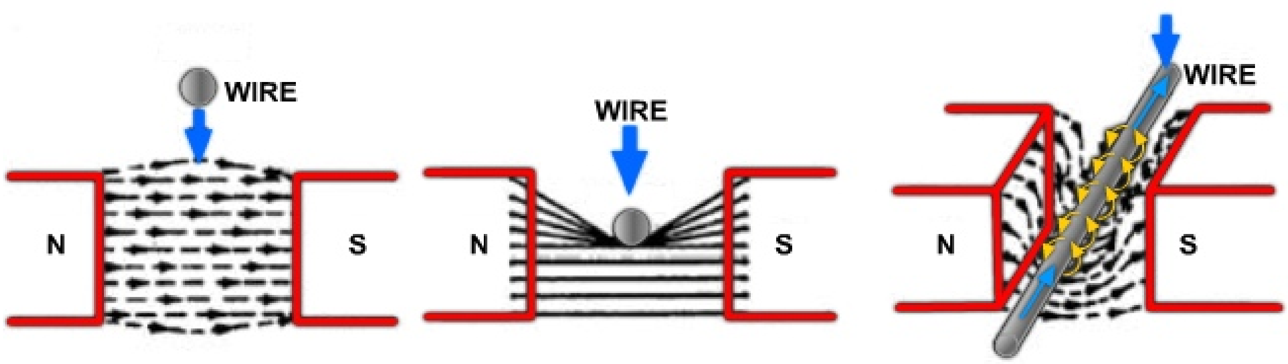


Figure 7-23 — Electromagnetism.

Moving the magnet can move the magnetic field or, if it is a magnetic field from an electromagnet, starting and stopping the current flow in the electromagnet can move it. Suppose an electromagnet, such as the one shown in *Figure 7-21*, has a wire held close to it. When the electromagnet is connected to a battery, current will start to flow through it. This current, as it starts to flow, builds up a magnetic field.

A magnetic field forms because of the current flow. This magnetic field might be considered to expand and move out from the electromagnet. As the lines of force move out, the wire will cut them. This wire will therefore have current induced in it. If the electromagnet is disconnected from the battery, these lines of force will disappear and current will stop flowing in the wire.

It can be seen now that current can be induced in a wire by three methods:

- The wire can be moved through the stationary magnetic field (this principle applied in a DC [Direct Current] generator).
- The wire can be held stationary and the magnet can be moved so the field is carried past the wire (this principle applied in an AC [Alternating Current] generator).
- The wire and electromagnet can both be held stationary and the current turned on and off to cause the magnetic field to build up and collapse so the magnetic field moves one way or the other across the wire (the principle applied in an ignition coil).

Summary

Knowledge of the electrical theories presented in this chapter is essential for the safe conduct and completion of your job as a construction mechanic. Your ability to apply this knowledge will help you when you deal with direct current and electrical circuits and when you are called upon to troubleshoot electrical circuits. During your career as a construction mechanic, you will apply these and other theories in your everyday job.

Review Questions (Select the Correct Response)

1. At least how many basic materials are in the universe?

   A. 400
   B. 300
   C. 200
   D. 100

2. The three basic particles that make up all elements are protons, electrons and _______.

   A. cytons
   B. neutrons
   C. diodes
   D. There are only two particles.

3. A group of electrons produces what type of electrical charge?

   A. Positive
   B. Negative
   C. Neutral
   D. Ionized

4. Electrons that have like charges perform what action?

   A. Attract each other
   B. Repel each other
   C. Contrast each other
   D. Distinguish each other

5. Scientists discovered that electron flow in an automotive electrical circuit flow in what manner?

   A. From positive to negative
   B. From front to back
   C. From back to front
   D. From negative to positive

6. Electrical energy is transferred through conductors by the movement of what?

   A. Free electrons
   B. Free protons
   C. Free neutrons
   D. Free quarks

7. What transistor design is the most often used in automotive applications?

   A. PPN
   B. NNP
   C. PNP
   D. NPN

8. In an electrical circuit, current (or electron) flow is measured in _______.

   A. voltage
   B. amperage
   C. resistance
   D. ohms

9. Using Ohm's law, what is the amperage in a circuit if the voltage is 13.8 and resistance is 2.25 ohms?

   A. 3.16
   B. 3.61
   C. 5.10
   D. 6.13

10. What type of circuit failure occurs when copper touches copper?

   A. Short circuit
   B. Open circuit
   C. Ground circuit
   D. Dead circuit

11. What type of circuit failure occurs when the fuse fails?

   A. Short circuit
   B. Open circuit
   C. Ground circuit
   D. Dead circuit

12. What type of circuit failure occurs when the wiring circuit is touching the vehicle frame?

   A. Short circuit
   B. Open circuit
   C. Ground circuit
   D. Dead circuit

13. To have a parallel circuit, you must have what minimum number of resistance units?

   A. Four
   B. Three
   C. Two
   D. One

14. What type of automotive circuit allows the disconnection or burning out of any individual component without affecting the operation of the others?

    A. Parallel
    B. Parallel-series
    C. Series
    D. Series-parallel

15. When the direction of current flow is known, what rule can be used to determine the north pole of an electromagnet?

    A. Right-hand
    B. Left-hand
    C. Lines-of-force
    D. Ohm's

16. How is electromagnetic induction produced in an AC generator?

    A. The wire is moved through a stationary magnetic field.
    B. The wire is stationary and the magnet is moved so the magnetic field is carried past the wire.
    C. The wire and electromagnet are both held stationary and current is turned on and off.
    D. Both the wire and electromagnet are moved, thereby alternating the magnetic field.

Trade Terms Introduced in this Chapter

Matter	Anything that has mass and occupies a volume.
Boron	The chemical element with atomic number 5 and the chemical symbol B. Boron is a trivalent metalloid element which occurs abundantly in the evaporite ores borax and ulexite. Elemental boron is used as a dopant in the semiconductor industry, while boron compounds play important roles as light structural materials, insecticides and preservatives, and reagents for chemical synthesis.
Electromotive force	The external work expended per unit of charge to produce an electric potential difference across two open-circuited terminals

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Heavy Duty Truck Systems 4th Edition, Sean Bennett, Delmar Cengage Learning Company, INC., 2006. (ISBN-13:978-1-4018-7064-5)

Automotive Technology, A systems Approach Fourth Edition, Jack Erjavec, The Thomson-Delmar Learning Company, Inc., 2005. (ISBN 1-4018-4831-1)

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