5

Prerequisite: Chapters 1, 2, 3, and 4

FUNDAMENTALS OF ELECTRICITY

OBJECTIVES

After reading this chapter, you should be able to:

- Define the terms *electricity* and *electronics.*
- Describe atomic structure.
- Outline how some of the chemical and electrical properties of atoms are defined by the number of electrons in their outer shells.
- Outline the properties of conductors, insulators, and semiconductors.
- Describe the characteristics of *static electricity.*
- Define what is meant by the *conventional* and *electron theories* of current flow.
- Describe the characteristics of magnetism and the relationship between electricity and magnetism.
- Describe how electromagnetic field strength is measured in common electromagnetic devices.
- Define what is meant by an electrical circuit and the terms *voltage, resistance,* and *current flow.*
- Outline the components required to construct a typical electrical circuit.
- Perform electrical circuit calculations using Ohm's Law.
- Identify the characteristics of DC and AC.
- Describe some methods of generating a current flow in an electrical circuit.
- Describe and apply Kirchhoff's First and Second Laws.

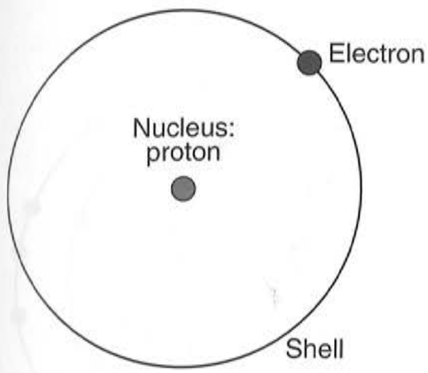
KEY TERMS

ampere
anode
armature
capacitor
cathode
circuit breakers
closed circuit
conductor
conventional theory
current flow
dielectric
electricity
electromotive force (EMF)
electronics
electron theory
electron
ground
hotel loads
insulator
ion
Kirchhoff's Laws
magnetomotive force (mmf)
negative temperature coefficient (NTC)
ohm
Ohm's Law
open circuit
parallel circuit
positive temperature coefficient (PTC)
resistance
semiconductors
series circuit
series-parallel circuits
shorepower
short circuit
solenoid
static electricity
step-down transformers
step-up transformer
thermocouple
transformer
valence
voltage
watt

INTRODUCTION

This chapter introduces basic electrical principles. These principles are applied in later chapters that deal with chassis electrical components. Any vehicle technician must have a good understanding of basic electricity, because almost every subcomponent on a modern truck is managed and monitored by electrical and electronic devices.

FIGURE 5–1 Hydrogen atom



a positive electrical charge, whereas neutrons have no electrical charge. The nucleus of an atom makes up 99.9 percent of its mass. This means that most of the weight of any atom is concentrated in its nucleus. The number of protons in the nucleus is the atomic number of any given element. The sum of the neutrons and protons is the atomic mass number. In a balanced or electrically neutral atom, the nucleus is surrounded by as many electrons as there are protons.

ELECTRONS AND PROTONS

All electrons are alike. All protons are alike. The number of protons associated with the nucleus of an atom identifies it as a specific element. Electrons have a tiny fraction of the mass of a proton. Under normal conditions, electrons are bound—that is, held in their orbital shells—to the positively charged nuclei of atoms by the attraction between opposite electrical charges.

Any atom may possess more or fewer electrons than protons. An atom with an excess or deficit of electrons retains the character of the element. Such an atom is described as *negatively* (an excess of electrons) or *positively* (a net deficit of electrons) charged and is known as an **ion**. For instance, a copper atom with a shortage or deficit of electrons could be called a positive copper ion, meaning that it would be inclined to steal electrons from other substances.

ATOMIC SHELLS

Each shell within the structure of an atom is an orbital path. The concentric shells of an atom proceed outward from the nucleus of an atom. The electrons in the shells closest to the nucleus of an atom are held most tightly. Those in the outermost shell are held more loosely and tend to be more inclined to move. As we have seen, the simplest element, *hydrogen*, has a single shell containing one electron. The most complex atoms may have seven shells. The maximum number of electrons that can occupy shells 1 through 7 are in sequence, progressing away from the nucleus: 2 (closest to the nucleus), 8, 18, 32, 50, 72, 98 (furthest from the nucleus). The heaviest elements in their normal states have only the first four shells fully occupied with electrons. The outer three shells are only partially occupied. The outermost shell in any atom is known as its **valence** shell. The number of electrons in the valence shell will dictate some basic electrical and physical characteristics of an element.

Chemical Properties of Atoms

The chemical properties of all the elements are defined by how their atoms' shells are occupied with electrons. Atomic elements with similar orbital structures will probably have other similarities in the way they behave. For instance, an atom of the element helium with an atomic number of 2 has a full inner shell, which also happens to be its valence or outermost shell. An atom of the element neon with an atomic number of 10 has both a full first and second shell (2 and 8). Its second shell is its valence. **Figure 5–2** shows a neon atom. Both helium and neon are relatively inert elements. "Inert" means that these elements are unlikely to participate in chemical reactions. Similarly, other more complex atoms that have eight electrons in their outermost shell (although this shell might not be full) will resemble neon in terms of their chemical inertness. In other words, we can say that atoms with a full valence shell are likely to have inert characteristics.

The atomic structure of an atom defines the chemical characteristics of an element. For instance, a copper atom has twenty-nine protons and twenty-nine electrons. This means that only one electron orbits the outer or valence shell (**Figure 5–3**). Unlike helium and neon, copper is reactive. It oxidizes easily and is also an excellent conductor of electricity. In fact, copper is often used as material for electrical wiring. Its hold on the electron in its valence shell is a light one; it both readily gives it up and acquires additional electrons.

FIGURE 5–2 Structure of a neon atom: The valence shell is full.

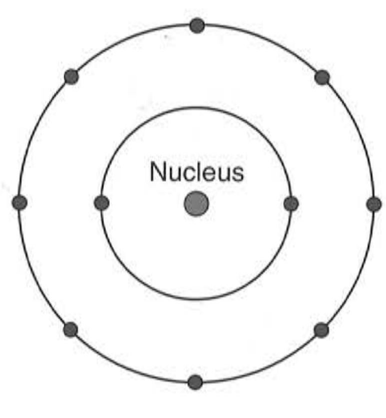
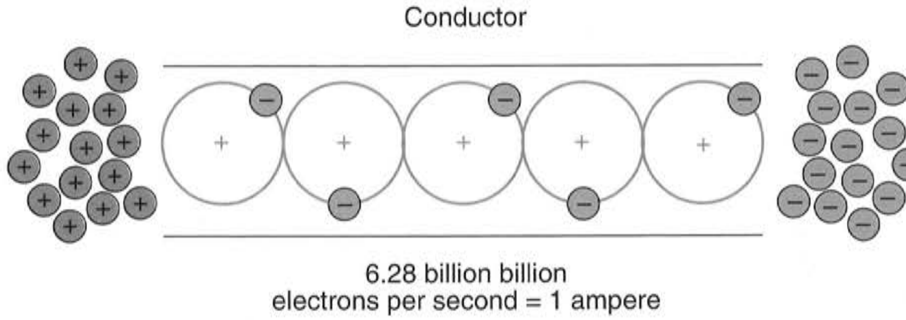


FIGURE 5–7 The rate of electron flow is measured in amperes.



An ampere, therefore, describes the number of electrons passing through a circuit over a specified time period. Specifically, 1 ampere is 6.28 billion billion (6.28×10^{18}) electrons passing a given point per second. This is shown in **Figure 5–7**. The ampere is the quantitative measurement of current. One ampere or 6.28 billion billion electrons passing a given point in a circuit in 1 second can be described as 1 *coulomb*. It is not especially important to remember these values other than to acknowledge that it is a large number.

A number of factors such as friction, heat, light, and chemical reactions can "steal" electrons from the surface of a material. When this happens, the surface becomes positively charged, meaning that it has a deficit of electrons. Atoms with a deficit of electrons are known as positive ions. Providing positive ions remain at rest, the surface will have a positive static electrical charge differential. Let us take a look at how this works in an everyday example. Every time someone walks across a carpet, electrons are "stolen" from the carpet surface. This has an electrifying effect (*electrification*) on both the substance from which electrons are stolen (the carpet) and the moving body (the person) that steals the electrons.

When this moving body has accumulated a sufficient charge differential (measured in voltage), the excess electrons will be discharged through an arc. This arc, seen as a spark, balances the charge. When the charge has been balanced, an electrically neutral state has been reestablished.

ATTRACTION AND REPULSION

Electrification results in both attractive and repulsive forces. In electricity, like charges repel and unlike charges attract. When a plastic comb is run through hair electrons will be stolen by the comb, giving it a negative charge. This means that the comb can now attract small pieces of paper, as shown in **Figure 5–8**. The attraction will continue until the transfer of electrons results in balancing the charge differential. This experiment will always work better on a dry day. Electrons can travel much more easily through humid air, and any accumulated charge will dissipate (be lost) rapidly. Two balloons rubbed on a woolen fiber will both acquire a negative charge. This enables the two balloons to "stick" to a wall, but at the same time they will tend to repel each other. The attraction of unlike charges and repulsion of like charges holds true in both electricity and magnetism.

An atom is held together because of the electrical tendency of unlike charges attracting and like charges repelling each other. Positively charged protons hold the negatively charged electrons in their orbital shells. Also, the electrons do not collide with each other because like electrical charges repel each other. All matter is composed of atoms. Electrical charge is a component of all atoms. When an atom is balanced (the number of protons match the number of electrons; see Figure 5–5), the atom can be described as being in an electrically neutral state. Given that atoms are the building blocks of all matter, it can be said that all matter is electrical in essence.

MOLECULES

Atoms seldom just float around by themselves. More often, they join with other atoms; that is, they bond chemically. Chemical bonding of atoms occurs when electrons in the valence shell of atoms are transferred or shared by a companion atom or atoms. When two

FIGURE 5–8 Unlike electrical charges attract

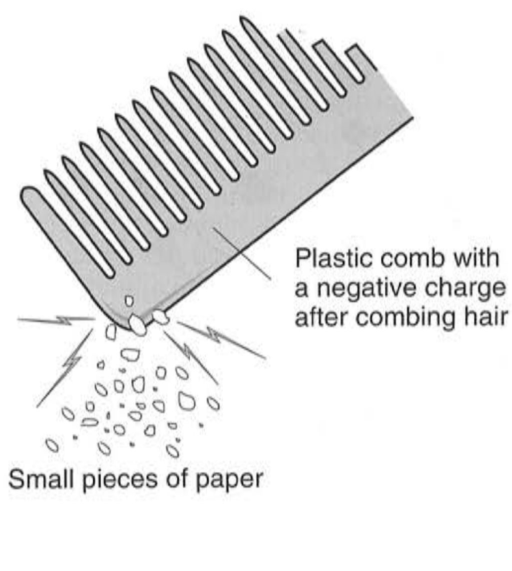
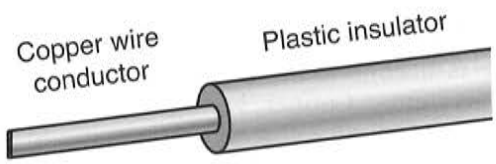


FIGURE 5–10 A copper wire conductor protected by a plastic insulator.



It is possible to flow very little current through such substances, even when they are subjected to massive charge differentials (very high voltages). Rubber, glass, and some plastics have extremely high resistivity. Both are commonly used as insulators. For instance, plastic is used to protect copper wiring in most vehicle electrical systems, as shown in **Figure 5–10**.

Between low- and high-resistance conductors and insulators is a group of materials known as semiconductors. All semiconductors have four electrons in their valence shell. The most commonly used semiconductors are silicon and germanium. These will be studied when electronics theory is introduced in Chapter 6.

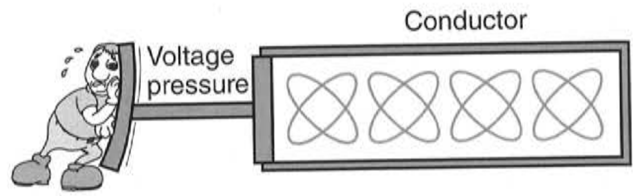
ELECTRON MOVEMENT

Electrons do not actually move through an electrical circuit at high velocity, although the force that moves them does. If a row of pool balls is lined up so that each kiss-contacts the other and the row is struck by a rapidly moving ball, the moving ball stops, imparting a force to the stationary balls that is transmitted through them at high speed but does not move any but the final ball in the row. Most of the force of the moving ball is transferred to the final ball in the row, which separates and moves off from the row. Electron movement through a conductor is somewhat similar. Although actual electron movement through a conductor is not rapid, the electromotive force travels through the conductor at nearly the speed of light.

5.3 CURRENT FLOW

Current flow will occur only when there is a path and a difference in electrical potential. This difference is known as *charge differential* or *potential difference* and is measured in *voltage.* Charge differential exists when the electrical source has a deficit of electrons and therefore is positively charged. Because electrons are negatively charged and unlike charges attract, electrons will flow toward a positive source when provided with a path. Charge differential is electrical pressure (**Figure 5–11**), and it is measured in voltage.

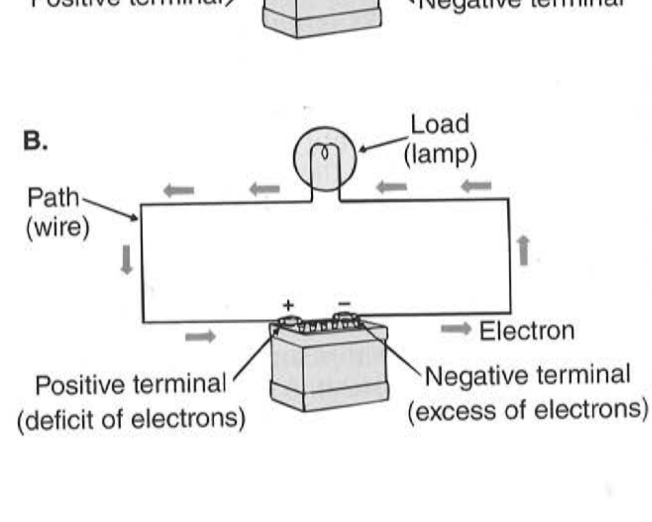
FIGURE 5–11 Voltage or charge differential is the pressure that causes electrons to move.



Initially many scientists thought that current flow in an electrical circuit had one direction of flow—that is, from positive to negative. This is known as the *conventional theory* of current flow. It originated from Ben Franklin's observations and conclusions from his kite in the electrical storm experiment. When the electron was discovered, scientists revised the theory of current flow and called it **electron theory**. In studying electricity, the technician should be acquainted with both the conventional and electron theories of current flow. However, vehicle schematics and voltmeters use the conventional theory almost exclusively. Conventional and electron theories of electrical circuit flow are shown in **Figure 5–12**.

A conductor such as a piece of copper wire contains billions of neutral atoms whose electrons move randomly from atom to atom, vibrating at high frequencies. When an external power source

FIGURE 5–12 Electrical circuit flow: (A) conventional theory; (B) electron theory.



The polarity of the electromagnet created can be determined by the right-hand rule for coils. The coiled wire should be held with the fingers pointed in the direction of conventional current flow (positive to negative), and the thumb will point to the north pole of the coil. This concept is demonstrated in Figure 5–15. The strength of an electromagnet is known as its *electromagnetic field force.*

ELECTROMAGNETIC FIELD FORCE

Electromagnetic field force is often quantified or measured as **magnetomotive force (mmf)**.

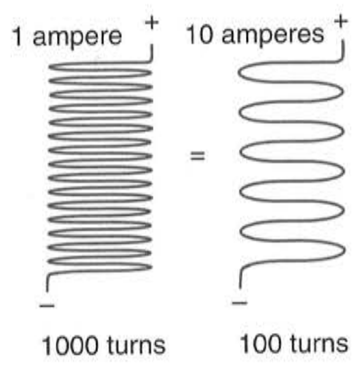
Magnetomotive force (mmf) is determined by two factors:

- The amount of current flowed through the conductor
- The number of turns of wire in a coil

Magnetomotive force is measured in ampere-turns (At). Ampere-turn factors are the number of windings (complete turns of a wire conductor) and the quantity of current flowed (measured in amperes). For instance, if a coil with 100 windings has 1 ampere of current flowed through it, the result will be a magnetic field strength rated at 100 At. An identical magnetic field strength rating could be produced by a coil with 10 windings with a current flow by 10 amperes. The actual field strength must factor in reluctance. In other words, the actual field strength of both coils would be increased if the coil windings were to be wrapped around an iron core. **Figure 5–17** shows a pair of coils of equal field strength, but because of its larger number of windings, the one on the left requires much less current flow.

A common use of an electromagnet would be that used in an automobile salvage yard crane. By switching the current to the lift magnet on and off, the operator can lift and release scrap cars. Electromagnetic principles are used extensively in vehicle electrical systems. They are the basis of every solenoid, relay, coil, generator, and electric motor.

FIGURE 5–17 Magnetic field strength is determined by the amount of amperage and the number of coils.



5.6 ELECTRICAL CURRENT CHARACTERISTICS

Electrical current is classified as either direct current or alternating current. Technicians should understand the basic characteristics of both. Electricity can be produced by any number of means, some of which have been discussed already. This section discusses the types of current flow and how electricity can be produced.

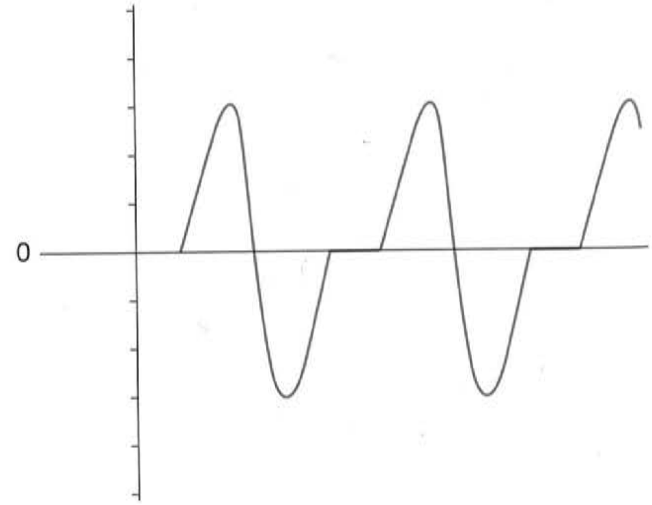
DIRECT CURRENT (DC)

Like water through a pipe, electrical current can be made to flow in two directions through a conductor. If the current flows in one direction only, it is known as direct current, usually abbreviated as DC. The current flow may be steady (continuous) or have a pulse characteristic (controlled variable flow). DC can be produced in a number of ways outlined later in this section. DC has many applications and is extensively if not quite exclusively used in highway vehicles throughout most of the chassis electrical circuits.

ALTERNATING CURRENT (AC)

Alternating current, or AC, describes a flow of electrical charge that cyclically reverses at high speed due to a reversal in polarity at the voltage source. AC is often shown in graph form (**Figure 5–18**). It is usually

FIGURE 5–18 Graphed AC voltage signal typical of that produced by an inductive pulse generator sensor



- Total circuit resistance will always be less than the lowest resistance load device in the circuit. As resistances are added in parallel, they provide additional paths for current flow; therefore, total circuit resistance must drop.
- The current flow through each load device will depend on its actual resistance. This may be calculated using Ohm's Law.
- Applied voltage is the same on each branch of a parallel circuit.
- The voltage drop through each path in a parallel circuit is the same and equals the source voltage.
- The sum of the current flows measured in amperage in the separate branches of a parallel circuit must equal the total amperage flowed through the circuit.

SERIES-PARALLEL CIRCUIT

Many circuits are constructed using the principles of both series and parallel circuits. These are known as **series-parallel circuits**. The principles used to calculate circuit values in series and parallel circuits are used to calculate circuit behavior in series-parallel circuits.

ELECTRICAL CIRCUIT TERMINOLOGY

The following terminology is used to describe both normal and abnormal behaviors in an electrical circuit.

Short Circuit

A **short circuit** describes what occurs in an electrical circuit when a conductor is placed across the connections of a component and some or all of the circuit current flow takes a shortcut. Short circuits are generally undesirable and can quickly overheat electrical circuits. Electricity will almost always choose to flow through the shortest possible path—that is, the path of least resistance—in order to complete a circuit. Short circuits result in excessive current flow, which can rapidly overheat wiring harnesses and cause vehicle fires.

Open Circuit

The term *open circuit* describes any electrical circuit through which no current flow occurs. A switch is used in electrical circuits to intentionally open them. An electrical circuit may also be opened unintentionally. This might occur when a fuse fails, a breaker opens, a wire breaks, or connections corrode.

Ground

The ground represents the point of a circuit with the lowest voltage potential. In vehicles, **ground** or *chassis ground* is integral. This means that the chassis forms the electrical path that acts to supply electrons for all components in the circuit. It has an excess of electrons because it is directly connected to the negative terminal of the battery. For instance, a clearance light has two terminals. One terminal is connected to the chassis ground, which has a negative potential (an excess of electrons). The second terminal is connected to a switch. When the switch is open, there is no path for current flow, so none takes place. The moment the switch is closed, a path for electrical current flow is provided. Electrons can now flow from the chassis ground (negative potential) through the light bulb filament, exiting at the positive terminal, passing through the closed switch, and returning to the positive terminal of the power source—that is, the battery.

This light bulb circuit can now be described as *energized*. Technicians used to working on vehicles always use the term *ground* to mean *chassis ground*. The voltage potential at true ground should measure close to zero.

SHOP TALK

In vehicles, one battery terminal is connected to ground, that is, the chassis. In today's vehicles, this is usually the negative terminal. So to complete a circuit a load must be connected by a current path only from the nongrounded terminal. This greatly reduces the amount of wiring required.

Short to Ground

The term *grounded circuit* is sometimes used to describe a short to ground. This means that when a circuit is closed, the electron flow bypasses the intended load by taking a shorter route to the positive point or terminal of the power source. Shorts to ground have almost no resistance. The result is excessive current flow and overheating.

High-Resistance Circuits

A high-resistance circuit is caused by loose or corroded terminals. In a high-resistance circuit, a path for current flow exists, but the path is too small for the number of electrons that are being pumped through it. The result is overheating.

OHM'S LAW

Ohm's Law says that an electrical pressure of 1V (volt) is required to move 1A (ampere) of current through a resistance of 1 Ω. It is a mathematical formula that technicians must know. In fact, just by playing around with a multimeter, you can prove it. This can be more fun for the beginner than struggling with the math, but doing both is probably best. It is simple to work with, so let's take a look at it:

I = "intensity" = current in amperes
E = EMF = pressure in voltage
R = resistance = resistance to current flow in Ω

$$E = I \times R \qquad R = \frac{E}{T} \qquad I = \frac{E}{R}$$

Ohm's Law can also be expressed in the units of measurement used in the following formulae:

$$V = A \times \Omega \qquad \Omega = \frac{V}{A} \qquad A = \frac{V}{\Omega}$$

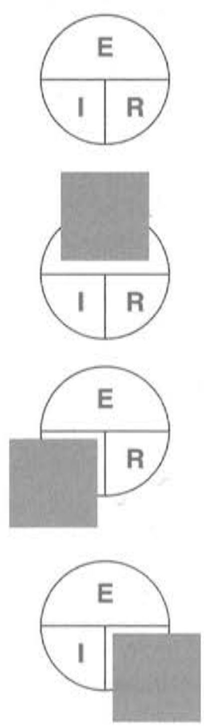
Or reference **Figure 5–28**, which shows the application of Ohm's Law formulae. Better still, memorize it—it will prove to be invaluable later when we perform electronic troubleshooting.

WORKING WITH OHM'S LAW

We can solve Ohm's Law with the circular diagram in Figure 5–28 by simply covering the value we wish to find and using simple algebra to calculate it. For instance, to calculate the amount of voltage required to push 4A through a resistance of 3 V, we would do the following: The unknown value is voltage represented by the letter *E* in the Ohm's Law formula. Cover the E. The result is that the I and R values are side by side. Construct an equation as follows:

$$E = I \cdot R$$
$$E = 4\,(\text{amps}) \cdot 3\,(\text{ohms}) = 12\,(\text{volts})$$

FIGURE 5–28 Ohm's Law graphic



Now we use another set of values and calculate current flow. To determine how much current will flow in a circuit in which there is a charge differential of 12V acting on a resistance of 4 Ω, first we cover the I, which represents current in the formula. Now we see E over R, so an equation can be constructed as follows:

$$I = \frac{E}{R} \qquad I = \frac{12V}{4\Omega} = 3A$$

Ohm's Law Applied to Series Circuits

Now we will use some of this theory in some actual circuits. In a series circuit all of the current flows through all of the resistances in that circuit. The sum of the resistances in the circuit defines the total circuit resistance. If a series circuit were to be constructed with 1Ω and 2Ω resistances, as shown in **Figure 5–29**, total circuit resistance (R_t) would be calculated as follows:

$$R_t = R_1 + R_2$$
$$R_t = 1\Omega + 2\Omega$$
$$R_t = 3\Omega$$

Notice that to construct the formula, each resistance has been identified with a number. Also, the letter *t* is often used to mean *total* when constructing formulae.

If the power source in the series circuit shown is a 12V battery, when the circuit is closed, current flow can be calculated using Ohm's Law as follows:

$$I = \frac{E}{R_t}$$
$$I = \frac{12V}{3\Omega}$$
$$I = 4\,A$$

Ohm's Law Applied to Parallel Circuits

According to Kirchhoff's Law of Current (see the next section), current flowed through a parallel circuit divides into each path in the circuit. When the current flow in each path is added, the total current equals the current flow leaving the power source. When calculating the current flow in parallel circuits, each

FIGURE 5–29 Series-circuit calculation

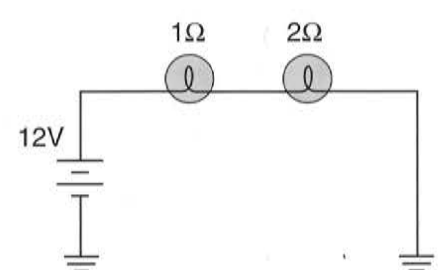


FIGURE 5–30 Parallel-circuit calculation

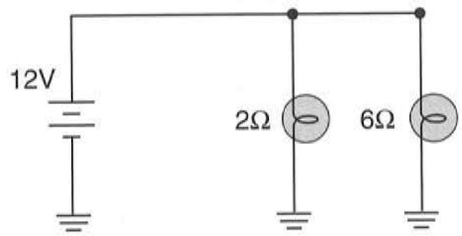
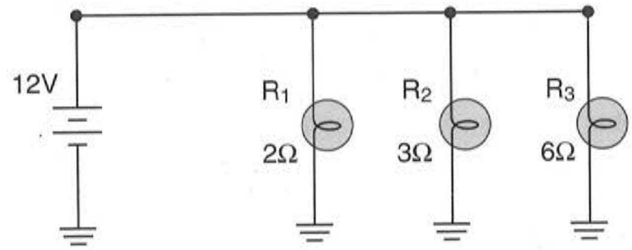


FIGURE 5–31 Multiple branch parallel circuit



current flow path must be treated as a series circuit, or the total resistance of the circuit must be calculated before calculating total current. When performing calculation on a parallel circuit, remember that more current will always flow through the path with the lowest resistance. This confirms what we said earlier in this chapter about electricity always choosing to flow through the path of least resistance. If a parallel circuit is constructed with 2Ω and 6Ω resistors in separate paths and supplied by a 12V power source as shown in **Figure 5–30**, total current flow can be calculated by treating each current flow path separately, as follows:

$$I_1 = \frac{12V}{2\Omega} = 6\,A$$

$$I_2 = \frac{12V}{6\Omega} = 2\,A$$

$$I_t = 8\,A$$

Note how more current flows through the path with the least resistance. Another means of accomplishing the same result can be used to calculate R_t:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_t = \frac{6\Omega \times 2\Omega}{6\Omega + 2\Omega} = \frac{12V}{8} = 1.5\Omega$$

$$I = \frac{E}{R}$$

$$I = \frac{12V}{1.5\Omega} = 8\,A$$

You may also use the following formula known as the reciprocal method to produce the same result:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_t} = \frac{1}{2\Omega} + \frac{1}{6\Omega}$$

Find the common denominator and solve as follows:

$$\frac{1}{R_t} = \frac{3+1}{6\Omega} = \frac{4}{6\Omega} = \frac{6\Omega}{4} = 1.5\Omega$$

Once you know the total resistance value, you use Ohm's Law to calculate current flow:

$$I = \frac{E}{R}$$

$$I = \frac{12V}{1.5\Omega} = 8\,A$$

R_t in Multiple Branch Parallel Circuits

The challenge of applying Ohm's Law to multiple branch parallel circuits is in calculating the total circuit resistance before using Ohm's formula. You should use the reciprocal method we used before. So in a parallel circuit with three branches, the reciprocal formula is as follows:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Take a look at **Figure 5–31** and apply the data to the foregoing formula as follows:

$$\frac{1}{R_t} = \frac{1}{2\Omega} + \frac{1}{3\Omega} + \frac{1}{6\Omega}$$

Find the common denominator:

$$R_t = \frac{3+2+1}{6\Omega} = \frac{6}{6} = 1\Omega$$

$$R_t = 1\Omega$$

Once you have calculated the R_t value, you can use Ohm's Law to calculate the other circuit conditions.

Series-Parallel Circuit

Some vehicle electrical circuits are of the series-parallel type. A series-parallel circuit combines the characteristics of both the series circuit and the parallel circuit. Once again, the key to applying Ohm's Law to this type of circuit is to first accurately calculate the circuit resistance. **Figure 5–32** shows how a series-parallel circuit calculation is achieved.

The first step is to resolve the resistance of the parallel branch of the circuit. With that done, you can treat the circuit as a series circuit. Follow the steps as outlined in Figure 5–32.

When performing circuit analysis and calculation, visualizing the circuit in terms of paths for current flow helps. When you learn how to visualize electricity

- An electromagnetic switch is used in a truck electrical circuit to enable a low-current circuit to control a high-current circuit.
- A relay is an example of an electromagnetic switch.
- A solenoid uses similar operating principles to an electromagnetic switch except that it converts electromagnetic energy into mechanical movement.
- Solenoids are used extensively in truck electrical circuits for functions such as starter engage mechanisms, diesel electronic unit injector controls, automatic transmission clutch controls, and suspension pilot switches.
- Piezo actuators function on the reversibility of piezoelectric effect. They can replace solenoids and have the advantage over solenoids of responding almost immediately to an electrical impulse.

REVIEW QUESTIONS

1. A material described as an insulator has how many electrons in its outer shell?
   a. less than 4
   b. 4
   c. more than 4
2. Which of the following is a measure of electrical pressure?
   a. amperes
   b. ohms
   c. voltage
   d. watts
3. Which of following units of measurement expresses electron flow in a circuit?
   a. volts
   b. watts
   c. farads
   d. amps
4. How many electrons does the element silicon have in its outer shell?
   a. 2
   b. 4
   c. 6
   d. 8
5. Who originated the branch of electricity generally described as *electromagnetism*?
   a. Franklin
   b. Gilbert
   c. Thomson
   d. Faraday
6. Which of the following elements could be described as being electrically inert?
   a. oxygen
   b. neon
   c. carbon
   d. iron
7. Which of the following is a measure of charge differential?
   a. voltage
   b. wattage
   c. amperage
   d. ohms
8. An element classified as a semiconductor would have how many electrons in its outer shell?
   a. less than 4
   b. 4
   c. more than 4
   d. 8
9. Which of the following describes resistance to movement to magnetic lines of force?
   a. reluctance
   b. inductance
   c. counter electromotive force
   d. capacitance
10. Use Ohm's Law to calculate the current flow in a series circuit with a 12V power source and a total circuit resistance of 6 Ω.
11. Calculate the power consumed in a circuit through which 3A are flowed at a potential difference of 24V.
12. A farad is a measure of:
    a. inductance.
    b. reluctance.
    c. charge differential.
    d. capacitance.
13. Technician A says that magnetism is a source of electrical energy in truck electrical systems. Technician B says that a chemical reaction is a source of electrical energy in truck electrical systems. Who is correct?
    a. Technician A only
    b. Technician B only
    c. both A and B
    d. neither A nor B
14. Which of the following is a measure of electrical circuit current flow?
    a. watts
    b. volts
    c. ohms
    d. amps
15. Resistance to current flow is measured in:
    a. amps
    b. volts
    c. watts
    d. ohms
16. Which of the following is the best insulator of electricity?
    a. copper
    b. aluminum
    c. distilled water
    d. tap water
17. Which type of circuit offers only one path for current flow?
    a. series
    b. parallel
    c. series-parallel
    d. open
18. A break in a circuit that causes a loss of continuity is called a:
    a. short.
    b. ground.
    c. open.
    d. overload.
19. Which of the following would cause high resistance in a closed electrical circuit?
    a. short to ground
    b. corroded terminals
    c. broken wire
    d. heavy gauge electrical wiring

20. If one branch of a parallel circuit has high resistance, how will total circuit current be affected?
    a. Current will increase.
    b. Current will decrease.
    c. Voltage will decrease.
    d. Voltage will increase.
21. When describing the negative post of a battery terminal in an energized electrical circuit, which of the following applies?
    a. It is the source of electrons flowing through the circuit.
    b. It has a deficit of electrons.
    c. It is more positive than the first load in the circuit.
    d. It is electrically neutral.
22. If an electrical connection in a closed electrical circuit heats up, which of the following would be the more likely cause?
    a. a blown fuse
    b. wire gauge thickness too large
    c. corroded connectors
    d. overcharged battery
23. When a dead short occurs, which of the following would be true?
    a. Circuit resistance increases.
    b. Current flow increases.
    c. Voltage increases.
    d. All of the above are true.
24. Which of the following components is used in a truck electrical circuit to convert electromagnetic energy into mechanical movement?
    a. an electromagnetic switch
    b. a relay
    c. a transformer
    d. a solenoid
25. A circuit protection device that opens when overloaded and then automatically resets is known as a:
    a. fuse
    b. ballast resistor
    c. cycling circuit breaker
    d. noncycling circuit breaker
26. According to Ohm's Law, what should happen to current flow if circuit resistance increases and voltage remains the same?
    a. It ceases.
    b. It increases.
    c. It decreases.
27. If you add up all the voltage drops (Kirchhoff's Second Law) in any closed electrical circuit, what should they add up to?
    a. 12 volts
    b. source voltage
    c. zero
    d. voltage at the ground terminal
28. What is the moving electrical component in a solenoid known as?
    a. the armature
    b. the coil
    c. the actuator
    d. the pinion
29. Which of the following devices is used to open and close electrical circuits?
    a. a solenoid
    b. a magnetic switch
    c. a transformer
    d. a capacitor
30. According to Watt's Law, if current flow through an electrical circuit increases, what is likely to happen to the power consumed?
    a. It increases.
    b. It decreases.
    c. It has no effect.