# The Complete Lab Manual for Electricity

Fourth Edition

Stephen L. Herman

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# The Complete Laboratory Manual for Electricity

## Fourth Edition

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**The Complete Lab Manual for Electricity, Fourth Edition**
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# The Complete Laboratory Manual for Electricity

# Preface

*The Complete Laboratory Manual for Electricity*, fourth edition, contains hands-on experiments that range from basic electricity through motor control circuits. The components used in the experiments in this manual are readily obtainable from a variety of sources and vendors. The manual assumes that the laboratory has access to 120 volts AC and 208 volts three-phase. Although the manual is written with the assumption of a 208-volt power source, most of the experiments can be performed with a 240-volt power supply. A material list is provided that lists the components necessary to perform all laboratory exercises. A suggested list of vendors is given in the Material List section.

Each unit begins with an explanation of the circuit to be connected in the laboratory. Examples of the calculations necessary to complete the exercise are given in an easy-to-follow, step-by-step procedure. If the power source is 240 volts instead of 208 volts, the student should simply substitute a value of 240 for 208 when doing calculations during the experiment. Students are expected to calculate electrical values and then connect a circuit to make measurements of electrical values.

*The Complete Laboratory Manual for Electricity*, fourth edition, provides the student with hands-on experience in constructing a multitude of circuits such as series, parallel, combination, RL series and parallel, RC series and parallel, and RLC series and parallel. Section 2 of this manual provides instruction on the basic types of switches that electricians must install whether working in a residential, commercial, or industrial application. Section 3 contains exercises in the basic types of alternating current loads such as resistive, inductive, and capacitive. Section 4 provides experiments with both single-phase and three-phase transformers.

Section 5 provides the student with hands-on experience connecting motor control circuits. This section begins with a simple start-stop push-button circuit and progresses to control circuit design.

*The Complete Laboratory Manual for Electricity*, fourth edition, is a must-have text for any curriculum dedicated to training electricians to work in a construction or industrial environment. Basic electricity, AC theory, transformers, and motor controls—this text has it all.

## New for the Fourth Edition

- Updated graphics.
- The fourth edition revision is the most comprehensive update since the text was first published. In previous editions, incandescent lamps were used as resistive loads because of their availability and cost. In the fourth edition, incandescent lamps have been replaced with fixed high-wattage resistors. The main reason for the change is that Congress has decided to phase out the availability of incandescent lamps over the next few years. Although fixed resistors are more expensive than incandescent lamps, they have the advantage that their resistance value is basically constant over a wide range of temperatures. This permits the student to make Ohm's law calculations before power is applied to the circuit and then make measurements to verify their calculations. The laboratory procedures for many of the units that are associated with Ohm's law have been rewritten to permit the students to make calculation and then measure the results.

## Instructor Site

An Instructor Companion website containing supplementary material is available. This site contains an Instructor Guide and an image gallery of text figures.

Contact Cengage Learning or your local sales representative to obtain an instructor account.

Accessing an Instructor

Companion Website from

SSO Front Door

1. Go to http://login.cengage.com and login using the instructor e-mail address and password.
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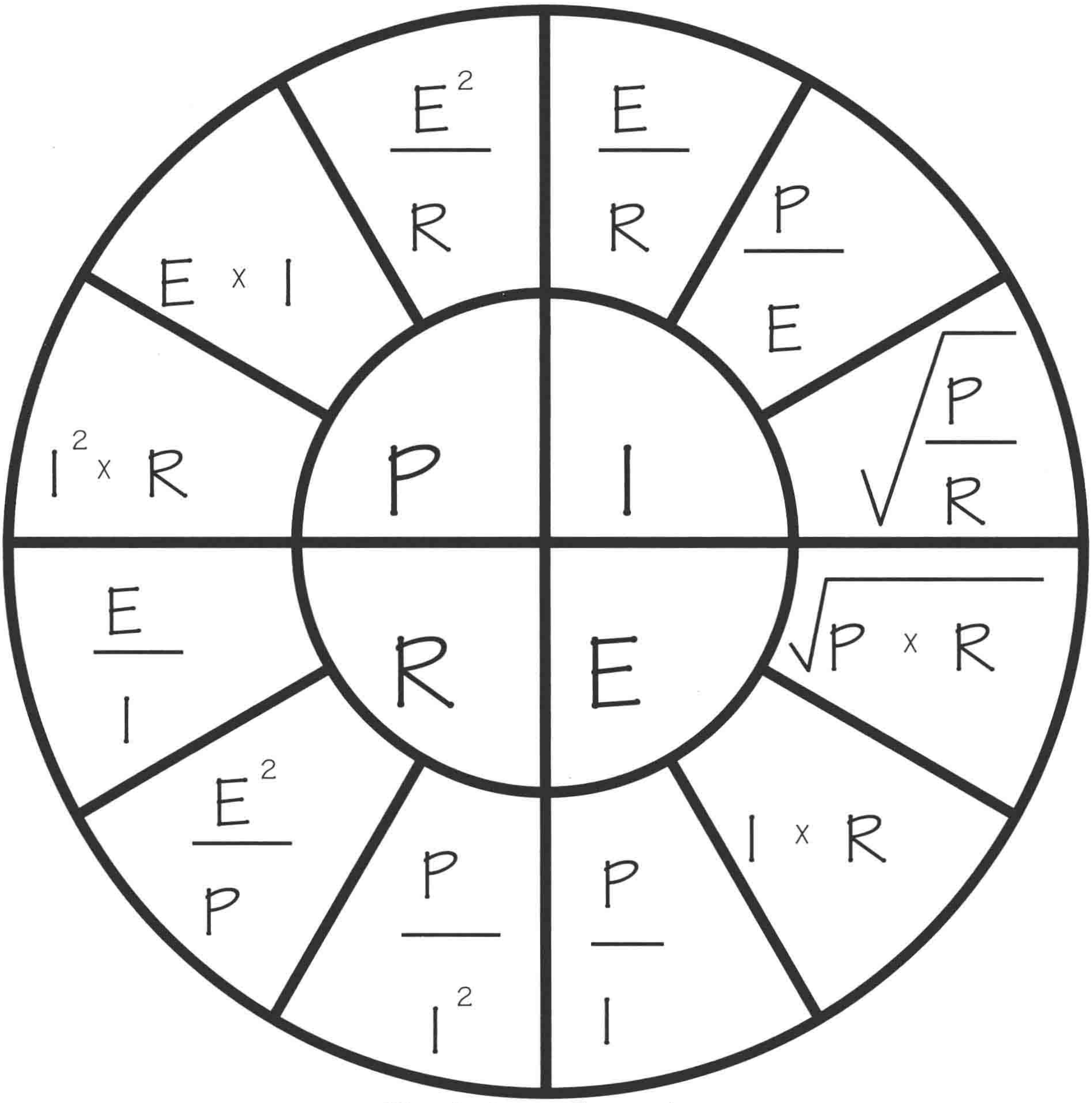



Ohm's Law Formulas

# Material List

| Quantity | Description |
|---|---|
| 2 | 250-ohm 60 watt (minimum) resistors |
| 6 | 150-ohm 100 watt (minimum) resistors |
| 2 | 100-ohm 144 watt (minimum) resistors |
| 10 | Color-coded resistors with different values |
| 3 | 0.5-kVA control transformers (two windings rated at 240 volts each and one winding rated at 120 volts) |
| 1 | 7.5-µf AC capacitor with a voltage rating not less than 240 VAC |
| 1 | 10-µf AC capacitor with a voltage rating not less than 240 VAC |
| 1 | 25-µf AC capacitor with a voltage rating not less than 240 VAC |
| 1 | 9-lead dual-voltage, three-phase motor (any horsepower) |

***CAUTION:*** *The wattage rating given for the resistors is a minimum value. Resistors with a higher wattage rating can be used without a problem. The wattage rating indicates the amount of heat that the resistor can dissipate. It should also be noted that the resistors will often become very hot during experiments and they should not be place near objects that can burn or will be damaged by heat. Take care when handling high wattage components because they can cause severe burns.*

| | |
|---|---|
| 2 ea. | 3-way switches |
| 1 ea. | 4-way switch |
| | Two-conductor romex wire (number of feet is determined by individual laboratory conditions) |
| | Three-conductor romex wire (number of feet is determined by individual laboratory conditions) |
| 1 ea. | Octagon metal box or PVC light fixture box |
| 3 ea. | Metal or PVC switch boxes |

**Motor Controls**

| | |
|---|---|
| 1 ea. | Control transformer to step your laboratory line voltage down to 120 VAC |
| 3 ea. | Three-phase motor starter that contains at least 2 normally open and 1 normally closed auxiliary contact |
| 3 ea. | Three-phase contactors (no overload relays) containing one normally open and one normally closed auxiliary contact |
| 3 ea. | Three-phase motors 1/3 to 1/4 hp or simulated motor loads. (*Note*: Assuming a 208-volt three-phase 4-wire system, a simulated motor load can be constructed by connecting three lamp sockets to form a wye connection. These lamps will have a voltage drop of 120 volts each. If a 240-volt three-phase |

system in is use, it may be necessary to connect two lamps in series for each phase. If two lamps are connected in series for each phase, these three sets of series lamps can then be connected wye or delta.)

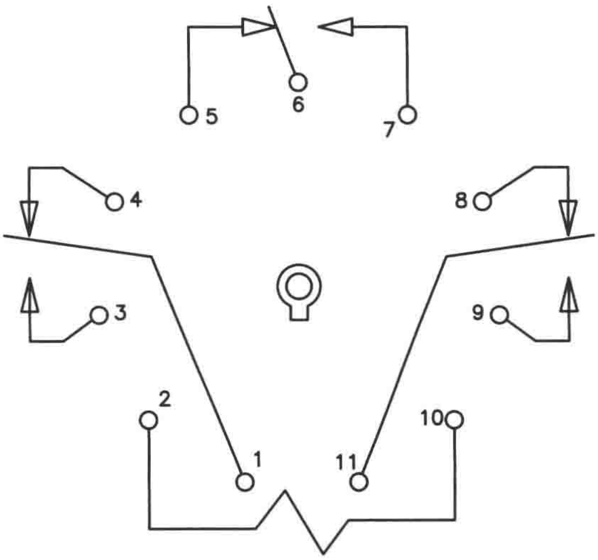
| | |
|---|---|
| 1 ea. | Three-phase overload relay or three single-phase overload relays with the overload contacts connected in series |
| 1 ea. | Reversing starter, or 2 three-phase contactors that contain 1 normally open and 1 normally closed contact, and 1 three-phase overload relay |
| 4 ea. | Double-acting push-buttons |
| 6 ea. | 3-way toggle switches to simulate float switches, limit switches, etc. |
| 4 ea. | Electronic timers (Dayton model 6A855 recommended) |
| 3 ea. | 11-pin control relays (120-volt coil) |
| 3 ea. | 8-pin control relays (120-volt coil) |
| 4 ea. | 11-pin tube sockets |
| 3 ea. | 8-pin tube sockets |
| 3 ea. | Pilot light indicators |
| 1 ea. | Three-phase power supply (This laboratory manual assumes the use of a 208-volt three-phase system. If an equivalent motor load is employed, the design may have to be modified to compensate for a higher voltage.) |

## Suppliers

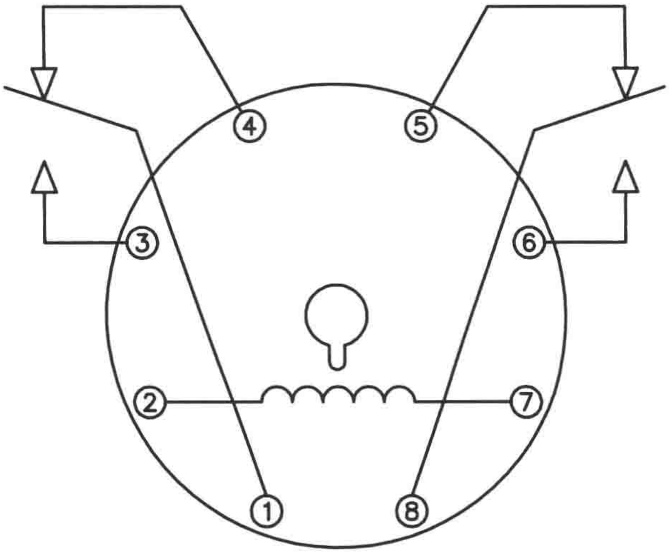
Most of the parts listed can be obtained from Grainger Industrial Supply (www.grainger.com). The Dayton model 6A855 timer is recommended because of its availability and price. Also, it is a multifunction timer and can be used as both an on- and off-delay device. It will also work as a one-shot timer and a pulse timer. Although the Dayton timer is recommended, any 11-pin electronic timer with the same pin configuration can be used. One such timer is available from Magnecraft (model TDR SRXP-120, www.magnecraft.com). This timer as also available from Mouser Electronics (www.mouser.com). Other electronic timers can be employed, but if they have different pin configurations, the wiring connections shown in the text will have to be modified to accommodate the different timer. Mouser Electronics is also a supplier for the wire-wound resistors.

The 8- and 11-pin control relays and sockets can be purchased from Grainger, Mouser Electronics, or Newark Electronics (www.newark.com). The control transformer used in the controls sections can be purchased from Mouser Electronics or Sola/Hevi-duty (www.solaheviduty.com). Model E250JN is recommended because it has primary taps of 208/240/277 volts. The secondary winding is 120/24. It is also recommended that any control transformer used be fuse protected. Another control transformer that can be used is available from Grainger. It is rated at 150 VA and has a 208-volt primary and 120-volt secondary. The 0.5-kVA control transformers are available from Grainger or Newark Electronics. Transformers rated at 0.5 kVA are used because they permit the circuit to be load heavy enough to permit the use of clamp-on type ammeters.

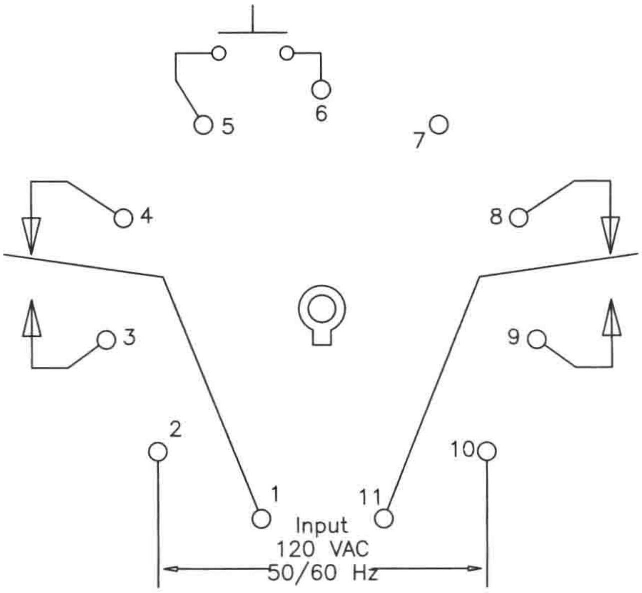
Stackable banana plugs are available from both Grainger and Newark Electronics. The oil-filled capacitors listed are available from Grainger. Color-coded resistors can be obtained from Newark Electronics or Mouser Electronics.



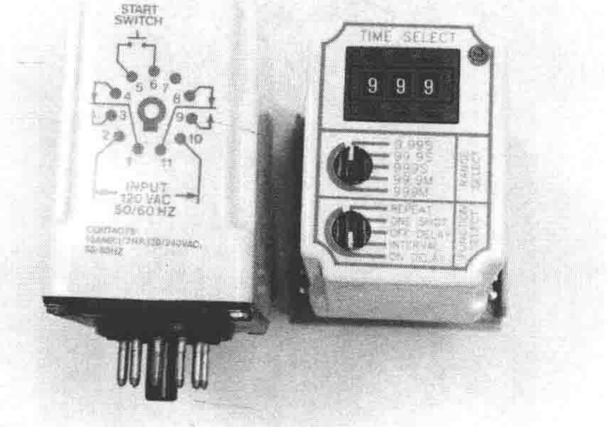

Connection diagram for an 11-pin relay.



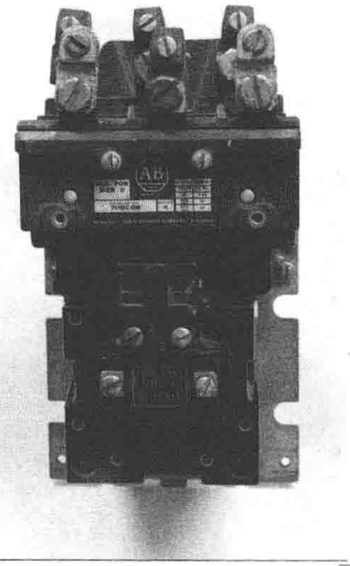

Connection diagram for an 8-pin relay.



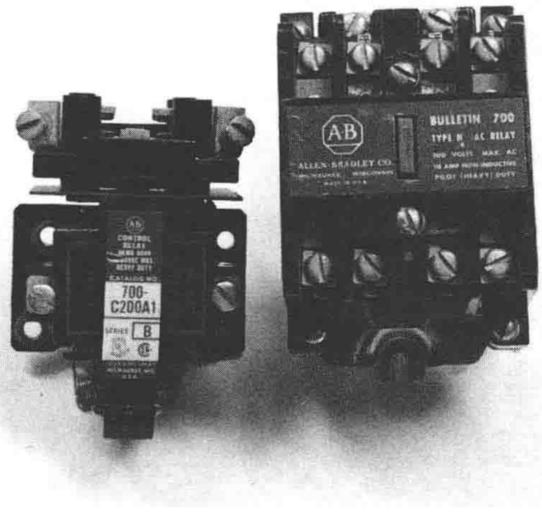

Connection diagram for a Dayton model 6A855 timer.




Dayton timer model 6A855. This timer mounts in an 11-pin tube socket and can be set to operate as a repeat timer, a one-shot timer, an interval timer, and an on-delay timer. The thumb-wheel switch sets the time value. Full range times can be set for 9.99 seconds to 999 minutes.

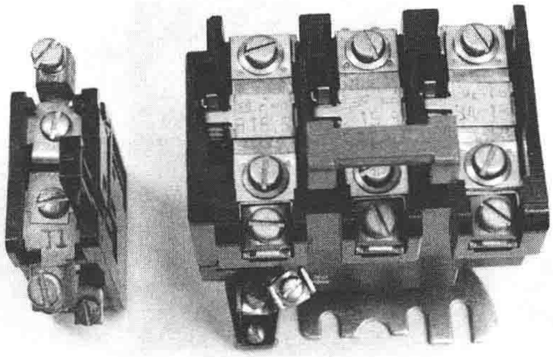


Three-phase contactor. This contactor contains one normally open auxiliary contact and three load contacts. The contactor differs from the motor starter in that the contactor does not contain an overload relay.

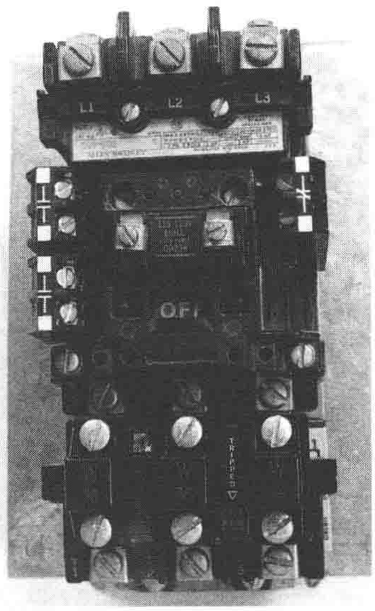



Control relays. These relays contain auxiliary contacts only and are intended to be used as part of the control circuit. They are capable of controlling low-current loads such as solenoid valves, pilot lights, and the like.

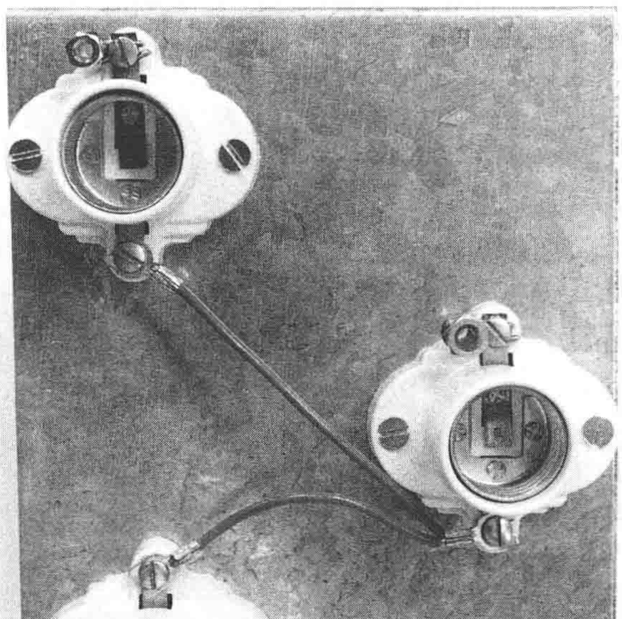

Eight-pin on-delay timing relay. This timer can be used as an on-delay timer only. Time setting is adjusted by the knob on top of the timer.



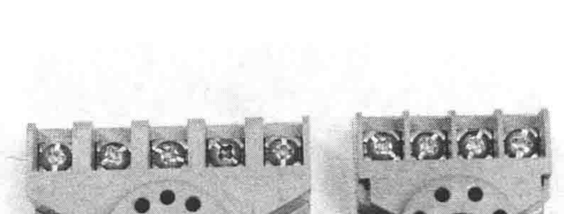
One single-phase and one three-phase overload relay. The three-phase overload relay contains three heaters but only one set of normally closed auxiliary contacts. If an overload should occur on any of the three lines, the contacts will open.



Three-phase motor starter with two normally open and one normally closed set of auxiliary contacts. Notice that a motor starter contains an overload relay as part of the unit.

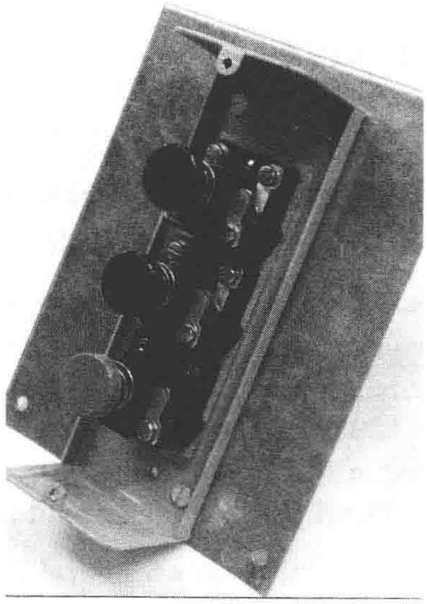


Light sockets mounted on a metal plate. The sockets have been connected to form a wye connection. This can be used to simulate a three-phase motor load.

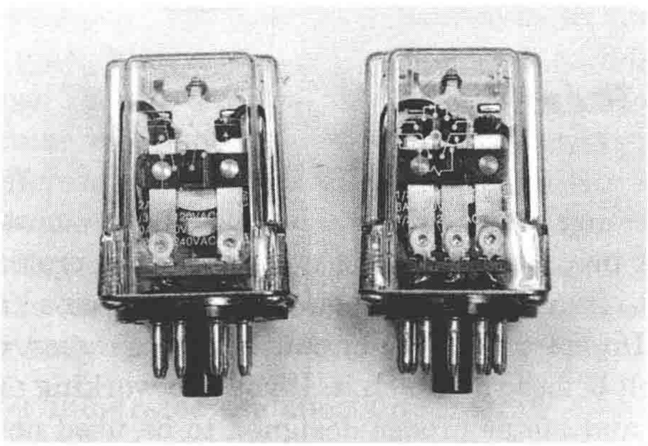


Eight- and 11-pin tube sockets. All wiring is done to the socket and the relay is then plugged into the socket.


Pneumatic off-delay timer. A microswitch has been added to the bottom to supply instantaneous contacts for the timer.



Three push-button station. The bottom push button is normally closed. The two top buttons are double action. Each contains both a normally open and normally closed set of contacts.



Eight- and 11-pin control relays contain two sets of double-acting contacts. Eleven-pin relays contain three sets of double-acting contacts.

# Safety

## Objectives

After studying this section, you should be able to:

- Discuss basic safety rules.
- Describe the effects of electric current on the body.

The purpose of this laboratory manual is to provide students of electricity with hands-on experience with electric circuits. Electricity is an extremely powerful force and should never be treated in a careless manner. This manual assumes a laboratory equipped with a 208/120 volt three-phase power system. Many of the experiments in this manual involve the use of full line voltage (208 or 120 volts). It is extremely important that you practice safety at all times. Please read and memorize the following safety rules:

- Never work on an energized circuit if it is possible to disconnect the power. When possible use a three-step check to make certain that the power is turned off. The three-step check is as follows:
  1. Test the meter on a known live circuit to make sure the meter is operating.
  2. Test the circuit that is to be de-energized with the meter.
  3. Test the meter on the known live circuit again to make certain that the meter is still operating.
- Install a warning tag at the point of disconnection to warn people not to restore power to the circuit.

## General Safety Rules

### Think

Of all the rules concerning safety, this one is probably the most important. No amount of safeguarding or "idiot proofing" a piece of equipment can protect a person as well as the person's taking time to think before acting. Many technicians have been killed by supposedly "dead" circuits. Do not depend on circuit breakers, fuses, or someone else to open a circuit. Test it yourself before you touch it. If you are working on high-voltage equipment, use insulated gloves and meter probes designed to be used on the voltage being tested. Your life is your own, so *think* before you touch something that can take it away.

### Avoid Horseplay

Jokes and horseplay have a time and place, but the time or place is not when someone is working on an electric circuit or a piece of moving machinery. Do not be the cause of someone's being injured or killed and do not let someone else be the cause of your being injured or killed.

### Do Not Work Alone

This is especially applicable when working in a hazardous location or on a live circuit. Have someone with you to turn off the power or give artificial respiration and/or cardiopulmonary resuscitation (CPR). One of the effects of severe electrical shock is that it causes breathing difficulties and can cause the heart to go into fibrillation.

### Work with One Hand When Possible

The worst case of electrical shock is when the current path is from one hand to the other. This causes the current to pass directly through the heart. A person can survive a severe shock between the hand and one foot that would otherwise cause death if the current path was from one hand to the other. Working with one hand can sometimes be an unsafe practice by itself. The best procedure is to turn off the power. If it is not possible to disconnect the power, wear insulated gloves when handling "hot" circuits. Also wear shoes that have insulated soles and use rubber mats to cover energized conductors and components when possible.

### Learn First Aid

Anyone working on electrical equipment should make an effort to learn first aid. This is especially true for anyone who must work with voltages above 50 volts. A knowledge of first aid, especially CPR, may save your life or someone else's.

### Effects of Electric Current on the Body

Most people have heard that it's not the voltage that kills but the current. Although this is a true statement, do not be misled into thinking voltage cannot harm you. Voltage is the force that pushes the current through the circuit. Voltage can be compared to the pressure that pushes water through a pipe. The more pressure available, the greater the volume of water flowing through a pipe. Students often ask how much current will flow through the body at a particular voltage. There is no easy answer to this question. The amount of current that can flow at a particular voltage is determined by the resistance of the current path. Different people have different resistances. A body will have less resistance on a hot day when sweating because salt water is a very good conductor. What a person ate and drank for lunch can have an effect on a body's resistance. The length of the current path can affect the resistance. Is the current path between two hands or from one hand to one foot? All of these factors affect body resistance.

The chart in Figure SF-1 illustrates the effects of different amounts of current on the body. This chart is general; electricity affects most people in this way. Some people may have less tolerance to electricity and others may have a greater tolerance.

A current of 2 to 3 milliamperes will generally cause a slight tingling sensation. The tingling sensation will increase as current increases and becomes very noticeable at about 10 milliamperes. The tingling sensation is very painful at about 20 milliamperes. Currents between 20 and 30 milliamperes generally cause a person to seize the line and not be able to let go of the circuit. Currents between 30 and 40 milliamperes cause muscular paralysis, and currents between 40 and 60 milliamperes cause breathing difficulty. By the time the current increases to about 100 milliamperes breathing is extremely difficult. Currents from 100 to 200 milliamperes generally cause death because the heart goes into fibrillation. Fibrillation is a condition in which the heart begins to "quiver" and the pumping action stops. Currents above 200 milliamperes generally cause the heart to squeeze shut. When the current is removed, the heart will generally return to a normal pumping action. This is the principle of operation of a defibrillator. It is often said that 120 volts is the most

| | |
|---|---|
| 0.002–0.003 amp | Sensation (a slight tingling) |
| 0.004–0.010 amp | Moderate sensation |
| 0.010–0.020 amp | Very painful |
| 0.020–0.030 amp | Unable to let go of the circuit |
| 0.030–0.040 amp | Muscular paralysis |
| 0.040–0.060 amp | Breathing difficulty |
| 0.060–0.100 amp | Extreme breathing difficulty |
| 0.100–0.200 amp | Death (fibrillation of the heart) |

**Figure SF-1** Effects of electric current on the body.

dangerous voltage to work with. The reason is that 120 volts generally causes a current flow between 100 and 200 milliamperes through the bodies of most people. Large amounts of current can cause severe electrical burns. Electrical burns are generally very serious because the burn occurs on the inside of the body. The exterior of the body may not look seriously burned, but the inside may be severely burned.

## Review Questions

1. What is the most important rule of electrical safety?

___

2. Why should a person work with only one hand when possible?

___

3. What range of electric current generally causes death?

___

4. What is fibrillation of the heart?

5. What is the principle of operation of a defibrillator?

# Contents

# SECTION 1 Measuring Instruments and Basic Electricity

## Unit 1 Measuring Instruments

### Objectives

After studying this unit, you should be able to

- Discuss the operation of a voltmeter.
- Describe differences between analog and digital voltmeters.
- Connect a voltmeter in a circuit.
- Discuss the operation of an ohmmeter.
- Measure resistance with an ohmmeter.
- Discuss differences between analog and digital ohmmeters.
- Discuss the operation of an ammeter.
- Describe the difference between in-line and clamp-on ammeters.
- Make a scale divider for clamp-on AC ammeters.

In order to conduct meaningful laboratory experiments, it is necessary to measure electrical quantities such as voltage, resistance, and current. In this unit basic measuring instruments such as voltmeters, ohmmeters, and ammeters will be presented. Their basic operation will be explained and examples of their use will be presented. It should be understood by those using electrical measuring instruments that they are not 100% accurate. Most meters have an accuracy of about +3%. This is the reason that two meters made by the same manufacturer and the same model may give different measurements. One meter may measure a voltage of 120 volts as 119.2 and the other measure the same source as 120.3. When making measurements with meters, always be aware that there may be some discrepancy between calculated and measured values. If the calculated and measured values are within about 3% of each other, they are generally considered to be the same.

### Voltmeters

Voltmeters are one of the most useful instruments in the electrical field. They are used to measure the potential difference (voltage) between two points. Voltage is often thought of as "electrical pressure." It is like measuring the amount of pressure available to push liquid through a pipe. Voltmeters can be divided into two major types: analog and digital.

## Analog Meters

Analog meters contain a pointer and scale. Most of them are part of a multimeter, which has the ability to measure several different electrical quantities (Figure 1-1). Multimeters are often called VOMs, which stands for volt-ohm-milliammeter. Since they are often part of a multimeter, it is generally necessary to choose the electrical quantity being measured. Most multimeters have the ability to measure both direct current (DC) and alternating current (AC). The meter shown in Figure 1-1, for example, can measure DC voltage (DCV), AC voltage (ACV), ohms (Rx1 and Rx10), and DC milliamps (DCmA). The position of the dial on the front of the meter determines the electrical quantity to be measured.

Analog multimeters can also be set to measure different ranges of voltage. The meter shown in Figure 1-1 has AC voltage ranges of 10, 50, 250, 500, and 1000 volts. These markings indicate the full-scale value of the meter when the indicator dial is set at one of them. Being able to set the meter for different full-scale ranges greatly increases the usefulness of the meter. If the meter were set for a value of 1000 volts, it would be very difficult to measure the voltage of a 24 volt system. If the meter were set to the 50 volt position, however, 24 volts could be measured accurately. When a voltage measurement is to be taken and the system voltage is not known, always start on the highest voltage range setting. A meter can never be hurt by connecting it to a voltage that is lower than the range setting. It is a simple thing to reset the meter to a lower range after an initial measurement has been made.

**Helpful Hint**

When a voltage measurement is to be taken and the system voltage is not known, always start on the highest voltage range setting.

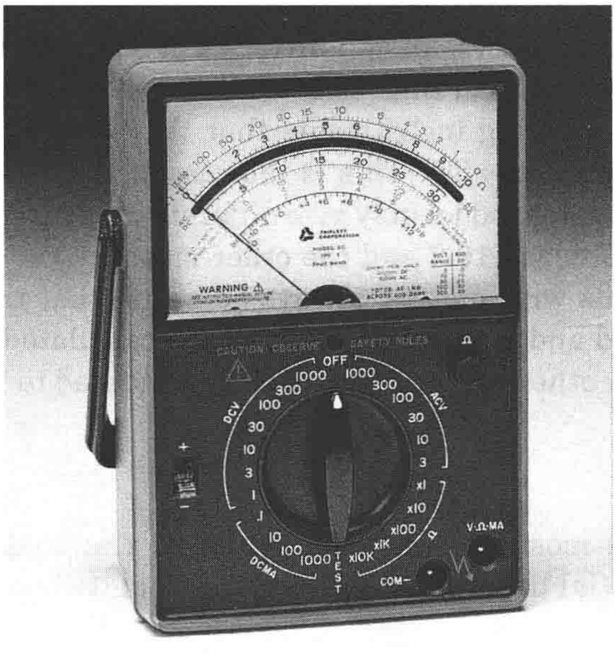



**Figure 1-1** Multimeter with an analog scale. (Courtesy of Triplett Test Equipment and Tools)

Another rule to remember when using a voltmeter is to make certain that the meter is set for the proper type of voltage. *Failure to do this can lead to serious injury.* If a DC voltage is to be measured and the meter has mistakenly been set for AC voltage, it will cause an inaccurate reading. The indicated voltage will be less than the actual voltage being measured.

**Helpful Hint**

When using a voltmeter, make certain that the meter is set for the proper type of voltage. Failure to do this can lead to serious injury.

If an AC voltage is to be measured and the meter has mistakenly been set to measure to DC voltage, the meter will indicate zero. Most analog-type meter movements are designed to operate on direct current. If an alternating current is applied to them, the pointer will try to move up scale during one-half cycle and down scale during the other. As a result, the pointer remains at zero. When the meter is set on the AC volt range, a rectifier inside the meter converts the AC voltage into DC, permitting the meter to operate.

**Helpful Hint**

If an AC voltage is to be measured and the meter has mistakenly been set to measure to DC voltage, the meter will indicate zero.

### Analog Voltmeter Operation

Analog voltmeters operate by connecting resistance in series with the meter movement. Assume, for example, that a meter movement requires 100 μA (microamperes; 0.000100 amp) at 1 volt to make the pointer move full scale. This meter movement has the ability to measure 1 volt. If more voltage is applied to it, it can be damaged or destroyed. To permit the meter to measure higher voltages, resistance is connected in series with it (Figure 1-2). Assume that a resistor is to be added that will permit the meter to measure 15 volts full scale. In a series circuit, the sum of the voltage drops must equal the applied voltage. Since the total voltage to be measured is 15 volts and the meter has a voltage drop of 1 volt, the resistor must drop 14 volts ($15 - 1 = 14$). Another rule for series circuits is that the current

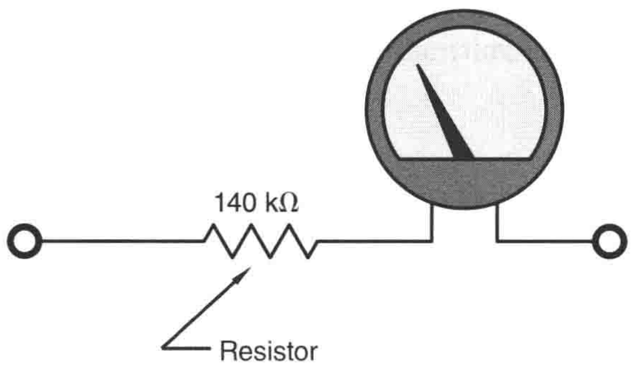



**Figure 1-2** Resistance is connected in series with the meter movement to change the full-scale value.

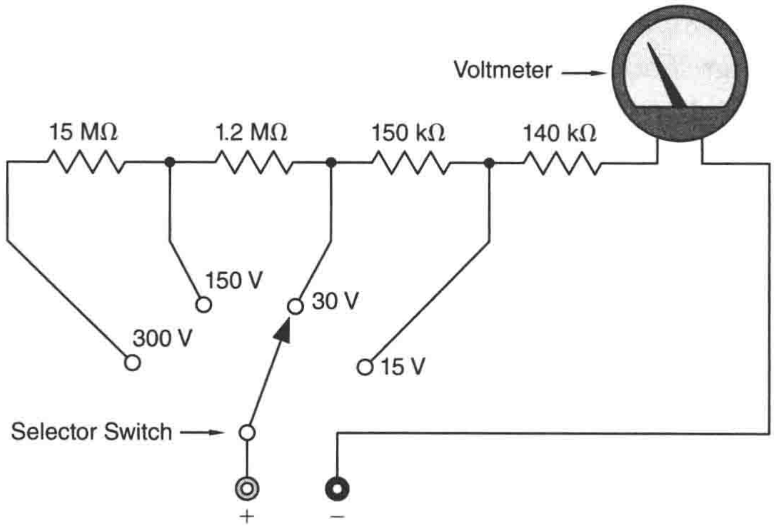



**Figure 1-3** A selector switch permits the meter to be set for different full-scale values.

at any point in the circuit must be the same. Since the meter requires a current of 100 μA, the resistor must have the same current. The resistance value needed to permit the meter to measure 15 volts is

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

$$R = \frac{14}{0.000100}$$

$$R = 140{,}000\ \Omega$$

A resistance of 140,000 Ω connected in series with the meter movement will convert the meter to a full-scale range of 15 volts.

Multirange settings are accomplished by connecting several resistors in series with the meter and permitting a range selection switch to change the amount of resistance connected in series with the meter. Assume that it is desirable to add full-scale range values of 30 volts, 150 volts, and 300 volts to the meter in Figure 1-2. The meter movement plus the 140,000 Ω resistor have a voltage drop of 15 volts at 100 μA. If the meter is to have a full-scale value of 30 volts, it will be necessary for the next resistor to have a value of 150,000 Ω (15/0.000100). The next resistor must have a voltage drop of 120 volts (150 − 30 = 120). The resistor value needed to produce a voltage drop of 120 volts at a current of 100 μA is 1,200,000 Ω (120/0.000100). The last resistor would have to have a voltage drop of 150 volts (300 − 150 = 150). The value needed for this resistor is 1,500,000 Ω (150/0.000100). A diagram of this type of multirange voltmeter is shown in Figure 1-3.

## Digital Meters

Digital voltmeters display the voltage value with numeric figures instead of a pointer. Figure 1-4 shows a digital multimeter set to read AC voltage. Like analog voltmeters, digital voltmeters are generally part of a multimeter, also. It is necessary to set a selector switch to the electrical quantity to be measured, such as AC volts, DC volts, ohms, and so on, and sometimes it is necessary to set the maximum range value. Some digital meters contain an auto-ranging function making it unnecessary to select a particular range value.


**Figure 1-4** Digital multimeter. (Courtesy of Triplett Test Equipment and Tools)

Digital voltmeters are different from analog meters in more ways than appearance. As discussed previously, analog meters insert resistance in series with the meter movement to permit the meter to be used at different full-scale values. This means that the internal resistance of the meter is different for each voltage setting. Most analog meters are marked with the ohms per volt for the meter; 20,000 Ω/VDC and 10,000 Ω/VAC is typical. The resistance of the meter can be computed by multiplying the ohms per volt value by the full-scale value of the meter. Assume that a meter indicates a resistance of 10,000 Ω/VAC for a meter and that the meter is set to indicate a full-scale value of 250 VAC. The resistance of the meter is 2,500,000 Ω (10,000 × 250). Note that the resistance of the meter will change each time the voltage range is changed.

Digital meters maintain the same amount of input resistance for all ranges. Typical input resistance for a digital voltmeter is 10 million ohms. The constant input resistance is accomplished by using a voltage divider. Digital voltmeters use high-impedance electronic components to measure voltage. This means that it is only necessary to supply the circuit with extremely small amounts of current for the meter to operate. A basic construction for a digital meter is shown in Figure 1-5. Digital voltmeters can be employed to measure voltage in almost any circumstance, but they are especially necessary when measuring the voltage in low-power circuits such as electronic circuit boards.

## Using the Voltmeter

Voltmeters are very high-resistance instruments. For this reason, they can be connected directly across the power source, as shown in Figure 1-6. When using a voltmeter, be certain that

1. The voltmeter is set to the proper quantity to be measured (DC or AC voltage).
2. The range setting is equal to or greater than the voltage to be measured. If there is any doubt, set the meter to the highest range and then reset the meter after taking an initial measurement.

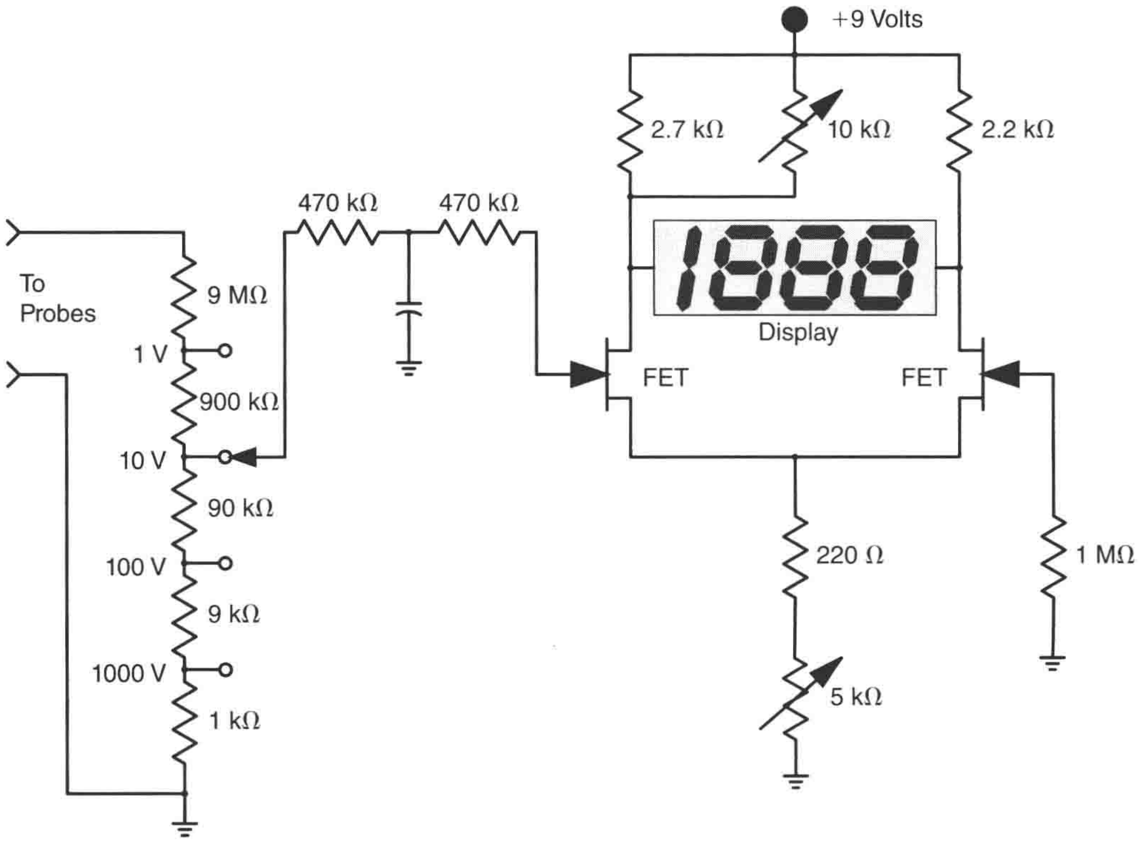



**Figure 1-5** Digital voltmeter.

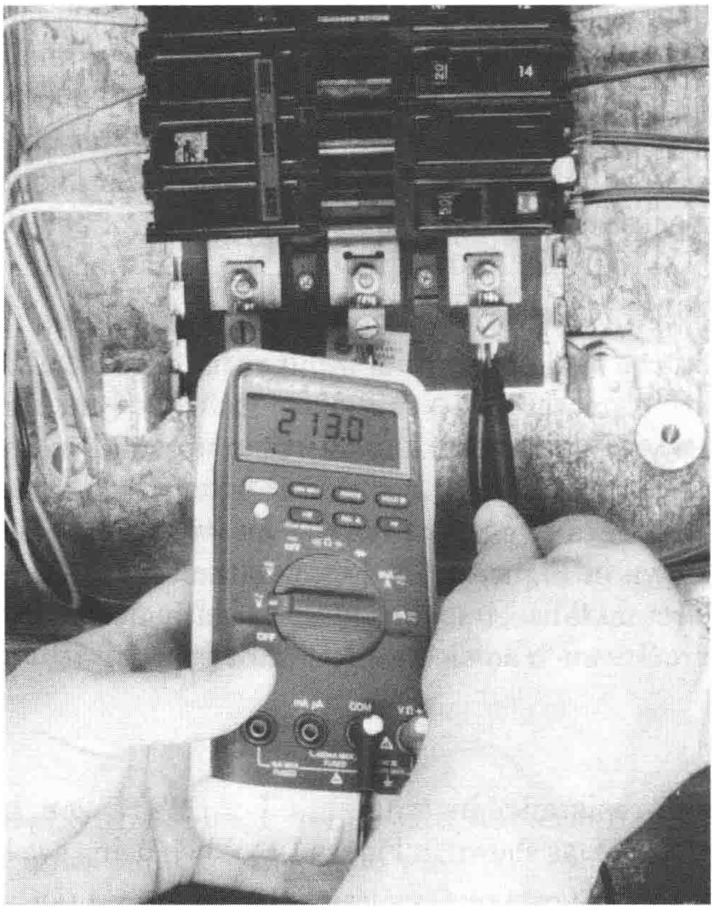



**Figure 1-6** A voltmeter can be connected directly to a power source.

**Helpful Hint**

When using a voltmeter be certain that:

1. The voltmeter is set to the proper quantity to be measured (DC or AC voltage).
2. The range setting is equal to or greater than the voltage to be measured. If there is any doubt, set the meter to the highest range and then reset the meter after taking an initial measurement.

## Safety Procedure

A set procedure is used when testing a circuit to ensure that the power is turned off.

1. Use the voltmeter to test a circuit that you know is energized.
2. Test the circuit in question with the voltmeter to make certain that the power is turned off.
3. Test the voltmeter again on a circuit that you know is energized to ensure that the voltmeter is still operating properly.

Safety is your responsibility. Your life is your own. Guard it well.

Voltmeters are also used to measure the voltage drop across components in a circuit. *Voltage drop* is the term used to describe the amount of voltage necessary to push current through a particular part of a circuit. The circuit shown in Figure 1-7 is a series circuit containing three resistors. Resistor $R_1$ has a resistance value of 80 Ω, $R_2$ has a value of 100 Ω, and $R_3$ has a resistance of 60 Ω. The circuit has an applied voltage of 120 volts. In a series circuit, the total resistance is the sum of the individual resistors. In this circuit the total resistance is 240 Ω (80 + 100 + 60). The total circuit current can be determined using Ohm's law (120/240 = 0.5 amp). Since the current is the same in a series circuit, 0.5 ampere

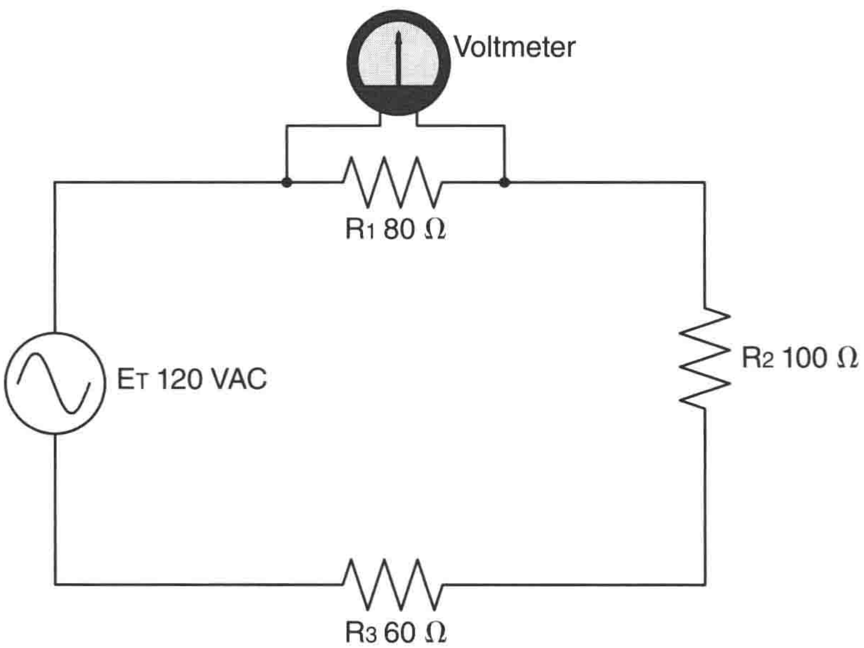



**Figure 1-7** Voltmeter used to measure the voltage drop across a resistor.

flows through all resistors. Since the resistance and current are known, the amount of voltage drop across each resistor can be determined.

$$E_1 = R_1 \times I_1$$

$$E_1 = 80 \times 0.5$$

$$E_1 = 40 \text{ volts}$$

The voltmeter shown in Figure 1-7 would indicate a value of 40 volts. This voltage drop indicates that it takes 40 volts to push 0.5 ampere of current through 80 Ω of resistance. If the voltmeter were to be connected across resistor $R_2$, it would measure a voltage drop of 50 volts, indicating that it requires 50 volts to push 0.5 ampere through 100 Ω of resistance.

## Ohmmeters

As with voltmeters, ohmmeters can be divided into two general categories: analog and digital. Analog ohmmeters use a pointer to indicate resistance value and are generally part of a multimeter. Ohmmeters must contain their own power source. They do not receive power from the circuit. The most important rule concerning the use of ohmmeters is that *ohmmeters should never be connected to a source of power*! Connecting an ohmmeter to a source of power will often result in destruction of the meter and sometimes injury to the person using the meter.

**Helpful Hint**

Ohmmeters should never be connected to a source of power!

A schematic for a basic analog ohmmeter is shown in Figure 1-8. It is assumed that the meter movement has a resistance of 1000 Ω and requires a current of 50 microamps (50 μA) to deflect the meter full scale. The power source will be a 3-volt battery. A fixed resistor with a value of 54 kΩ is connected in series with the meter movement, and a variable resistor with a value of 10 kΩ is connected in series with the meter and R1. These resistance values were chosen to ensure there would be enough resistance in the circuit to limit

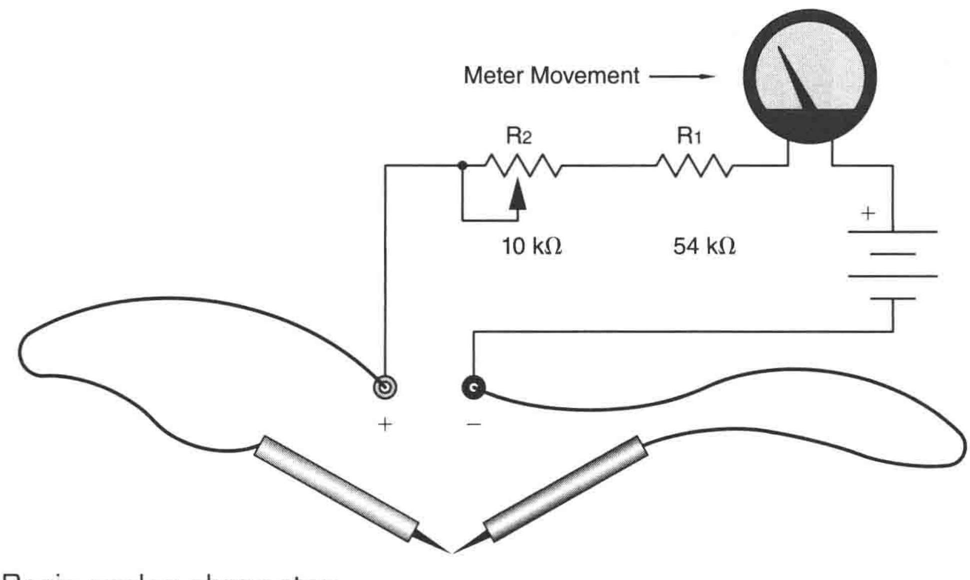



**Figure 1-8** Basic analog ohmmeter.

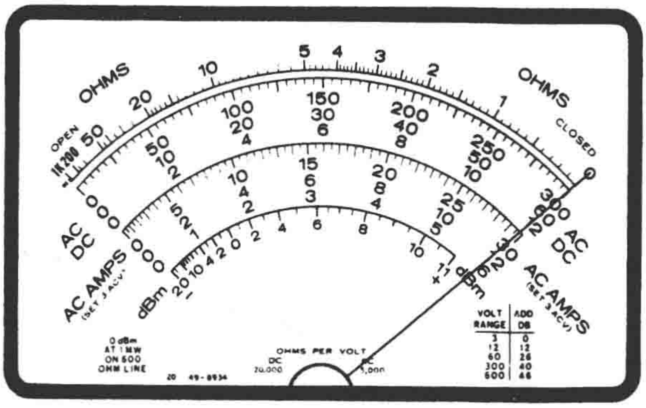



**Figure 1-9** Adjusting the ohmmeter to zero.

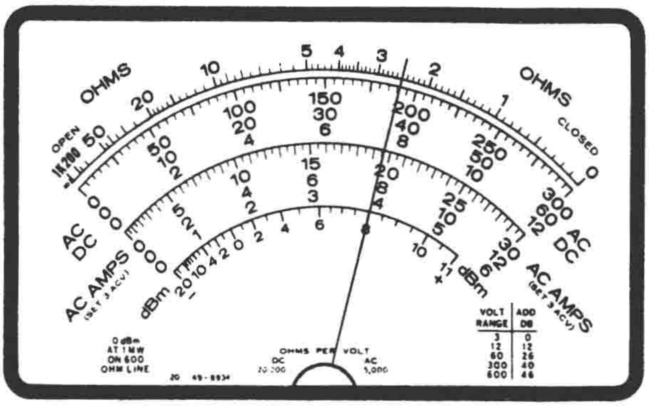



**Figure 1-10** Reading the ohmmeter.

the current flow through the meter movement to 50 μA. If Ohm's law is used to compute the resistance needed (3 volts/0.000050 amp = 60,000 ohms), it will be seen that a value of 60 kΩ is needed. This circuit contains a total of 65,000 ohms (1,000 meter + 54,000 + 10,000). The circuit resistance can be changed to a value as low as 55,000 ohms by adjusting the variable resistor, however. The reason for this is to compensate for the voltage drop of the battery as it ages and becomes weaker.

When resistance is to be measured, the meter must first be zeroed. This is done with the ohms-adjust control, the variable resistor, located on the front of the meter. To zero the meter, connect the leads together (Figure 1-8), and turn the ohms-adjust knob until the meter indicates 0 at the far right end of the scale, as shown in Figure 1-9. When the leads are separated, the meter will again indicate infinity resistance at the left side of the meter scale. When the leads are connected across a resistance, the meter will again indicate up scale. Since resistance has been added to the circuit, less than 50 μA of current will flow and the meter will indicate some value other than zero. Figure 1-10 shows a meter indicating a resistance of 2.5 ohms, assuming the range setting is Rx1.

**Helpful Hint**

When resistance is to be measured, the meter must first be zeroed.

Ohmmeters can have different range settings such as Rx1, Rx100, Rx1000, or Rx10,000. These different scales can be obtained by adding different values of resistance in the meter circuit and resetting the meter to zero. An ohmmeter should always be readjusted to zero when the scale is changed. On the Rx1 setting, the resistance is measured straight off the resistance scale located at the top of the meter. If the range is set for Rx1,000, however, the reading must be multiplied by 1000. The ohmmeter reading shown in Figure 1-10 would be indicating a resistance of 2500 ohms if the range had been set for Rx1000. Notice that the ohmmeter scale is read backward from the other scales. Zero ohms is located on the far right side of the scale and maximum ohms is located at the far left side. It generally takes a little time and practice to read the ohmmeter properly. An analog ohmmeter being used to measure the resistance of an armature is shown in Figure 1-11.

**Helpful Hint**

The ohmmeter scale is read backward from the other scales.

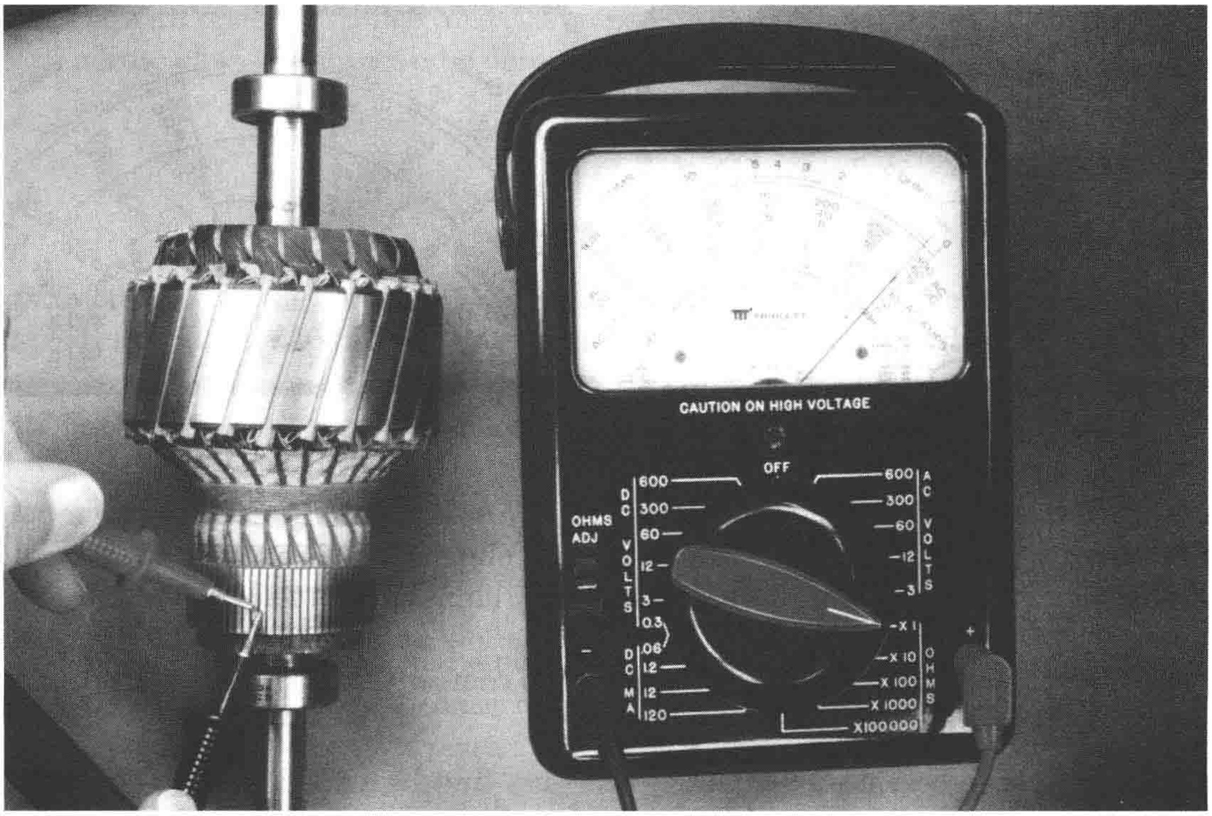



**Figure 1-11** Analog ohmmeter being used to measure armature resistance.

### Digital Ohmmeters

Digital ohmmeters display the resistance in figures instead of using a meter movement. When using a digital ohmmeter, care must be taken to notice the scale indication on the meter. For example, most digital meters will display a "K" on the scale to indicate kilo-ohms or an "M" to indicate megohms (kilo means 1000 and mega means 1,000,000). If the meter is showing a resistance of 0.200 K, it means 0.200 × 1000 or 200 Ω. If the meter indicates 1.65 M, it means 1.65 × 1,000,000 or 1,650,000 Ω.

Appearance is not the only difference between analog and digital ohmmeters. Their operating principle is also different. Analog meters operate by measuring the amount of current change in the circuit when an unknown value of resistance is added. Digital ohmmeters measure resistance by measuring the amount of voltage drop across an unknown resistance. In the circuit shown in Figure 1-12, a constant current generator is used to supply a known amount of current to a resistor, Rx. It will be assumed that the amount of current supplied is 1 milliamp (0.001). The voltage dropped across the resistor is proportional to the resistance of the resistor and the amount of current flow. For example, assume the value of the unknown resistor is 4700 Ω. The voltmeter would indicate a drop of 4.7 volts when 1 ma of current flowed through the resistor. The scale factor of the ohmmeter can be changed by changing the amount of current flow through the resistor. Digital ohmmeters generally exhibit an accuracy of about ±1%. A digital ohmmeter being used to measure the resistance of an armature is shown in Figure 1-13.

## Ammeters

The ammeter, unlike the voltmeter, is a very low-resistance device. Ammeters that are inserted into the circuit must be connected in series with the load to permit the load to limit the current flow, as shown in Figure 1-14. An ammeter has a typical impedance of

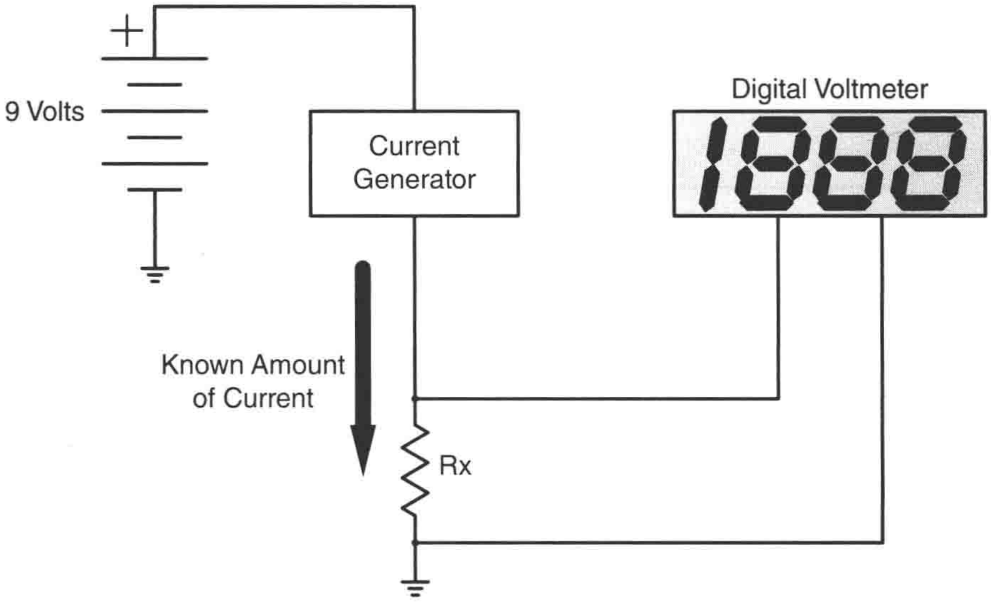



**Figure 1-12** Digital ohmmeters operate by measuring the voltage drop across a resistor when a known amount of current flows through it.

less than 0.1 Ω. If this meter is connected in parallel with the power supply, the resistance of the ammeter is the only thing to limit the amount of current flow in the circuit. Assume that an ammeter with a resistance of 0.1 Ω is connected across a 240-volt AC line. The current flow in this circuit would be 2400 amps (240/0.1 = 2400). The blinding flash of light would be followed by the destruction of the ammeter. Ammeters connected directly into the circuit as shown in Figure 1-14 are referred to as in-line ammeters. Figure 1-15 shows an ammeter of this type.


**Figure 1-13** Digital ohmmeter being used to measure resistance.

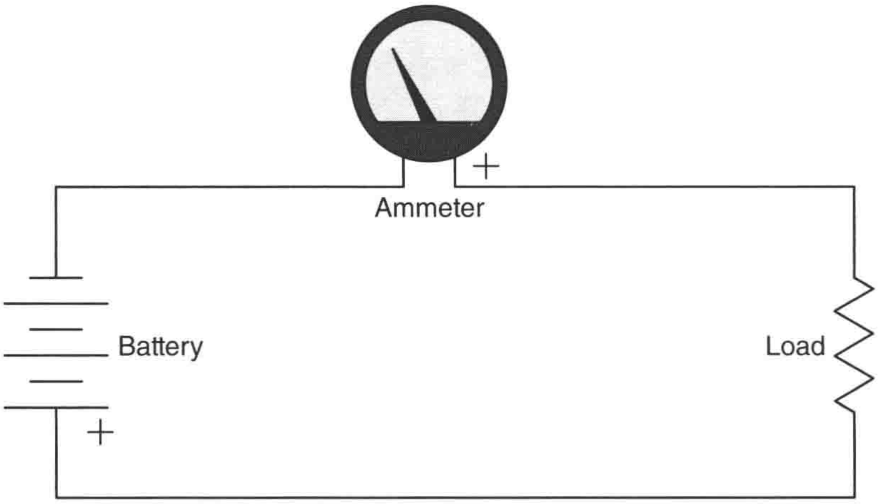



**Figure 1-14** An ammeter connects in series with the load.

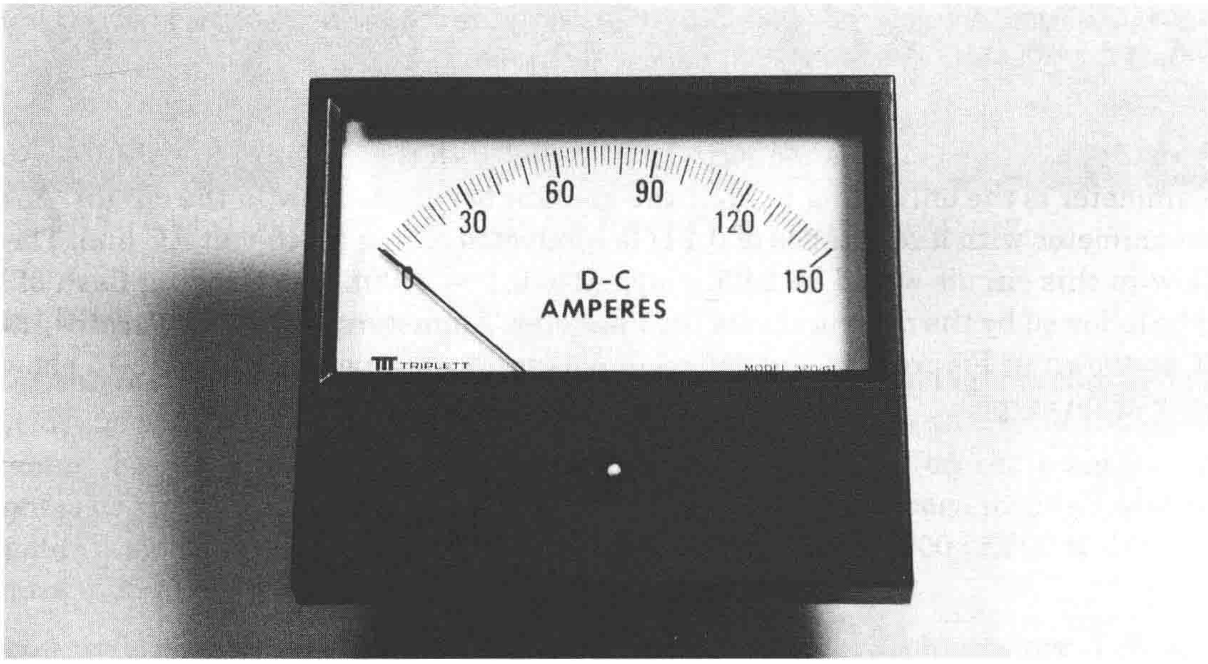



**Figure 1-15** In-line ammeter.

## DC Ammeters

Analog DC ammeters are constructed by connecting a common moving coil type of meter across a shunt. A shunt is a low-resistance device used to conduct most of the circuit current away from the meter movement. Since the meter movement is connected in parallel with the shunt, the voltage drop across the shunt is the voltage applied to the meter. Most ammeter shunts are manufactured to have a voltage drop of 50 mV (millivolts). If a 50 mV meter movement is connected across the shunt as shown in Figure 1-16, the pointer will move to the full-scale value when the rated current of the shunt is flowing. In the example shown, the ammeter shunt is rated to have a 50 mV drop when 10 amps of current is flowing in the circuit. Since the meter movement has a full-scale voltage of 50 mV, it will indicate the full-scale value when 10 amps of current is flowing through the shunt. An ammeter shunt is shown in Figure 1-17.

Ammeter shunts can be purchased to indicate different values. If the same 50 mV movement is connected across a shunt designed to drop 50 mV when 100 amps of current flows through it, the meter will now have a full-scale value of 100 amps.

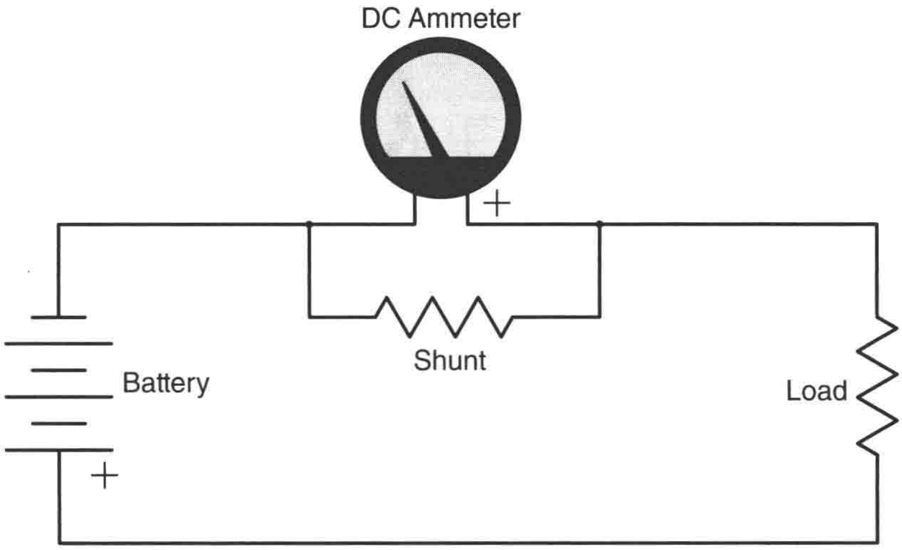



**Figure 1-16** A shunt is used to set the value of an ammeter.

## Multirange DC Ammeters

Many ammeters are designed to operate on more than one range. This is done by connecting the meter movement to different shunts. When this type of meter is used, care must be taken that the shunt is never disconnected from the meter. This would cause the meter movement to be inserted in series with the circuit and full-circuit current would flow through the meter. Two basic methods are used for connecting shunts to a meter movement. One method is to use a make-before-break switch. This type of switch is designed so that it will make contact with the next shunt before it breaks connection with the shunt it is connected to (Figure 1-18). This method does create a problem, however: contact resistance. Notice in Figure 1-18 that the rotary switch is in series with the shunt resistors. This causes the contact resistance to be added to the shunt resistance, which can cause inaccuracy in the meter reading.

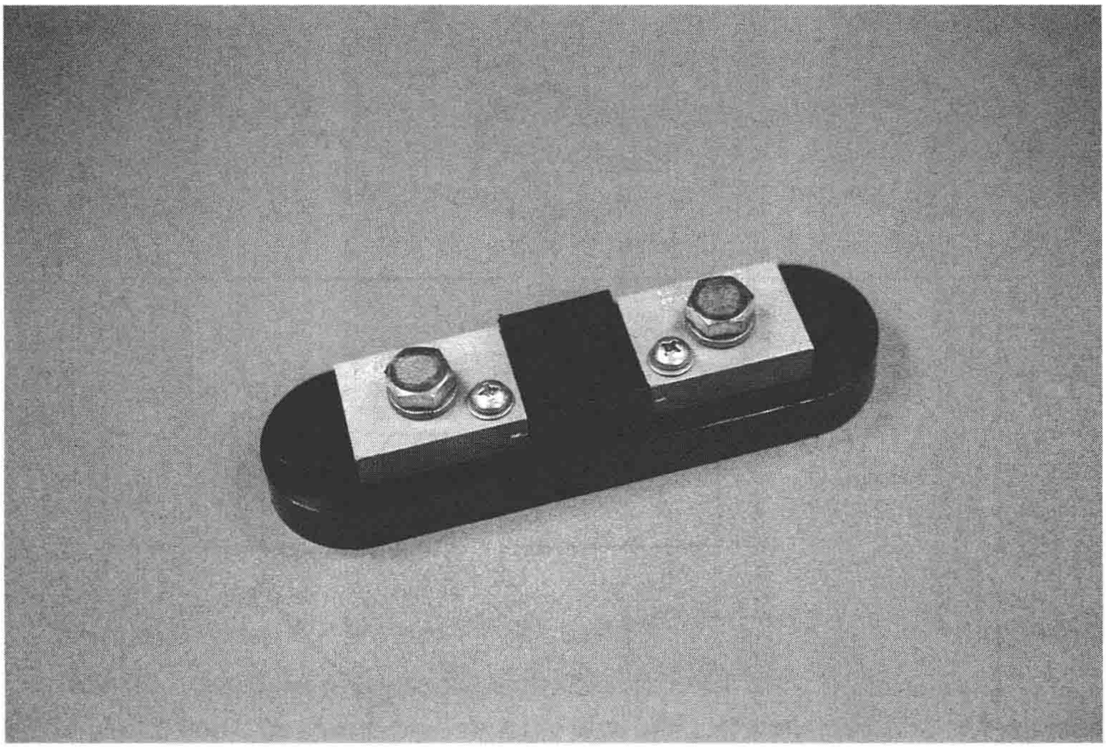


**Figure 1-17** Ammeter shunt.

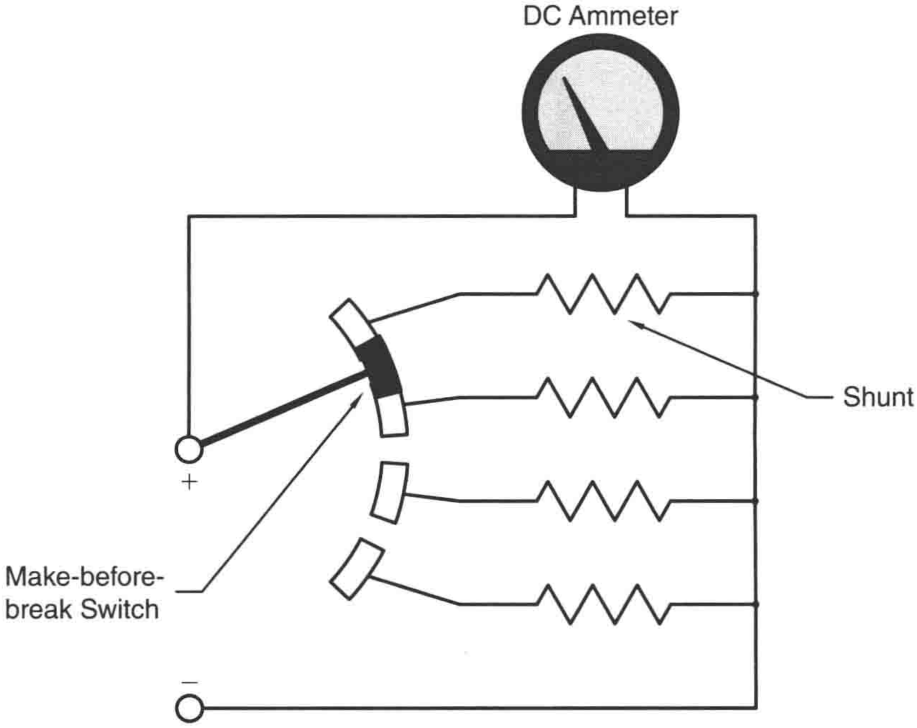



**Figure 1-18** A make-before-break switch is used to change meter shunts.

### The Ayrton Shunt

The second method is to use an Ayrton shunt (Figure 1-19). In this type of circuit, connection is made to different parts of the shunt and the meter movement is never disconnected from the shunt. Also, notice that the switch connections are made external to the shunt and meter. This prevents contact resistance from affecting the accuracy of the meter.

### Alternating Current Ammeters

Shunts can be used with AC ammeters to increase their range but cannot be used to decrease their range. Most AC ammeters use a current transformer instead of shunts to

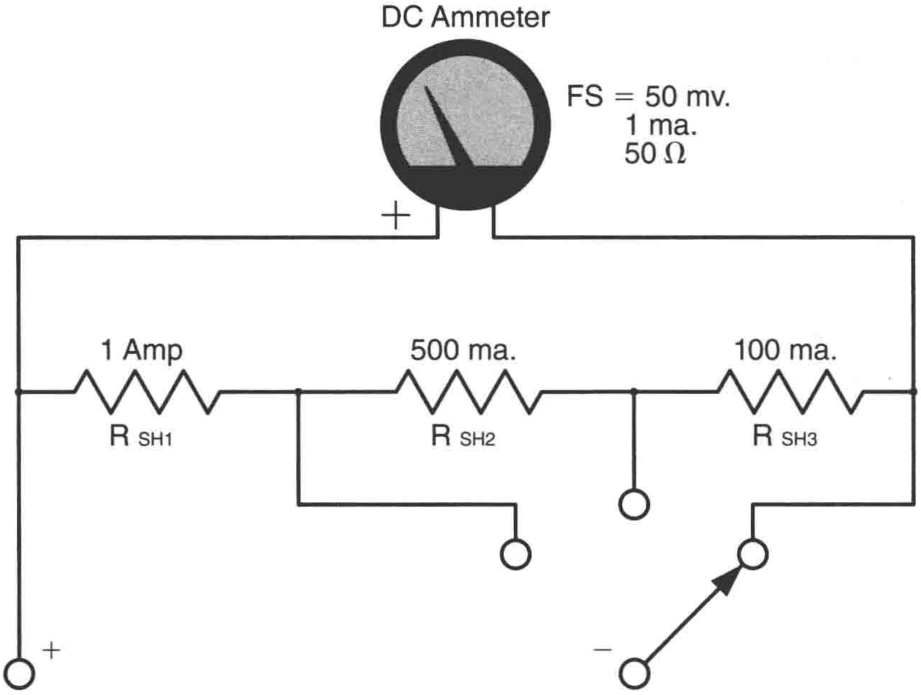



**Figure 1-19** Ayrton shunt.

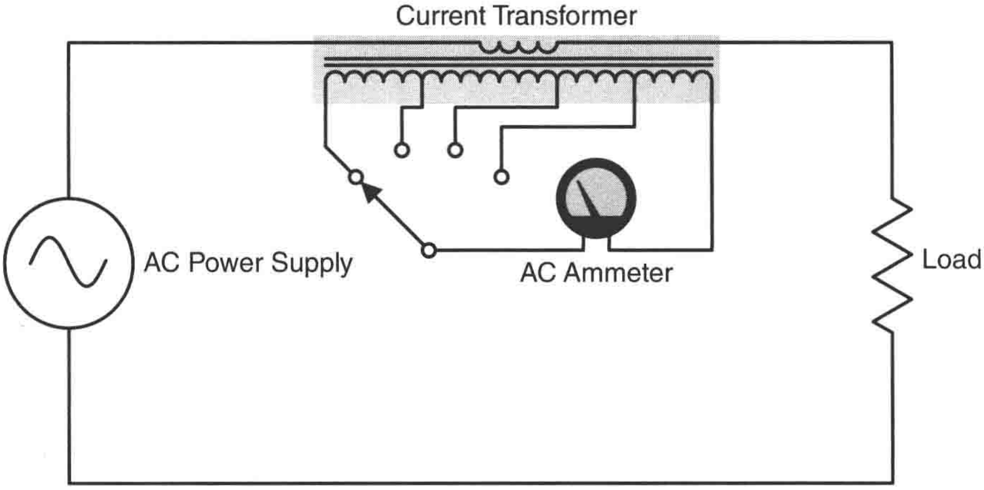



**Figure 1-20** A current transformer is used to change the range of an AC ammeter.

change scale values. This type of ammeter is shown in Figure 1-20. The primary of the transformer is connected in series with the load, and the ammeter is connected to the secondary of the transformer. Notice that the range of the meter is changed by selecting different taps on the secondary of the current transformer. The different taps on the transformer provide different turns-ratios between the primary and secondary of the transformer.

## Clamp-On Ammeters

Many electricians use the clamp-on type of AC ammeter (Figure 1-21 A, B, and C). To use this type of meter, the jaw of the meter is clamped around one of the conductors supplying power to the load, as seen in Figure 1-22. The meter is clamped around only one of the lines. If the meter is clamped around more than one line, the magnetic fields of the wires cancel each other and the meter indicates zero.

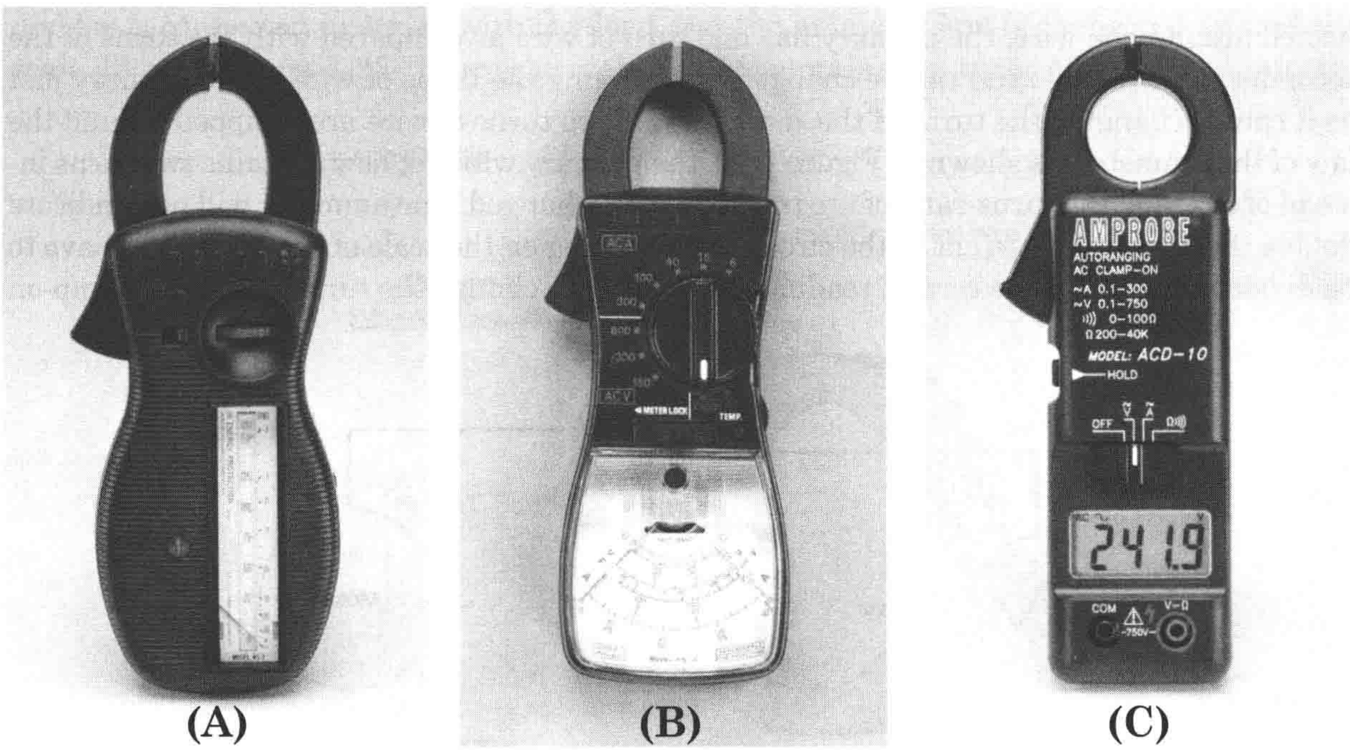



**Figure 1-21** (A) Analog-type clamp-on ammeter with vertical scale. (B) Analog-type clamp-on ammeter with flat scale. (C) Clamp-on ammeter with digital scale. (Advanced Test Products)

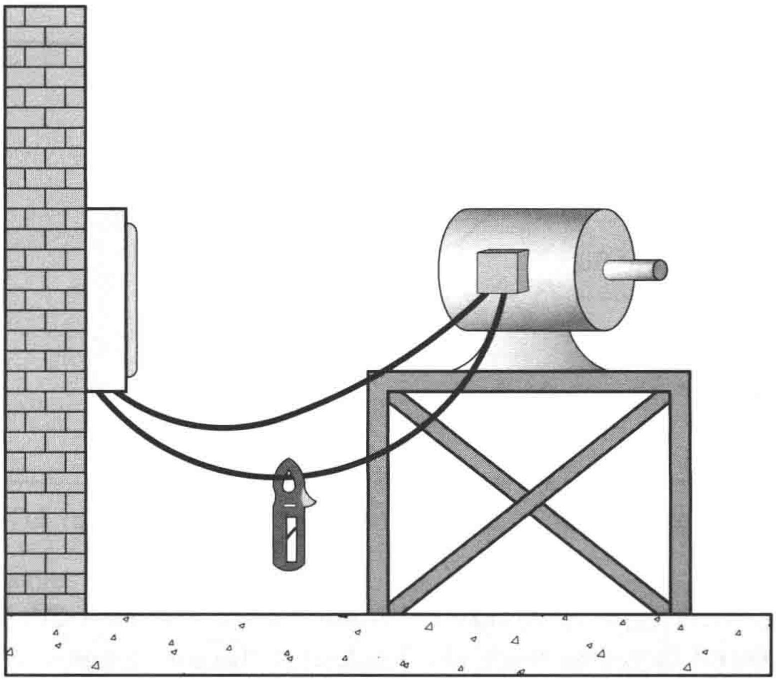


**Figure 1-22** The clamp-on ammeter connects around only one conductor.

This type of meter also uses a current transformer to operate the meter. The jaw of the meter is part of the core material of the transformer. When the meter is connected around the current-carrying wire, the changing magnetic field produced by the AC current induces a voltage into the current transformer. The strength of the magnetic field and its frequency determine the amount of voltage induced in the current transformer. Since 60 Hz is a standard frequency throughout the United States and Canada, the amount of induced voltage is proportional to the strength of the magnetic field.

The clamp-on type of ammeter can have different range settings by changing the turns-ratio of the secondary of the transformer just as the in-line ammeter does. The primary of the transformer is the conductor around which the movable jaw is connected. If the ammeter is connected around one wire, the primary has one turn of wire as compared with the turns of the secondary. The turns-ratio can be changed by changing the turns of wire of the primary just as it can by changing the turns of the secondary. If two turns of wire are wrapped around the jaw of the ammeter, as shown in Figure 1-23, the primary winding now contains two turns instead of one, and the turns-ratio of the transformer is changed. The ammeter will now indicate double the amount of current in the circuit. The reading on the scale of the meter will have to be divided by 2 to get the correct reading. The ability to change the turns-ratio of a clamp-on

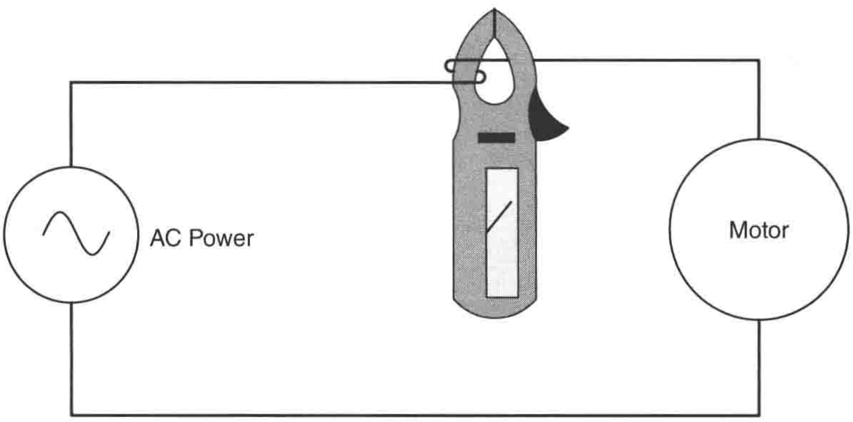



**Figure 1-23** Looping the conductor around the jaw of the ammeter changes the ratio.

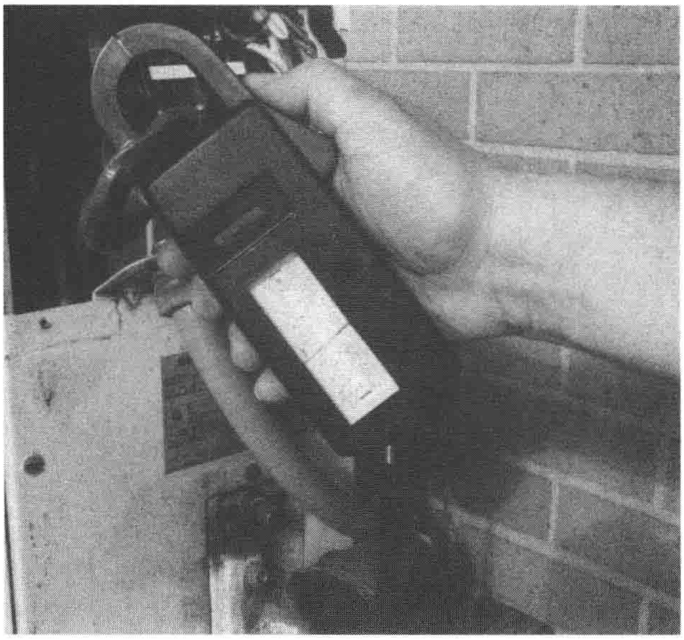


**Figure 1-24** Scale divider used with clamp-on ammeter. The ammeter indicates a value of 3.25 amperes. If the scale divider has a ratio of 10:1, the actual current is 0.325 amp.

ammeter can be very useful for measuring low currents. Changing the turns-ratio is not limited to wrapping two turns of wire around the jaw of the ammeter. Any number of turns can be wrapped around the jaw of the ammeter and the reading will be divided by that number.

## Ammeter Scale Divider

A very useful and simple-to-construct device that can be used to permit clamp-on-type ammeters to accurately measure low values of current is an ammeter scale divider (Figure 1-24). The scale divider is made by winding ten turns of wire around a nonconductive core material such as plastic. A piece of PVC pipe works well. The ten turns of wire are wrapped with tape to hold them together and alligator clips are attached to each end of the wire. The scale divider is connected in series with the load and the ammeter jaw is connected around the scale divider (Figure 1-25). Since the scale divider contains ten turns of wire, the ammeter

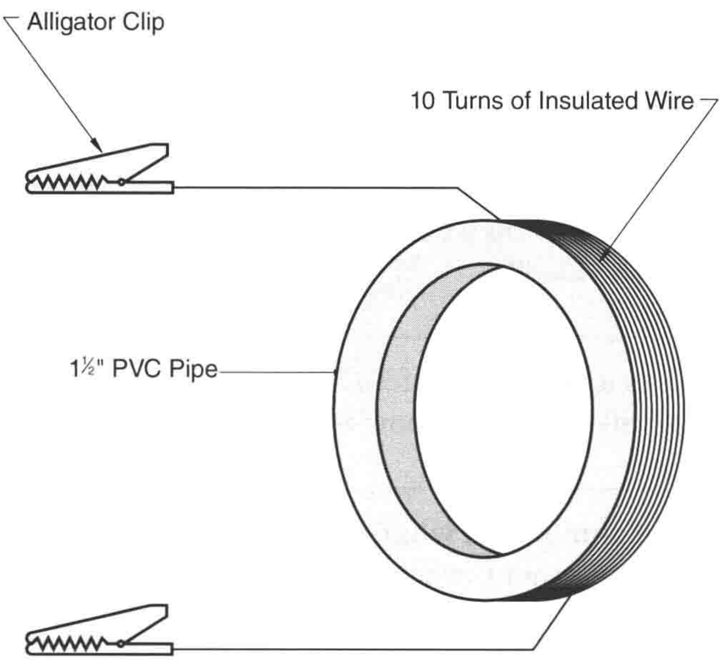



**Figure 1-25** Construction of ammeter scale divider.

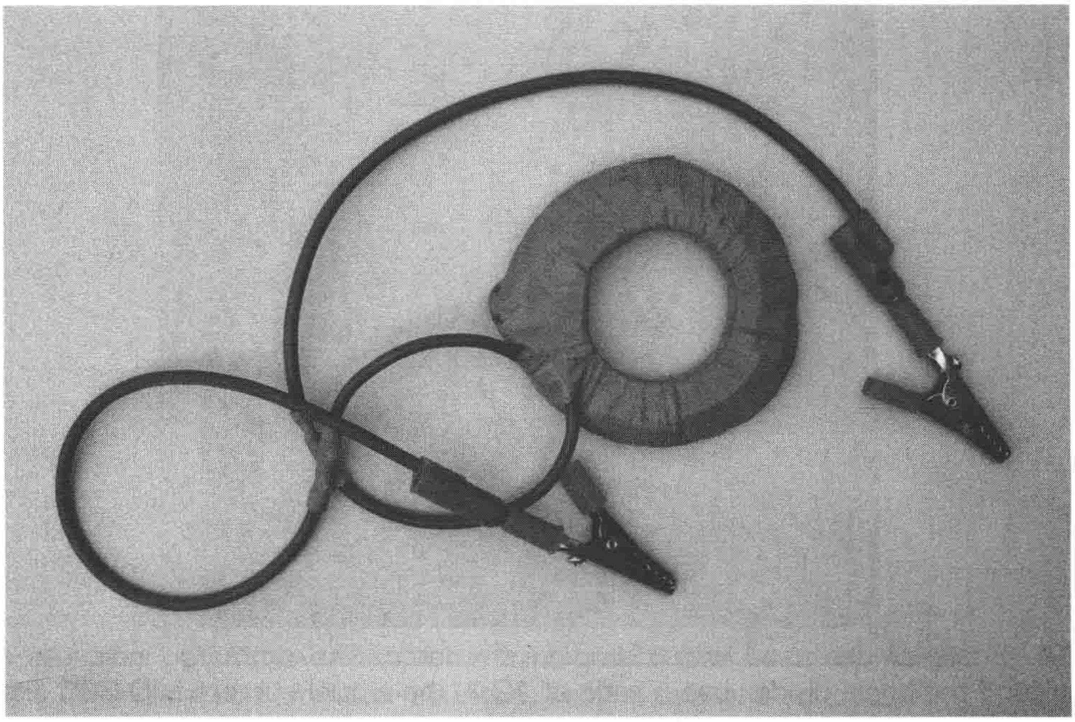


**Figure 1-26** Ammeter scale divider.

scale can be divided by 10. If the ammeter has a full-range value of 6 amps, the ammeter will have a full range of 0.6 amp when the scale divider is used. The scale divider is a very useful tool when measuring low current values with a clamp-on type of ammeter. It is recommended that a scale divider be used when measuring low current values in the experiments presented in this manual. A typical scale divider is shown in Figure 1-26.

## Review Questions

1. What are the two major types of voltmeters?

______________________________

2. How can the full-scale voltage range of a voltmeter be increased?

______________________________

3. A DC voltmeter has a resistance rating of 20,000 ohms per volt. The voltmeter is set for a value of 150 volts full scale. What is the resistance of the meter?

______________________________

4. To measure voltage drop, should a voltmeter be connected across (in parallel) with the load or in series with the load?

______________________________

5. A digital voltmeter has a resistance of 10 MΩ (megohms). If the meter is used to measure the voltage of a 480 volt panel, how much current will flow through the meter?

______________________________

6. When using an analog ohmmeter, what should be done each time the meter is used to make a resistance measurement or the range setting is changed?

______________________________

______________________________

7. What is the most important rule concerning the use of ohmmeters?

8. Briefly explain the method used by digital ohmmeters to measure resistance.

9. When measuring the current in a circuit, should an in-line ammeter be connected across (in parallel) with the load or in series with the load?

10. Do ammeters have high internal resistance or low internal resistance?

11. A clamp-on–type AC ammeter is to be used to measure the current flow in a circuit. Should the meter be clamped around one conductor or more than one conductor to get the most accurate measurement?

12. A scale divider with ten turns of wire is connected in series with the load. The jaw of the clamp-on ammeter is connected around the scale divider. The ammeter is set for a full-scale range of 30 amperes. The ammeter indicates a current value of 12 amperes. What is the actual amount of current flow in the circuit?

# Unit 2 Ohm's Law

## Objectives

After completing this unit you should be able to

- Measure resistance with an ohmmeter.
- Measure current with an ammeter.
- Measure voltage with a voltmeter.
- Make Ohm's law calculations.

Ohm's law is the basic law concerning electric circuits. This unit will deal with the calculation and measurement of voltage, current, and resistance.

## Materials Required

1 100 ohm resistor with a minimum watt rating of 175

1 150 ohm resistor with a minimum watt rating of 100

1 250 ohm resistor with a minimum watt rating of 100

1 AC voltmeter

1 AC ammeter (in-line or clamp-on)

1 Ohmmeter

Connection wires

120 volt AC power supply

Most conductors exhibit some amount of resistance change when they are heated. Most metals will increase their resistance with an increase of temperature; semi-conductor materials will decrease their resistance with an increase of temperature. This laboratory manual uses high-wattage wire-wound resistors for resistive loads. Caution must be exercised when using these components because they will become very hot and can cause severe burns. Also, the resistors should not be placed on or near materials that can burn. The resistive element of a wire-wound resistor is generally made of nichrome. Nichrome is an alloy that has a resistance of 675 ohms per mil-foot at 20 °C. Copper has a resistance of 10.4 ohms per mil-foot at 20 °C. Also, nichrome has a temperature coefficient of 0.0002 ohms per °C. This simply means that it exhibits very little change in resistance with a large change in temperature.

These high-wattage components are used in this manual to permit the circuit current to be great enough that it can be measured with a clamp-type ammeter. It may be necessary or convenient to use the scale divider discussed in Unit 1 to obtain more accurate current measurements.

## LABORATORY EXERCISE

Name ______________________________________________ Date __________

1. Use an ohmmeter to measure the resistance of the 100 Ω resistor. To make the measurement, zero the ohmeter (if necessary) and connect one probe to one end of the resistor and the other probe to the opposite end of the resistor, Figure 2-1.

   R = __________ Ω

2. Use an AC voltmeter to test the terminal voltage of the AC power supply to be used for this experiment. Make certain that the voltmeter is set to indicate AC volts and that the range setting is greater than 120 volts, Figure 2-2. Turn on the power and measure the voltage of the power supply.

   __________ Volts

3. **Make certain that the power is turned off.** Using the 100-ohm resistor, connect the circuit shown in Figure 2-3. A clamp-on-type AC ammeter may be substituted for the in-line ammeter shown in the drawing.

4. Using the Ohm's law formula shown, compute the amount of current that should flow in the circuit. Use 120 volts for the value of E.

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

   I = __________ amps

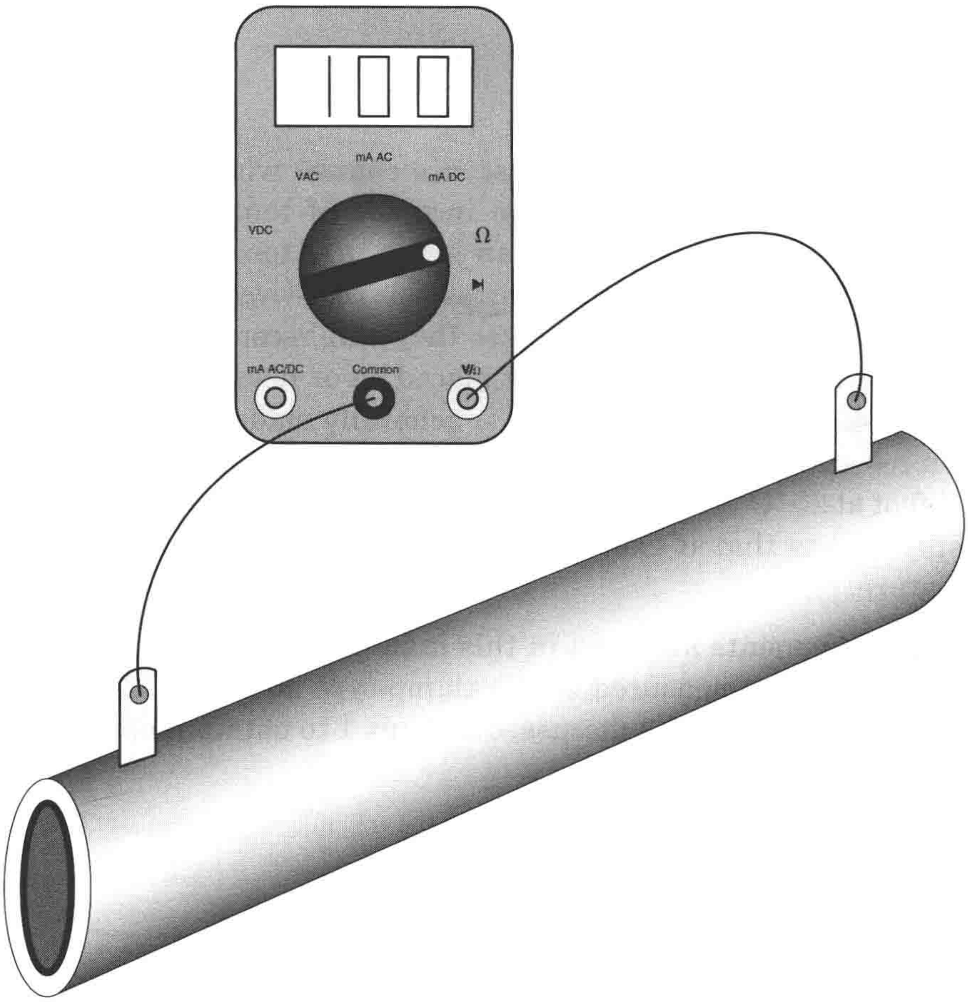



**Figure 2-1** Measuring the resistance of a resistor.

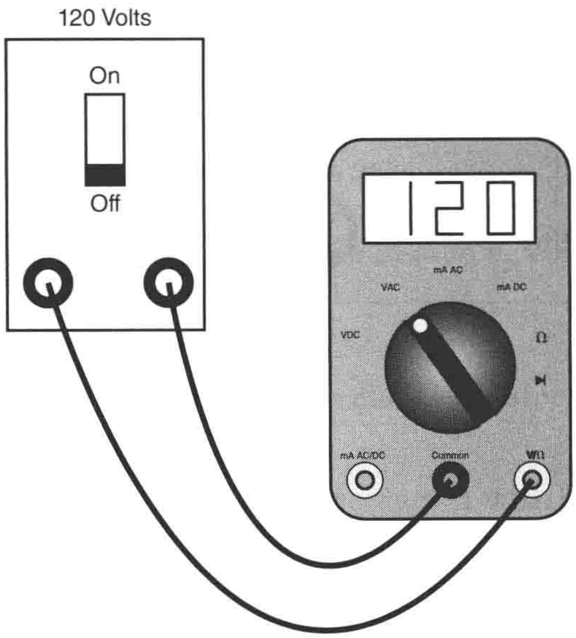



**Figure 2-2** Testing the power supply with a voltmeter.

5. Turn on the AC power supply and measure the current flow through the 100 Ω resistor.

   I = ______________ amps

6. Connect the AC voltmeter across the 100 Ω resistor as shown in Figure 2-4. Is the voltage the same as that measured at the power supply?

   ______________

7. Use the measured values of voltage and current to compute the resistance of the resistor.

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

   R = ______________ Ω

   Did the resistance increase or decrease? ______________

   Amount of increase or decrease ______________ Ω

8. **Turn off the power supply.**

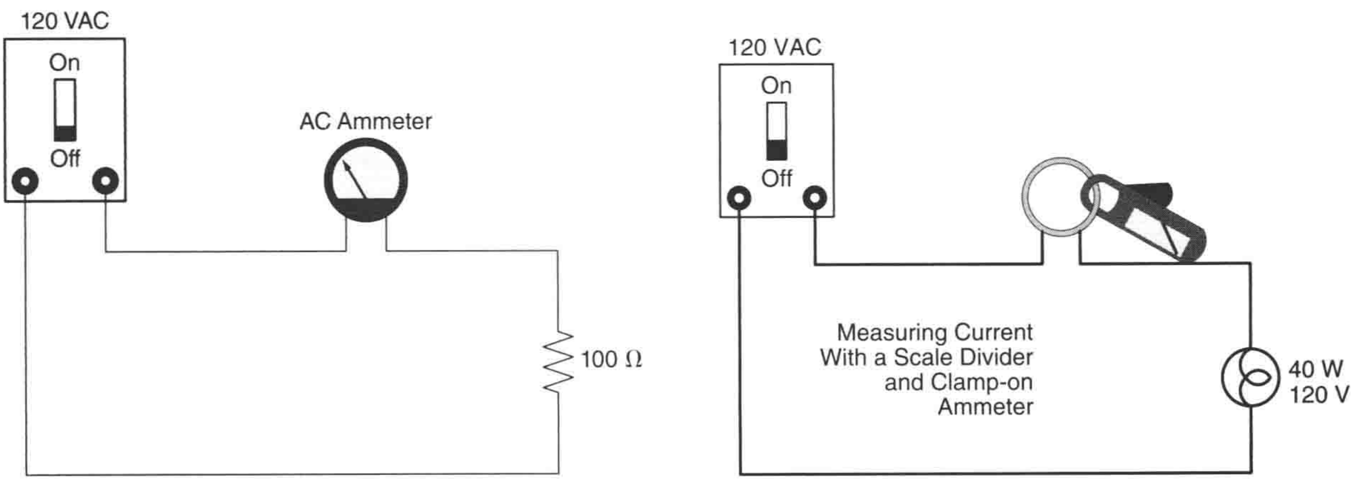



**Figure 2-3** An in-line ammeter connects in series with the load.

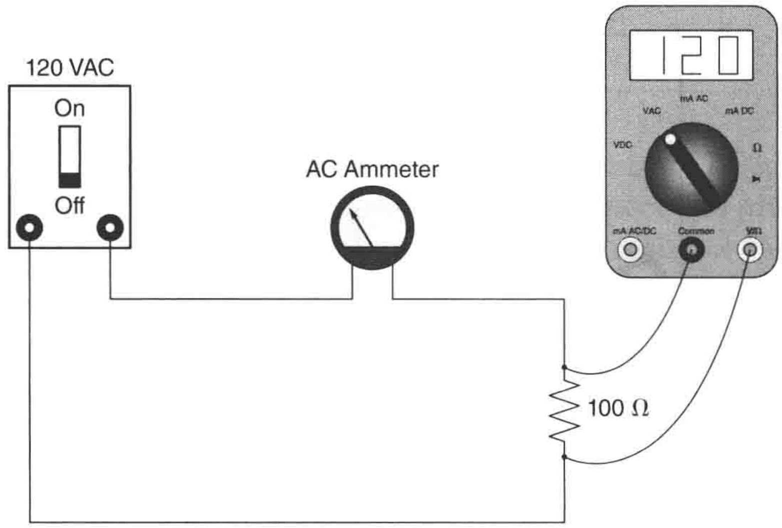



**Figure 2-4** Measuring the voltage drop across the resistor.

9. Use an ohmmeter to measure the resistance of a 150-Ω resistor.

   R = _______________ Ω

10. Remove the 100-Ω resistor from the circuit and replace it with the 150-Ω resistor.
11. Using the formula shown, compute the amount of current that should flow in this circuit.

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

   I = _______________ amps

12. Turn on the power and measure the current flow in the circuit and the voltage drop across the resistor. If a clamp-type ammeter is used, it is recommended to connect the 10:1 scale divider in the circuit as shown in Figure 2-5. This can increase the accuracy of the measurement. If the ammeter is set on a 15-amp range, for example, the meter would have a full-scale range of 1.5 amps.

   I = _______________ amps

   E = _______________ volts

13. **Turn off the power supply.**

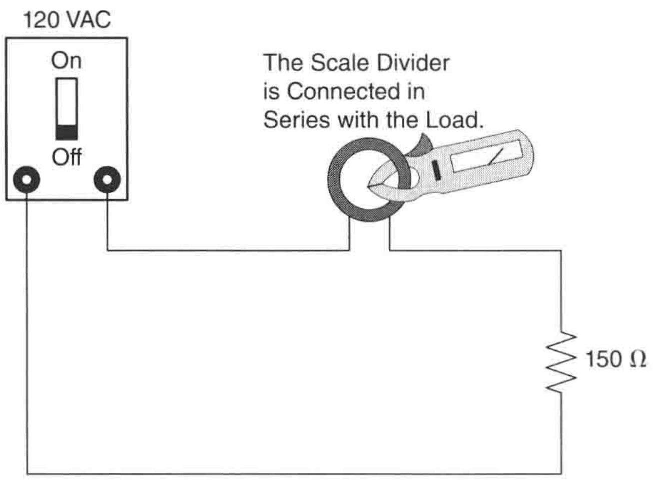



**Figure 2-5** The scale divider is connected in series with the load.

14. Using Ohm's law, compute the resistance in the circuit.

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

R = ______________ Ω

15. Compare this value with the measured resistance in step 9. What is the difference in resistance?

R = ______________ Ω

16. Use an ohmmeter to measure the resistance of a 250-Ω resistor at room temperature.

R = ______________ Ω

17. Remove the 150 Ω-resistor from the circuit and replace it with the 250-Ω resistor.

18. Using the formula shown, compute the amount of current that should flow in this circuit.

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

I = ______________ amps

19. Turn on the power and measure the current flow in the circuit and the voltage drop across the lamp.

I = ______________ amps

E = ______________ volts

20. **Turn off the power supply.**

21. Using Ohm's law, compute the resistance in the circuit.

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

R = ______________ Ω

22. Compare this value with the measured resistance in step 16. What is the difference in resistance?

R = ______________ Ω

23. Disconnect the circuit and return the components to their proper place.

## Review Questions

1. A 50 Ω resistor is connected to a 240 volt source. How much current will flow through the resistor?

______________________________________________

2. How much power (watts) is being consumed by the resistor in question 1?

______________________________________________

3. An electric heating element is rated at 1,500 watts when connected to 240 volts. How much current would flow in this circuit?

______________________________________________

4. What is the resistance of the heating element in question 3?

_______________

5. Assume that the voltage in question 3 is reduced to 120 volts. How much current would flow in the circuit?

_______________

6. If the voltage connected to a 1,500 watt heating element in question 3 were to be reduced to 120 volts, how much power would the heating element actually consume?

_______________

7. Assume that a 100 watt lamp connected to a 120 volt circuit burns out and is replaced with a 150 watt lamp. How much more current will the 150 watt lamp draw?

_______________

8. A resistive heating element has a current draw of 2.3 amperes and a resistance of 12 Ω. How much power is the heating element consuming?

_______________

9. A heating element has a resistance of 52 Ω and a current draw of 4 amperes. How much voltage is connected to the heating element?

_______________

10. How much power is being consumed by the heating element in question 9?

_______________

# Unit 3 Series Circuits

## Objectives

After studying this unit, you should be able to

- List the three rules concerning series circuits.
- Determine the total resistance of a series circuit.
- Determine the voltage drops across individual components of a series circuit.
- Connect a series circuit.
- Measure values of voltage and current in a series circuit.

Series circuits are characterized by the fact that they contain only one path for current flow. There are three rules concerning series circuits that, when used with Ohm's law, permit values of current, voltage, and resistance to be determined.

Assume that an electron leaves the negative terminal of the battery in Figure 3-1 and must travel to the positive terminal. Notice that the only path the electron can travel is through each resistor. Since there is only one path for current flow, the current must be the same at any point in the circuit. Regardless of where an ammeter is connected in the circuit, it will indicate the same value. The first rule concerning series circuits states that the current must be the same at any point in the circuit.

**Helpful Hint**

The first rule concerning series circuits states that the current must be the same at any point in the circuit.

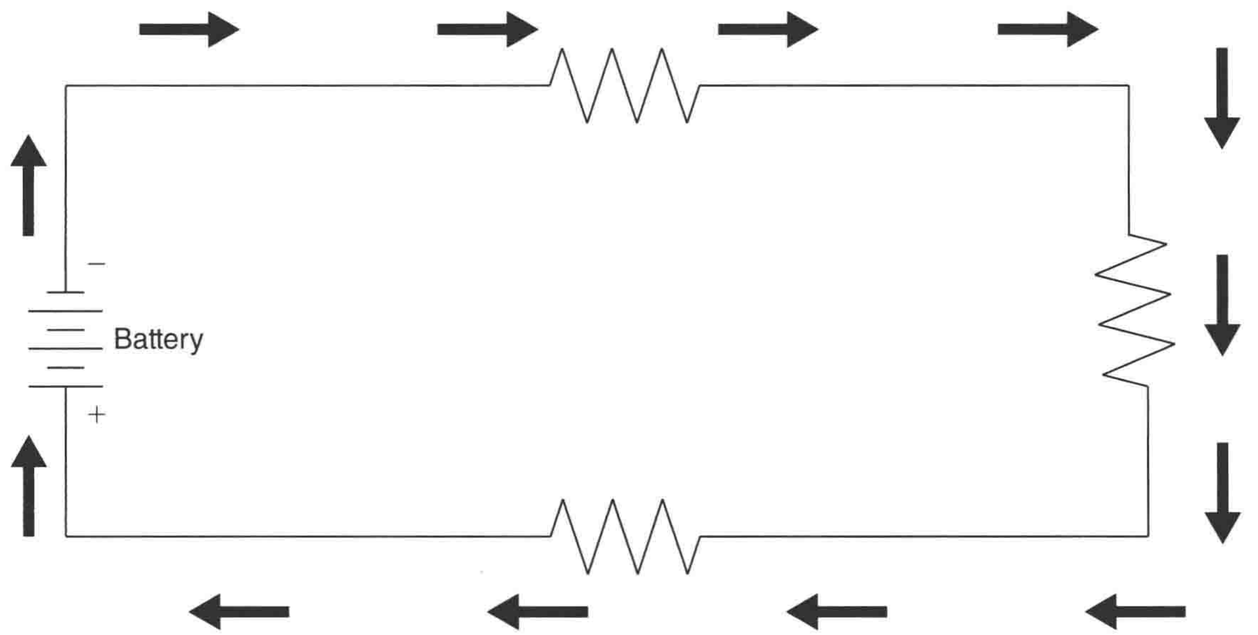



**Figure 3-1** Current must flow through all parts of a series circuit.

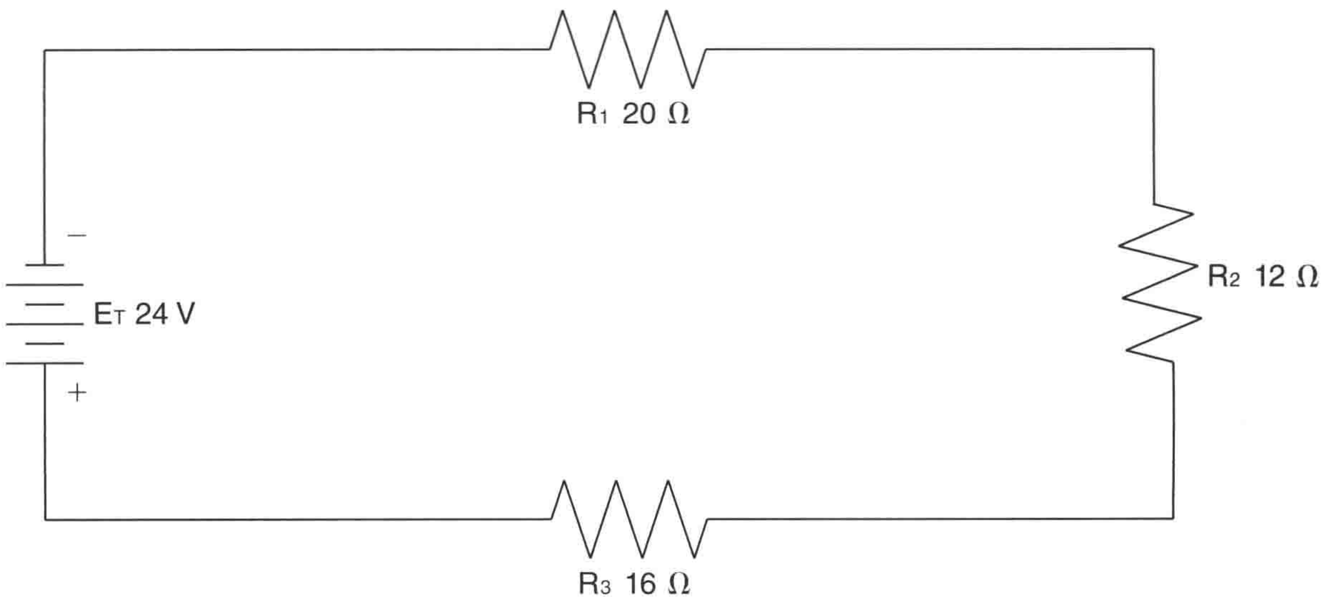



**Figure 3-2** Resistance values are added to the circuit.

In Figure 3-2, values are added to the resistors shown in Figure 3-1. Resistor $R_1$ has a value of 20 Ω, $R_2$ has a value of 12 Ω, and resistor $R_3$ has a value of 16 Ω. Since current must pass through each of these resistors, each hinders the flow of current. The total amount of hindrance to current flow is the combined ohmic value of each resistor. The second rule of series circuits states that the total resistance is the sum of the individual resistances. The total circuit resistance can be determined by adding the values of all the resistors (20 + 12 + 16 = 48 Ω). The circuit shown in Figure 3-2 indicates a total voltage ($E_T$) of 24 volts for this circuit. Now that the total circuit resistance is known and the applied voltage is known, the circuit current can be determined using Ohm's law.

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

$$I = \frac{24}{48}$$

$$I = 0.5 \text{ amp}$$

**Helpful Hint**

The second rule of series circuits states that the total resistance is the sum of the individual resistances.

Since the current is the same at any point in a series circuit, 0.5 amp flows through each resistor. Now that the amount of current flowing through a resistor is known, the amount of voltage drop across each resistor can be computed using Ohm's law.

$$E_1 = I \times R_1$$

$$E_1 = 0.5 \times 20\ \Omega$$

$$E_1 = 10 \text{ volts}$$

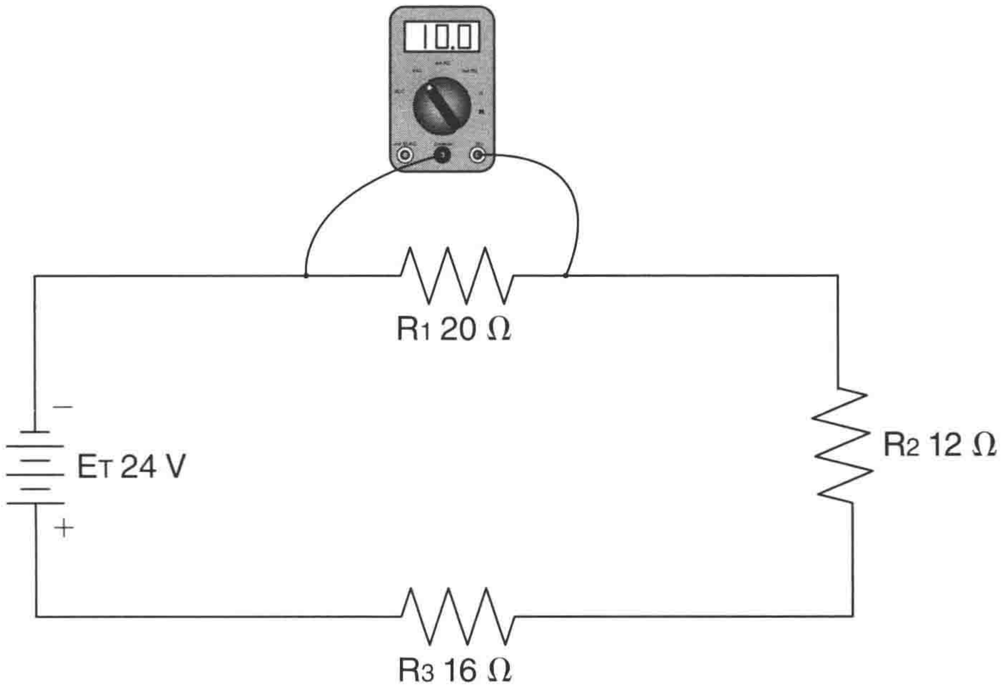



**Figure 3-3** Measuring the voltage drop across resistor $R_1$

If a voltmeter were to be connected across resistor $R_1$, it would indicate a value of 10 volts (Figure 3-3). This 10 volts represents the amount of electrical pressure necessary to push 0.5 amp through 20 ohms of resistance. The amount of voltage drop across resistors $R_2$ and $R_3$ can be computed using Ohm's law also.

$$E_2 = I \times R_2$$

$$E_2 = 0.5 \times 12$$

$$E_2 = 6 \text{ volts}$$

$$E_3 = I \times R_3$$

$$E_3 = 0.5 \times 16$$

$$E_3 = 8 \text{ volts}$$

Notice that if all the voltage (pressure) drops are added, they will equal the applied voltage of the circuit (10 + 6 + 8 = 24 volts). The third rule of series circuits states that the total voltage is equal to the sum of the voltage drops around the circuit.

Another rule concerning circuits is that watts (power) will add in any type of circuit. This rule is true not only for series circuits but also for parallel and combination circuits. The total wattage of any type circuit will be the sum of all the individual power-consuming devices in the circuit.

**Helpful Hint**

The third rule of series circuits states that the total voltage is equal to the sum of the voltage drops around the circuit. Another rule concerning circuits is that watts (power) will add in any type of circuit.

## LABORATORY EXERCISE

Name ______________________________________________ Date __________

## Materials Required

2 100 ohm resistors

1 150 ohm resistor

1 250 ohm resistor

1 AC ammeter (In-line or clamp-on. If a clamp-on type is used, the use of a scale divider is recommended.)

1 AC voltmeter

120 volt AC power supply

208 volt AC power supply

Connecting wires

1 Ohmmeter

1. Connect the circuit shown in Figure 3-4.
2. Compute the total resistance of the circuit using the following formula:

$$R_T = R_1 + R_2 + R_3 + R_N$$

   Note: $R_N$ simply means the number of resistors in the circuit, whether there are 3 or 23.

   $R_T$ = ______________ $\Omega$
3. Disconnect the circuit from the power supply and measure the total resistance of the circuit with an ohmmeter as shown in Figure 3-5. Compare the measured value with the computed value.

   $R_T$ = ______________ $\Omega$

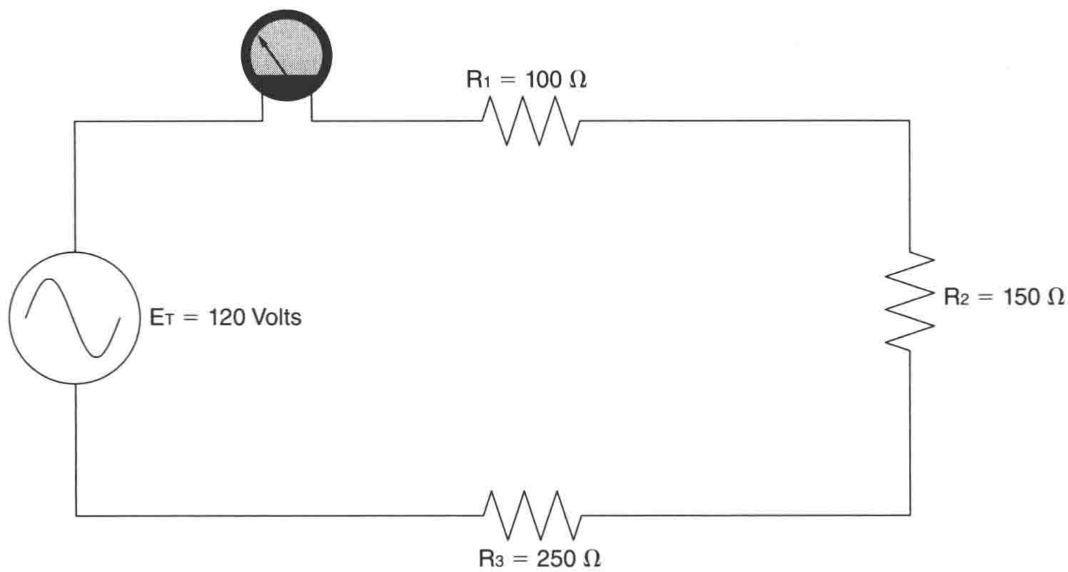



**Figure 3-4** Connecting the first series circuit.

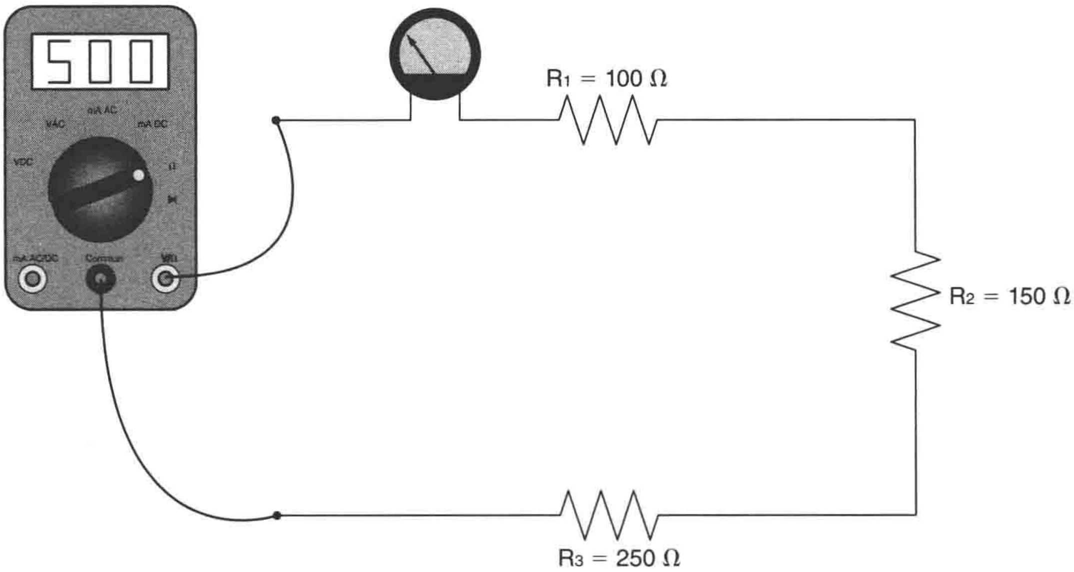



**Figure 3-5** An ohmmeter is used to measure the total resistance of the circuit.

4. Assuming that the circuit is connected to a 120 volt source, calculate the total circuit current using the following formula:

$$I_T = \frac{E_T}{R_T}$$

$I_T$ = _______________ A

5. Reconnect the circuit to the 120 volt power source. Turn on the power and measure the total circuit current. Compare this value with the computed value. **Turn off the power.**

$I_T$ = _______________ A

6. Now that the total circuit current is known, compute the voltage drop across each of the resistors using the following formula:

$$E = I \times R$$

100 Ω = _______________ volts

150 Ω = _______________ volts

250 Ω = _______________ volts

7. Turn on the power and measure the voltage drop across each resistor with an AC voltmeter. Compare these measured values with the calculated value in step 6. **Turn off the power.**

100 Ω = _______________ volts

150 Ω = _______________ volts

250 Ω = _______________ volts

8. Reconnect the circuit to a source of 208 volts as shown in Figure 3-6.
9. Assuming a circuit voltage of 208 volts, calculate the total circuit current using the following formula: (Note: round off the answer to the second decimal place or hundredths of an amp.)

$$I_T = \frac{E_T}{R_T}$$

$I_T$ = _______________ A

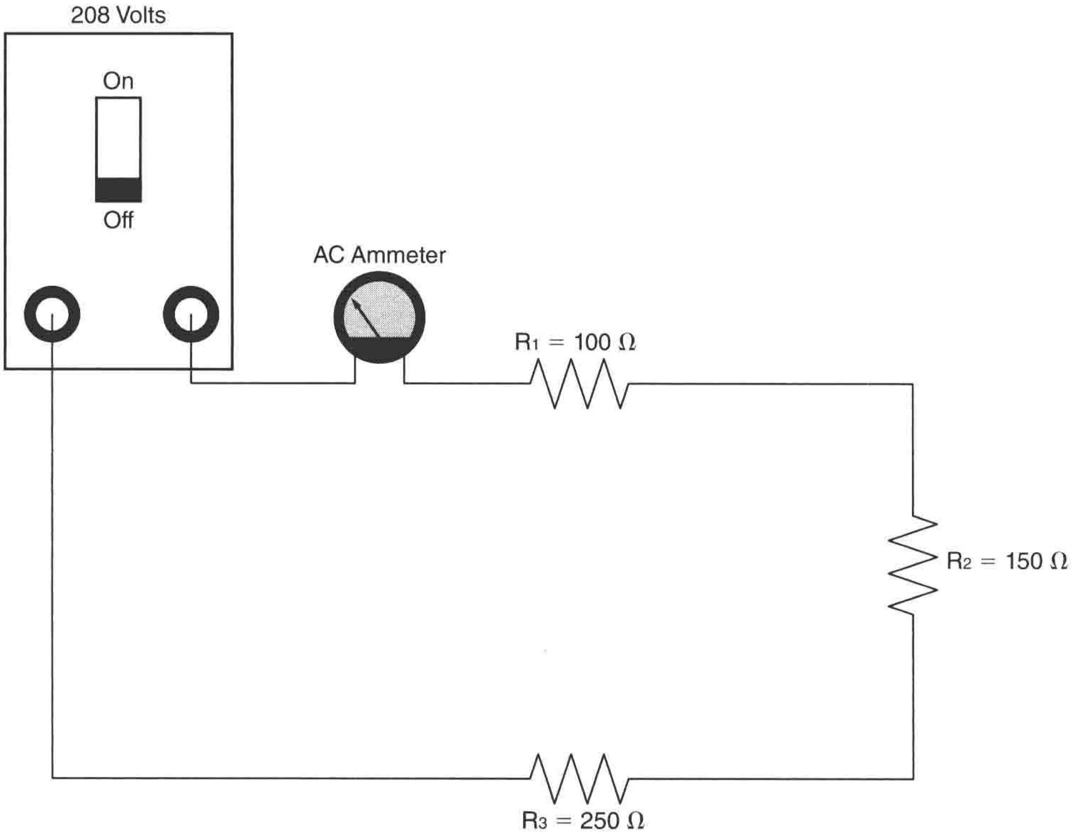



**Figure 3-6** The circuit is connected to a 208-volt source.

10. Turn on the power and measure the total circuit current. Compare the measured value with the computed value. **Turn off the power.**

    $I_T$ = ______________ A

11. Calculate the voltage drop across each component using the following formula:

$$E = I \times R$$

    100 Ω = ______________ volts

    150 Ω = ______________ volts

    250 Ω = ______________ volts

12. Turn on the power and measure the voltage drop across each resistor. Compare the measured values with the computed values. **Turn off the power.**

    100 Ω = ______________ volts

    150 Ω = ______________ volts

    250 Ω = ______________ volts

13. Turn on the power and measure the actual voltage applied to the circuit with a voltmeter. **Turn off the power.**

14. Add the measured values of voltage in step 12. Compare the sum to the measured value in step 13. Is the sum of the voltage drops across each resistor approximately the same as the circuit voltage?

    ______________

15. Reconnect the circuit as shown in Figure 3-7.

16. Compute the total resistance of the circuit using this formula:

$$R_T = R_1 + R_2 + R_3 + R_N$$

    $R_T$ = ______________ Ω

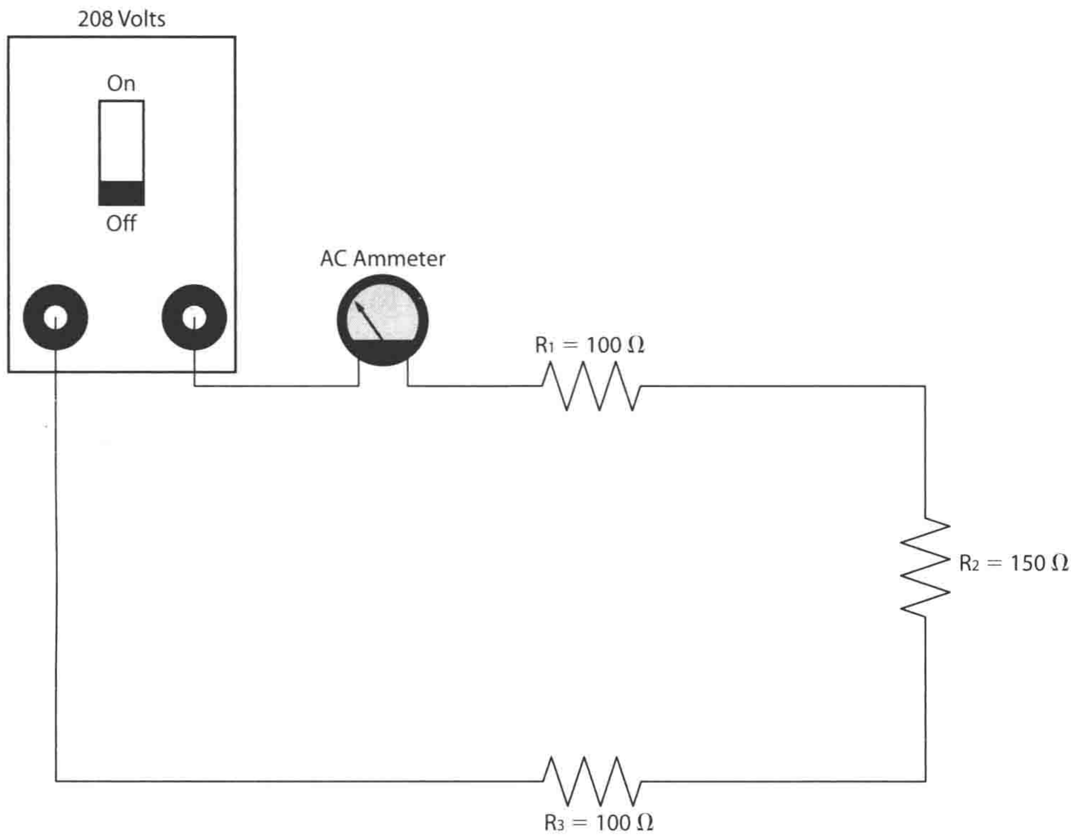



**Figure 3-7** Second series circuit.

17. Disconnect the circuit from the power supply and measure the total resistance of the circuit with an ohmmeter. Compare the measured value with the computed value.

    $R_T$ = ______________ Ω

18. Reconnect the circuit to a source of 208 volts as shown in Figure 3-7.

19. Assuming a circuit voltage of 208 volts, calculate the total circuit current using the following formula: (Note: Round off the answer to the second decimal place or hundredths of an amp.)

$$I_T = \frac{E_T}{R_T}$$

    $I_T$ = ______________ A

20. Turn on the power and measure the total circuit current. Compare the measured value with the computed value. **Turn off the power.**

    $I_T$ = ______________ A

21. Calculate the voltage drop across each component using the following formula:

$$E = I \times R$$

    100 Ω = ______________ volts

    150 Ω = ______________ volts

    100 Ω = ______________ volts

22. Turn on the power and measure the voltage drop across each resistor. Compare the measured values with the computed values. **Turn off the power.**

    100 Ω = ______________ volts

    150 Ω = ______________ volts

    100 Ω = ______________ volts

23. Turn on the power and measure the actual voltage applied to the circuit with a voltmeter. **Turn off the power.**
24. Add the measured values of voltage in step 22. Compare the sum to the measured value in step 23. Is the sum of the voltage drops across each resistor approximately the same as the circuit voltage?

 ______________

25. Disconnect the circuit and return the components to their proper place.

## Review Questions

1. State the three rules for series circuits.

 ______________________________________________

 ______________________________________________

 ______________________________________________

 ______________________________________________

 ______________________________________________

 ______________________________________________

2. A series circuit has a total resistance of 1220 Ω. Resistor $R_1$ has a resistance of 220 Ω, $R_2$ has a resistance of 200 Ω, and $R_3$ has a resistance of 470 Ω. What is the value of resistor $R_4$?

 ______________________________________________

3. A circuit has three resistors connected in series. Resistor $R_1$ has a value of 16 Ω, $R_2$ has a value of 36 Ω, and $R_3$ has a value of 8 Ω. If the circuit is connected to a 12 volt battery, how much voltage is dropped across resistor $R_1$?

 ______________________________________________

4. A circuit contains two resistors connected in series. Resistor $R_1$ has a value of 1200 Ω and resistor $R_2$ has a value of 1600 Ω. Resistor $R_1$ has a voltage drop of 24 volts. What is the total voltage applied to the circuit?

 ______________________________________________

5. Three resistors are connected in series to a 120 volt power source. Resistor $R_2$ has a value of 200 Ω and a voltage drop of 50 volts. What is the total resistance of the circuit?

 ______________________________________________

6. Three resistors are connected in series to a 48 volt power source. Resistor $R_2$ has a voltage drop of 18 volts and resistor $R_3$ has a voltage drop of 16 volts. How much voltage is dropped across resistor $R_1$?

 ______________________________________________

7. A 150 watt incandescent lamp is connected to 120 volts. How much current will flow in this circuit?

 ______________________________________________

8. A series circuit contains four resistors. The circuit is connected to a 24 volt power source. The circuit consumes a total power of 360 watts. Resistor $R_1$ consumes 40 watts, $R_2$ consumes 65 watts, and $R_3$ consumes 85 watts. What is the resistance of resistor $R_4$?

 ______________________________________________

# Unit 4 Parallel Circuits

## Objectives

After studying this unit, you should be able to

- List the three rules concerning parallel circuits.
- Determine the total resistance of a parallel circuit.
- Determine the current through individual components of a parallel circuit.
- Connect a parallel circuit.
- Measure values of voltage and current in a parallel circuit.

Parallel circuits are characterized by the fact that they have more than one path for current flow. There are three rules concerning parallel circuits that, when used in conjunction with Ohm's law, permit values of voltage, current, and resistance to be determined for almost any parallel circuit. As with series circuits, the total power consumption of the circuit is the sum of the power consumption of each component of the circuit.

A parallel circuit containing three resistors is shown in Figure 4-1. Assume that current leaves the negative terminal of the battery and must return to the positive terminal. Part of the circuit current will flow through resistor $R_1$ and return to the battery. The remainder of the current will flow to resistors $R_2$ and $R_3$. Part of the current will again split and flow through resistor $R_2$, permitting the remainder of the current to flow to resistor $R_3$. Notice in this circuit that there are three separate paths for the current to flow. The first rule for parallel circuits states that the total current is the sum of the currents through each branch of the circuit. Assume that the circuit shown in Figure 4-1 is connected to a 120 volt power source and that a current of 0.5 amp flows through resistor $R_1$, 1.5 amps flows through resistor $R_2$, and 2 amps flows through resistor $R_3$ (Figure 4-2).

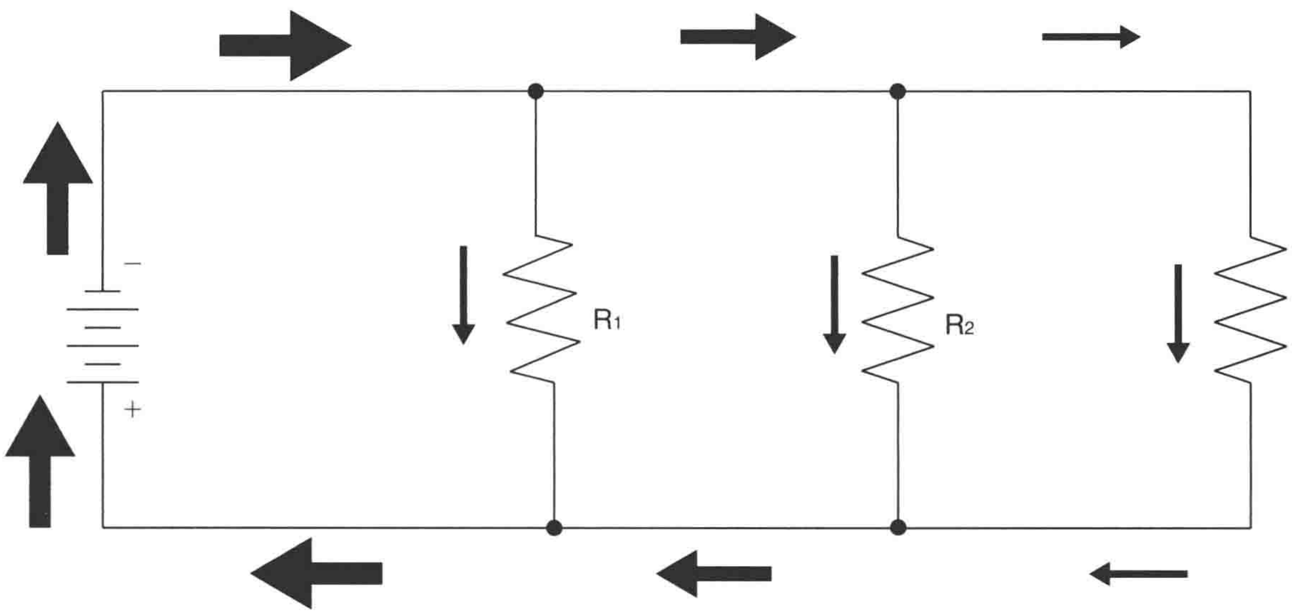



**Figure 4-1** Current flows through more than one path in a parallel circuit.

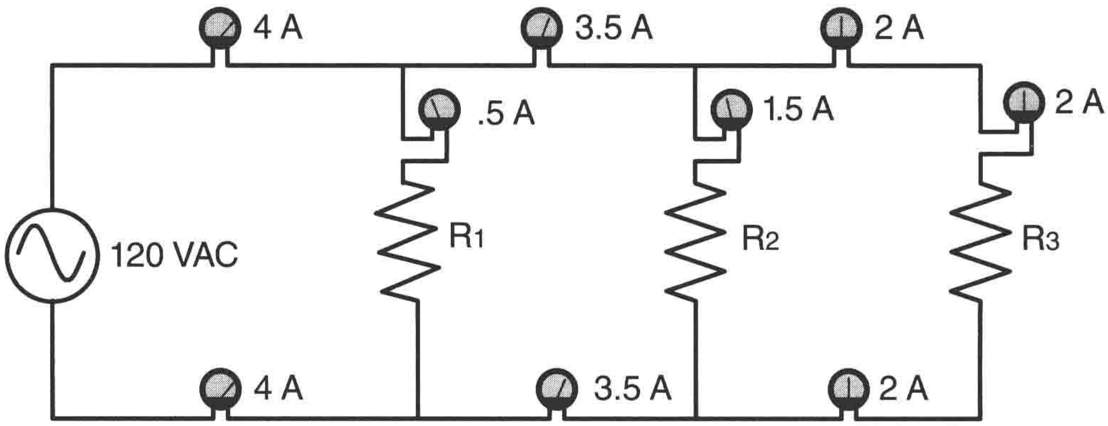



**Figure 4-2** The total circuit current is equal to the sum of the currents through each branch.

**Helpful Hint**

The first rule for parallel circuits states that the total current is the sum of the currents through each branch of the circuit.

Notice in Figure 4-2 that each branch is connected directly to the power source. If a voltmeter were connected across each branch, it would be seen that the source voltage is applied across each branch. The second rule for parallel circuits states that the voltage is the same across all branches of a parallel circuit. Since the voltage across each branch is known and the amount of current flowing through each is known, the resistance of each branch can be determined using Ohm's law.

**Helpful Hint**

The second rule for parallel circuits states that the voltage is the same across all branches of a parallel circuit.

$$R_1 = \frac{E_1}{I_1}$$

$$R_1 = \frac{120}{0.5}$$

$$R_1 = 240\ \Omega$$

$$R_2 = \frac{E_2}{I_2}$$

$$R_2 = \frac{120}{1.5}$$

$$R_2 = 80\ \Omega$$

$$R_3 = \frac{E_3}{I_3}$$

$$R_3 = \frac{120}{2}$$

$$R_3 = 60\ \Omega$$

It is also possible to determine the total resistance of the circuit using Ohm's law.

$$R_T = \frac{E_T}{I_T}$$

$$R_T = \frac{120}{4}$$

$$R_T = 30\ \Omega$$

The circuit resistance values are shown in Figure 4-3. Also, notice that the total circuit resistance is less than any single resistor in the circuit. To understand this, recall that resistance is hindrance to the flow of current. Each time another branch is connected to the power source, another path for current flow is created. This reduces the hindrance to current flow for the circuit. The total resistance of a parallel circuit will always be less than the resistance of any single branch. There are three formulas used to calculate the total resistance of a parallel circuit when only resistance values are known. The first formula is called the "product over sum" formula. This formula can calculate the total resistance of only two parallel resistors at a time. The product over sum formula is

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

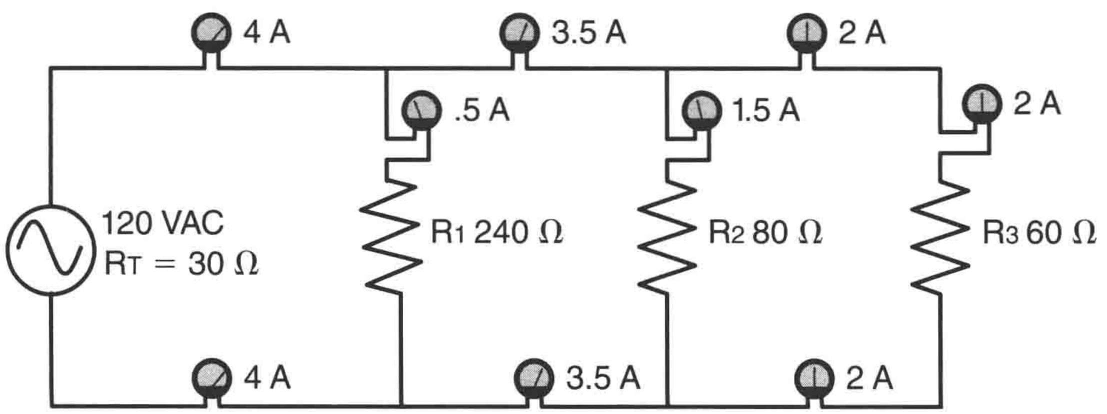



**Figure 4-3** Determining circuit resistance values.

**Helpful Hint**

The total resistance of a parallel circuit will always be less than the resistance of any single branch.

To determine the total resistance of the circuit shown in Figure 4-3, the parallel resistance of the first two resistors will be determined first.

$$R_T = \frac{240 \times 80}{240 + 80}$$

$$R_T = \frac{19200}{320}$$

$$R_T = 60\ \Omega$$

The total resistance of the first two resistors is 60 ohms. These two resistors are connected in parallel with another 60 Ω resistor, however. To find the parallel resistance of that connection, use the parallel resistance of the first two resistors as $R_1$ and the value of the next resistor as $R_2$ and repeat the calculation.

$$R_T = \frac{60 \times 60}{60 + 60}$$

$$R_T = \frac{3{,}600}{120}$$

$$R_T = 30\ \Omega$$

This process is repeated for each resistor until all the resistors have been substituted in the formula.

The second formula used to calculate parallel resistance is called the "reciprocal formula." The reciprocal of any number can be determined by dividing that number into 1. The third rule for parallel circuits states that the reciprocal of the total resistance is equal to the sum of the reciprocals of each branch. The basic reciprocal formula is shown below.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_N}$$

**Helpful Hint**

The third rule for parallel circuits states that the reciprocal of the total resistance is equal to the sum of the reciprocals of each branch.

This formula can be modified to solve for RT instead of the reciprocal of RT.

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_N}}$$

This is the most-used formula for solving parallel resistance because almost all scientific calculators have a reciprocal key (1/X). Any number shown on the display of a calculator is on the X axis. When the 1/X key is pressed, the calculator will divide any number shown on the display into 1. To find the total resistance of the circuit shown in Figure 4-3 using the reciprocal formula, press the following keys on a scientific calculator:

240 1/X + 80 1/X + 60 1/X =

The sum of the reciprocals of each branch is now on the calculator display. To find the total resistance, press the 1/X key again and this will give the reciprocal of the sum of the reciprocals.

**Example:** Find the total resistance of the following resistors connected in parallel:

1200 Ω, 2200 Ω, 1600 Ω, 3000 Ω, and 2400 Ω

Press the following calculator keys:

1200 1/X + 2200 1/X + 1600 1/X + 3000 1/X + 2400 1/X = 1/X

The answer should be 375.5 Ω.

The third formula for calculating parallel resistance is special and can be used only when all resistor values are the same. The formula is

$$R_T = \frac{R}{N}$$

N stands for the number of resistors connected in parallel. Assume that four 100 Ω resistors are connected in parallel. To determine their total resistance, divide the resistance of one resistor by the total number of resistors.

$$R_T = \frac{100}{4}$$

$$R_T = 25\ \Omega$$

## LABORATORY EXERCISE

Name ________________________________________ Date __________

### Materials Required

2 100 ohm resistors

1 150 ohm resistor

1 250 ohm resistor

1 AC ammeter (In-line or clamp-on. If a clamp-on type is used, the use of a scale divider is recommended.)

1 AC voltmeter

1 Ohmmeter

120 volt AC power supply

Connecting wires

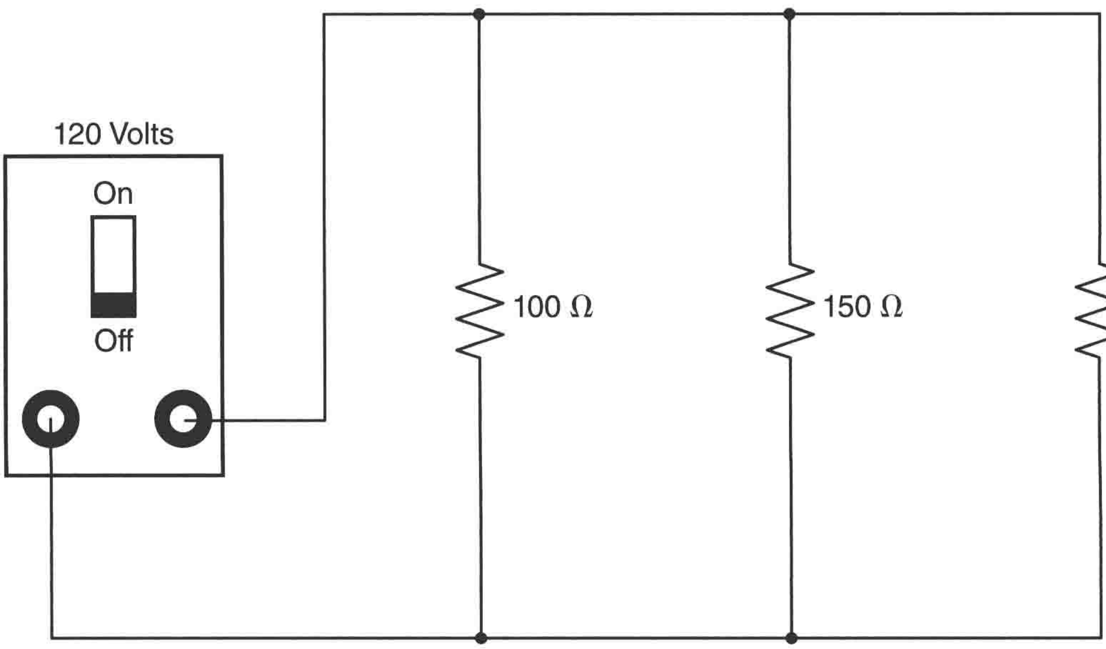



**Figure 4-4** Connecting the first parallel circuit.

1. Connect the circuit shown in Figure 4-4.
2. Calculate the total circuit resistance using the following formula: (Note: Round off the answer to the second decimal place or hundredth of an ohm.)

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

   $R_T$ = ____________ Ω

3. Disconnect the circuit from the power supply and measure the total circuit resistance with an ohmmeter. Compare this value with the computed value. Are the values within 5 percent of each other?

   ____________

4. Turn on the 120 VAC power and check the output voltage with an AC voltmeter. **Turn off the power.**

   ____________ volts

5. Reconnect the circuit to the power source. Turn on the power and measure the voltage across each resistor using the AC voltmeter.

   (100 Ω) ____________ volts
   (150 Ω) ____________ volts
   (250 Ω) ____________ volts

6. **Turn off the power supply.**
7. Calculate the current flow through each branch of the circuit using the following formula:

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

   (100 Ω) ____________ A
   (150 Ω) ____________ A
   (250 Ω) ____________ A

8. Connect an ammeter in series with the 100 ohm resistor.
9. Turn on the power supply and measure the current flow through the resistor.

   $I_{(100\Omega)}$ ____________ amps
10. **Turn off the power supply.**
11. Remove the AC ammeter from the branch containing the 100 ohm resistor and connect it in series with the 150 ohm resistor. Be sure to reconnect the 100 ohm resistor back into the circuit.
12. Turn on the power supply and measure the current flow through the 150 ohm resistor.

   $I_{(150\Omega)}$ ____________ amps
13. **Turn off the power supply.**
14. Remove the AC ammeter from the branch containing the 150 ohm resistor and connect it in series with the 250 ohm resistor. Reconnect the 150 ohm resistor back into the circuit.
15. Turn on the power and measure the current flow through the 250 ohm resistor.

   $I_{(250\Omega)}$ ____________ amps
16. **Turn off the power supply.**
17. Calculate the total circuit current. ($I_T = I_{(100\Omega)} + I_{(150\Omega)} + I_{(250\Omega)}$)

   $I_T =$ ____________ amps
18. Disconnect the AC ammeter from the branch containing the 250 ohm resistor and reconnect it in series with one of the conductors connected to the power supply. This will permit the total circuit current to be measured. Reconnect the 250 ohm resistor back into the circuit.
19. Turn on the power supply and measure the total current of the circuit. Compare this value with the computed value.

   $I_T =$ ____________ amps
20. **Turn off the power supply.**
21. Replace the 250 ohm resistor with a second 100 ohm resistor as shown in Figure 4-5.

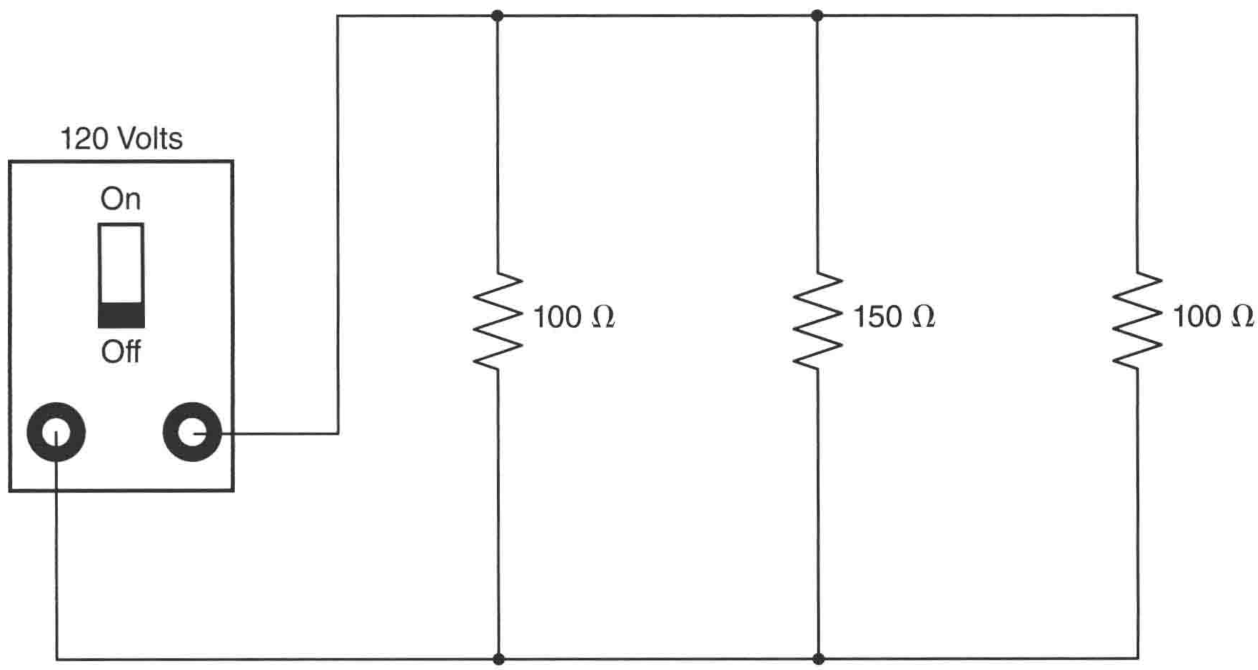



**Figure 4-5** Connecting the second parallel circuit.

22. Calculate the total circuit resistance using this formula. (Note: Round off the answer to the second decimal place or hundredth of an ohm.)

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

$R_T$ = ___________ Ω

23. Disconnect the circuit from the power supply and measure the total circuit reistance with an ohmmeter. Compare this value with the computed value. Are the values within 5 percent of each other?

___________

24. Turn on the 120 VAC power and check the output voltage with an AC voltmeter.

___________ volts

25. Measure the voltage across each resistor using the AC voltmeter.

(100 Ω) ___________ volts

(150 Ω) ___________ volts

(250 Ω) ___________ volts

26. **Turn off the power supply.**

27. Calculate the current flow through each branch of the circuit using the following formula:

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

(100 Ω) ___________ A

(150 Ω) ___________ A

(250 Ω) ___________ A

28. Connect an ammeter in series with the first 100 ohm resistor.

29. Turn on the power supply and measure the current flow through the resistor.

$I_{(100\Omega)}$ ___________ amps

30. **Turn off the power supply.**

31. Remove the AC ammeter from the branch containing the first 100 ohm resistor and connect it in series with the 150 ohm resistor. Be sure to reconnect the 100 ohm resistor back into the circuit.

32. Turn on the power supply and measure the current flow through the 150 ohm resistor.

$I_{(150\Omega)}$ ___________ amps

33. **Turn off the power supply.**

34. Remove the AC ammeter from the branch containing the 150 ohm resistor and connect it in series with the second 100 ohm resistor. Reconnect the 150 ohm resistor back into the circuit.

35. Turn on the power and measure the current flow through the second 100 ohm resistor.

$I_{(100\Omega)}$ ___________ amps

36. **Turn off the power supply.**

37. Calculate the total circuit current. ($I_T = I_{(100\Omega)} + I_{(150\Omega)} + I_{(100\Omega)}$)

$I_T$ = ___________ amps

38. Disconnect the AC ammeter from the branch containing the second 100 ohm resistor and reconnect it in series with one of the conductors connected to the power supply. This will permit the total circiuit current to be measured. Reconnect the second 100 ohm resistor back into the circuit.

39. Turn on the power supply and measure the total current of the circuit. Compare this value with the computed value.

    $I_T$ = ___________ amps

40. **Turn off the power supply.** Disconnect the circuit and return the components to their proper place.

## Review Questions

1. State the three rules for parallel circuits.

___________________________________________

___________________________________________

___________________________________________

___________________________________________

___________________________________________

___________________________________________

2. A circuit has four resistors connected in parallel. The resistor values are as follows: $R_1$ = 150 kΩ, $R_2$ = 220 kΩ, $R_3$ = 180 kΩ, and $R_4$ = 330 kΩ. What is the total resistance of this circuit?

___________________________________________

3. Refer to the resistor values in question 2. Assume that resistor $R_2$ has a current of 0.945 mA flowing through it. How much current is flowing through resistor $R_4$?

___________________________________________

4. A circuit contains three resistors connected in parallel and has a total power consumption of 14 watts. Resistor $R_1$ has a power consumption of 6.2 watts, $R_2$ consumes 4.8 watts. Resistor $R_3$ has a value of 192 Ω. What is the voltage applied to the circuit?

___________________________________________

5. A circuit contains four resistors connected in parallel. Resistor $R_1$ has a current flow of 0.25 amp, $R_2$ has a current flow of 0.3 amp, $R_3$ has a current flow of 0.45 amp, and $R_4$ has a current flow of 0.7 amp. What is the total current flow in this circuit?

___________________________________________

6. A circuit has the following resistors connected in parallel: 18 Ω, 24 Ω, 12 Ω, and 10 Ω. What is the total resistance of this circuit?

___________________________________________

7. A parallel circuit contains three resistors. The total resistance of the circuit is 8 Ω. Resistor $R_1$ has a value of 24 Ω, and $R_2$ has a value of 18 Ω. What is the value of resistor $R_3$?

___________________________________________

# Unit 5 Combination Circuits

## Objectives

After studying this unit, you should be able to

- Determine series and parallel paths through an electric circuit.
- Use measured values of voltage, current, and resistance in a combination circuit to determine unknown electrical quantities.
- Use measuring instruments to determine electrical quantities in a combination circuit.
- Solve combination circuit problems using Ohm's law.

Combination circuits contain both series and parallel paths in the same circuit. In order to solve unknown values, it is imperative to be able to identify which components are in series and which are in parallel. To determine which components are in series and which are in parallel, trace the current path through the circuit. In the circuit shown in Figure 5-1, resistors $R_2$ and $R_3$ are connected in parallel. Resistor $R_1$ is connected in series with $R_2$ and $R_3$. Assume that current leaves the negative terminal of the battery and must return to the positive terminal. All the current in the circuit must flow through resistor $R_1$ because there is no other path by which the current can travel from the negative to the positive terminal. Resistor $R_1$ is, therefore, in series with the rest of the circuit because the definition of a series circuit is a circuit that has only one path for current flow.

After leaving resistor $R_1$, the current path can divide. Part of the current will flow through resistor $R_2$ and part will flow through $R_3$. The amount of current that flows through each is determined by their resistance values. Since the current has more than one path, resistors $R_2$ and $R_3$ are connected in parallel with each other. After leaving resistors $R_2$ and $R_3$, the current proceeds to the positive battery terminal.

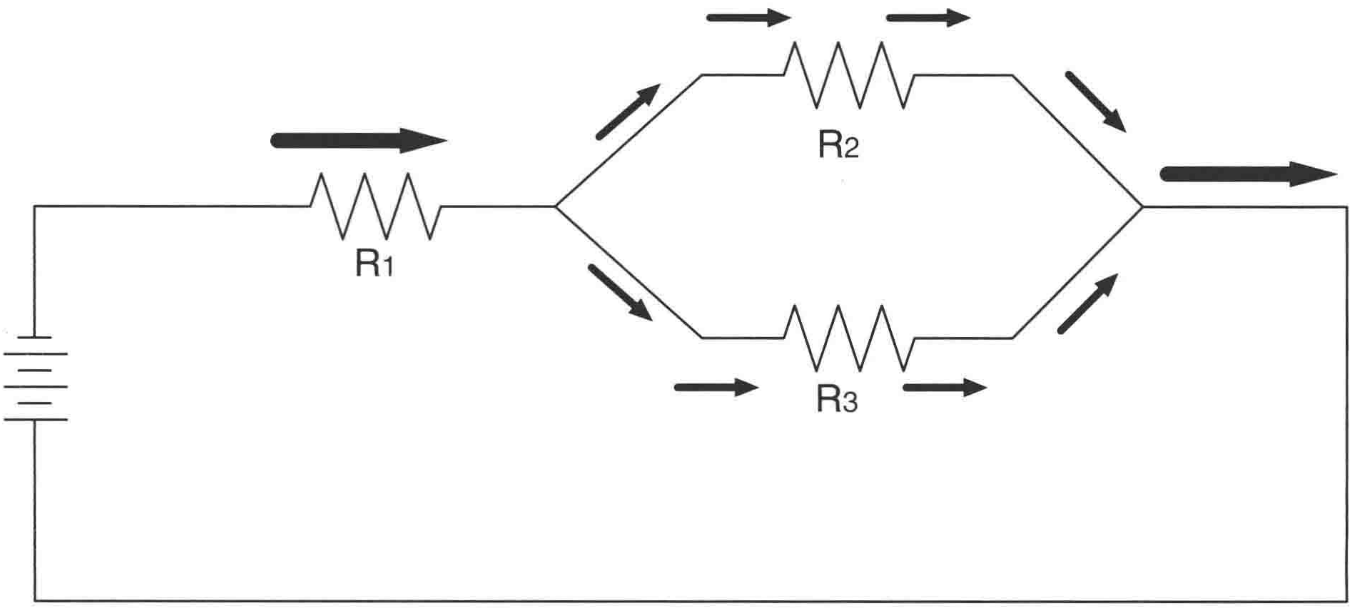



**Figure 5-1** Tracing the current path through a simple combination circuit.

## Example Circuit #1

Values of resistance and voltage have been added to the circuit in Figure 5-2. Resistor $R_1$ has a value of 36 Ω, $R_2$ has a value of 40 Ω, and $R_3$ has a value of 60 Ω. The battery has a terminal voltage of 30 volts. The following electrical values will be determined for this circuit:

$R_T$ - Total resistance of the circuit

$I_T$ - Total circuit current

$I_1$ - Current flow through resistor $R_1$

$E_1$ - Voltage drop across resistor $R_1$

$E_2$ - Voltage drop across resistor $R_2$

$E_3$ - Voltage drop across resistor $R_3$

$I_2$ - Current flow through resistor $R_2$

$I_3$ - Current flow through resistor $R_3$

When solving values for a combination circuit, it is generally helpful to reduce the circuit to a simple series or parallel circuit and then work back through the circuit in a step-by-step procedure. This is accomplished by combining series or parallel components to form a single resistance value. In the circuit shown in Figure 5-2, resistors $R_2$ and $R_3$ are connected in parallel. These two resistors can be combined into one resistor value by determining their total resistance value.

$$R_T = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\frac{1}{R_N}}$$

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

$$R_T = \frac{1}{40+60}$$

$$R_T = 24\ \Omega$$

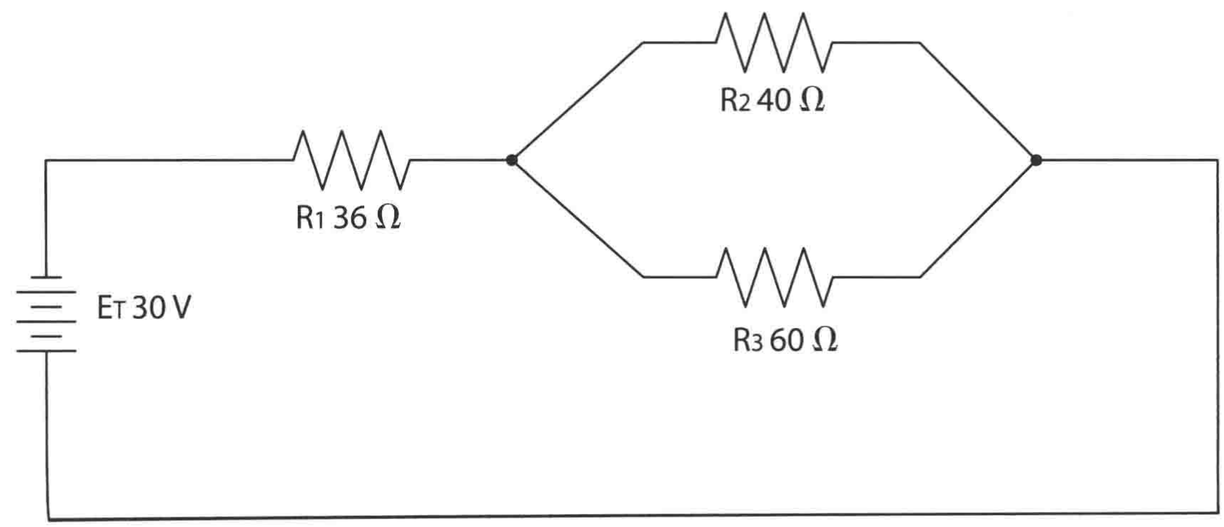



**Figure 5-2** Values are added to the circuit.

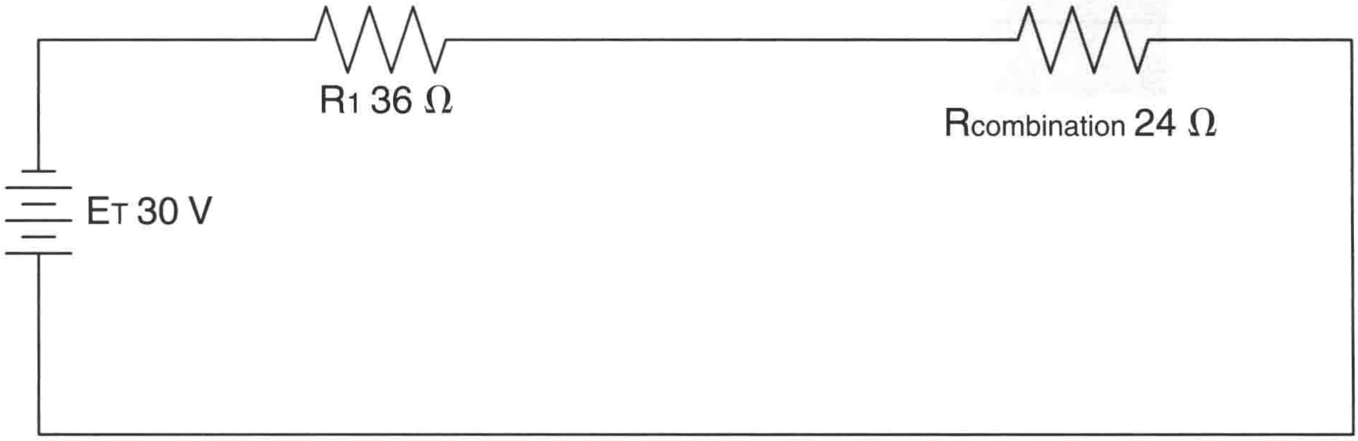



**Figure 5-3** The circuit has become a simple series circuit.

The total resistance for resistors $R_2$ and $R_3$ will form resistor $R_{combination}$. The circuit has been redrawn in Figure 5-3. Notice that resistors $R_2$ and $R_3$ have been replaced by $R_{combination}$. The circuit is now a simple series circuit containing two resistors, $R_1$ and $R_{combination}$. One of the rules for series circuits states that the total resistance is equal to the sum of the individual resistances. The total circuit resistance can be determined by adding the two resistance values together.

$$R_T = R_1 + R_{combination}$$
$$R_T = 36 + 24$$
$$R_T = 60\ \Omega$$

Now that the total resistance is known, the total current can be determined using Ohm's law.

$$I = \frac{E}{R}$$
$$I_T = \frac{30}{60}$$
$$I_T = 0.5 \text{ amp}$$

In a series circuit, the current is the same through all parts of the circuit. Therefore, the resistors $R_1$ and $R_{combination}$ have a current of 0.5 amp flowing through them. The voltage drop across each resistor can now be determined using Ohm's law.

$$E_1 = 0.5 \times 36$$
$$E_1 = 18 \text{ volts}$$
$$E_{combination} = 0.5 \times 24$$
$$E_{combination} = 12 \text{ volts}$$

These added circuit values are shown in Figure 5-4.

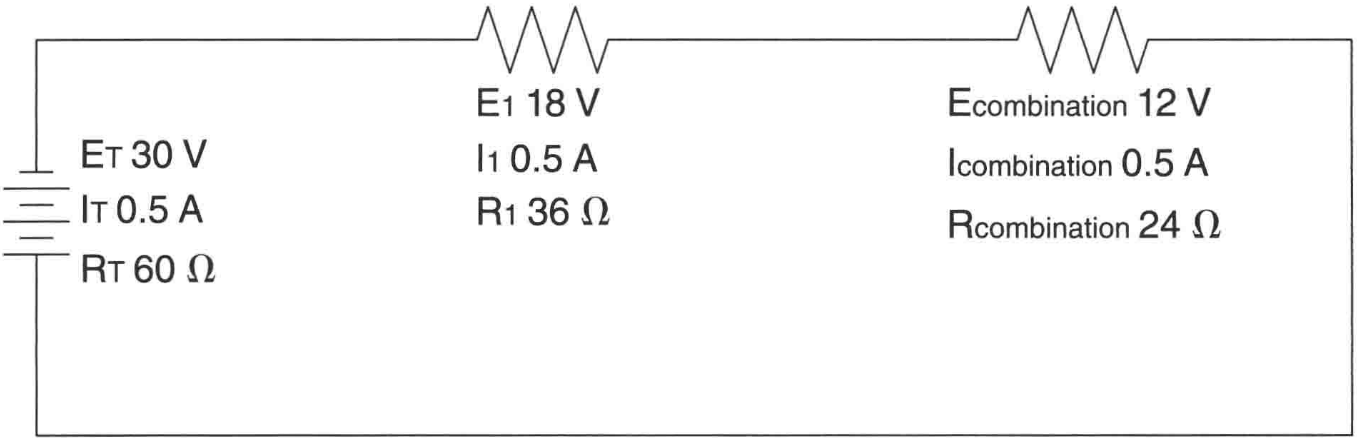



**Figure 5-4** Values for the series circuit have been determined.

Resistor $R_{combination}$ is in reality resistors $R_2$ and $R_3$. The values that apply to $R_{combination}$, therefore, apply to resistors $R_2$ and $R_3$. If a voltmeter were to be connected across the parallel circuit containing $R_2$ and $R_3$, it would indicate the same voltage drop as that across $R_{combination}$, as shown in Figure 5-5. One of the rules of parallel circuits is that the voltage must be the same across all branches of the circuit. Therefore, 12 volts is dropped across resistors $R_2$ and $R_3$.

Now that the voltage across resistors $R_2$ and $R_3$ is known, the current flow through each can be determined using Ohm's law.

$$I_2 = \frac{12}{40}$$

$$I_2 = 0.3 \text{ amp}$$

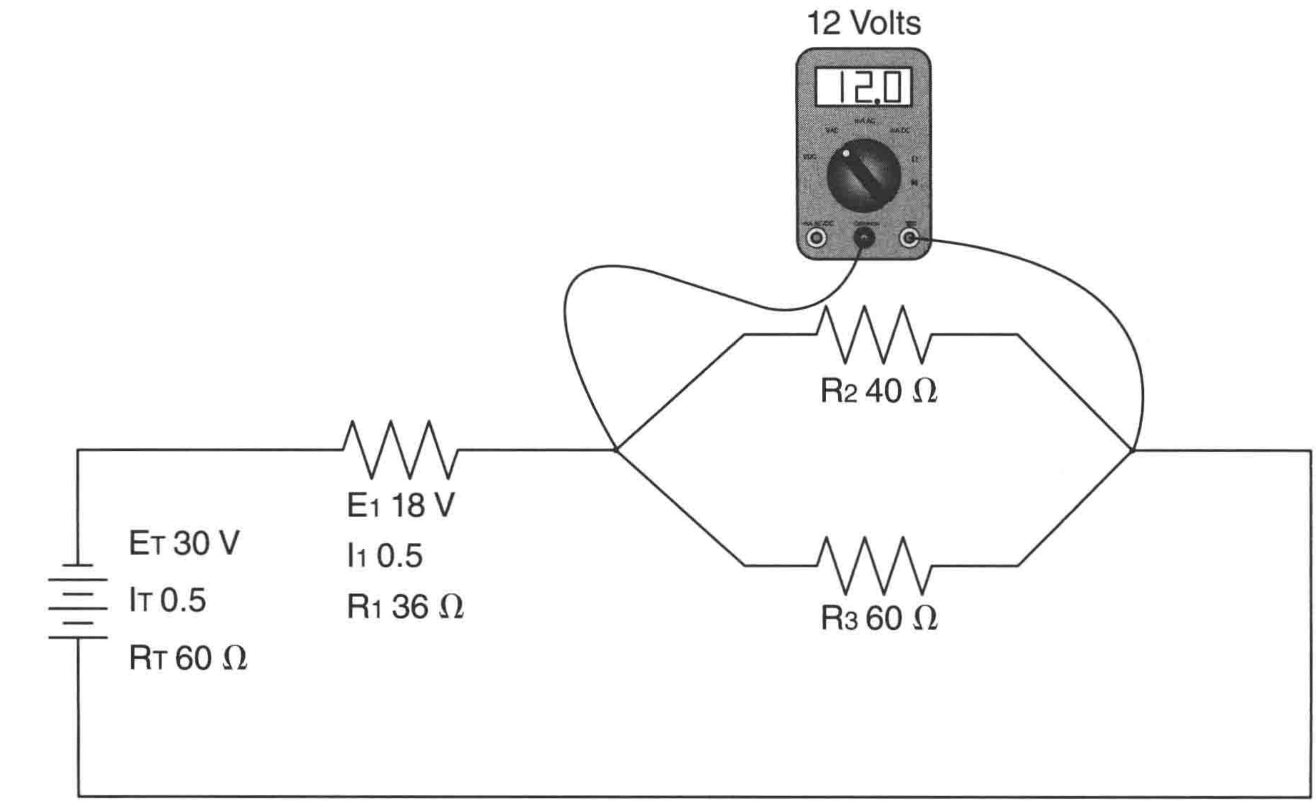



**Figure 5-5** The same voltage is dropped across the two parallel resistors as is dropped across the combination resistor.