# CHAPTER 3 Basic Circuits, Laws, and Measurements

## Learning Outcomes

*This chapter will help you to:*

**3-1** *Specify* the four essential parts of a complete circuit.

**3-2** *Identify* circuit components and symbols.

**3-3** *Use* electrical laws and formulas to solve electrical problems involving I, V, R, P, and W, time and cost.

**3-4** *Connect* and read panel meters and multimeters to measure resistance, voltage, and current.

You are now familiar with electrical quantities and units. Now you are ready to explore the circuits, laws, and devices used to control and measure these quantities and units.

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## 3-1 Circuit Essentials

Many complete electric circuits contain six parts:

1. An *energy source* to provide the voltage needed to force current (electrons) through the circuit
2. *Conductors* through which the current can travel
3. *Insulators* to confine the current to the desired paths (conductors, resistors, etc.)
4. A *load* to control the amount of current and convert the electric energy taken from the energy source
5. A *control device,* often a switch, to start and stop the flow of current
6. A *protection device* to interrupt the circuit in case of a circuit malfunction

The first four of the above six parts are essential parts. All complete circuits use them. The control device (item 5) and/or the protection device (item 6) will be omitted in some circuits. Item 6 is the most often omitted item. A complete electric circuit has an uninterrupted path for current (electrons) to flow from the negative terminal of the energy source through the load and control device to the positive terminal of the energy source.

The simplest electric circuit contains only one load, one voltage source, and one control device. It is sometimes referred to as a *simple circuit* to distinguish it from more complex circuits. A single-cell flashlight is an example of a simple circuit. Figure 3-1(*a*) shows (in cross section) the construction details of such a flashlight.

**Simple circuit**

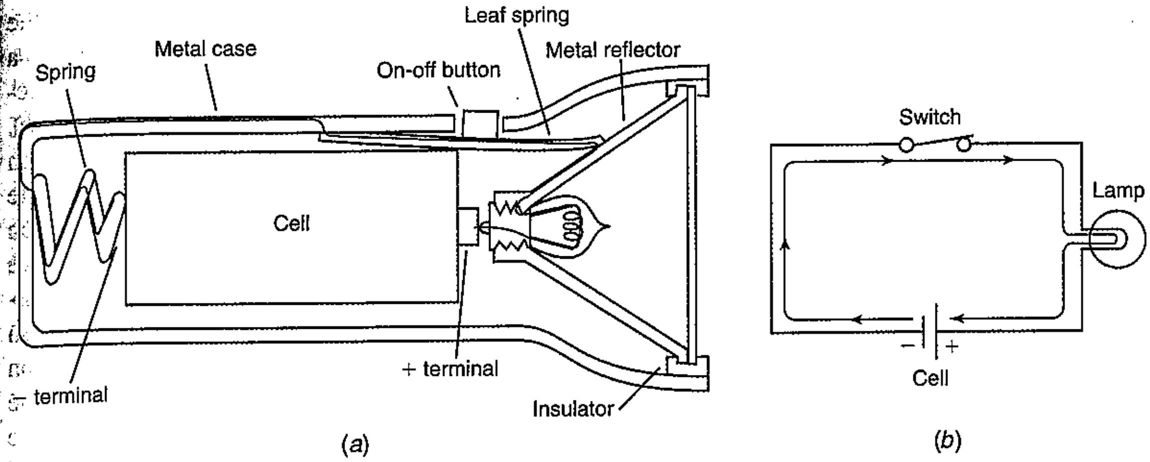



**Fig. 3-1** Flashlight. (*a*) Cross-sectional drawing. (*b*) Schematic diagram.

Electron flow (current) in the flashlight circuit can be traced by referring to Fig. 3-1. Electrons leave the negative end of the cell, travel through the spring, the metal case, the leaf spring of the switch, the metal reflector, and the light bulb, and back to the positive end of the cell. Note that the spring, case, and reflector are conductors for the flashlight circuit. It is quite common in electric devices for structural parts of the device to serve also as conductors. For example, both an automobile frame and the chassis of many electronic devices serve as circuit conductors.

## 3-2 Circuit Symbols and Diagrams

In describing an electric circuit, you will find it more convenient to use symbols to represent electric components than to draw pictures of the components. A resistor and the symbol used to represent it are shown in Fig. 3-2. This same symbol is used for all fixed resistors regardless of the material from which they are made. Other common electric components and their symbols are shown in Fig. 3-3. It should be noticed that there is no symbol to distinguish insulated from noninsulated conductors. Insulation is assumed to be present wherever it is needed to keep components and conductors from making electric contact. In constructing an electric circuit that is described by electrical symbols, the circuit builder must determine where insulation is needed.

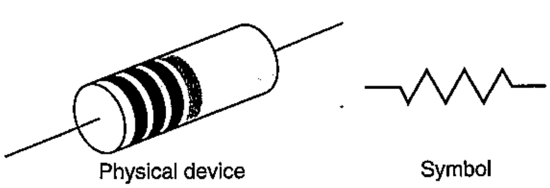


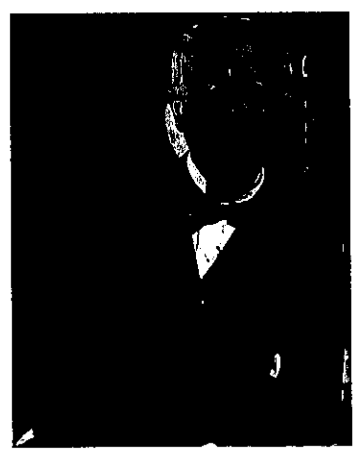

**Fig. 3-2** Resistor and its symbol.

**Schematic diagram**

A drawing that uses only symbols to show how components are connected together is called a *schematic diagram.* A schematic diagram shows only how the parts are electrically interconnected. The physical size and the mechanical arrangements of the parts are in no way indicated. Also, accessories, such as battery or lamp holders, are not indicated. Unless the schematic diagram is accompanied by some form of pictorial drawing, the physical arrangement of the electric components is left to the discretion of the circuit builder.

### *History of* Electronics

**Thomas Edison**
One of the inventions Thomas Edison is well known for is the light bulb. Through his experiments, he discovered that electrons are emitted when the filament of an incandescent light bulb is heated by passing an electric current through it. (*Encyclopedia of Electronics, Gibilisco* and Sclater, McGraw-Hill, 1990.)



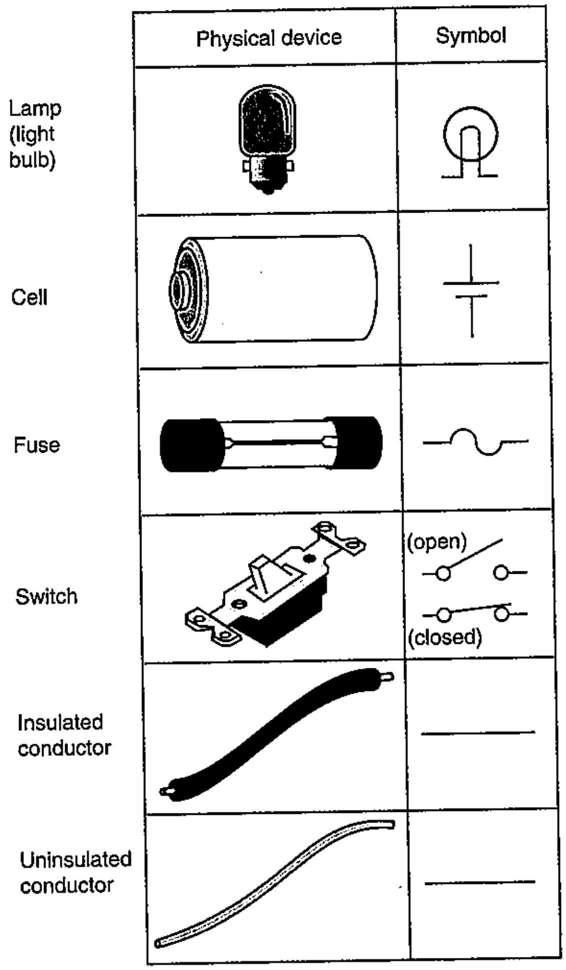



**Fig. 3-3** Electric components and their symbols.

**Direction of current flow**

A schematic diagram of the flashlight illustrated in Fig. 3-1(*a*) is shown in Fig. 3-1(*b*). Current can also be traced in the schematic diagram. The line with the arrowheads indicates the *direction of current flow.* The electrons (current) flow from the negative end of the cell through the closed switch and the lamp and back to the positive end of the cell. The conductor between the negative terminal of the cell and the switch in Fig. 3-1(*b*) represents the spring and the metal case in Fig. 3-1(*a*). The contact between the positive end of the cell and the light bulb in Fig. 3-1(*a*) is represented by the long line in the schematic diagram. Notice that lines in a schematic do not necessarily indicate a wire, but they do indicate a path for current to flow through.

In this text, we will always use the direction of electron flow as the direction of current flow. For a voltage source like the cell in Fig. 3-1(*b*), electrons flow out of the negative terminal (which has an excess of electrons) around the circuit to the positive terminal (which has a deficiency of electrons). Therefore, the direction of current flow is as indicated in Fig. 3-1(*b*). Many books (especially those dealing with transistors, digital circuits, and other solid-state devices) use conventional current flow, which assumes that current flows out of the positive terminal of the source and into the negative terminal of the source. Any circuit or system can be analyzed using either electron-flow direction or conventional-flow direction. Many people find it easier to visualize, and remember, the electron-flow direction than the conventional direction of current.

**Common ground symbol**

The *common ground symbol* shown in Fig. 3-4 is often used in schematic diagrams—especially in schematic diagrams for complex circuits and systems. The symbol does not represent any specific electric component. Rather, it represents a common electric point in an electric circuit (or an electric system) that is a common connecting point for many components. For example, the metal frame or chassis of an automobile is the common ground for the many electric circuits used in the automobile. Usually, the negative terminal of the car battery is

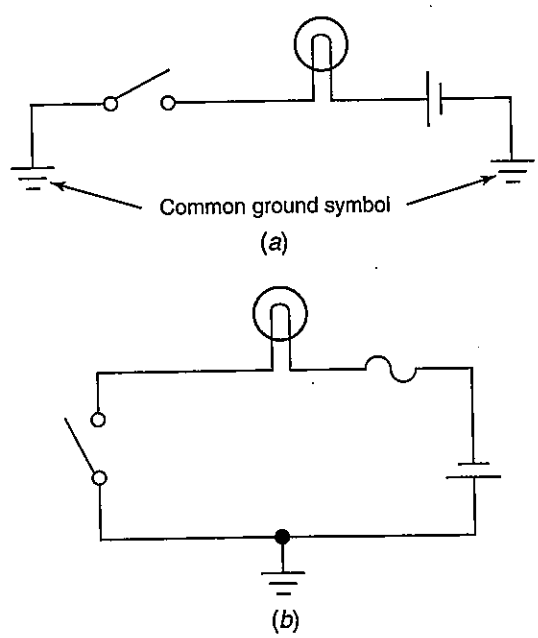



**Fig. 3-4** Common grounds. (*a*) A conductive path exists between the common grounds. (*b*) The switch and the positive terminal are connected to the common ground.

connected only to the frame or chassis. Then, any circuit that needs an electric connection to the negative terminal of the battery can be physically (and electrically) connected to any convenient spot on the frame or chassis. This idea is illustrated in Fig. 3-4(*a*), where the two ground symbols tell us that there is a conductive path between them. Figure 3-4(*b*) shows another way to indicate that a circuit is connected to a common ground.

**Electrical values**

The *electrical values* of the components used in the circuit can also be included on the schematic diagram. This is done in one of two ways. In the first method, shown in Fig. 3-5(*a*), the values of the components are printed beside the symbols for the components. In the second method, shown in Fig. 3-5(*b*), an identifying letter or symbol is printed beside each component and the values of the components are given in an accompanying parts list.

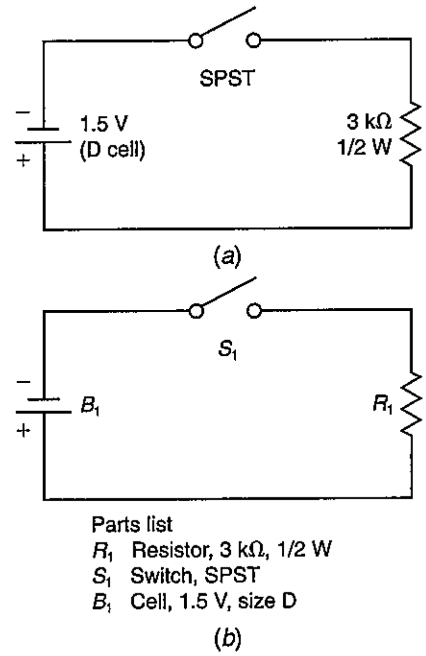



**Fig. 3-5** Specifying component values. (*a*) Values given on the diagram. (*b*) Values given in a parts list.

## Self-Test

*Answer the following questions.*

1. What are the six parts of a complete circuit?
2. True or false. Component values are always given on a schematic diagram.
3. True or false. The conductors in an electric circuit are always insulated wire conductors.
4. Draw the symbol for a lamp, a resistor, and a conductor.
5. What is a schematic diagram?
6. True or false. The chassis or frame of a device can serve as a conductor for more than one circuit.
7. True or false. A schematic diagram is used to show both the electrical and the mechanical layout of a circuit.
8. Which part of a complete circuit is most often omitted?

## 3-3 Calculating Electrical Quantities

**You May Recall**

. . . that in previous chapters you learned how to use relationships between electrical quantities to calculate other electrical quantities.

In this section we work with more relationships of electrical quantities. These new relationships emphasize quantities which can be easily measured or are commonly specified by manufacturers of electrical products.

### Ohm's Law

**Ohm's law**

The relationship between current ($I$), voltage ($V$), and resistance ($R$) was discovered by a German scientist named Georg Ohm. This relationship is named *Ohm's law* in his honor. Ohm found that the current in a circuit varies directly with the voltage when the resistance is kept constant. While keeping the resistance

## History of Electronics

**Georg Simon Ohm**

The unit of measure for resistance (ohm) is named for German physicist Georg Simon Ohm. Ohm is also known for his development of Ohm's law:

Voltage = current × resistance

constant, Ohm varied the voltage across the resistance and measured the current through it. In each case, when he divided the voltage by the current, the result was the same. In short, this is Ohm's law, which can be stated as "The current is directly proportional to the voltage and inversely proportional to the resistance."

Written as a mathematical expression, Ohm's law is

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

$$\text{Current } (I) = \frac{\text{voltage } (V)}{\text{resistance } (R)} \quad \text{or} \quad I = \frac{V}{R}$$

This equation allows you to determine the value of the current when the voltage and the resistance are known.

Of course, Ohm's law can be rearranged to solve for either resistance or voltage. The rearranged relationships are

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

$$\text{Resistance } (R) = \frac{\text{voltage } (V)}{\text{current } (I)} \quad \text{or} \quad R = \frac{V}{I}$$

and

$$\text{Voltage } (V) = \text{current } (I) \times \text{resistance } (R)$$

or

$V = IR$

$$V = IR$$

An aid to remembering the Ohm's law relationships is shown in the divided circle of Fig. 3-6. To use the aid, just cover the quantity you want to find and perform the multiplication or division indicated. Cover the $V$ of Fig. 3-6, and the remainder of the circle indicates $I$ times $R$. Thus, voltage ($V$) equals current ($I$) times resistance ($R$). Cover the $R$, and the remainder of the circle shows voltage ($V$) divided by the current ($I$). Finally, if the current ($I$) is covered, the indicated operation is to divide the voltage ($V$) by resistance ($R$).

**EXAMPLE 3-1**

How much current ($I$) flows in the circuit shown in Fig. 3-7?

**Given:** Voltage ($V$) = 2.8 volts (V)
Resistance ($R$) = 1.4 kilohm (1.4 kΩ)

**Find:** Current ($I$)

**Known:** $I = \frac{V}{R}$, 1.4 kΩ = 1400 Ω

**Solution:** $I = \frac{2.8\text{ V}}{1400\ \Omega}$
= 0.002 ampere (A)

**Answer:** The current is 0.002 A.

**EXAMPLE 3-2**

A lamp has a resistance of 96 ohms. How much current flows through the lamp when it is connected to 120 volts?

**Given:** $R = 96\ \Omega$
$V = 120\text{ V}$

**Find:** $I$

**Known:** $I = \frac{V}{R}$

**Solution:** $I = \frac{120\text{ V}}{96\ \Omega} = 1.25\text{ A}$

**Answer:** The current through the lamp equals 1.25 A.

Notice in the preceding examples that the answers for the current are in their base units. This is because both voltage and resistance are also in base units. Remember that an ohm is

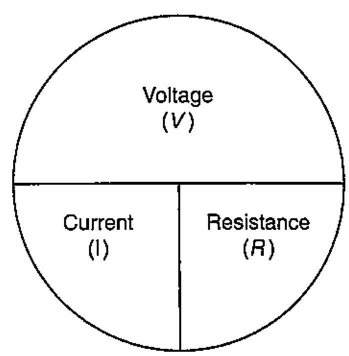



**Fig. 3-6** Ohm's law circle.

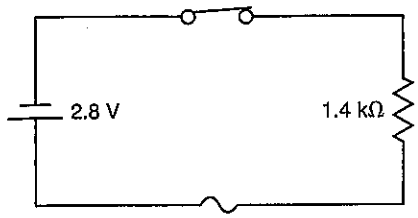



**Fig. 3-7** Circuit diagram for example 3-1.

defined as 1 volt per ampere. Therefore, Ohm's law can be expressed in base units as follows:

$$1 \text{ ampere} = \frac{1 \text{ volt}}{1 \text{volt/ampere}}$$

This expression reduces to 1 ampere = 1 ampere, which shows that proper units were used.

**EXAMPLE 3-3**

The manufacturer specifies that a certain lamp will allow 0.8 ampere of current when 120 volts is applied to it. What is the resistance of the lamp?

| | |
|---|---|
| **Given:** | Current ($I$) = 0.8 ampere (A)<br>Voltage ($V$) = 120 volts (V) |
| **Find:** | Resistance ($R$) |
| **Known:** | $R = \frac{V}{I}$ |
| **Solution:** | $R = \frac{120 \text{ V}}{0.8 \text{ A}} = 150$ ohms (Ω) |
| **Answer:** | The resistance of the lamp is 150 Ω. |

**EXAMPLE 3-4**

How much voltage is required to cause 1.6 amperes in a device that has 30 ohms of resistance?

| | |
|---|---|
| **Given:** | $R = 30\ \Omega$<br>$I = 1.6$ A |
| **Find:** | $V$ |
| **Known:** | $V = IR$ |
| **Solution:** | $V = 1.6 \text{ A} \times 30\ \Omega = 48$ V |
| **Answer:** | The voltage applied to the device must be 48 V. |

**EXAMPLE 3-5**

The current flowing through a 10-kΩ resistor is 35 mA. What is the potential energy difference (voltage) across the resistor?

| | |
|---|---|
| **Given:** | $R = 10 \text{ k}\Omega = 10{,}000\ \Omega$<br>$I = 35 \text{ mA} = 0.035$ A |
| **Find:** | $V$ |
| **Known:** | $V = IR$ |
| **Solution:** | $V = 0.035 \text{ A} \times 10{,}000\ \Omega$<br>$= 350$ V |
| **Answer:** | The voltage across the resistor is 350 V. |

Notice in example 3-5 that $I$ in mA times $R$ in kΩ would also yield $V$ in V because m ($10^{-3}$) times k ($10^3$) cancel each other.

## Calculating Power

**You May Recall**

. . . that we previously learned how to find the amount of power when energy and time were known.

Now we are going to work with the relationship between current, voltage, and power. Since current and voltage are easily measured quantities, you will be using this relationship quite often in electrical work.

In circuits where the load is entirely resistance, power is equal to current times voltage. Expressed as a formula, we have

$$\text{Power } (P) = \text{current } (I) \times \text{voltage } (V)$$

or

$$P = IV$$

***P = IV***

Power is in its base unit of watts when voltage is in volts and current is in amperes.

**EXAMPLE 3-6**

What is the power input to an electric heater that draws 3 amperes from a 120-volt outlet?

| | |
|---|---|
| **Given:** | Current ($I$) = 3 amperes (A)<br>Voltage ($V$) = 120 volts (V) |
| **Find:** | Power ($P$) |
| **Known:** | $P = IV$ |
| **Solution:** | $P = 3 \text{ A} \times 120$ V<br>$= 360$ watts (W) |
| **Answer:** | The power input to the electric heater is 360 W. |

specifying the cost rate of gasoline in cents per gallon. The cost of anything is equal to the total quantity times the cost rate. If potatoes cost 10¢ per pound (cost rate) and you buy 10 pounds, the cost is \$1. That is, the cost is equal to the rate times the quantity. The cost of electric energy is

**Cost = rate × energy**

$$\text{Cost} = \text{rate} \times \text{energy}$$
$$= \text{cents per kilowatthour} \times \text{kilowatthours}$$

### EXAMPLE 3-14

What is the cost of 120 kWh of energy if the rate is 6¢ per kWh?

**Given:** $W = 120$ kWh
Rate = 6¢ per kWh
**Find:** Cost
**Known:** Cost = rate × energy
**Solution:** Cost = 6¢ per kWh × 120 kWh = 720¢ = \$7.20
**Answer:** The cost is \$7.20.

### EXAMPLE 3-15

What is the cost of operating a 100-watt lamp for 3 hours if the rate is 6¢ per kWh?

**Given:** $P = 100$ W
$t = 3$ h
Rate = 6¢ per kWh
**Find:** Cost
**Known:** Cost = rate × energy, $W = Pt$
**Solution:** $W = 100\text{ W} \times 3\text{ h} = 300\text{ Wh} = 0.3\text{ kWh}$
Cost = 6¢ per kWh × 0.3 kWh = 1.8¢
**Answer:** It costs 1.8¢ to operate the lamp for 3 hours.

### EXAMPLE 3-16

An electric iron operates from a 120-volt outlet and draws 8 amperes of current. At 9¢ per kWh, how much does it cost to operate the iron for 2 hours?

**Given:** $V = 120$ V
$I = 8$ A
$t = 2$ h
Rate = 9¢ per kWh
**Find:** Cost
**Known:** Cost = rate × energy
$W = Pt$, $P = IV$
**Solution:** $P = 8\text{ A} \times 120\text{ V} = 960\text{ W}$
$W = 960\text{ W} \times 2\text{ h} = 1920\text{ Wh} = 1.92\text{ kWh}$
Cost = 9¢ per kWh × 1.92 kWh = 17.3¢
**Answer:** The cost is 17.3¢.

Notice the order in which the "Known" in example 3-16 is listed. The procedure outlined below was used in developing the order in which the "Known" formulas are listed.

1. Write the formula needed to solve for the quantity to be found. Look at the quantities to the right of the equals sign in this formula. If one of these quantities is not listed in the "Given" row, write the formula needed to find it ($W = Pt$).
2. Look at the right-hand half of the formula just written ($W = Pt$). If a quantity there is not listed in the "Given" row, write the formula needed to find it ($P = IV$).
3. Look at the right-hand half of ($P = IV$). The "Given" row lists both ($I$ and $V$). The problem can now be solved.

The above procedure should always be used to reduce complex problems into a series of simple steps.

## Self-Test

*Answer the following questions.*

9. Express the answer to example 3-6 in kilowatts.
10. Express the answer to example 3-10 in milliwatts.
11. Refer to Fig. 3-5(*a*). How much current flows when the switch is closed?

12. What is the resistance of a semiconductor device that allows 150 milliamperes of current when 600 millivolts of voltage is connected to it?
13. What is the power of a hair dryer that operates from 120 volts and draws 4.5 amperes of current?
14. How much current is required by a 1000-watt toaster that operates from a 120-volt outlet?
15. What is the power rating of an automobile tape deck that requires 2.2 amperes from a 12.6-volt battery?
16. A miniature lamp has 99 ohms of resistance when lit. It operates from a 6.3-volt battery. What is the power rating of the lamp?
17. An electric heater draws 8 amperes from a 240-volt source. How much energy does it convert in 9 hours?
18. The current through a 100-ohm resistor is 200 milliamperes. How much energy does the resistor convert to heat in 10 minutes?
19. An electric water heater has a 3000-watt heating element. The element is on for 3 hours. What is the cost if the rate is 4¢ per kilowatthour?
20. A string of Christmas tree lights draws 0.5 amperes from a 120-volt outlet. At 8¢ per kilowatthour, how much does it cost to operate the lights for 40 hours?

## 3-4 Measuring Electrical Quantities

Most electrical quantities are measured with a device called a *meter.* Voltage is measured with a *voltmeter,* current with an *ammeter,* resistance with an *ohmmeter,* and power with a *wattmeter.*

### Panel Meters

A meter that measures only one of the above quantities is called a *panel meter.* Panel meters are often permanently connected (wired) into a circuit to provide continuous monitoring of an electrical quantity. The meters may be either analog or digital.

#### ANALOG PANEL METER

An analog panel meter is shown in Fig. 3-9. With this meter, the needle can point anywhere on the scale. When an analog meter is read, the reading is generally taken to the nearest minor-division mark. If the pointer is halfway between marks, it is read as a half-division. Before reading a meter scale, you must figure out the value of each division of the scale. Look at the scale on the meter in Fig. 3-9. Notice that there is a heavy line halfway between 4 and 6. This heavy line represents five units. Now count the number of divisions (called *minor divisions*) between 4 and 5. Since there are five minor divisions between 4 and 5, each minor division has a value of 0.2 unit. Therefore, each minor division on the scale represents 0.2 ampere. Suppose the needle (pointer) on the meter in Fig. 3-9 is pointing to the second mark to the right of the 8 mark. The meter would be indicating 8.4 amperes.

#### DIGITAL PANEL METER

The digital panel meter (DPM) shown in Fig. 3-10 eliminates the need to decide which mark is closest to the pointer. There is no guesswork in trying to decide whether the meter reading is 184.8 or 184.9.

Digital meters are usually specified by the number of digits in their readout. When the

**Voltmeter**

**Ammeter**

**Ohmmeter**

**Wattmeter**

**Panel meter**

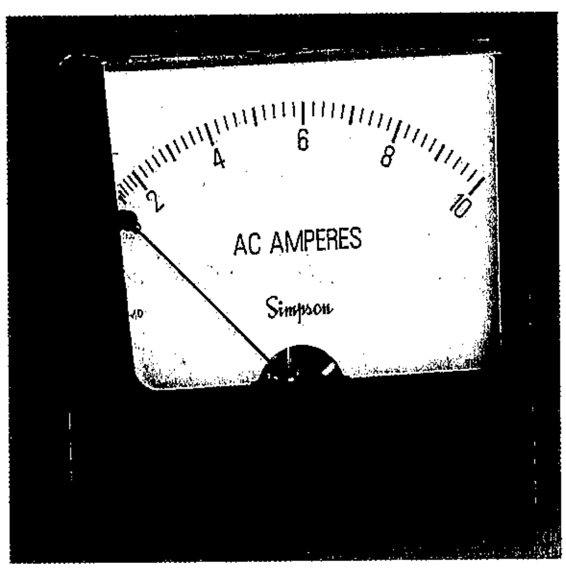



**Fig. 3-9** Panel meter.

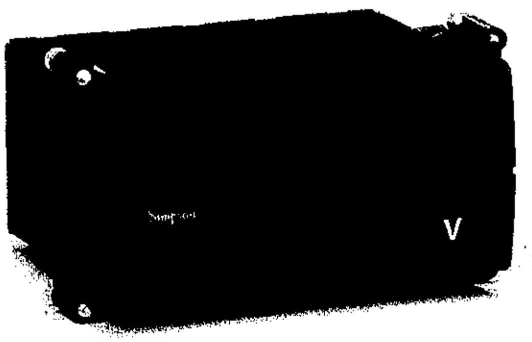


**Fig. 3-10** Digital panel meter.

most significant (leftmost) digit can be only a 0 or a 1, it is counted as a *half-digit*. The 200-volt DPM in Fig. 3-10 is a 3½-digit meter. Even though it is called a 200-volt meter, it can measure a maximum of 199.9 volts.

**Half-digit**

## Multimeters

Often a single meter serves as a voltmeter, an ammeter, and an ohmmeter. Meters that are capable of measuring two or more electrical quantities are known as *multimeters*. Multimeters use the same basic mechanism to indicate the amount of a quantity as panel meters. However, the multimeter also includes some circuitry (switches, resistors, etc.) inside its housing or case.

**Multimeters**

### ANALOG MULTIMETER

Like most analog multimeters, the meter in Fig. 3-11 has multiple scales printed on its face and can measure current, voltage, and resistance. An analog meter that can measure these three quantities is often called a *volt-ohm-milliammeter (VOM).*

**Volt-ohm-milliammeter (VOM)**

Although the various analog multimeters may look different, all of them have *functions, ranges,* and *scales. Function* refers to the *quantity being measured. Range* refers to the *amount* of the quantity that can be measured. Which *scale* of the meter is used depends on both the function and the range to which the meter is set. Proper use of the multimeter involves selection of the correct function, range, and scale. Once you understand the relationships between (1) function and scale and (2) range and scale, using any multimeter is possible.

**Functions**

**Ranges**

**Scales**

The VOM (multimeter) in Fig. 3-11 has five functions (ac voltage, dc voltage, dc current, resistance, and continuity). The function switch (on the left side of the meter) has four positions. One position (AC VOLTS ONLY) is used for measuring ac voltage. Two positions (−DC and +DC) are used for measuring dc voltage, dc current, and resistance. Which quantity is being measured in either of these two positions is determined by the position of the range switch (located in the center of the meter). The fourth position (note symbol) is used for checking continuity. In this position, a tone is emitted whenever there is a low-resistance path for current between the test-probe tips.

Except for the resistance function, the range indicates the *maximum* amount of a quantity that can be measured on a given range setting. For the resistance function, the range indicates the amount by which the ohm scale is to be multiplied.

The ohm scale on the meter in Fig. 3-11 is different from most voltage and current scales in three ways. First, it is reverse-reading. Second, it is nonlinear. Third, the number of minor divisions between the heavy lines (and the numbered lines) is not the same throughout the scale. Therefore, the value of a minor division varies across the scale.

The bottom scale on the VOM in Fig. 3-11 is a dB (decibel) scale. A dB is 1/10 of a bel, which is a unit of relative power or change in power. For example, the power output of an audio amplifier relative to the power input of the amplifier can be expressed in bels or decibels. The decibel is a nonlinear (logarithmic) unit that expresses changes in power levels in much the same way that the human ear perceives changes in the audio power output of a speaker. To the ear, a change in audio power from 0.2 W to 2 W is perceived as just as large a change as changing from 2 W to 20 W. Both represent a power change of 10 dB.

A VOM does not measure power. However, since $P = V^2/R$, voltage levels can be used to determine dB as long as the measured voltage is measured across the same value of resistance as was used in developing the dB scale on the meter. The value of resistance, as well as the

## ABOUT ELECTRONICS

**Blackouts Can Be Costly** In our technological society, industries are dependent on machines controlled by sensitive electronic devices. Because of this dependence, blackouts cost businesses 3 to 5 billion dollars per year in production downtime and lost data.

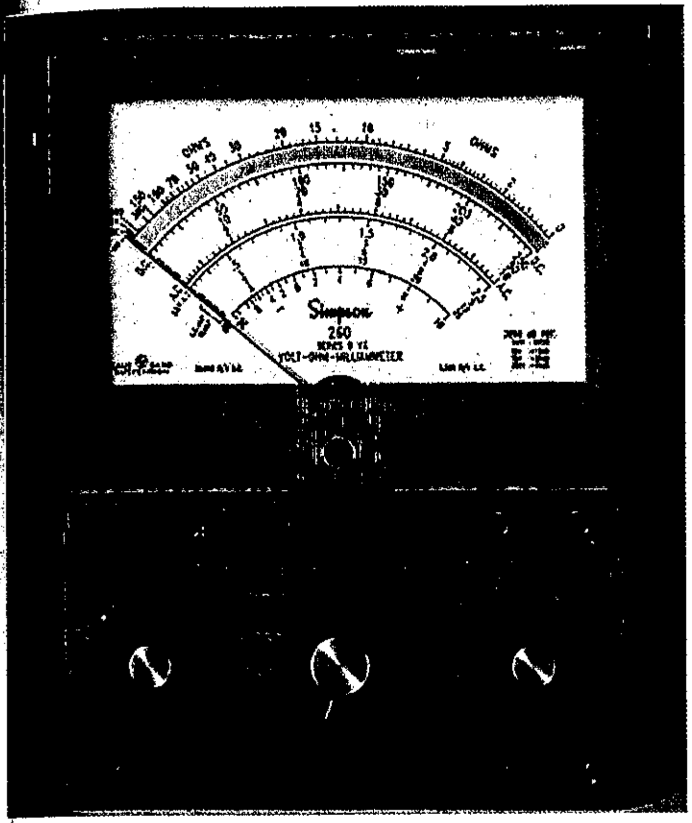


**Fig. 3-11** Multimeter (VOM).

power dissipated by the resistor at 0 dB, is given on the face of the meter and/or in the manual supplied with the meter. A common reference is 1 mW dissipated by a 600-Ω resistor.

The dB scale is calibrated for the smallest ac voltage range. A chart on the meter face tells one how many dB to add to the scale reading when on larger ac voltage ranges.

#### EXAMPLE 3-17

The meter in Fig 3-11 is set to the R × 100 range. The needle points to the second mark to the left of the 20 mark. How much resistance is the meter indicating?

**Solution:** Between 20 and 30 there are five divisions; each division is worth 2 units (30 − 20 = 10; 10 ÷ 5 = 2). The scale indicates 24 units (20 + 2 + 2). Since the meter is on the R × 100 range

$R = 24 \times 100\ \Omega$
$= 2400\ \Omega$

**Answer:** The meter indicates 2400 Ω.

When more than one scale is available for a given function and range, select the scale that ends in a number equal to the range or a power of 10 of the range.

#### EXAMPLE 3-18

Refer to Fig. 3-11. Assume that the function switch is on + DC, the range switch is on 25 V, and the needle points one division left of the 200 mark on the 0 to 250 scale.

**Solution:** The heavy mark between 150 and 200 represents 175. Between 175 and 200 there are five divisions; so, each division is worth 5 units. The scale reading is, therefore, 195. To make the scale fit the range, the scale must be divided by 10. Thus, the measured voltage is 19.5 V (195 ÷ 10 = 19.5).

**Answer:** The meter indicates 19.5 V dc.

#### EXAMPLE 3-19

Assume the same conditions as in example 3-18 except that the range is 2.5 V. How much voltage does the meter indicate?

**Solution:** Read the same scale as in example 3-18. Now the scale reading of 195 must be divided by 100 to make the 250 scale match the 2.5-V range. Therefore, the measured voltage is 1.95 V (195 ÷ 100 = 1.95).

**Answer:** The voltage is 1.95 V dc.

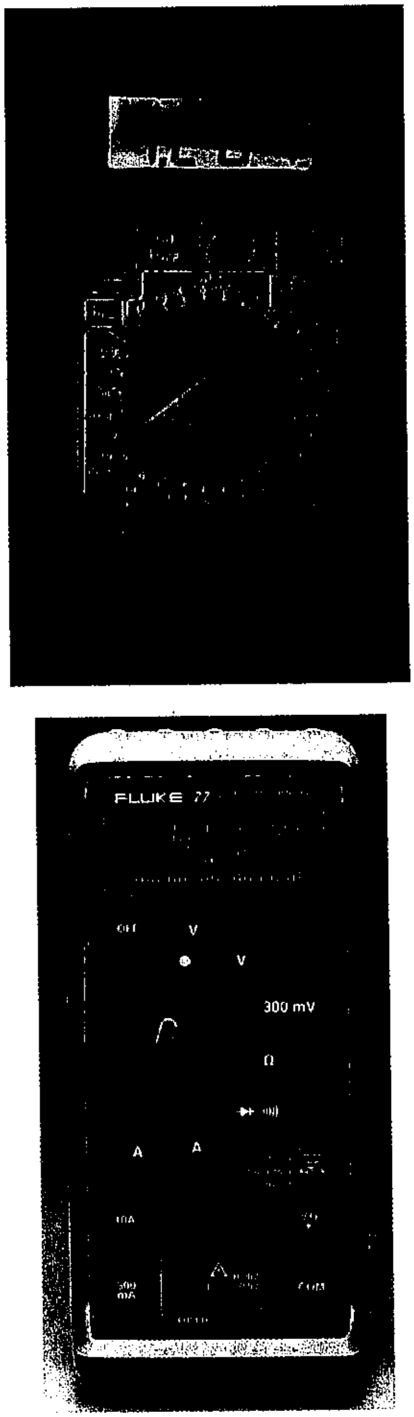
Notice in Fig. 3-11 that there is a separate (slightly nonlinear) scale for the 2.5 V ac range. Having a separate scale for the lowest ac voltage range is very common for analog multimeters.

Another common feature of multimeters is having two or more ranges for one setting of the range switch (see Fig 3-11). These additional ranges are selected by inserting the test leads in the appropriate (labeled) jacks.

### DIGITAL MULTIMETER

**Digital multimeters (DMMs)**

With *digital multimeters (DMMs),* like those shown in Figs. 3-12 and 3-13, there are no scales to worry about. The decimal point in the display changes when the range is changed so the display reading never has to be multiplied or divided to obtain the correct reading. Thus, the resistance ranges on the DMM tell the maximum resistance a range can measure rather than indicating a multiplier.




(a)

(b)

**Fig. 3-12** Digital multimeters. These are handheld (portable) units. (*a*) Note the combined function and range switch. (*b*) This meter is autoranging.

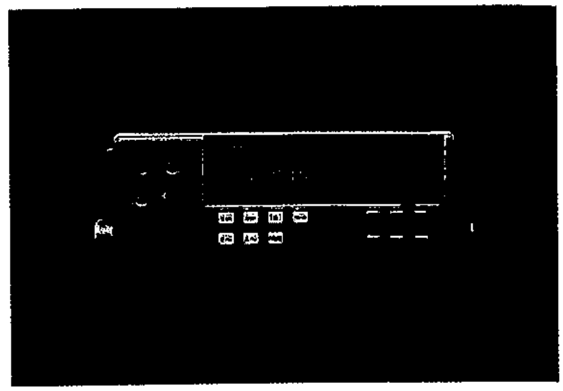


**Fig. 3-13** Digital multimeter with separate push-button switches for function and range.

**Autoranging**

The operator must select the correct function and ranges for the meters in Figs. 3-12(*a*) and 3-13. The meter in Fig. 3-13 uses separate push buttons to select the functions and the ranges, and the meter in Fig. 3-12(*a*) uses a common rotary switch. More sophisticated DMMs automatically select the correct range, so the operator must only ensure that the meter is on the correct function. Meters of this type [see Fig. 3-12(*b*)] are said to be *autoranging.*

## Using Multimeters

All electrical quantities to be measured are applied to the meter through test leads. A typical test lead is illustrated in Fig. 3-14. For most measurements, the test leads plug into the two jacks in the lower right-hand corner of the meter shown in Fig. 3-11. A black lead goes in the COMMON − jack, and a red lead in the + jack. The black lead is negative and the red lead positive when the function switch is in the +DC position. When the function switch is in the −DC position, the black lead (COMMON −) is positive. Of course, the red lead also reverses polarity. The +DC position should be used except when special measurements are being made. In this way, the red lead is positive. Red is the color often used to indicate positive in electric circuits.

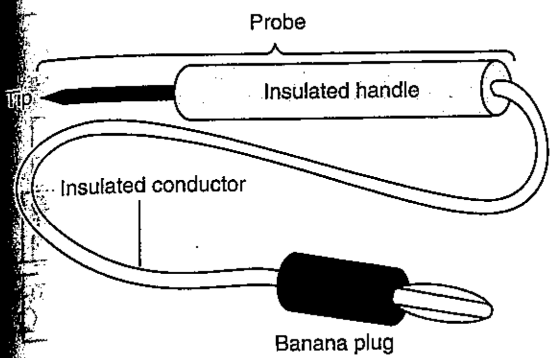



**Fig. 3-14** Test lead.

The DMM has no +DC and −DC switch positions. If reverse polarity is applied to a DMM, a minus (−) sign appears ahead of the digits. The magnitude of the indicated value is still correct.

## Measuring Resistance

When resistance is measured, the VOM must first be ohms-adjusted. The *ohms-adjust control* is labeled "zero OHMS" in Fig. 3-11. This control is rotated until the meter indicates zero on the ohms scale *when the test-lead tips are touching each other.* The ohms-adjust control must be adjusted for each range of the ohms function. Thus, every time the range is changed, the leads must be touched together and the meter adjusted to zero. No such adjustment is needed with the DMM.

The ohmmeter function of any multimeter uses a cell, battery, or power supply inside the meter housing. That is, it has its own source of energy. Therefore, any other energy source must be disconnected from any circuit in which resistance is to be measured. Never measure the resistance of a load when power (the energy source) is connected to the circuit. Doing this damages the ohmmeter. Figure 3-15(*a*) illustrates the correct technique for measuring the resistance of a lamp. Notice in Fig. 3-15(*b*) the symbols used for the ohmmeter and the test-lead connection.

The procedure used in measuring resistance is as follows:

1. Remove power from the circuit.
2. Select an appropriate range in the ohms function. The appropriate range is the one that gives the best resolution.
3. When using the VOM, short (touch) the test leads. Turn the ohms-adjust control until the pointer reads 0 ohms.
4. Connect, or touch, the test leads to the terminals of the device whose resistance is to be measured. Except for some electronic components, the polarity of the ohmmeter leads is unimportant.

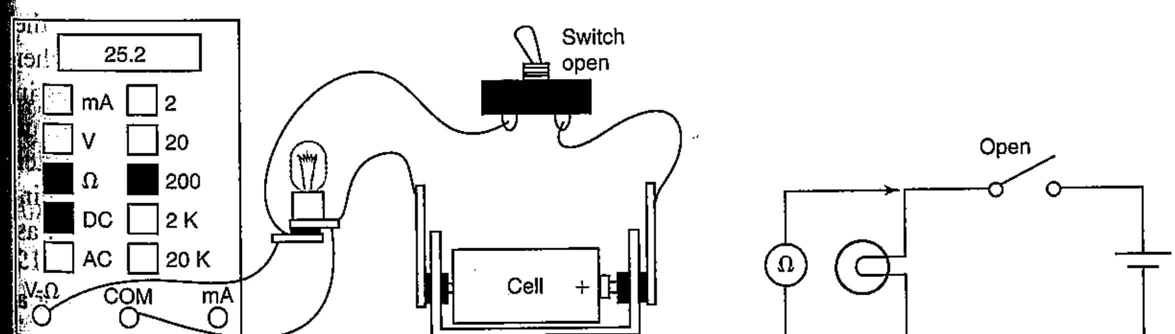
**Ohms-adjust control**

When measuring resistance, do not touch the metal parts of the test leads with your hands. If you do, you will be measuring your body's resistance as well as the circuit's resistance. This will not harm you, but you may not obtain the correct resistance reading for the circuit.

## Measuring Voltage

**Voltage measurements**

*Voltage measurements* are the easiest electrical measurements to make. They are also the most common. Voltage measurements are made with power connected to the circuit. Remember, ALWAYS follow recommended safety procedures when working with energized circuits. The




(*a*) Pictorial presentation (*b*) Schematic diagram

**Fig. 3-15** Measuring resistance. Notice that the power source is disconnected from the load by the open switch.

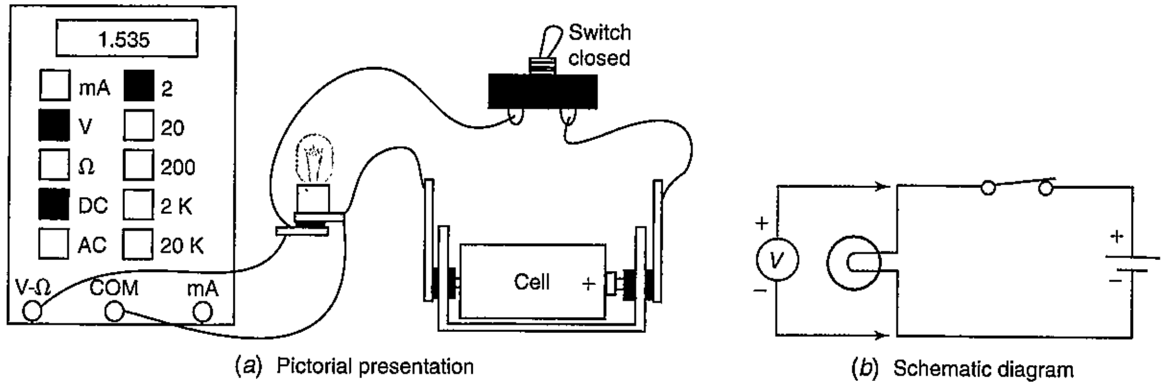



**Fig. 3-16** Lamp voltage being measured. The switch must be closed.

following procedure is used to make voltage measurements:

1. Select the correct voltage function (ac or dc) for the type of voltage used in the circuit.
2. Select a range that is greater than the expected voltage.
3. Determine the polarity of the voltage to be measured by looking at the schematic diagram or at the battery terminals. This step is omitted when measuring alternating current because the polarity reverses every fraction of a second.
4. Connect the negative (black) lead of the multimeter to the negative end of the voltage to be measured. Touch (or connect) the positive (red) lead of the meter to the positive end of the voltage. In other words, observe polarity when measuring voltage with a multimeter or voltmeter. If you do not, the meter pointer of the VOM may bend when it tries to rotate counterclockwise.

Figure 3-16 shows the correct connections for measuring dc voltage. In this figure, the meter is measuring the voltage across the lamp. Notice that the switch is in the closed position. If the switch were open, there would be no voltage across the lamp and the meter would indicate 0 volts. A load has a voltage across it only when current is flowing through it. If the meter were connected across the cell, as in Fig. 3-17, the meter would indicate the cell's voltage regardless of whether the switch were open or closed. As long as the switch is closed, the meter reading is the same in Figs. 3-16 and 3-17. That is, the voltage output of the cell appears across the lamp when the switch is closed.

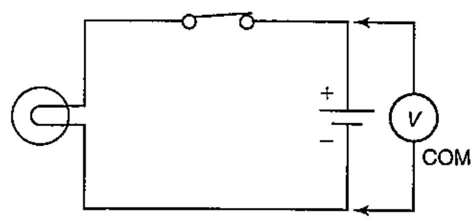



**Fig. 3-17** Cell voltage being measured. The switch may be either open or closed.

## Measuring Current

**Current measurements**

*Current measurements* are made much less frequently than either resistance or voltage measurements. This is because the circuit usually has to be physically interrupted to insert the meter. In Fig. 3-18, the circuit has been physically interrupted by disconnecting one end of the lead between the cell and the lamp. The meter is then connected between the end of the wire and the lamp. As shown in Fig. 3-19, the meter can just as well be connected on either side of the switch. All three meter locations in Fig. 3-19 are correct, and all three locations yield the same results. Remember, the meter must be inserted into the circuit so that the circuit current flows through the meter as well as the load.

In using the current function of a DMM or a VOM, follow these steps:

1. Select the current function.
2. Select a range that is greater than the expected current.

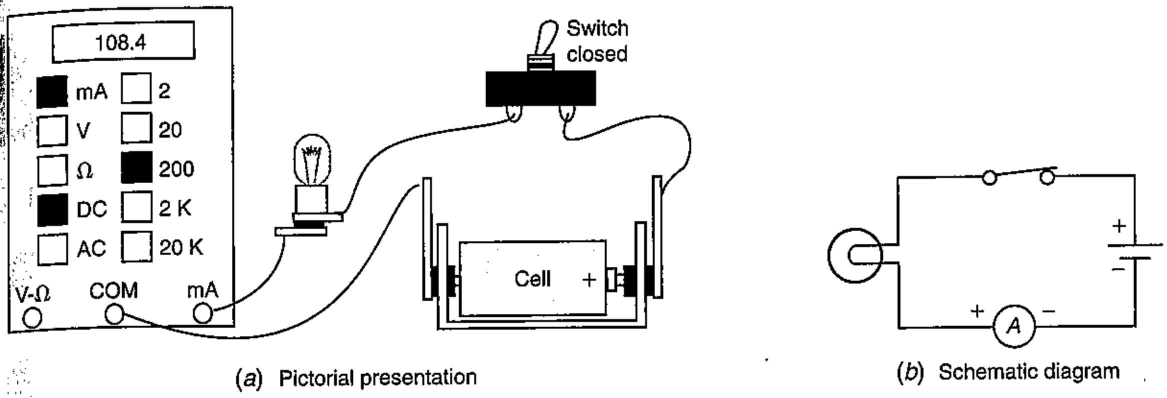



**Fig. 3-18** Current being measured. Current must flow through both the meter and the load.

3. Physically interrupt the circuit.
4. Observing polarity, connect the DMM or VOM between the points created by the interruption. Correct polarity can be determined by tracing current (electron flow). As indicated in Fig. 3-19, current enters the negative terminal and leaves the positive terminal of the meter.

A meter can be easily damaged, and so it should be used with care. Reverse polarity on a VOM may bend the pointer. However, most damage to multimeters and ammeters occurs when they are incorrectly connected to the circuit. If you connect an ammeter, or a multimeter on the current function, into a circuit in the same way you connect a voltmeter, you may destroy the meter. Even if the meter is not completely destroyed, its accuracy will be greatly decreased.

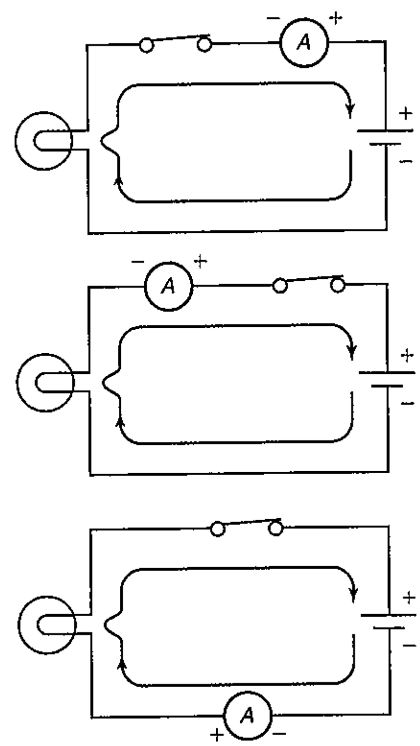



**Fig. 3-19** Ammeter location. The location of the ammeter with respect to the lamp or the switch does not change the amount of current.

## Self-Test

*Answer the following questions.*

21. In Fig. 3-9 the needle rests three divisions to the right of the 6 mark. How much current is the meter indicating?
22. Refer to Fig. 3-11. The needle points one mark to the right of 20. The range is set on R × 100. What is the resistance?
23. Refer to Fig. 3-11. Assume that the meter is on the DC function and the 100-mA range. The needle is pointing to 20 on the third scale from the top. How much current is indicated by the meter?
24. True or false. The resistance function of the DMM should be adjusted whenever a new range is selected.

25. True or false. A 10-volt DPM that can indicate a maximum voltage of 9.99 volts is a 2½-digit meter.
26. True or false. Most DMMs are autofunctioning.
27. Summarize the procedure for measuring resistance with the VOM.
28. Summarize the procedure for measuring voltage.
29. Summarize the procedure for measuring current.
30. True or false. Of the possible misuses of an ammeter, reverse polarity is usually the most damaging.
31. Why does a VOM have both a +DC and a −DC function?
32. True or false. Many multimeters have a power function.

# Chapter 3 Summary and Review

## Summary

1. Electric components are represented by symbols in schematic diagrams; sometimes their electrical values are also included on the diagrams.
2. Sometimes the physical structure of a device also serves as a conductor in a circuit.
3. Current is directly proportional to voltage and inversely proportional to resistance.
4. A panel meter measures only one quantity.
5. Multimeters measure several quantities.
6. VOMs have functions, ranges, and scales.
7. The ohmmeter function of the VOM must be adjusted every time the range is changed.
8. No ohms adjustment is required with a DMM.
9. Polarity must be observed when measuring dc voltage.
10. Polarity must be observed when measuring direct current.
11. Ammeters are easily damaged by incorrect connections to a circuit.
12. Multimeters may have separate switches for selecting function and range.
13. Many digital meters have automatic range and polarity switching.
14. A readout digit that will always be either a 0 or a 1 is specified as a half-digit.

## Related Formulas

$V = IR$

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

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

$P = IV$

$P = I^2R$

$P = \frac{V^2}{R}$

$W = Pt$

Cost = rate × energy

## Chapter Review Questions

*For questions 3-1 to 3-12, determine whether each statement is true or false.*

3-1. The metal chassis of an electric device is often used as a conductor. (3-1)

3-2. Current is directly proportional to voltage and inversely proportional to resistance. (3-3)

3-3. A watt is equal to 1 volt divided by 1 ampere. (3-3)

3-4. A 60-watt, 120-volt lamp requires less current than a 40-watt, 120-volt lamp. (3-3)

3-5. A 60-watt, 120-volt lamp has less resistance than a 100-watt, 120-volt lamp. (3-3)

3-6. An electric circuit must be physically interrupted to measure voltage in the circuit. (3-4)

3-7. An ohmmeter contains its own energy source. (3-4)

3-8. Always observe polarity when measuring direct current. (3-4)

3-9. Correct polarity for an ammeter requires that current (electrons) enter the positive terminal of the meter. (3-4)

3-10. All DMMs are autoranging. (3-4)

3-11. A VOM has only one ohmmeter scale. (3-4)

## Chapter Review Questions...continued

3-12. The function switch on the VOM is set in the −DC position to make the common negative jack the negative terminal of the VOM. (3-4)

*Answer the following questions.*

3-13. List the four essential parts of an electric circuit. (3-1)

3-14. Draw the schematic symbols for the following components: (3-2)
  a. Lamp
  b. Conductor
  c. Resistor
  d. Cell
  e. Open switch

3-15. Measuring which quantity (voltage, current, or resistance) requires physically interrupting the circuit? (3-4)

3-16. Measuring which quantity (voltage, current, or resistance) requires removing power from the circuit or component? (3-4)

3-17. The range of a digital meter is 0000 to 1999. What is the digit rating of this meter? (3-4)

3-18. What name is often used to refer to an analog multimeter that can measure $V$, $I$, and $R$? (3-4)

3-19. How do the resistance range markings on the VOM differ from those on the DMM?

3-20. Why doesn't the readout of a DMM have to be multiplied or divided by some number when the range is changed?

## Chapter Review Problems

3-1. What is the resistance of a lamp which draws 240 milliamperes when connected to a 12.6-volt battery? (3-3)

3-2. How much current does a 500-W lamp draw from a 120-V source? (3-3)

3-3. How much power does a heater require if it draws 11 amperes from a 240-volt circuit? (3-3)

3-4. A toaster draws 5 amperes from a 120-volt outlet. How much energy does it use in 2 hours? (3-3)

3-5. How much would it cost to operate the toaster in problem 3-4 if energy costs 12¢ per kWh? (3-3)

3-6. How much voltage is required to force 40 milliamperes of current through a 1-kilohm resistor? (3-3)

3-7. What is the cost per kWh if it costs $1.91 to operate a 240-V heater that draws 6 A for 12 hours? (3-3)

3-8. What is the resistance of a 150-W, 120-V lamp? (3-3)

3-9. An analog multimeter is on the DC voltage function and the 5-V range. On the 0 to 50 scale the needle stops at 38. What is the value of the voltage being measured? (3-4)

3-10. A digital multimeter is on the DC voltage function and the 50-V range. The digital readout indicates 04.340. What is the value of the voltage being measured? (3-4)

## Critical Thinking Questions

3-1. Using base unit equivalents, prove that current in amperes multiplied by voltage in volts yields power in watts.

3-2. Some of the example circuits in this chapter include fuses. Yet, the fuses were ignored in calculating resistance, voltage, and current. Does this mean that fuses have no resistance? Explain.

3-3. From the way an ammeter is used to measure current in a circuit, would you conclude that it has a very high or a very low internal resistance? Why?

3-4. Assume that you are purchasing a multimeter for personal use. Would you buy a DMM or VOM? Why?

3-5. It costs $1.20 to operate a heater for 6 hours on a 240-V source. What is the resistance of the heater if energy costs 8¢/kWh?

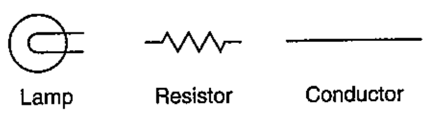
3-6. Prove that energy will be in joules when current is in amperes, time is in seconds, and the formula is $W = I^2Rt$.

3-7. Explain how you could measure the current in Fig. 3-15 without disconnecting any circuit conductors.

3-8. When you measure the resistance of a 60-W, 120-V lamp, it is approximately 17 Ω. Using its rated wattage and voltage, calculate its resistance. Explain the large difference between the measured and calculated values.

3-9. Explain what will happen to the power of a circuit if the source voltage is doubled and the resistance is not changed

## Answers to Self-Tests

1. source of energy, conductors, insulators, load, control device, and protection device
2. F
3. F
4. 

5. A schematic diagram is a drawing which uses symbols for electric components. It indicates the connections between the components.
6. T
7. F
8. protection device
9. 0.36 kW
10. 225 mW
11. **Given:** $V = 1.5\text{ V}, R = 3\text{ k}\Omega = 3000\ \Omega$
    **Find:** $I$
    **Known:** $I = \frac{V}{R}$
    **Solution:** $I = \frac{1.5\text{ V}}{3000\ \Omega} = 0.0005\text{ A}$
    **Answer:** The current is 0.0005 A, or 0.5 mA.
12. **Given:** $I = 150\text{ mA} = 0.15\text{ A}$
    $V = 600\text{ mV} = 0.6\text{ V}$
    **Find:** $R$
    **Known:** $R = \frac{V}{I}$
    **Solution:** $R = \frac{0.6\text{ V}}{0.15\text{ A}} = 4\ \Omega$
    **Answer:** The resistance is 4 Ω.
13. **Given:** $V = 120\text{ V}, I = 4.5\text{ A}$
    **Find:** $P$
    **Known:** $P = IV$
    **Solution:** $P = 4.5\text{ A} \times 120\text{ V} = 540\text{ W}$
    **Answer:** The dryer is a 540-W dryer.
14. **Given:** $P = 1000\text{ W}, V = 120\text{ V}$
    **Find:** $I$
    **Known:** $I = \frac{P}{V}$
    **Solution:** $I = \frac{1000\text{ W}}{120\text{ V}} = 8.3\text{ A}$
    **Answer:** The current for the 1000-W toaster is 8.3 A.
15. **Given:** $I = 2.2\text{ A}, V = 12.6\text{ V}$
    **Find:** $P$
    **Known:** $P = IV$
    **Solution:** $P = 2.2\text{ A} \times 12.6\text{ V} = 27.72\text{ W}$
    **Answer:** The tape deck requires 27.72 W.
16. **Given:** $R = 99\ \Omega, V = 6.3\text{ V}$
    **Find:** $P$
    **Known:** $P = \frac{V^2}{R}$
    **Solution:** $P = \frac{(6.3)^2}{99} = 0.4\text{ W}$
    **Answer:** The power rating of the lamp is 0.4 W.
17. **Given:** $I = 8\text{ A}, V = 240\text{ V}, t = 9\text{ h}$
    **Find:** $W$
    **Known:** $W = Pt, P = IV$
    **Solution:** $P = 8\text{ A} \times 240\text{ V} = 1920\text{ W}$
    $W = 1920\text{ W} \times 9\text{ h}$
    $= 17{,}280\text{ Wh} = 17.28\text{ kWh}$
    **Answer:** The energy converted is 17.28 kWh.
18. **Given:** $R = 100\ \Omega, I = 200\text{ mA} = 0.2\text{ A},$
    $t = 10\text{ min} = 600\text{ s}$
    **Find:** $W$
    **Known:** $W = Pt, P = I^2R, \text{Ws} = \text{J}$

**Solution:** $P = (0.2)^2 \times 100 = 4$ W
$W = 4 \text{ W} \times 600 \text{ s}$
$= 2400 \text{ Ws} = 2400 \text{ J}$

**Answer:** The resistor converts 2400 J of electric energy to heat energy.

19. **Given:** $P = 3000$ W, $t = 3$ h, rate = 4¢ per kWh
**Find:** Cost
**Known:** Cost = rate × $W$, $W = Pt$
**Solution:** $W = 3000 \text{ W} \times 3 \text{ h} = 9000 \text{ Wh}$
$= 9 \text{ kWh}$
Cost = 4¢ per kWh × 9 kWh
= 36¢
**Answer:** The cost is 36¢.

20. **Given:** $I = 0.5$ A, $V = 120$ V, rate = 8¢ per kWh, $t = 40$ h
**Find:** Cost
**Known:** Cost = rate × $W$, $W = Pt$, $P = IV$
**Solution:** $P = 0.5 \text{ A} \times 120 \text{ V} = 60 \text{ W}$
$W = 60 \text{ W} \times 40 \text{ h} = 2400 \text{ Wh}$
$= 2.4 \text{ kWh}$
Cost = 8¢ per kWh × 2.4 kWh
= 19.2¢
**Answer:** The cost is 19.2¢.

21. 6.6 amperes
22. 1900 ohms (19 × 100)
23. 40 milliamperes
24. F
25. F
26. F
27. Remove the power from the circuit, select the ohm function, select the correct range, and connect the test leads to the device or component being measured. If a VOM is used, the meter must also be ohms-adjusted.
28. Select the correct voltage function, select the correct range, determine the polarity of the voltage, and—observing polarity—connect the meter to th circuit.
29. Select the current function, select the correct range, interrupt the circuit, and—observing polarity—connect the meter between the interrupted points.
30. F
31. They are provided so that test lead polarities can be reversed without changing the lead connections to the meter.
32. F