electronics

Lesson 2101A-10
Fractions and Decimal Numbers

Lesson 2101B-10
Reciprocals, Percentage and
Powers of Numbers

AUTO-PROGRAMMED® Lessons

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Frontispiece: *Solar calculator courtesy of Sharp.*

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A Chat with Your Instructor

You are about to start the first in a series of eight mathematics lessons. We hope that you find your study of them a pleasant, even an enjoyable experience. You may find what many before you have found—math can be fun!

You might wonder why, in an electronics course, we require that you study mathematics. The answer is simple: you have to have a sound knowledge of mathematics if you are to fully understand electronics. Many of the problems that you will come across in your study of electronics boil down to problems in mathematics. Perhaps more important, when you are out on the job, actually working in the electronics field, you will encounter many problems that can best be solved mathematically.

True, it is possible to learn a great deal about electronics without a knowledge of mathematics. However, you'd be like the worker who has an incomplete set of tools. You really need a good set of mathematical "tools" to help you study and work more efficiently in electronics.

To aid you in your study of mathematics, we strongly recommend that you purchase a scientific calculator, in case you don't already own one. It should have the following features:

(1) *A square-root key.*
(2) *Scientific notation.* The instructions included with your calculator will indicate if your calculator has scientific notation. If you aren't sure that the calculator you have picked out has scientific notation, don't buy it. Select another model that states that it does have this important capability.
(3) *Reciprocal key.* This key is normally marked

$$\frac{1}{X}.$$

In addition to these three features, we strongly urge you to get a calculator that has logarithmic and trigonometric function keys (marked **LOG**, **SIN**, **COS**, and **TAN**). While we won't use these keys in the eight lessons to follow, you will probably need them later on as you progress further with your electronics studies.

The money that you invest now in a good scientific calculator will pay you big dividends later on, by simplifying your work and reducing the amount of time spent in solving problems.

Lesson 2101A-9
Fractions and
Decimal Numbers

USING FRACTIONS IN ELECTRONICS

Fractions play a most important role in electronics. The expression of Ohm's law for current I, for example is $\frac{E}{R}$, which is, of course, a fraction. Similarly, to determine resistance R, we must solve another fraction, $\frac{E}{I}$. The use of fractions isn't just confined to Ohm's law, either. Electronics formulas contain many fractions that you'll be introduced to in later lessons, such as $C = \frac{t}{R}$ $\left(R = \frac{t}{C} \right)$, $I = \frac{P}{E}$ $\left(\text{or } E = \frac{P}{I} \right)$, and $X = \frac{1}{\omega C}$ $\left(\text{or } C = \frac{1}{\omega X} \right)$ —to mention just a few.

1 FRACTION MEANS "DIVIDE" . . . In a fraction, the number or letter above the bar is called the *numerator,* and the number or letter below the bar is called the *denominator.* Thus, in the fraction $\frac{5}{6}$, the numerator is 5 and the denominator is 6. In the fraction $\frac{E}{R}$, similarly, the numerator is E and the denominator is R.

One meaning of a fraction is that the numerator is to be divided by the denominator. Thus, $\frac{12}{3}$ means $12 \div 3$, which is 4. The fraction $\frac{E}{R}$ means that the voltage E is to be divided by the resistance R.

In electronics, division is usually indicated as a fraction. Consequently, the division sign, $\div$, is rarely used. Thus, in electronics, instead of $16 \div 2$, we usually write $\frac{16}{2}$. Similarly, we write $\frac{P}{E}$ rather than $P \div E$.

As soon as you answer each question, check with the answer given at the end of this exercise.

1. Change each of the following expressions to the equivalent form that is commonly used in electronics:
   (a) $3 \div 7$ is the same as _$\frac{3}{7}$_.   (d) $1 \div R$ is the same as _$\frac{1}{R}$_.
   (b) $2 \div 3$ is the same as _$\frac{2}{3}$_.   (e) $Q \div 2$ is the same as _$\frac{Q}{2}$_.
   (c) $Q \div C$ is the same as _$\frac{Q}{C}$_.

2. Complete the following statements:
   (a) The numerator of the fraction $\frac{3}{4}$ is _3_. The denominator is _4_.
   (b) The numerator of the fraction $\frac{R}{Z}$ is _R_. The denominator is _Z_.

3. Remembering that "fraction means divide," complete the following:
   (a) $\frac{24}{6} = $ _4_   (c) $\frac{21}{3} = $ _7_   (e) $\frac{54}{9} = $ _6_

   (b) $\frac{8}{2} = $ _4_   (d) $\frac{35}{7} = $ _5_

4. If $X = 5$ ohms and $Z = 12$ ohms, the fraction $\frac{X}{Z} = $ _$\frac{5}{12}$_.

5. (a) Given the formula $I = \frac{P}{E}$; if $P = 10$ and $E = 5$, $I = $ _2_.

   (b) Given the formula $R = \frac{t}{C}$; if $t = 2000$ and $C = 4$, $R = $ _500_.

   (c) Given the formula $E = \frac{Q}{C}$; if $Q = 750$ and $C = 25$, $E = $ _30_.

6. (a) The resistance R of a circuit is found by dividing the time constant t by the capacitance C. The formula for resistance R is _$\frac{t}{C}$_.

   (b) If the time constant is 40 and the capacitance is 2, the resistance R is _20_ ohms.

7. (a) The current I in a circuit is found by dividing the power P by the voltage E. The formula for current I is _$\frac{P}{E}$_.

   (b) If the power is 20 watts and the voltage is 5 volts, the current $I = $ _4_ amperes.

8. The diagram of a simple lamp circuit is shown in Fig. 1. Current is _.5_ A.
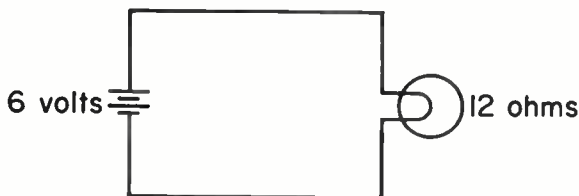
$$I = \frac{E}{R}$$

Fig. 1

ANSWERS

1. (a) $\frac{3}{7}$; (b) $\frac{2}{3}$; (c) $\frac{Q}{C}$; (d) $\frac{1}{R}$; (e) $\frac{Q}{2}$

2. (a) 3, 4; (b) R, Z

3. (a) 4; (b) 4; (c) 7; (d) 5; (e) 6

4. $\frac{5}{12}$

5. (a) $I = \frac{P}{E} = \frac{10}{5} = 2$; (b) $R = \frac{t}{C} = \frac{2000}{4} = 500$; (c) $E = \frac{Q}{C} = \frac{750}{25} = 30$.

6. (a) $R = \frac{t}{C}$; (b) $R = \frac{t}{C} = \frac{40}{2} = 20$

7. (a) $I = \frac{P}{E}$; (b) $I = \frac{P}{E} = \frac{20}{5} = 4$ A

8. $\frac{1}{2}$ A or 0.5 A . . . From Ohm's law for current, $I = \frac{E}{R} = \frac{6}{12} = \frac{1}{2}$ A

2 THE IMPORTANCE OF CORRECT UNITS

2 THE IMPORTANCE OF CORRECT UNITS . . . Before substituting values into a formula, you must check to see that the values are expressed in terms of the units called for by the formula. For example, don't substitute a value in inches when the formula calls for a value in feet.

To illustrate, consider the following formula for the length of a floor:

$$\text{Length, in feet} = \frac{\text{area, in square feet}}{\text{width, in feet}}$$

It is simpler to write this formula as

$$L = \frac{A}{W}$$

where L = length, in feet

A = area, in square feet

W = width, in feet

The following example illustrates the use of this formula when all quantities are given in the desired units.

Example . . . Find the length of a floor which has an area of 200 sq ft and is 20 ft wide.

Solution . . . The formula calls for the area in square feet and the width in feet. Since $A = 200$ sq ft and $W = 20$ ft, these dimensions are given in the correct units and can be substituted directly into the formula:

$$L = \frac{A}{W}$$
$$= \frac{200 \text{ sq ft}}{20 \text{ ft}}$$
$$= 10 \text{ ft, } ans.$$

The following example illustrates the use of the same formula when the quantities are not expressed in the desired unit.

Example . . . Find the length, in feet, of a floor when the area is 10 sq yd and the width is 108 in.

Solution...$A = 10$ sq yd; $W = 108$ in. Here, A is given in square yards instead of square feet as called for by the formula and W is given in inches instead of feet. Before we attempt to solve for L, therefore, we must convert the values for A and W into the units called for by the formula.

To convert A in square yards to A in square feet, we note that

$$1 \text{ sq yd} = 3 \text{ ft} \times 3 \text{ ft}$$
$$= 9 \text{ sq ft,}$$

and therefore

$$A \text{ in square feet} = 9 \times A \text{ in square yards}$$
$$= 9 \times 10$$
$$= 90 \text{ sq ft}$$

Similarly, to convert W in inches to W in feet, we note that 1 ft $= 12$ in, therefore:

$$W \text{ in feet} = \frac{W \text{ in inches}}{12}$$
$$= \frac{108}{12}$$
$$= 9 \text{ ft}$$

Now that we know that $A = 90$ sq ft and $W = 9$ ft, we can solve the problem:

$$L = \frac{A}{W}$$
$$= \frac{90 \text{ sq ft}}{9 \text{ ft}}$$
$$= 10 \text{ ft, } ans.$$

WHAT HAVE YOU LEARNED?

1. (a) If one box weighs 2 lb, and a second box weighs 48 oz, the total weight of the two boxes is ____5____ pounds. (Note that there are 16 oz in a pound.)

   (b) Converting units to other units is something we do every day. In this problem, all units must be converted to cents. A youngster carries two dimes, a half dollar, ten pennies, three quarters, and nine nickles. The child is carrying ____2____ dollars.

2. The formula for the speed of an automobile is

$$V = \frac{X}{t}$$

where V = speed, in miles per hour
   X = distance, in miles
   t = time, in hours

$$\frac{160}{240} \quad \frac{160}{4} = 40 = 40$$

The speed of a car that travels 160 miles in 240 min is ____40____ miles per hour.

3. The formula for the width of a platform is

$$W = \frac{A}{L}$$

where W = width, in yards
   A = area, in square yards $54 \text{ sq}' = 12 \text{ yds} \, 6 \text{ sq yds}$
   L = length in yards 2

If a platform has an area of 54 sq ft and a length of 72 in., its width is ____6 3____ yds.

ANSWERS

1. (a) 5 lb . . . Since there are 16 oz in a pound, the second box weighs 3 lbs

(b) $2 . . . The younster carries

2 dimes	=	$ .20
1 half dollar	=	.50
10 pennies	=	.10
3 quarters	=	.75
9 nickels	=	.45
		$2.00

2. 40 miles per hr . . . $X = 160$ miles, and time $t = 240$ min, but the problem calls for t in hours. Since there are 60 min in 1 hr, $t = 240$ min $= \dfrac{240}{60} = 4$ hr. Then

$$V = \frac{X}{t}$$
$$= \frac{160}{4}$$
$$= 40 \text{ miles per hr}$$

3. $W = 3$ yd . . . $A = 54$ sq ft, but the formula calls for A in square yards. Since there are 9 sq ft in 1 sq yd, $A = \dfrac{54}{9} = 6$ sq yd. L is given as 72 in, but the formula calls for this dimension in yards. Since there are 36 in. in a yard, $L = \dfrac{72}{36} = 2$ yd. Then

$$W = \frac{A}{L}$$
$$= \frac{6}{2}$$
$$= 3 \text{ yd}$$

3 MULTIPLYING IN FORMULAS

3 MULTIPLYING IN FORMULAS . . . So far we have discussed only formulas in which the right-hand term is a fraction, such as $C = \dfrac{t}{R}$ and $f = \dfrac{V}{\lambda}$. Here we will discuss formulas that involve multiplication, such as $E = I \times R$, $\omega = \dfrac{2 \times \pi}{t}$, and $f = \dfrac{\omega}{2 \times \pi}$.

To indicate multiplication in formulas, it is customary to place the symbols together and *omit the multiplication sign, $\times$, between symbols.* Thus, we write AB rather than $A \times B$, 2π rather than $2 \times \pi$, and $\dfrac{2\pi fl}{R}$ rather than $\dfrac{2 \times \pi \times f \times l}{R}$.

Example . . . Let $P = E_1 I_1$. If $E_1 = 30$ and $I_1 = 2$, $P = $ _____.

Solution . . . $P = E_1 \times I_1$
$= 30 \times 2$
$= 60$, *ans.*

Explanation . . . We rewrite $P = E_1 I_1$ as $P = E_1 \times I_1$, since two letters or symbols together without a sign between them should be multiplied.

Example . . . $P = E_1 I_1 + E_2 I_2$. If $E_1 = 20$, $I_1 = 10$, $E_2 = 5$, and $I_2 = 30$, $P =$ _____ .

Solution . . .
$$
\begin{aligned}
P &= E_1 I_1 + E_2 I_2 & \text{(1)}\\
&= E_1 \times I_1 + E_2 \times I_2 & \text{(2)}\\
&= 20 \times 10 + 5 \times 30 & \text{(3)}\\
&= 200 + 150 & \text{(4)}\\
P &= 350, \text{ ans.} & \text{(5)}
\end{aligned}
$$

Explanation . . . Note that we must perform the multiplications before we can add. That is, we first find $E_1 \times I_1$ and $E_2 \times I_2$, as shown in step 4, and then add them as in step 5.

Example . . . Let $K = \dfrac{I_1 R_1}{I_2 R_2}$. If $I_1 = 5$, $R_1 = 20$, $I_2 = 4$, and $R_2 = 5$, $K =$ _____ .

Solution . . .
$$
\begin{aligned}
K &= \frac{I_1 R_1}{I_2 R_2}\\
&= \frac{5 \times 20}{4 \times 5}\\
K &= 5, \text{ ans.}
\end{aligned}
$$

WHAT HAVE YOU LEARNED?

1. Rewrite the following electronic formulas, omitting the multiplication sign:
   (a) $Q = C \times E =$ _$Q = CE$_
   (b) $E = I_1 \times R_1 + I_2 \times R_2 =$ _$E = I_1 R_1 + I_2 R_2$_
   (c) $H = \dfrac{4 \times \pi \times N \times i}{L} =$ _$H = \dfrac{4\pi N i}{L}$_
   (d) $X_C = \dfrac{1}{2 \times \pi \times f \times C} =$ _$X_C = \dfrac{1}{2\pi FC}$_

2. Complete the following statements:
   (a) If $t = RC$, $R = 4000$, and $C = 2$, $t =$ _$8,000$_ _____ .
   (b) If $R = \dfrac{KL}{m}$, $K = 2$, $L = 30$, and $m = 5$, $R =$ _____ .
   (c) If $I_1 = \dfrac{N_2 I_2}{N_1}$, $N_2 = 5$, $I_2 = 4$, and $N_1 = 10$, $I_1 =$ _____ .
   (d) If $K = \dfrac{E_1 R_2}{E_2 R_1}$, $E_1 = 3$, $R_2 = 40$, $E_2 = 6$, and $R_1 = 2$, $K =$ _____ .
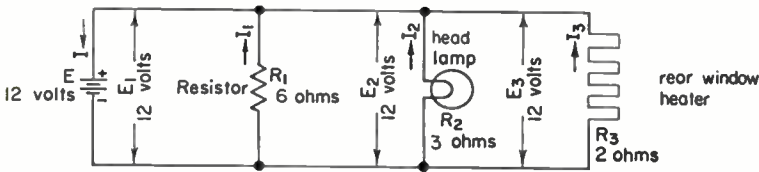
Fig. 2

3. In the circuit in Fig. 2, the same battery voltage E is applied across three circuit elements: a resistor, a lamp, and a heater. I is the total current supplied by the battery; I_1 is the current flowing through the resistor R_1; I_2 is the current flowing through the lamp R_2; and I_3 is the current flowing through the heater R_3. If $E = 12$ volts, $R_1 = 6$ ohms, $R_2 = 3$ ohms, and $R_3 = 2$ ohms,

    (a) $I_1 = $ _____, $I_2 = $ _____, $I_3 = $ _____ (Hint: Use Ohm's law for current.)

    (b) $P_1 = $ _____, $P_2 = $ _____, $P_3 = $ _____ (Hint: Use the formula $P = EI$, where P, in watts, is the power used by the element; E, in volts, is the voltage applied across the element; and I, in amperes, is the current flowing through the element.)

    (c) Find the total power P used by the three elements. (Use the formula $P = P_1 + P_2 + P_3$.) $P = $ _____

    (d) The total battery current I is found by the formula $I = I_1 + I_2 + I_3$. $I = $ _____

    (e) Find the total power supplied by the battery. (Use the formula $P = EI$, where P, in watts, is the total power supplied by the battery; E, in volts, is the battery voltage; and I, in amperes, is the total battery current.) $P = $ _____

ANSWERS

1. (a) $Q = CE$; (b) $E = I_1 R_1 + I_2 R_2$; (c) $H = \frac{4\pi Ni}{L}$; (d) $X_C = \frac{1}{2\pi fC}$

2. (a) $8000 \ldots t = RC = 4000 \times 2 = 8000$

    (b) $12 \ldots R = \frac{KL}{m} = \frac{2 \times 30}{5} = 12$

    (c) $2 \ldots I_1 = \frac{5 \times 4}{10} = \frac{20}{10} = 2$

    (d) $10 \ldots K = \frac{E_1 R_2}{E_2 R_1} = \frac{3 \times 40}{6 \times 2} = \frac{120}{12} = 10$

3. (a) $I_1 = 2$ A, $I_2 = 4$ A, $I_3 = 6$ A . . . Since $I = \dfrac{E}{R}$, current through resistor R_1 is $I_1 = \dfrac{12}{6} = 2$ A; current through the headlamp R_2 is $I_2 = \dfrac{12}{3} = 4$ A; and current through the rear window heater R_3 is $I_3 = \dfrac{12}{2} = 6$ A.

   (b) $P_1 = 24$ watts, $P_2 = 48$ watts, and $P_3 = 72$ watts . . . For resistor R_1, $P_1 = E_1I_1$ $= 12 \times 2 = 24$ watts. For the lamp, $P_2 = E_2I_2 = 12 \times 4 = 48$ watts. For the window heater, $P_3 = E_3I_3 = 12 \times 6 = 72$ watts.

   (c) 144 watts . . . $P = P_1 + P_2 + P_3 = 24 + 48 + 72 = 144$ watts.

   (d) $I = 12$ A . . . $I = I_1 + I_2 + I_3 = 2 + 4 + 6 = 12$ A.

   (e) 144 watts . . . $E = 12$ volts and $I = 12$ A. $P = EI = 12 \times 12 = 144$ watts. Note that this answer agrees with the answer to problem 3(c). This confirms that the power supplied by the battery is the same as the total power consumed by all of the circuit elements.

4 CANCELLATION . . . After the numerical values have been substituted into the fraction of a formula, the work can often be shortened by the use of *cancellation*. *However, remember that you can't cancel until you have done any additions or subtractions required in the numerator or denominator* (see second example below).

Example . . . $\dfrac{4 \times 7}{7 \times 5} =$ _____

Solution . . . $\dfrac{4 \times \not{7}}{\not{7} \times 5} = \dfrac{4}{5}$, *ans.*

Explanation . . . Like terms—7's in this case—that appear one above and one below the fraction line are canceled (deleted). In this problem, this leaves 4 above and 5 below to form the answer.

Example . . . Simplify the following problem by cancellation:
$$\frac{6 \times 7}{6 + 1} = \underline{\hspace{3cm}}$$

Solution . . . $\dfrac{6 \times 7}{6 + 1} = \dfrac{6 \times \not{7}}{\not{7}} = 6$, *ans.*

Explanation . . . The problem, as stated, cannot be immediately solved by cancellation because the denominator contains an addition sign, $+$. Therefore, we must first eliminate the plus sign by adding the 1 to the 6. Cancellation can then be used.

Cancellation is not limited to deleting like terms, as in the examples above. You may also cancel by dividing any two terms—one in the numerator and one in the denominator—by any number that will divide evenly into the two terms.

Example . . . $\dfrac{3 \times 2 \times 5 \times 7}{4 \times 3 \times 7 \times 3} =$ _____

Solution . . . $\dfrac{\cancel{3} \times \cancel{2}^{1} \times 5 \times \cancel{7}}{\cancel{4}_{2} \times \cancel{3} \times \cancel{7} \times 3} = \dfrac{1 \times 5}{2 \times 3} = \dfrac{5}{6}$, *ans.*

Explanation . . . We can cancel the two 3's and the two 7's, because a 3 and a 7 appear both above and below the fraction line. But we can also cancel further. Note that a 2 appears above the fraction line, and a 4 appears below. Dividing each number by 2, we cross out the 2 above the fraction line and mark a "1" above it, showing that $\dfrac{2}{2} = 1$. In the same way, we draw a line through the 4, but place a 2 below it, indicating that $\dfrac{4}{2} = 2$.

Example . . . $\dfrac{7 \times 5 \times 6}{9 \times 7 \times 4} =$ _____

Solution . . . $\dfrac{\cancel{7} \times 5 \times \cancel{6}^{1}}{\cancel{9}_{3} \times \cancel{7} \times \cancel{4}_{2}} = \dfrac{5 \times 1}{3 \times 2} = \dfrac{5}{6}$

Explanation . . . Since one 7 appears above the fraction line and another below, the 7's can immediately be canceled. Thus the fraction becomes $\dfrac{5 \times 6}{9 \times 4}$. To cancel further, note that the 6 in the numerator and the 9 in the denominator are each divisible by 3. Canceling them gives us

$$\dfrac{5 \times \cancel{6}^{2}}{\cancel{9}_{3} \times 4}$$

and, since the 2 in the numerator and the 4 in the denominator are both divisible by 2, we can cancel still further:

$$\dfrac{5 \times \cancel{6}^{\cancel{2}^{1}}}{\cancel{9}_{3} \times \cancel{4}_{2}} = \dfrac{5 \times 1}{3 \times 2} = \dfrac{5}{6}$$

WHAT HAVE YOU LEARNED?

1. Simplify the following problems by cancellation (where possible):

(a) $\dfrac{3 \times 5}{5 \times 4} = $ _____

(b) $\dfrac{9 \times 3}{13 \times 7} = $ _____

(c) $\dfrac{4 \times 3}{9 \times 8} = $ _____

(d) $\dfrac{7 + 14}{7 \times 9} = $ _____

(e) $\dfrac{8 \times 11 \times 6}{9 \times 4 \times 11} = $ _____

(f) $\dfrac{2 \times 3 \times 4 \times 9}{6 \times 7 \times 9 \times 2} = $ _____

(g) $\dfrac{2 + 4 - 1}{7 \times 5} = $ _____

(h) $\dfrac{RCE}{CEQ} = $ _____

2. Let $I_1 = \dfrac{I_2 N_2}{N_1}$. If $I_2 = 2$, $N_2 = 10$, and $N_1 = 2$, $I_1 = $ _____ .

3. If $X = \dfrac{3LW}{4GH}$, $L = 4$, $W = 7$, $G = 7$, and $H = 6$, $X = $ _____ .

ANSWERS

1. (a) $\dfrac{3}{4}$ . . . $\dfrac{3 \times \cancel{5}}{\cancel{5} \times 4} = \dfrac{3}{4}$. The 5's can be canceled because they appear both above and below the fraction line.

(b) $\dfrac{27}{91}$ . . . $\dfrac{9 \times 3}{13 \times 7} = \dfrac{27}{91}$. The numbers in this problem do not yield to cancellation because (1) no number is repeated in the numerator and denominator; (2) no whole number (except 1) can be divided into a term in the numerator and one in the denominator.

(c) $\dfrac{1}{6}$ . . . $\dfrac{\overset{1}{\cancel{4}} \times \overset{1}{\cancel{3}}}{\underset{3}{\cancel{9}} \times \underset{2}{\cancel{8}}} = \dfrac{1 \times 1}{3 \times 2} = \dfrac{1}{6}$

(d) $\dfrac{1}{3}$ . . . $\dfrac{7 + 14}{7 \times 9} = \dfrac{\overset{1}{\cancel{21}}}{\underset{3}{\cancel{63}}} = \dfrac{1}{3}$. Because there is a plus sign in the numerator, we must add before we can cancel.

(e) $\dfrac{4}{3}$ . . . $\dfrac{\overset{2}{\cancel{8}} \times \cancel{11} \times \overset{2}{\cancel{6}}}{\underset{3}{\cancel{9}} \times \underset{1}{\cancel{4}} \times \cancel{11}} = \dfrac{2 \times 2}{3 \times 1} = \dfrac{4}{3}$

(f) $\dfrac{2}{7}$ . . . $\dfrac{\overset{1}{\cancel{2}} \times \cancel{3} \times \overset{2}{\cancel{4}} \times \cancel{9}}{6 \times 7 \times \cancel{9} \times \underset{1}{\cancel{2}}} = \dfrac{1 \times 2}{7} = \dfrac{2}{7}$

(g) $\dfrac{1}{7}$ . . . $\dfrac{2 + 4 - 1}{7 \times 5} = \dfrac{6 - 1}{7 \times 5} = \dfrac{\cancel{5}}{7 \times \cancel{5}} = \dfrac{1}{7}$. Again, we must eliminate the addition and subtraction signs before attempting to cancel.

(h) $\dfrac{R}{Q} \cdots \dfrac{R\cancel{C}\cancel{E}}{\cancel{C}\cancel{E}Q} = \dfrac{R}{Q}$. Both the C's and E's can be canceled, because a C and an E appear both above and below the fraction line.

2. $10 \ldots I_1 = \dfrac{I_2 N_2}{N_1} = \dfrac{\cancel{2} \times 10}{\cancel{2}} = 10$

3. $X = \dfrac{1}{2} \cdots X = \dfrac{\overset{1}{\cancel{3}} \times \cancel{4} \times \cancel{7}}{\cancel{4} \times \cancel{7} \times \underset{2}{\cancel{6}}} = \dfrac{1}{2}$

HOW DECIMALS ARE USED IN ELECTRONICS

5 MEANING OF DECIMALS . . . Many quantities in electronics are expressed in terms of *decimals*. A decimal is a fraction whose denominator is either 10 or the product of two or more 10's. Thus, the denominator may be 100, 1000, 10,000, 100,000, and so on. Decimals may be written in fraction form as

$$\dfrac{3}{10} \qquad \dfrac{5}{10} \qquad \dfrac{3}{100} \qquad \dfrac{25}{100} \qquad \dfrac{167}{1000} \qquad \dfrac{2755}{10,000} \qquad \text{etc.}$$

The denominator of a decimal is usually not written out; instead, it is indicated by the use of a *decimal point*. Thus, the decimals given in the preceding paragraph in fraction form would be written respectively, as 0.3, 0.5, 0.03, 0.25, 0.167, and 0.2755.

If a number is *mixed*—that is, contains both a whole number and a fraction—the whole number is written in front of the decimal point and the fraction is written after the decimal point. For example, $2\dfrac{5}{10}$ is written in decimals as 2.5.

The rule for locating the decimal point is very important and should be memorized: *In a decimal, the number of digits after the decimal point is equal to the number of zeros in the unwritten denominator.* Thus, the decimal 0.7 indicates that there is one zero in the denominator. In other words, the decimal would be written in fraction form as $\dfrac{7}{10}$. The mixed number 1.82, with two digits after the decimal point, could be written as $1\dfrac{82}{100}$. The decimal 7.045, which has three digits after the decimal point, could be written as $7\dfrac{45}{1000}$, which has three zeros in the denominator.

14 Adding or removing zeros from the end of a decimal does not change its value. Thus, 7.30 may be rewritten 7.3, 7.300, 7.3000, 7.30000, and so on without affecting its value.

WHAT HAVE YOU LEARNED?

1. Write the following in fractional form. (Hint: *The number of zeros in the denominator* of the fraction must equal the *number of digits after the decimal point* in the decimal.)

(a) 0.7 = _____   (d) 0.73 = _____   (g) 2.08 = _____

(b) 0.07 = _____   (e) 0.073 = _____   (h) 4.3 = _____

(c) 0.007 = _____   (f) 0.743 = _____

2. Express the following in decimal form:

(a) A tenth of a dollar = $ _____

(b) A half of a dollar = $ _____

(c) A quarter of a dollar = $ _____

(d) $\frac{1}{10}$ of an ohm = _____ ohm

(e) $\frac{3}{10}$ of an ampere = _____ ampere

(f) $\frac{75}{1000}$ of a volt = _____ volt

(g) $\frac{375}{1000}$ of an inch = _____ inch

(h) $\frac{2}{1,000,000}$ of an ampere = _____ ampere

(i) $\frac{432}{10,000}$ of a megahertz = _____ megahertz

ANSWERS

1. (a) $\frac{7}{10}$; (b) $\frac{7}{100}$; (c) $\frac{7}{1000}$; (d) $\frac{73}{100}$; (e) $\frac{73}{1000}$; (f) $\frac{743}{1000}$;

(g) $\frac{208}{100}$ $\left(\text{or } 2\frac{8}{100}\right)$; (h) $\frac{43}{10}$ $\left(\text{or } 4\frac{3}{10}\right)$

2. (a) $.10 or $\frac{10}{100}$ of a dollar.

(b) $.50

(c) $.25 or $\frac{25}{100}$ of a dollar.

(d) 0.1 ohm.

(e) 0.3 ampere

(f) 0.075 volt . . . The number of digits after the decimal point must equal the number of zeros in the denominator of the fraction.

(g) 0.375 in.

(h) 0.000002 amp.

(i) 0.0432 megahertz.

6 ADDING AND SUBTRACTING DECIMALS . . . To add or subtract decimals, write the numbers so that the decimal points are located directly under each other and then proceed as with whole numbers. Place the decimal point in the answer under the other decimal points.

Example . . . $41.67 + 0.5 + 200 + 3.425 = $ _____

Solution . . .   41.670
                    0.500
                  200.000
                    3.425
                  245.595 , *ans.*

Explanation . . . The numbers are written with the decimal points located directly under each other. Zeros have been added at the ends of figures so that each figure will have the same number of decimal places. As stated in the preceding section, adding or removing zeros after a decimal will not change the value of the decimal. As shown above, though, adding zeros is sometimes a useful device, because the values of the decimals in relation to each other can be more easily seen.

Please work the problems below without using a calculator. That way, you can be sure that you understand the decimal point as it applies to addition and subtraction. You may repeat the problems using a calculator if you need the practice.

WHAT HAVE YOU LEARNED?

1. (a) $47 + 0.003 = $ _____

   (b) $21.611 + 6888.32 + 3.4167 = $ _____

   (c) $37.1065 + 432.07 + 4.20733 + 11.706 = $ _____

   (d) $21.611 - 8.78 = $ _____

   (e) $53 - 0.0501 = $ _____

   (f) $10 - 2.32 + 5 = $ _____ (Hint: Note that two operations, addition and subtraction, are involved.)

   (g) Which is the larger number, 3.31 or 3.297?

   (h) Which is the larger number, 4.03 or 4.005?

2. (a) If $R = R_1 + R_2 + R_3$, and if $R_1 = 7.23$ ohms, $R_2 = 47,000$ ohms, and $R_3 = 36.98$ ohms, $R = $ _____ .

(b) If $I = I_1 + I_2 - I_3$, and if $I_1 = 2.5$ A, $I_2 = 14.93$ A, and $I_3 = 7.938$ A, $I = $ _____ .

(c) If $P = P_1 - P_2$, $P_1 = 23,748.92$ watts, and $P_2 = 14,621.436$ watts, $P = $ _____ .

3. (a) In Fig. 3, if $R = R_1 + R_2 + R_3$, $R = $ _____ .

(b) Since $E = IR$, if $I = 10$, $E = $ _____ .
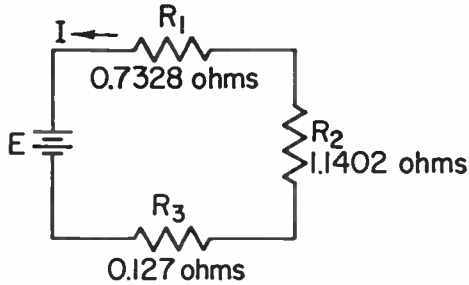
(c) If power $P = EI$, $P = $ _____

Fig. 3

ANSWERS

1. (a) 47.003 . . .   47.000
                         .003
                      _____
                       47.003

In any whole number, such as 47, the decimal point is considered to be at the end of the number. Here, though, as an aid in adding, zeros have been placed after the decimal point that follows 47.

(b) 6913.3477 . . .   21.6110
                     6888.3200
                        3.4167
                    _____
                     6913.3477

(c) 485.08983 . . .   37.10650
                      432.07000
                        4.20733
                       11.70600
                    _____
                      485.08983

(d) 12.831 . . .   21.611
                    −8.780
                  _____
                    12.831

(e) 52.9499 . . .   53.0000
                     −.0501
                   _____
                     52.9499

(f) 12.68 . . . $10 - 2.32 + 5 = 10 + 5 - 2.32 = 15 - 2.32 = 12.68$. In the solution shown, the numbers to be added, 5 and 10, are combined first. Then, from this sum—which is 15—the number 2.32 is subtracted.

(g) 3.31 . . . To see whether 3.31 or 3.297 is larger, add zeros to the end of 3.31 to provide an equal number of decimal places for both numbers. This gives 3.310, as compared with 3.297. We see immediately that while both numbers contain the same whole number 3, one whole number is followed by 310 one-thousandths and the other by only 297 one-thousandths. Therefore, 3.31 is the larger of the two numbers.

(h) 4.03 . . . 4.030 versus 4.005, or 30 one-thousandths versus 5 one-thousandths.

2. (a) 47,044.21 ohms

(b) 9.492 amp . . .

$$\begin{array}{r} 2.50 \\ +14.93 \\ \hline 17.43 \end{array} \qquad \begin{array}{r} 17.430 \\ -7.938 \\ \hline 9.492 \ \text{A} \end{array}$$

(c) 9127.484 watts

3. (a) $R = 2.0$ ohms . . .

$$\begin{array}{r} 0.7328 \\ 1.1402 \\ 0.1270 \\ \hline 2.0000 \ \text{ohms} \end{array}$$

(b) $E = 20$ volts . . . $E = 10 \times 2 = 20$ volts

(c) $P = 200$ watts . . . $P = EI = 20 \times 10 = 200$ watts

7 MULTIPLYING DECIMALS . . . Decimals are multiplied like whole numbers, but special attention must be given to placing the decimal point in the answer. The rule to use is that the number of decimal places in the answer equals the sum of the decimal places in the numbers being multiplied.

If we multiply 201 by 3254, we come up with 654054. No problem. But what if we multiply 20.1 by 32.54? Note that there is one digit (decimal place) after the decimal point in 20.1 and two digits (decimal places) after the decimal point in 32.54. Therefore, we have to point off $1 + 2 = 3$ decimal places in the answer. Thus $20.1 \times 32.54 = 654.054$.

As another example, $0.0423 \times 0.00253 =$' ? The sum of the decimal places in the two numbers is $4 + 5 = 9$. Since $423 \times 253 = 107019$, we must add some extra zeros in front of this number before we can point off 9 places. We then come up with $0.0423 \times 0.00253 = 0.000107019$. We now have the necessary 9 digits after the decimal point in the answer.

If you use a calculator, it will automatically put the decimal point in the right spot in the answer (and thus save you from many a careless error). But whether you use a calculator or not, you should know how to place the decimal point as explained above.

WHAT HAVE YOU LEARNED?

Work these problems without using a calculator. Then check your answer using your calculator, if you have one.

1. Indicate the number of decimal places in each of the following numbers:
   (a) 31.29   (d) 0.70831   (f) 0.0089276100
   (b) 12.2   (e) 0.00059   (g) 3.14159265
   (c) 479.030

2. Find E, in volts, when
   (a) $I = 2.1$ A; $R = 7$ ohms
   (b) $I = 15.2$ A; $R = 57.31$ ohms
   (c) $I = 21.29$ A; $R = 2.934$ ohms
   (d) $I = 0.00152$ A; $R = 0.0743$ ohms

3. Find P, in watts, when
   (a) $I = 2.75$ A; $E = 5$ volts
   (b) $I = 29.3$ A; $E = 75.79$ volts
   (c) $I = 1.534$ A; $E = 0.00345$ volts

ANSWERS

1. (a) Two . . . There are two decimal places in 31.29, because there are two digits to the right of the decimal point.
   (b) One; (c) three; (d) five; (e) five; (f) ten; (g) eight
2. (a) 14.7 volts . . . $E = IR = 2.1 \times 7 = 14.7$ volts
   (b) 871.112 volts . . . $E = IR = 15.2 \times 57.31$

$$
\begin{array}{r}
57.31 \\
\times\quad 15.2 \\
\hline
11462 \\
28655 \\
5731 \\
\hline
871.112
\end{array}
$$

Because there are two decimal places in the number to be multiplied and there is one decimal place in the multiplier, there must be three decimal places in the answer.

   (c) 62.46486 . . . $E = IR = 21.29 \times 2.934 = 62.46486$ volts
   (d) 0.000112936 volts . . . $E = IR = 0.00152 \times 0.0743$

$$
\begin{array}{r}
.00152 \\
\times\quad .0743 \\
\hline
456 \\
608 \\
1064 \\
\hline
0.000112936
\end{array}
$$

There are five decimal places in the number to be multiplied and four decimal places in the multiplier. Hence, there must be nine decimal places in the answer. In order to locate the decimal point, we must add three zeros before the number 112936.

3. (a) 13.75 watts . . . $P = EI = 2.75 \times 5 = 13.75$ watts
   (b) 2220.647 watts
   (c) 0.00529230 watts or 0.0052923 watts . . . Zeros at the end of a decimal value do not change the size of the number, and so can be dropped.

8 CHECKING DECIMAL POINT LOCATION . . . An answer in which the decimal point is incorrectly located is wrong. Even if you use a calculator, decimal point errors can creep in. (For example, the decimal may have been misplaced while copying the answer from the calculator display.) The best technicians always examine the decimal-point position in their final answer to a problem to see if it makes sense or not.

For example, if we multiply 2.17 by 12.23 correctly, we get 26.5391. To verify the location of the decimal point, we notice that 2.17×12.23 is very roughly equal to 2×12, or 24. This is in rough agreement with the answer of 26.5391, and therefore checks the placement of the decimal point. However, if the answer to the check had been 2.4, say, or 240, it would have signaled that the answer to the problem was wrong, because there would have been an obvious difference between the answer obtained and the approximate answer.

As another example, does $1.42 \times 2.97 = 0.42174$, 4.2174, or 42.174? We can see that 1.42×2.97 is very roughly equal to $1 \times 3 = 3$. Since 3 is in the same ball park as 4.2174, we know that this is the right answer, and that 0.42174 and 42.174 are wrong.

WHAT HAVE YOU LEARNED?

1. Check the location of the decimal points in the answers to each of the following problems, noting whether they are right or wrong. If wrong, relocate the decimal point to its correct position.
   (a) $7.2 \times 1.1 = 79.2$
   (b) $21.75 \times 33.96 = 738.63$
   (c) $246.795 \times 0.00753 = 18.5836635$

2. Mentally position the decimal point in each of the answers below.
   (a) $11.1 \times 10.3 = 11433$
   (b) $0.25 \times 82.4 = 20600$
   (c) $0.012 \times 0.473 = 5676$

1. (a) Wrong; should be 7.92 . . . To check the position of the decimal point, multiply
$7 \times 1 = 7$. This check shows that the final decimal should be much smaller than 79.2.
   (b) Right . . . To check, multiply approximately comparable figures, such as 20×30.
This gives 600, which is in hundreds, as is the answer.
   (c) Wrong; should be 1.85836635 . . . To check, use a sample problem such as $200 \times 0.007 = 1.4$. This shows that an answer of 18+ is much too high.
2. (a) 114.33 . . . Check: $11 \times 10 = 110$
   (b) 20.6 . . . Check: $0.2 \times 80 = 16$
   (c) 0.005676 . . . Check: $0.01 \times 0.5 = 0.005$

9 MULTIPLYING BY 10'S . . . No matter how many calculators you own—even if you have one in every pocket—you should still be able to multiply mentally by 10, 100, 1000, and so on, and do it easily. Here's how:

To multiply any number by 10, simply move the decimal point over one place to the right; to multiply by 100, move the decimal point two places to the right; to multiply by 1000, move the decimal point three places to the right; and so forth. In other words, *move the decimal point one place to the right for each zero in the multiplier.*

Example . . . $4 \times 100 = $ _____

Solution . . . 400

Explanation . . . Because there are two zeros in 100, move the decimal point two places to the right. Since 4 may be written 4.00,
$$100 \times 4 = 100 \times 4.00$$
$$= 400$$

Example . . . $26.3578 \times 1000 = $ _____

Solution . . . 26,357.8

Explanation . . . The multiplier 1000 contains three zeros. Therefore, we move the decimal point in 26.3578 three places to the right.

Do not use your calculator in working the following problems.

1. Use the procedure for multiplying by 10's to solve the following problems:
   (a) $6.875 \times 100 =$ _____
   (b) $1000 \times 41.286 =$ _____
   (c) $6 \times 10,000 =$ _____
   (d) $0.0047 \times 10 =$ _____
   (e) $0.00251 \times 10,000 =$ _____
   (f) $247.1 \times 1000 =$ _____
   (g) $1000 \times 1000 =$ _____

2. A given voltage applied across a circuit causes a current of 2 mA (milliamperes) to flow. Raising this voltage to 1000 times its original value increases the current 1000 times. The new value of current is _____ mA.

3. The lowest frequency, f_1, to which a certain loudspeaker will respond is 100 Hz (1 hertz = 1 cycle per second).
   (a) When f_1 is multiplied by 100, the new frequency, _____ Hz, can still be heard as a sound.
   (b) When f_1 is multiplied by 10,000, the new frequency, _____ Hz, falls within the standard broadcast band.
   (c) When f_1 is multiplied by 100,000, the new frequency, _____ Hz, is one used by radio station WWV of the National Bureau of Standards.

ANSWERS

1. (a) 687.5 . . . $6.875 \times 100 = 687.5$. Move the decimal point one place to the right for each zero in the multiplier.
   (b) 41,286 . . . $1000 \times 41.286 = 41,286$
   (c) 60,000 . . . $6 \times 10,000 = 6.0000 \times 10,000 = 60,000$. In any whole number, the decimal point is considered to be at the end of the number. Also, zeros can be added to the end of any decimal without changing its value.
   (d) 0.047 . . . $0.0047 \times 10 = 0.047$. Because the multiplier (for convenience, we consider 10 to be the multiplier) contains one zero, we move the decimal point one place to the right.
   (e) 25.1 . . . $0.00251 \times 10,000 = 0.00251 = 25.1$. (Here, we have indicated graphically how the decimal point is moved four places to the right.)
   (f) 247,100 . . . $247.1 \times 1000 = 247.100 = 247,100$. After adding zeros at the end of the number to be multiplied, we move the decimal point three places to the right.
   (g) 1,000,000 . . . $1000 \times 1000 = 1000.000 = 1,000,000$
2. 2000 . . . Increasing the voltage increases the current 1000 times. Since the original current was 2 mA, $1000 \times 2 = 2000$ mA.
3. (a) 10,000 . . . $100 \times 100 = 10,000$ Hz.
   (b) 1,000,000 . . . $100 \times 10,000 = 100.0000 = 1,000,000$ Hz
   (c) 10,000,000 . . . $100 \times 100,000 = 100.00000 = 10,000,000$ Hz

10

MULTIPLYING BY 0.1, 0.01, 0.001, etc . . . Just as it is important to be able to multiply quickly by 10's, 100's, and so on, so it is important to be able to multiply quickly by tenths, hundredths, thousandths, etc.

To multiply by 0.1, 0.01, 0.001, 0.0001, etc., *move the decimal point one place to the left* in the number being multiplied *for each digit to the right of the decimal point* in the multiplier.

Example . . . 32.68 × 0.01 = _____

Solution . . . 0.3268, *ans.*

Explanation . . . Since there are two digits to the right of the decimal point in the multiplier, the decimal point in the number being multiplied must be moved two places to the left.

Example . . . 427 × 0.00010 = _____

Solution . . . 427 × 0.0001 = 0.0427, *ans.*

Explanation . . . First remove all zeros from the end of the multiplier. Because there are four digits remaining to the right of the decimal point in the multiplier, we must move the decimal point in the number 427 four places to the left. To move the decimal point four places to the left, we must add a zero between 427 and the decimal point.

WHAT HAVE YOU LEARNED?

Do not use your calculator in working the following problems.

1. Use the procedure for multiplying by tenths, hundredths, and so forth to solve the following problems.
    (a) 4.7 × 0.1 = _____
    (b) 237 × 0.1 = _____
    (c) 0.035 × 0.1 = _____
    (d) 63,000 × 0.01 = _____
    (e) 7 × 0.001 = _____
    (f) 23 × 1000 × 0.001 = _____
    (g) 23 × 1000 × 0.00001 = _____
    (h) 0.1 × 0.1 = _____
    (i) 100 × 0.01 = _____
    (j) 0.00251 × 10,000 = _____
    (k) 0.178 × 0.0001 = _____

2. A useful relationship to know is that 1 A = 1000 mA. (Hint: To convert amperes to milliamperes, multiply by 1000.)

 (a) 2 A = _____ mA

 (b) 0.5 A = _____ mA

 (c) 2.5 A = _____ mA

 (d) 17.6 A = _____ mA

3. Since 1 A = 1000 mA, it follows that 1 mA must equal $\frac{1}{1000}$ A = 0.001 A.

(Hint: To convert milliamperes to amperes, multiply by 0.001.)

 (a) 1 mA = _____ A   (d) 2000 mA = _____ A

 (b) 2 mA = _____ A   (e) 3500 mA = _____ A

 (c) 500 mA = _____ A   (f) 6326 mA = _____ A

4. (a) In a DC circuit, if E = 20 volts and R = 200 ohms, I = _____ A

 = _____ mA.

 (b) If E = 3 volts and R = 6 ohms, I = _____ mA.

 (c) If E = 10 volts and R = 10,000 ohms, I = _____ mA.

5. In Fig. 4, meter A reads the current through the resistor R, while voltmeter V reads the voltage drop across R.

 (a) If the current reading is 10 mA and R = 50,000 ohms, the voltmeter reading is _____ volts.

 (b) If the current reading is 5 mA and R = 50,000 ohms, the voltmeter reading is _____ volts.

 (c) If the current reading is 50 mA and R = 82 kilohms, the voltmeter reading is _____ kv (kilovolts). (Hint: 1 mA = 0.001 A, 1 kilohm = 1000 ohms, and 1 kV = 1000 volts.)
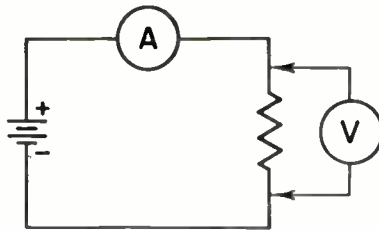

Fig. 4

ANSWERS

1. (a) 0.47 . . . 4.7 × 0.1 = 0.47. Because there is one digit to the right of the decimal point in the multiplier (0.1), we must move the decimal point one place to the left in the number being multiplied (4.7).

(b) 23.7 . . . 237 × 0.1 = 23.7

(c) 0.0035 . . . 0.035 × 0.1 = 0.0035

(d) 630 . . . 63,000 × 0.01 = 630.00 = 630. Here, there are two digits to the right of the decimal point in the multiplier (0.01). Hence, we move the decimal point of the number being multiplied two places to the left.

(e) 0.007 . . . 7 × 0.001 = 0.007. To move the decimal point three places to the left in the number being multiplied (7), we must place two zeros before the number.

(f) 23 . . . 23 × 1000 × 0.001 = 23,000 × 0.001 = 23.000 = 23. Notice that the final answer is the same as the original number to be multiplied. This is because 1000 × 0.001 = 1.

(g) 0.23 . . . 23 × 1000 × 0.00001 = 23,000 × 0.00001 = 0.23

(h) 0.01

(i) 1 . . . 100 × 0.01 = 1

(j) 25.1 . . . 0.00251 × 10,000 = 25.1

(k) 0.0000178 . . . 0.178 × 0.0001 = 0.0000178. Because there are four digits to the right of the decimal point in the multiplier (0.0001), we must move the decimal point in the number 0.178 four places to the left. We add four zeros before the number to locate the decimal point.

2. (a) 2000 mA . . . 2 A × 1000 = 2000 mA

(b) 500; (c) 2500; (d) 17,600

3. (a) 0.001 A . . . 1 mA × 0.001 = 0.001 A

(b) 0.002

(c) 0.5 A . . . 500 × 0.001 = 0.5 amp

(d) 2; (e) 3.5; (f) 6.326

4. (a) 0.1 amp, 100 mA . . . Use the formula,

$$I = \frac{E}{R} = \frac{20}{200} = \frac{1}{10} = 0.1 \text{ A}$$

Then 0.1 A × 1000 = 100 mA

(b) 500 mA . . .

$$I = \frac{E}{R} = \frac{3}{6} = 0.5 \text{ A}$$

Then 0.5 × 1000 = 500 mA

(c) 1 mA . . .

$$I = \frac{E}{R} = \frac{10}{10,000} = \frac{1}{1000} \text{ A} = 1 \text{ mA}$$

5. (a) 500 volts . . . Use the formula $E = IR$, where E is in volts, I is in amperes, and R is in ohms. I is given in milliamperes, and must therefore be converted to amperes for use in the formula:

$$I = 10 \text{ mA} = 10 \times 0.001 = 0.01 \text{ A}$$

Then

$$E = IR = 0.01 \times 50,000 = 500 \text{ volts}$$

(b) 250 volts . . . Converting 5 mA to amperes, 5 × 0.001 = 0.005 A. Then

$$E = IR = 0.005 \times 50,000 = 250 \text{ volts}$$

(c) 4.1 kV . . . $I = 50$ mA = 50 × 0.001 = 0.05 A; $R = 82$ kilohms = 82 × 1000 = 82,000 ohms. Then $E = IR = 0.05 \times 82,000 = 4,100$ volts. Since there are 1000 volts in 1 kV, $E = \frac{4100}{1000} = 4.1$ kV.

EXAMINATION

Each examination question is followed by a number of selections. Circle the number in front of the correct selection for each question. When you have finished, transfer your answers to the Answer Sheet provided.

1. In order to make sure that the decimal point is located correctly in your answer, you should
   (1) rework the problem at least twice.
   (2) always use a calculator, never attempting to work a problem mentally.
   (3) make a second calculation, using easy-to-figure numbers that will give you a ball-park answer.

2. The expression $\frac{19}{5}$ means
   (1) 5 is added to 19.
   (2) 5 is divided by 19.
   (3) 19 is multiplied by 5.
   (4) 19 is divided by 5.

3. To find C in the problem
$$C = \frac{3 \times 7}{3 + 7}$$
   you would first
   (1) rewrite the problem as
$$C = \frac{3 \times 7}{3} + \frac{3 \times 7}{7}$$
   (2) cancel out the 7's.
   (3) add the 3 to the 7 in the denominator.
   (4) cancel out the 3's.

4. Shown below is the work of Pat and Terry in finding the value of
$$\frac{12 + 24}{6 \times 8 \times 3}$$
   Pat's work:
$$\frac{\overset{2}{\cancel{12}} + \overset{3}{\cancel{24}}}{\cancel{6} \times \cancel{8} \times \cancel{3}} = 2$$

Terry's work:

$$\frac{12 + 24}{6 \times 8 \times 3} = \frac{\overset{6}{\overset{\cancel{2}}{\cancel{36}}}}{\underset{4}{\cancel{6} \times \cancel{8} \times \cancel{3}}} = \frac{1}{4}$$

Which person worked the problem correctly? Why?
  (1) Pat worked the problem correctly, by first cancelling as much as possible.
  (2) Both Pat and Terry's answers are correct, since there are two correct answers to the problem.
  (3) Neither worked the problem correctly.
  (4) Terry worked the problem correctly by removing the + sign in the numerator before cancelling.

5. The beta (β) of a certain transistor is equal to the collector current divided by the base current. If we let I_c represent the collector current and I_b the base current, which one of the following equations correctly expresses the statement in formula form?

  (1) $I_c = \frac{I_b}{\beta}$

  (2) $\beta = \frac{I_b}{I_c}$

  (3) $\beta = \frac{I_c}{I_b}$

  (4) $I_b = \beta I_c$

  (5) $I_c = \frac{\beta}{I_b}$

6. The mixed number $8\frac{5}{1000}$ is expressed in decimal form as which of the following?
  (1) 0.085   (2) 8.5   (3) 8.05   (4) 0.85   (5) 8.005

7. Which of the following is equal to 200 millivolts?
  (1) 0.0002 volts
  (2) 0.02 volts
  (3) 2 volts
  (4) 0.2 volts

8. How much is 0.5×5?
  (1) 0.25   (2) 0.025   (3) 2.5   (4) 25   (5) 0.0025

9. What is 39.08 times 0.000324? 27
    (1) 12.66192
    (2) 1.266192
    (3) 0.1266192
    (4) 0.01266192
    (5) 0.001266192

10. Multiply 29.68 by 0.00001. What is the result?
    (1) 0.2968
    (2) 0.02968
    (3) 0.002968
    (4) 0.0002968
    (5) 0.00002968
    (6) 0.000002968

END OF EXAM

Lesson 2101B-9
Reciprocals, Percentages
and Powers of Numbers

11 HOW ACCURATE SHOULD YOUR ANSWER BE? . . . When dividing numbers, the question that naturally arises is how may places the division should be carried to. If you divide 4 by 3, for example, is it adequate the carry the answer to only two places, as 1.3? Or should you carry it further, to 1.33—or still further, to 1.333, or even to 1.33333333?

This question is of particular concern if you are not using a calculator, since arithmetic problems get laborious indeed when many decimal places are involved. But it is also important with a calculator. Some calculators display as many as twelve digits, and you won't want to copy down any more of these digits than you actually need.

Experience shows that answers accurate to three *significant figures* are adequate for most practical electronics problems. It is all we expect of you in this course, for example, if you are not using a calculator. (We suggest that you keep at least four significant figures if you are using a calculator, since very little extra work is involved.) The significant figures in a number are the digits of the number, *excluding* any zeros at the beginning or end put there for the purpose of placing the decimal point. Each of the numbers 1.33, 468, and 52.3, for example, has three significant figures, since each has three digits. Each of the numbers 1.333, 1333, 460.6, and 46.06 has four significant figures. Each of the numbers 1.3 and 13 has two significant figures.

Suppose you read the current in a circuit on your meter as 1.62 mA. You would say that you have read the meter to an accuracy of three significant figures. If you convert your reading to amperes by multiplying by 0.001, the result (0.00162 A) is still accurate to three significant figures. The reason is that the accuracy was determined by how carefully you read the meter, and it would not be affected by converting from one unit to another. The zeros in front of the digits 162 are not part of your meter reading, but were added after the reading was made in order to place the decimal point. They have nothing to do with the accuracy of your reading, and are therefore not significant figures. The three significant figures in 0.00162 are the 1, the 6, and the 2.

Similarly, the reading of 1.62 mA can be changed to microamperes (μA) by multiplying by 1000, giving 1620 μA, which is still accurate to three significant figures. The zero was added to properly locate the decimal point, and is not a

significant figure.

In summary, the number of significant figures in a value is the number of digits, *except* the zeros at the end of a whole number or at the beginning of a decimal.

Example . . . State the number of significant figures in each of the values listed.

Solution . . .
387.56	Five significant figures
0.00027	Two significant figures . . . Don't count zeros at the beginning of a decimal.
0.0002700	Four significant figures . . . Count the zeros at the end of a decimal, but not those at the beginning.
48,000.000	Two significant figures . . . Don't count the zeros at the end of a whole number.
40085	Five significant figures
0.040085	Five significant figures . . . Don't count the zeros at the beginning of a decimal.
4008500	Five significant figures . . . Don't count the zeros at the end of a whole number.
60,009	Five significant figures

Example . . . Round the following numbers off to three significant figures:

Solution . . .
4.68335	4.68, *ans.*
28.768	28.8, *ans.* . . . when rounding, you should increase the last retained digit by 1 when the following digit is 5 or greater.
0.0004482	0.000448, *ans.*
836,487	836,000, *ans.*
3.002	3.00, *ans.* . . . When rounding a number off to three figures, retain the zeros needed at the end to make three figures.
50.07	50.1, *ans*

Your calculator may have a key that can be set so that only two digits after the decimal point are retained in the display (or some other specific number of decimal

places). This key is for business and accounting purposes, and should never be used for technical or scientific calculations. Suppose, for example, you want to find the current through a 700-ohm resistor with 5 volts across it. By Ohm's law, this will be $5/700 = 0.00714$ A (to three significant figures). If your calculator is set to display only two decimal places, you would read 0.00 as the current, which is of course useless. You would have cut out all three of the significant figures!

WHAT HAVE YOU LEARNED?

1. To how many significant figures should your answer to problems in this course be carried?

2. How many significant figures are there in each of the following numbers?

(a) 7	(e) 400,082	(h) 0.0000007945
(b) 0.393	(f) 404	(i) 23,000,000
(c) 424.1	(g) 0.0000300	(j) 23.0025
(d) 324.921		

3. Round off each of the following numbers to three significant figures.

(a) 46.3528	(d) 234,876	(g) 82.06
(b) 0.22242	(e) 0.030417	(h) 32.999
(c) 0.000573194	(f) 5.502	

4. Solve to three significant figures:
   (a) If $I = 10.10$ A and $R = 2.02$ ohms, $E =$ _____.
   (b) If $E = 100.7465$ volts and $I = 0.6295$ A, P (in watts) $=$ _____.
   (Hint: Use $P = EI$.)

ANSWERS

1. Three . . . Of course, your answer will not be wrong if you carry to more than three.

2. (a) One	(e) Six	(h) Four
(b) Three	(f) Three	(i) Two
(c) Four	(g) Three	(j) Six
(d) Six		
3. (a) 46.4	(d) 235,000	(g) 82.1
(b) 0.222	(e) 0.0304	(h) 33.0
(c) 0.000573	(f) 5.50	

4. (a) 20.4 . . . $E = IR = 10.10 \times 2.02 = 20.4020 = 20.4$ volts. E, as computed, is shown with six significant figures. Becaue only three significant figures are required, we may strike the unneeded digits at the end.

   (b) 63.4 watts . . . $P = EI = 100.7465 \times 0.6295 = 63.41992175 = 63.4$. If you are working this problem without a calculator, you can save a lot of tedious work by rounding off both voltage and current to three significant figures *before* multiplying. Because the fourth digit in 100.7465 is 5 or greater, we add 1 to the third digit, giving us 101. Similarly, the fourth digit in 0.6295 is 5; therefore, we add 1 to the preceding digit (9), giving us 0.630.

Note: If you are using a calculator, we suggest that you keep four or more significant figures in the intermediate steps, even though you may cut the final answer down to three significant figures. For example, 100.7465 could be entered in the keyboard in full, or you could enter the number as 100.7 or as 100.75. If you enter both numbers in full, your display will read 63.41992175, but you can copy this off as 63.4 or as 63.42. The answer 63.4 watts is a more accurate answer than the 63.6 watts obtained when rounding off for hand calculations, but 63.6 is accurate enough for most purposes.

12 DIVISION OF DECIMALS . . . Decimals in division, just as in multiplication, are treated like whole numbers, but special attention must be given to placing the decimal point in the answer.

An illustration of a division problem is shown below. The *divisor*, *dividend*, and *quotient* (answer) are identified.

$$\begin{array}{r} 20 \quad \text{quotient} \\ \text{divisor} \quad 24\ \overline{)\ 480} \quad \text{dividend} \end{array}$$

One important rule for dividing decimals is this: *first eliminate the decimal point from the divisor.* To do so, move the decimal point to the right end of the divisor. Note the number of places you have moved the decimal point, and then move the decimal point in the dividend an equal number of places to the right. Place the decimal point in the quotient directly above the decimal point in the dividend.

Example . . . In the following division problem, eliminate the decimal point from the divisor and place the decimal point in the quotient: $0.0211\ \overline{)\ 0.004362}$

Solution . . . $0.0_12_21_31_4.\ \overline{)\ 0.0_10_24_33_4.62} = 211\ \overline{)\ 43.62}$

Explanation . . . The decimal point in the divisor was moved four places to the right. Therefore, the decimal point in the dividend was also moved four places to the right. The decimal point in the quotient is placed directly above the decimal point in the dividend.

Next, divide the divisor into the dividend. Place the first digit of the quotient directly over the last digit used in the dividend for finding the first digit of the quotient.

32   Example . . . In the following problem, locate the first digit of the quotient:

211) 43.62

Solution . . . $\dfrac{.2}{211\ \overline{)\ 43.62}}$

Explanation . . . 211 cannot be divided into 4 or into 43. But it can be divided into 436 (about 2 times). Therefore, place a 2 in the quotient directly over the 6 in the dividend.

Complete the division

Example . . . Complete the solution of the following problem to four significant figures and round off to three significant figures.

$$\dfrac{.2}{211\ \overline{)\ 43.62}}$$

Solution . . .
```
            .2067  = 0.207
211 ) 43.6200
      422
      1420
      1266
       1540
       1477
```

Explanation . . . Note that two zeros have been added to the end of the dividend. They permit you to carry out the quotient to the required number of significant figures.

Be very careful to keep each digit in the quotient directly above the last digit in the dividend used in getting that digit in the quotient. Notice that the 6 in the quotient in the example above goes above the first zero of the dividend, since this zero was the last digit brought down to form 1420 (into which 211 is divided to get the 6). Before the zero was brought down to form 1420, the 2 of the dividend was brought down to form 142. Since the divisor, 211, would not divide into 142, a zero was placed in the quotient above the 2 in the dividend.

Place a zero in the quotient after the decimal point each time the divisor is tried but will not go into the available part of the dividend. Such zeros locate the decimal point and are as essential as any other digits in the answer.

Example . . . 324) 0.7642 = _____

$$\text{Solution} \dots 324 \overline{)\ 0.764200} \quad .002358$$

```
          .002358
324 ) 0.764200
      648
      1162
       972
      1900
      1620
      2800
      2592
       208
```

Explanation . . . To locate the first digit of the quotient, note that 324 can't be divided into 7. Therefore, *place a zero* in the quotient after the decimal point and directly above the 7. Likewise, 324 can't be divided into 76. Therefore, *place a zero* in the quotient above the 6. But 324 can be divided into 764 two times; therefore, place a 2 in the quotient above the 4, and so forth.

WHAT HAVE YOU LEARNED?

1. Solve each of the following problems. Carry the quotients to four digits, and round off to three significant figures.

(a) $\dfrac{31.7}{2.68}$ = _____

(b) $\dfrac{0.0049}{231.1}$ = _____

(c) $\dfrac{400.5}{681}$ = _____

(d) $\dfrac{0.000497}{0.01011}$ = _____

(e) $\dfrac{14}{236}$ = _____

(f) $\dfrac{271}{11.48}$ = _____

(g) $\dfrac{3}{487}$ = _____

(h) $\dfrac{1}{425}$ = _____

(i) $\dfrac{1}{500}$ = _____

(j) $\dfrac{1}{67,000}$ = _____

(k) $\dfrac{0.14}{23}$ = _____

(l) $\dfrac{760,000}{0.04}$ = _____

(m) $\dfrac{0.01}{0.01}$ = _____

(n) $\dfrac{0.01}{0.003}$ = _____

(o) $\dfrac{3.04}{200}$ = _____

(p) $\dfrac{0.00012}{0.006}$ = _____

(q) $\dfrac{0.0008}{4000}$ = _____

(r) $\dfrac{2}{0.2}$ = _____

(s) $\dfrac{4250}{1}$ = _____

2. (a) In a DC circuit, E = 9.3 volts, I = 3.1 A, R = _____.
   (b) If E = 97.7 volts, I = 3.16 A, R = _____.
   (c) If E = 141 volts, I = 0.707 A, R = _____.

3. In the formula $C = \frac{t}{R}$, where C is capacitance, in farads; t is time, in seconds; and R is resistance, in ohms:

   (a) If $t = 2$ sec and $R = 1000$ ohms, $C =$ _____ farad.
   (b) If $t = 0.001$ sec and $R = 20$ ohms, $C =$ _____ farad.
   (c) If $t = 1.8$ sec and $R = 2200$ ohms, $C =$ _____ farad.

ANSWERS

1. (a) 11.8 . . .

$$
\begin{array}{r}
11.8 \\
2.68 \overline{\smash{\big)}\ 31.700} \\
\underline{268} \\
2220 \\
\underline{2144} \\
76
\end{array}
$$

(b) 0.0000212	(h) 0.00235	(n) 3.33
(c) 0.588	(i) 0.00200*	(o) 0.0152
(d) 0.0492	(j) 0.0000149	(p) 0.0200*
(e) 0.0593	(k) 0.00609	(q) 0.000 000 200*
(f) 23.6	(l) 19,000,000	(r) 10.0
(g) 0.00616	(m) 1.00	(s) 4250

2. (a) 3 ohms . . . $R = \frac{E}{I} = \frac{9.3}{3.1} = 3.00*$

   (b) 30.9 ohms; (c) 199 ohms

3. (a) 0.00200 . . . $C = \frac{t}{R} = \frac{2}{1000} = 0.00200$ farad

   (b) 0.0000500 farad

   (c) 0.000818 . . . $C = \frac{t}{R} = \frac{1.8}{2200} = 0.000818$ farad

13 CHANGING FRACTIONS TO DECIMALS . . . Earlier, we said that a fraction is a form for division. That is, in a fraction such as $\frac{6}{7}$, the numerator 6 is to be divided by the denominator 7.

A fraction can be converted to a decimal merely by carrying out the indicated division in the manner of topic 12.

---

*It is OK to leave the two zeros off of the end. However, the zeros can be useful because they show that the answer is correct to three significant figures.

1. Convert the following fractions to decimals by dividing in the manner of topic 12.

(a) $\frac{1}{10}$ = _____

(b) $\frac{3}{7}$ = _____

(c) $\frac{39}{21}$ = _____

(d) $1\frac{41}{100}$ = _____

(e) $11\frac{5}{7}$ = _____

ANSWERS

1. (a) 0.1;   (b) 0.428 (or 0.429);   (c) 1.86
   (d) 1.41 . . . To solve for the mixed number, simply convert the fraction to a decimal and add the whole number.   (e) 11.7

14 RECIPROCALS . . . The reciprocal of a given number is 1 divided by that number. Thus, the reciprocal of 2 is $\frac{1}{2}$, that of 34 is $\frac{1}{34}$; that of 92,300 is $\frac{1}{92,300}$; and that of 0.000592 is $\frac{1}{0.000592}$.

The reciprocal is converted to decimal form simply by carrying out the indicated division. Although a reciprocal is no more than a fraction with a numerator of 1, it finds a great many applications in electronics.

WHAT HAVE YOU LEARNED?

1. Find the reciprocals of the following numbers in decimal form:

   (a) 4   (d) 1000   (g) 0.521
   (b) 8   (e) 0.002   (h) 0.000732
   (c) 64   (f) 6370

2. The conductance, in siemens of a circuit is equal to the reciprocal of the circuit resistance, in ohms.
   (a) A 150-ohm resistor has a conductance of _____ siemens.
   (b) A 0.025-ohm resistor has a conductance of _____ siemens.
   (c) A 5000-ohm resistor has a conductance of _____ siemens.
   (d) Conductance is the reciprocal of _____.

3. In a certain circuit, $B = \frac{1}{X_1} + \frac{1}{X_2} + \frac{1}{X_3}$. If $X_1 = 0.25$, $X_2 = 3.33$, and $X_3 = 14.3$, $B =$ _____.

4. $t = \frac{1}{f}$, where f is the frequency of an alternating current, in Hz (cycles per

second) and t is the period, or time for each cycle, in seconds. If $f = 60$ Hz, the time required for each cycle is _____ second.

5. $X_C = \dfrac{1}{2\pi f C}$, where X_C is capacitive reactance, in ohms; $\pi = 3.14$; $f =$ frequency, in hertz; and $C =$ capacitance, in farads. If $f = 60$ Hz and $C = 0.00005$ farad, $X_C = $ _____ ohms. (Hint: Perform the multiplication in the denominator and then solve the reciprocal.)

6. When three resistances R_1, R_2, and R_3 are in parallel, the combined resistance is found by the formula

$$R = \frac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}}$$

If R_1, R_2, and R_3 are 18.3 ohms, 4.67 ohms, and 5.5 ohms, respectively, the combined resistance is _____ ohms. (Hint: First convert each reciprocal to its decimal value.)

ANSWERS

1. (a) 0.250;   (b) 0.125;   (c) 0.0156   (d) 0.001;(e) 500;
   (f) 0.000157;   (g) 1.92;   (h) 1366 (or 1370 if rounded off)
2. (a) 0.00667;   (b) 40;   (c) 0.0002   (d) resistance.
3. 4.37 . . . $B = \dfrac{1}{X_1} + \dfrac{1}{X_2} + \dfrac{1}{X_3}$

   $= \dfrac{1}{0.25} + \dfrac{1}{3.33} + \dfrac{1}{14.3}$

   $= 4 + 0.300 + 0.0699$

   $B = 4.37$

4. 0.0167 . . . $t = \dfrac{1}{f} = \dfrac{1}{60} = 0.0167$ sec

5. 53.1 ohms . . . $X_C = \dfrac{1}{2\pi f C} = \dfrac{1}{2 \times 3.14 \times 60 \times 0.00005}$

   $2 \times 3.14 \times 60 \times 0.00005 = 0.01884$
   and

   $$\dfrac{1}{0.01884} = 53.07855$$

   $$= 53.1 \text{ ohms}$$

6. 2.22 . . . $R = \dfrac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}} = \dfrac{1}{\dfrac{1}{18.3} + \dfrac{1}{4.67} + \dfrac{1}{5.5}}$

$$\dfrac{1}{18.3} = 0.0546 \qquad \dfrac{1}{4.67} = 0.214 \qquad \dfrac{1}{5.5} = 0.182$$

R then $= \dfrac{1}{0.0546 + 0.214 + 0.182} = \dfrac{1}{0.451} = 2.22$ ohms

15 PERCENTAGE . . . Electronic quantities are frequently expressed in terms of percent. For example, the efficiency of the final stage of a transmitter or the effectiveness of a filter in a power supply is often expressed in terms of percent.

One percent of a number is one one-hundredth of that number. Similarly, 12 percent of a number is $\dfrac{12}{100}$, or 0.12 of it.

To express a decimal in percent form, move the decimal point two places to the right and add either the percent sign (%) or the word "percent." Thus, 0.0147 is equal to 1.47% (or 1.4 percent). Conversely, when a value is given in percent form, it can be changed to a simple decimal by moving the decimal point two places to the left and discarding the % sign or the word "percent." Thus, 37% (or 37 percent) is equal to 0.37. Note that values expressed in terms of percent should be changed to decimals before being used in computations.

Example . . . 25% of 32 = _____.

Solution . . . 0.25 × 32 = 8

Explanation . . . Change 25% to a decimal by moving the decimal point two places to the left. (Although the decimal point is not shown in the term 25%, it is understood to be at the end of the number.) Then multiply in the usual manner.

Example . . . 3.5 is _____ percent of 56.

Solution . . . $\dfrac{3.5}{56} = 0.0625 = 06.25\% = 6.25\%$

Explanation . . . Divide 3.5 by 56. Then, change to the percent form by moving the decimal point two places to the right and adding the percent sign.

WHAT HAVE YOU LEARNED?

1. Express the following percentages in decimal form:
   (a) 2%   (b) 17%   (c) 150%

2. Express the following decimals in percentage form:
   (a) 0.09   (b) 2.75   (c) 0.875

3. 7.1% of 148 = _____

4. 241% of 100 = _____

5. 41 is _____ percent of 612.

6. 1 is _____ percent of 1000.

7. The efficiency of any device is equal to its power output divided by its power input. This can be stated as

$$\eta = \frac{P_o}{P_i} \times 100$$

where η is the efficiency, in percent; P_o is the output power, in watts; and P_i is the input power, in watts.

If the input power to the final stage of a citizens-band transmitter is 5 watts and the output power is 3 watts, the efficiency of the final stage is _____ percent.

8. Two resistors are each rated at 2200 ohms. Resistor A has a tolerance of 10% and B a tolerance of 2%. This means that the actual resistance of A will be within 10% of its rated value, and that of B within 2%.
   (a) The actual resistance of the $\pm 10\%$ resistor will lie between _____ ohms and _____ ohms.
   (b) The actual resistance of the $\pm 2\%$ resistor will lie between _____ ohms and _____ ohms.

9. The voltage regulation of a power supply is given by the formula

$$\text{regulation (reg)} = \frac{E_n - E_f}{E_f}$$

where E_n is the no-load voltage and E_f is the full-load voltage. When the no-load voltage is 150 volts and the full-load voltage is 130 volts, the regulation is _____ percent.

1. (a) 0.02;   (b) 0.17;   (c) 1.50
2. (a) 9%;   (b) 275%;   (c) 87.5%
3. 10.5 . . . 7.1% = 0.071;   0.071 × 148 = 10.5
4. 241

5. 6.70% . . . $\dfrac{41}{612} = 0.06699 = 6.70\%$

6. 0.1 . . . $\dfrac{1}{1000} = 0.001 = 0.1\%$

7. 60 . . . $\eta = \dfrac{P_o \times 100}{P_i} = \dfrac{3 \times 100}{5} = 60\%$

8. (a) 1980 (and) 2420 . . . 10% of 2200 = 220 ohms

    maximum vlaue = 2200 + 220 = 2420 ohms

    minimum value = 2200 − 220 = 1980 ohms

    (b) 2156 and 2244

9. 15.4 . . . $\text{reg} = \dfrac{E_n - E_f}{E_f} = \dfrac{150 - 130}{130} = \dfrac{20}{130} = 0.1538 = 15.4\%$

POWERS OF A NUMBER

16 THE MEANING AND USE OF POWERS OF A NUMBER . . . When a number is multiplied by itself one or more times, we call this raising the number to a certain power. For example, 4×4 indicates that 4 is being raised to its second power. Similarly, $2 \times 2 \times 2$ indicates that 2 is being raised to its third power, since three 2's are being multiplied.

To indicate that a number is being raised to a certain power, a *superscript*—a second number set next to and *above* the first number—is used. Thus, 4^2 means 4 is being raised to its second power, which is equal to $4 \times 4 = 16$. Similarly, 2^3 means 2 is being raised to its third power, which is another way of saying $2 \times 2 \times 2 = 8$.

When a number is raised to its second power, it is usually referred to as being "squared." Thus 37^2 is 37 squared, which is $37 \times 37 = 1369$. When a number is raised to its third power, it is said to be "cubed." Thus, 7^3 may be called 7 cubed, and it equals $7 \times 7 \times 7$, which is 343.

Sometimes, letter symbols are raised to certain powers. Thus,

$$E^4 = E \times E \times E \times E$$
$$R^2 = R \times R$$

Example . . . $3^4 =$ _____

Solution . . . $3^4 = 3 \times 3 \times 3 \times 3 = 81$, *ans.*

Explanation . . . The superscript tells you that the 3 should appear 4 times in the expression for multiplication.

Example . . . Given the formula $P = EI$, express P in terms of I and R only. (Hint: $E = IR$.)

Solution . . . $P = EI = (IR)I = I \times I \times R = I^2R$, ans.

Explanation . . . $P = EI$. Substituting IR for E, we get $P = (IR) \times I$, etc. To state the formula $P = I^2R$ in words, we say that power P equals current I squared, or I^2, times the resistance R.

Example . . . Given the formula $P = I^2R$, find P when I is 3 and R is 4.

Solution . . . $P = I^2R = 3^2 \times 4 = 3 \times 3 \times 4 = 36$, ans.

Powers higher than the square are rarely required in electronics, but squares are much used. Most electronic calculators have a simplified means of squaring a number, so that the number to be squared only has to be entered once. If this is not the case with your calculator, the number can be simply multiplied by itself on the machine without involving much extra work.

WHAT HAVE YOU LEARNED?

1. In the problem $12 \times 12 \times 12$, the number 12 is being raised to its third _____.

2. Solve the following:
   (a) 211^2 = _____
   (b) 6^3 = _____
   (c) 100^4 = _____
   (d) When $E = 7$, E^2 = _____
   (e) When $I = 0.524$, I^2 = _____

3. (a) $P = I^2R$. If $I = 2.63$ and $R = 12$, $P = $ _____.
   (b) $P = \dfrac{E^2}{R}$. If $E = 31.5$ and $R = 12$, $P = $ _____.

4. In the circuit in Fig. 5, a toaster, a lamp, and a resistor are connected across a voltage source. The resistance of each unit and the current drawn by each unit are marked. Using the formula $P = I^2R$, where I is in amperes and R is in ohms, find the power used by each of the three devices.

    (a) Power P_1 used by the resistor = _____ watts.

    (b) Power P_2 used by the lamp = _____ watts.

    (c) Power P_3 used by the toaster = _____ watts.

    (d) Total power P used by all three elements = _____ watts.
       (Hint: $P = P_1 + P_2 + P_3$.)
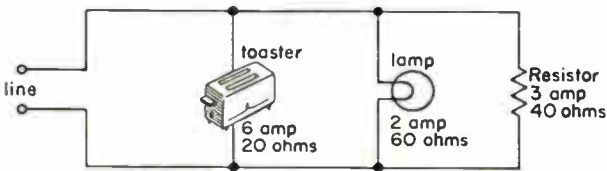
Fig. 5

ANSWERS

1. Power
2. (a) 44,521 . . . $211^2 = 211 \times 211 = 44,521$
   (b) 216 . . . $6 \times 6 \times 6 = 216$
   (c) 100,000,000 . . . $100^4 = 100 \times 100 \times 100 \times 100 = 100,000,000$
   (d) 49 . . . $E^2 = 7 \times 7 = 49$ (e) 0.275
3. (a) 83.0 . . . $P = I^2R = I \times I \times R = 2.63 \times 2.63 \times 12 = 83.0$

   (b) 82.7 . . . $P = \dfrac{E^2}{R} = \dfrac{31.5 \times 31.5}{12} = 82.7$
4. (a) 360 . . . $P_1 = I^2R_1 = 3 \times 3 \times 40 = 360$ watts
   (b) 240;
   (c) 720
   (d) 1320 . . . $P = P_1 + P_2 + P_3 = 360 + 240 + 720 = 1320$ watts

17 WORKING PROBLEMS IN THE PROPER ORDER . . . When a number of different steps are involved in working a problem, you must make sure that you do the steps in the correct order. The thing to remember is that *multiplications must be done first*, before any adding or subtracting is done.

Example . . . $2 + 3 \times 4 + 5 = $ _____.

Solution . . . $2 + 3 \times 4 + 5 = $
              $2 + 12 + 5 = 19$, *ans.*

Explanation . . . First multiply the 3 by the 4, and then add. Note that you would get the wrong answer if you did one or both of the additions first.

Example . . . Find K in the formula below if $R_1 = 0.2$ and $R_2 = 20$.

$$K = \frac{2 + R_1R_2}{R_2 - 12}$$

Solution . . . $K = \dfrac{2 + 0.2 \times 20}{20 - 12}$ (1)

$$= \frac{2 + 4}{20 - 12}$$ (2)

$$K = \frac{\overset{3}{6}}{\underset{4}{8}} = \frac{3}{4} \text{ , } ans.$$ (3)

Explanation . . . After the given values are substituted in the formula, the multiplication is done as shown in step 2. No cancellation can be done until both the numerator and denominator are free of plus and minus signs—something you never want to forget. Therefore, after step 2 is completed, the values in the numerator are added, and the values in the denominator subtraced, as indicated. Since the resulting value (8) is free of plus and minus signs, cancellation can now be done.

Now let's look at the problem $20 - 6 + 4$. Since there are no multiplication signs, you can work the problem in any order you want—but keep on your toes. Notice that the minus sign is in front of the 6, and *only* the 6, is to be subtracted. Don't make the mistake of subtracting $6 + 4$ from the 20, which would give the wrong answer of 10. Since $20 - 6$ is 14 and $14 + 4$ is 18, the correct answer is 18. Another way to add the 20 and the 4, to give 24, and then subtract the 6 to give 18.

If a problem has parentheses, the rule to remember is that the part of the problem within the parentheses should be worked first. After this is done, follow the working order explained above. For example, to find the value of $20 - (6 + 4)$, first add the 6 and 4 in parentheses. The problem then becomes $20 - 10$, which equals 10, the answer.

Example . . . Find K in the formula below if $R_1 = 3$ and $R_2 = 5$.
$$K = 2 + R_1R_2 + (2 + R_1)R_2$$

Solution . . . $K = 2 + 3 \times 5 + (2 + 3)5$
Working the part in parentheses first, $K = 2 + 3 \times 5 + 5 \times 5$
Doing the multiplications next, $K = 2 + 15 + 25 = 42$, *ans.*

1. Find the value of the expression $4 \times 10 + 15 - 18 \times 2$.
2. Find the value of the fraction $\dfrac{4 + 8 \times 7 - 4}{6 - 2}$.
3. What is the value of $(8 + 3) \times 4$?
4. Find the value of the fraction $\dfrac{64 \, (3 + 4 \times 2)}{4 \times 2}$.

ANSWERS

1. 19 . . . Perform the multiplication first: $4 \times 10 + 15 - 18 \times 2 = 40 + 15 - 36$. Now do the addition and subtraction as indicated, $55 - 36 = 19$, *ans.*

2. 14 . . . The numerator of the fraction is the expression $4 + 8 \times 7 - 4$. The denominator is $6 - 2$. Before you try to divide, you should find a single number to be used as the dividend and another as a divisor. $4 + 8 \times 7 - 4 = 4 + 56 - 4 = 56$. $6 - 2 = 4$ $56/4 = 14$, *ans.*

3. 44 . . . Since the problem includes a parenthesis, that part should be worked first $(8 + 3) = 11$. So $11 \times 4 = 44$, *ans.*

4. 88 . . . To find the value of the numerator, first replace the parenthesis and the number and signs inside the parentheses by a single number. Here are the steps for finding this number: $4 \times 2 = 8$ and $3 + 8 = 11$. The value of the numerator is $64(3 + 4 \times 2) = 64 \times 11 = 704$. Since the denominator is the product of 4 and 2, or 8, the given expression becomes $704/8 = 88$, *ans.*

18 SUMMARY PROBLEMS TO INCREASE YOUR SKILLS . . . The basic principles involved in working with formulas have been covered. The problems that follow will give you additional practice with the principles most often missed by students.

WHAT HAVE YOU LEARNED?

1. Fill in the blanks:
   (a) There are 1,000 milliamperes in one ampere. Therefore to convert amperes to milliamperes, you would multiply by _____, and to convert milliamperes to amperes you would multiply by _____.
   (As an example, 50 amperes is equal to _____ mA, and 50 mA is equal to _____ amperes.)
   (b) There are 1000 millivolts in one volt. Therefore, 400 millivolts is equal to _____ volts, and 1.6 volts is equal to _____ mV.
   (c) There are 1000 ohms in one kilohm. Therefore, 0.28 ohms is equal to _____ kilohms, and 0.28 kilohms is equal to _____ ohms.

2. In the formula $t = \dfrac{L}{R}$, where t is the time (in seconds), L is the inductance (in henrys), and R is the resistance (in ohms), what is the value of t (in minutes) if L is 320 millihenrys (there are 1000 millihenrys in a henry), and R is 0.004 kilohms?

3. A parallel circuit has two branches. 16.4 amperes flows in one branch and 85 milliamperes in the other. What is the exact total current? (It would be the sum of the two branch currents.)

4. Given the formula $Q = \dfrac{G}{3 + hR}$, find the value of Q if h is equal to $\dfrac{1}{5}$, R is equal to 20, and G is equal to 60.

5. What is the area in square inches of a square that is 0.3 ft on each side? (There are 144 square inches in a square foot.)

6. One formula for circuit power is $P = \dfrac{E^2}{R}$, where P is the power (in watts), E is the voltage (in volts), and R is the resistance (in ohms). If the voltage is 6 volts and the resistance 3 kilohms, what is the power (in milliwatts)?

ANSWERS

1. (a) 1000; 0.001; 50,000; 0.05 . . . Compare with problems 2 and 3 on page 22.
   (b) 0.4 volts; 1600 mV
   (c) 0.00028 kilohms; 280 ohms
2. 0.00133 minutes . . . You must always remember when using formulas to change the given units to the units required by the formula. 320 millihenrys = 0.32 henrys, and 0.004 kilohms equal 4 ohms. Hence, $t = \dfrac{L}{R} = \dfrac{0.32}{4} = 0.08$ seconds. Notice that the information with the formula says that t will be in seconds. Since the question asks for the answer in minutes, $\dfrac{0.08}{60} = 0.00133$, the time in minutes.
3. 16.485 amperes . . . Notice that one value is given in amperes and the other in milliamperes. You can add values only if they are in the same units. 85 mA = 0.085 amperes. 16.4 + 0.085 = 16.485 amperes, the answer.

4. 8.57 . . . $Q = \dfrac{G}{3 + hR}$

$$= \dfrac{60}{3 + \dfrac{1}{5} \times 20}$$

$$= \dfrac{60}{3 + 4}$$

$$= \dfrac{60}{7}$$

$$Q = 8.57$$

You must remember: (1) you can't cancel as long as there is a + sign in either the numerator or the denominator (see Topic 4). Hence, you can't cancel the 3 into the 60. (2) When you have both + and × signs in the denominator (or the numerator), you must multiply before you add (see Topic 17).

5. 12.96 sq in . . . $0.3^2 = 0.3 \times 0.3 = 0.09$ sq ft. Changing to square inches, $0.09 \times 144 = 12.96$ sq in.

6. 12 milliwatts . . . First of all you must change kilohms to ohms, since the formula says that R must be in ohms. 3 kilohms = 3000 ohms.

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

$$= \frac{6^2}{3000}$$

$$= \frac{36}{3000}$$

$P = 0.012$ watts

Now 0.012 watts must be changed to milliwatts: 0.012 watts = 12 milliwatts.

LESSON 2101B-9
RECIPROCAL PERCENTAGE, AND POWERS OF NUMBERS

EXAMINATION

Each examination question is followed by a number of selections. Circle the number in front of the correct selection for each question. When you have finished, transfer your answers to the Answer Sheet provided. Then use the special envelope provided to mail the examination to the school as soon as it is completed.

1. For most of the practical problems you will encounter in electronics, your answers should be accurate
   (1) to three decimal places.
   (2) to three digits.
   (3) to three significant figures.
   (4) to three percent.

2. In which of the statements below is the second value given incorrectly rounding off to three significant figures?
   (1) 319473 rounds off to 319000
   (2) 0.00053274 rounds off to 0.00053
   (3) 40.297643 rounds off to 40.3
   (4) 3.14159 rounds off to 3.14

3. What is 0.3 squared?
   (1) 9   (2) 0.9   (3) 0.09   (4) 0.33

4. What is the square of 0.02?

    (1) 0.04   (2) 0.4   (3) 0.004   (4) 0.0004   (5) 0.022

5. You are given the formula

$$D = V \times T$$

where D is the total distance travelled by a projectile

       V is the velocity of the projectile

       T is the time it took to travel the distance D

If V = 24 feet per second and T = 30 milliseconds, how many inches did the projectile travel?

(1) 7200 inches

(2) 7.2 inches

(3) 8.64 inches

(4) 600 inches

6. What is the value of 0.000439×73.2 rounded off to three significant figures?

(1) 0.0000321

(2) 0.000321

(3) 0.00321

(4) 0.0321

(5) 0.321

(6) 3.21

7. If you divide 3 by 4, you get the decimal 0.75. Changed to percentage, the decimal 0.75 is equal to

    (1) 0.75 percent   (2) 75 percent   (3) 0.0075 percent   (4) 7.5 percent

8. The conductance of a circuit, in siemens (S), is equal to the reciprocal of the circuit resistance, in ohms. If the circuit has a resistance of 300 ohms, what is the circuit conductance?

    (1) 0.000333 S   (2) 333 S   (3) 0.00333 S   (4) 0.0333 S

    (5) 0.333 S

9. What is the value of $30 - 6 + 4$?

(1) 28

(2) 20

(3) Both 20 and 28 are correct answers, depending upon how the problem is worked.

10. The formula for finding the total capacitance of five capacitors in series is

$$C = \cfrac{1}{\dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3} + \dfrac{1}{C_4} + \dfrac{1}{C_5}}$$

What is the combined series capacitance, C, if $C_1 = 2$ pF (picofarads); C_2
= 3 pF; $C_3 = 4$ pF; $C_4 = 5$ pF; and $C_5 = 6$ pF.
(1) 20 pF   (2) 0.690 pF   (3) 0.05 pF   (4) 1.45 pF

END OF EXAM
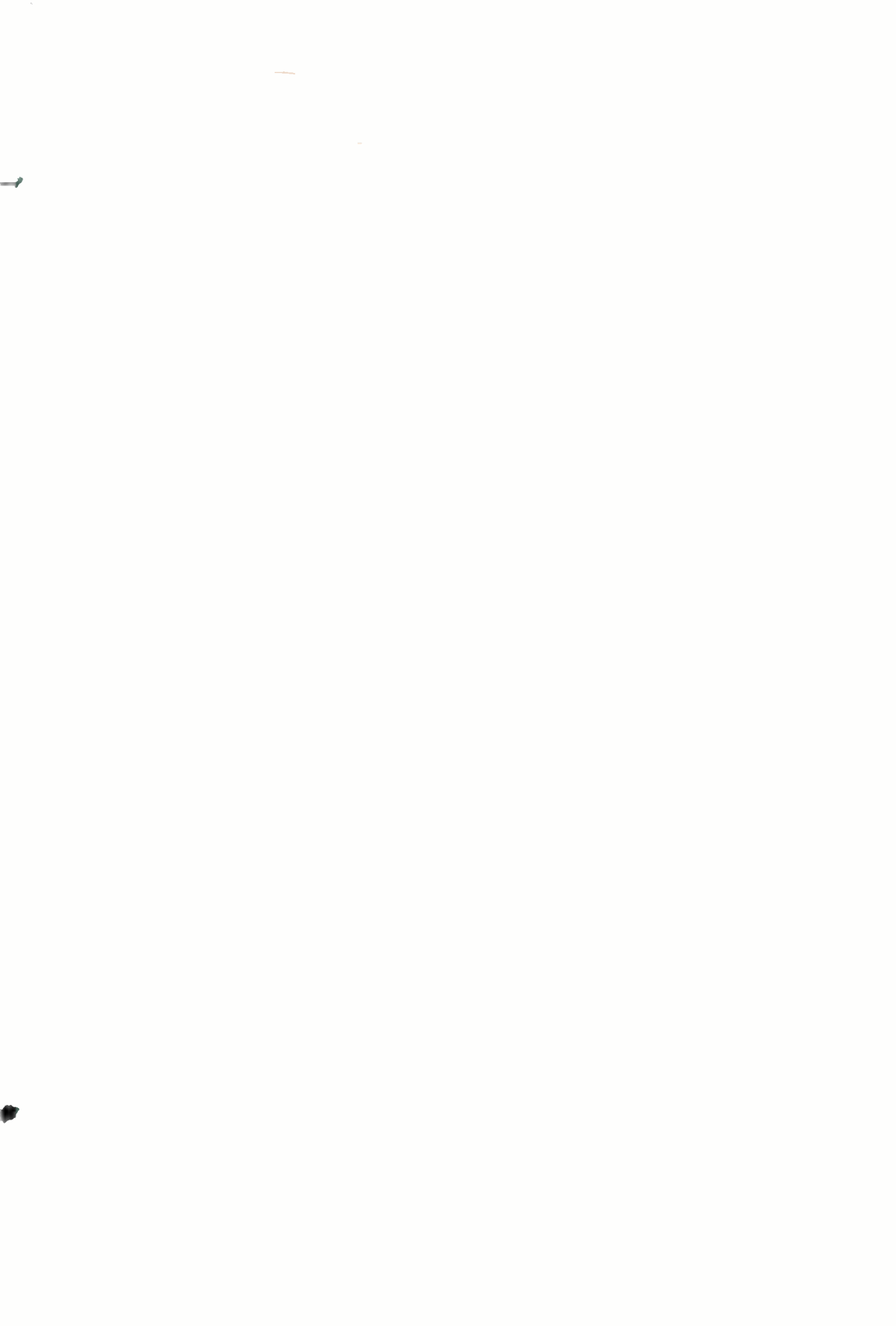
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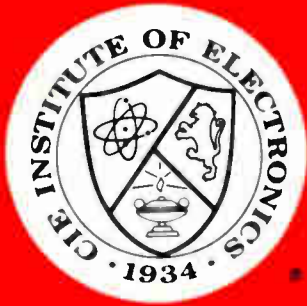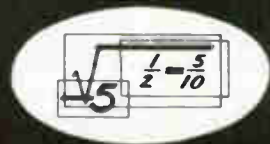
electronics

Lesson 2102A-2
Roots of Numbers, Ratio and Proportion

Lesson 2102B-2
Inverse Proportion and Negative Numbers

AUTO-PROGRAMMED*Lessons

ABOUT THE AUTHOR

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Frontispiece: *Solar calculator courtesy of Sharp.*

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Lesson 2102A-2
Roots of Numbers, Ratio and Proportion

Lesson 2102B-2
Inverse Proportion and Negative Numbers

By BERNARD D. ROSS
Technical Staff

A Chat with Your Instructor

In this volume you will study square roots, the use of square roots in formulas, the properties of a right triangle, ratios and proportions, how negative numbers are used in electronics, and how to sum up voltages around a series circuit or loop.

This is a wide-ranging assignment, but we have it divided into two easy lessons so that it will be easy to learn.

As explained in the topic on square roots, never forget the importance of first pointing off a number into periods, starting at the decimal point. This is such a simple operation that many beginning students think it is unnecessary. As a result, failing to point off a number into periods is the most common cause of error in extracting the square root.

Pay particular attention to topics on ratio and proportion. No other subject in mathematics will be of as much help to you in understanding electronics. Almost every lesson in this course and almost every article on electronics that you will read will make some reference to a ratio or proportion.

The topics in this volume have been carefully selected to cover the facts you will need to know in order to handle practical problems in electronics. Hence, it is worthwhile to study.

Make regular study a habit. It will make learning easier and will help you retain what you have already learned.

Lesson 2102A-1
Roots of Numbers,
Ratio and Proportion

ROOTS

1 THE MEANING OF ROOTS . . . The *square root* of a number is the value which, when raised to the second power, will give that number. Thus, the square root of 64 is 8, because $8^2 = 8 \times 8 = 64$.

The symbol for finding a square root is the radical sign, $\sqrt{}$. For example, $\sqrt{64}$ means "the square root of 64."

The *cube root* of a number is the value which, when raised to the third power, will give that number. Thus, the cube root of 8 is 2, because $2^3 = 2 \times 2 \times 2 = 8$.

The symbol for finding a cube root is the radical sign with a small 3 placed at the upper left. For example, $\sqrt[3]{8}$ means "the cube root of 8."

Roots greater than the cube root are indicated by using a higher number by the radical sign. Thus, $\sqrt[5]{32}$ means "the fifth root of 32," which is 2 because $2^5 = 2 \times 2 \times 2 \times 2 \times 2 = 32$.

WHAT HAVE YOU LEARNED?

1. $\sqrt{4} = \underline{2}$

2. $\sqrt{25} = \underline{5}$

3. $\sqrt{81} = \underline{9}$

4. $\sqrt{144} = \underline{12}$

5. $\sqrt{1} = \underline{1}$

6. $\sqrt{0} = \underline{0}$

7. $\sqrt[3]{27} = \underline{3}$

8. $\sqrt[4]{16} = \underline{2}$

9. $\sqrt{36} + \sqrt{49} = \underline{13}$

10. $\sqrt{9 + 16} = \underline{5}$

11. If 10 kW (kilowatts) of power are supplied to a DC circuit and the resistance of the circuit is 100 ohms, the current flow is _____10_____ amperes. (Hint: $I = \sqrt{\dfrac{P}{R}}$, where I is in amperes, P is in watts, and R is in ohms.)

$$\frac{10,000}{100} = 100 \quad \sqrt{100} = 10$$

1. 2   2. 5   3. 9   4. 12   5. 1   6. 0   7. 3   8. 2
9. 13 . . . $\sqrt{36} + \sqrt{49} = 6 + 7 = 13$
10. 5 . . . $\sqrt{9 + 16} = \sqrt{25} = 5$
11. 10 . . . $I = \sqrt{\dfrac{P}{R}} = \sqrt{\dfrac{10 \times 1000}{100}} = \sqrt{100} = 10$

2 INTRODUCTION TO SQUARE ROOTS . . . You found some square roots in the last topic simply by inspection. This is only possible for values that have small whole-number roots. You likely learned in school an arithmetic method of extracting the square root. Because this method is complicated and laborious, it is not much used any more, and we will not teach it here. We will quite soon in this lesson introduce you to more modern and much simpler ways of extracting the square root. But there are a few introductory items to take up first.

The first thing to note is that the decimal point position makes a surprising difference in square root problems. For example, the square root of 25 is 5, but the square root of 2.5 is 1.581. Similarly, the square root of 0.01 is 0.1, but the square root of 0.1 is 0.3162. You should verify these values, which may astonish you, by squaring 1.581 and 0.3162. You won't come up with exactly 2.5 and 0.1 because the square root values 1.581 and 0.3162 are only correct to the four significant figures shown; they are not exact. If you use a calculator to square numbers, be sure to read the instruction manual for the calculator. You will likely find that there is a short cut method for squaring a number on your calculator.

We want to emphasize that before you take the square root of a number, you must have the decimal point of the number in the right place. If you don't, you may come up with a root that bears no resemblance to the true square root.

Because extracting the square root so heavily involves the decimal point, we now come to a matter of essential importance in square root work, separating numbers into periods. Failure to do this is the most frequent mistake made by students in extracting square roots.

3 SEPARATING NUMBERS INTO PERIODS . . . It is frequently necessary to point off numbers into *periods* of two figures each before you can find the square root. To point off into periods, you *always start at the decimal point*, going out to both the right and left.

Example . . . Point off the number 24,656.213.

Solution . . . 2'46'56.21'30

Explanation . . . You can rapidly point off periods by inserting marks after each period, 2'46'56.21'30, *starting from the decimal point* and going to both left and right. Notice that a zero has been added at the end of the number to complete the second period to the right of the decimal point. Notice also that the comma used to point off a number in thousands is *not* used when a number is pointed off into periods.

For every period in the number, there will be one digit in the root. The root of 2'46'56.21'30, for example, is 157.02. This has three digits in front of the decimal point and two digits following to correspond to the three periods in front of the decimal point in the number and the two periods following.

To see the importance of pointing off into periods, let's consider two problems, $\sqrt{25,000}$ and $\sqrt{250,000}$. Point off these two numbers into periods, we obtain 2'50'00 and 25'00'00. Since no decimal point is shown in these numbers, the decimal point is at the end, so that is where we started for pointing off. The first period is 2 for the first number, and 25 for the second number. Because these first periods are different, the figures in the root will be different. $\sqrt{25,000} = $ 158.1 while $\sqrt{250,000} = 500$. Since both numbers have three periods in front of the decimal point, both roots will have three digits in front of the decimal point. *Each period in pointing off represents one digit in the square root.*

As another example to show the significance of pointing off into periods, consider these two problems: $\sqrt{0.000,000,25}$ and $\sqrt{0.000,002,5}$ (such small numbers are common in electronics). Pointing off into periods: 0.00'00'00'25 and 0.00'00'02'50. The first significant period (that is, the first period that is not all zeros) is 25 for the first number and 2 for the second. Because these first periods are different, the figures in the roots will be different. $\sqrt{0.000,000,25} = 0.0005$, while $\sqrt{0.00'00'02'5} = 0.001581$. Since the first number has three periods of zeros before the first significant period (the first period that is not all zeros), the root will have three zeros (one for each period) ahead of the first significant digit. The second number has two periods that are all zeros, and therefore there are two zeros in the root ahead of the first significant digit.

We show below in graphic form the relationship between periods and roots. Notice that the digits of the roots can have only two sets of values, 5 when the first significant period is 25, and 1581 when the first significant period is 2. That there are only two possible sets of digital values is always the case in extracting the square root.

Relationship between periods and roots

Number	2'50'00.00	0.25'
Root	1 5 8 1	0 5
Number	25'00.	0.02'50'00'00
Root	5 0	0 1 5 8 1
Number	2'50.00'00	0.00'25
Root	1 5 8 1	0 0 5
Number	25	0.00'02'50'00'00
Root	5	0 0 1 5 8 1
Number	2.50'00'00	0.00'00'25
Root	1 5 8 1	0 0 0 5

WHAT HAVE YOU LEARNED?

1. Separate into periods as required for extracting the square root:
   (a) 364,871.10   *36 48 71,10*   *(3)*
   (b) 65,000.2140   *6 50 00 . 21 40*   *(3)*
   (c) 87,823   *8 78 23 (3)*
   (d) 421.70   *4 21 .70 (2)*

2. For each of the numbers in question 1, state how many digits there will be in front of the decimal point in the root.

3. Separate into periods as required for extracting the square root:
   (a) 0.000,471,3   *0.00 04 71 30*   *0.00 47 13*
   (b) 0.000,000,5   *0. 00 00 00 50*
   (c) 0.08   *0.08*
   (d) 0.006   *0. 00 60*

4. For the numbers in Problem 3, state how many zeros should be placed between the decimal point and the first significant figure of the square root.
   (a) one   *(d) one*
   (b) Three
   (c) None   ANSWERS

1. (a) 36'48'71.10'
   (b) 6'50'00.21'40
   (c) 8'78'23
   (d) 4'21.70
2. For additional clarification, we follow the answers with the square roots of the numbers. You will not be asked to extract these roots until you have completed Topic 4.
   (a) Three . . . 604.04
   (b) Three . . . 254.95
   (c) Three . . . 296.35
   (d) Two . . . 20.535
3. (a) 0.00'04'71'30
   (b) 0.00'00'00'50
   (c) 0.08'
   (d) 0.00'60
4. The answers are followed by the square roots.
   (a) One . . . 0.021709
   (b) Three . . . 0.000,707,11
   (c) Zero . . . 0.28284
   (d) One . . . 0.07746

4 EXTRACTING SQUARE ROOTS . . . The easiest way to extract the square root of a number is to use an electronic calculator. Many calculators—even some of the cheapest ones—have a square root key. With such a calculator you just punch in the number, press the square root sign, and you then have the square root displayed. Nothing could be simpler.

If your calculator does not have a square root key, it can still be used to quickly extract the square root. Appendix A in the back of this lesson shows you how to do it.

If you don't have a calculator, you can use tables to extract the square root. Appendix B will show you how to do it. The tables will give answers accurate enough for nearly all requirements in electronics. Tables of logarithms can also be used to extract the square root, but a calculator is best and should be used if you have one. Otherwise use the square root tables.

You may use any method you prefer for finding the square root for the purpose of this course.

Remember to always check your answer! If you find $12 = \sqrt{144}$, then 12 times 12 must equal 144.

WHAT HAVE YOU LEARNED?

Extract the following square roots, using the method of your choice. Although we give answers to many significant figures for the benefit of those using a calculator with a square root key, such a high degree of accuracy is not needed. Answers accurate to three or four significant figures are all that are needed.

1. $\sqrt{93,421}$ 9. $\sqrt{0.00025}$ 17. $\sqrt{10}$

2. $\sqrt{0.000014}$ 10. $\sqrt{2}$ 18. $\sqrt{100}$

3. $\sqrt{12,251}$ 11. $\sqrt{20}$ 19. $\sqrt{1000}$

4. $\sqrt{7574}$ 12. $\sqrt{0.0000004}$ 20. $\sqrt{4.5}$

5. $\sqrt{757.4}$ 13. $\sqrt{64,000,000}$ 21. $\sqrt{50}$

6. $\sqrt{25}$ 14. $\sqrt{6,400,000}$ 22. $\sqrt{802}$

7. $\sqrt{2.5}$ 15. $\sqrt{3.811}$ 23. $\sqrt{0.000001}$

8. $\sqrt{0.25}$ 16. $\sqrt{0.6369}$

24. Verify the square roots given in the answers for Topic 3.

1. 305.648   Check: $(305.648)^2 = 93,420.7$
2. 0.00374
3. 110.684
4. 87.0287
5. 27.5209
6. 5
7. 1.58114
8. 0.5
9. 0.01581
10. 1.41421
11. 4.47214
12. 0.00063246
13. 8000
14. 2529.82
15. 1.952
16. 0.79806
17. 3.16228
18. 10
19. 31.6228
20. 2.1213
21. 7.07107
22. 28.3196
23. 0.001

5 SOLVING FORMULAS CONTAINING ROOTS . . . When a root appears as a term in a problem, *first find the root* and then solve the problem in the usual way.

Example . . . $6 + \sqrt{3^2 + 4^2} =$ _____

Solution . . . $6 + \sqrt{3^2 + 4^2} = 6 + \sqrt{9 + 16}$
$$= 6 + \sqrt{25} = 6 + 5 = 11, \text{ ans.}$$

WHAT HAVE YOU LEARNED?

1. In the formula $K = \dfrac{M}{\sqrt{L_p L_s}}$ if $M = 20$, $L_p = 10$, and $L_s = 30$, $K =$ _____1.16_____ .

    $10 \times 30k = \sqrt{300}\,K = \frac{20}{17.3} = 1.16$

2. In the formula $Z = \sqrt{R^2 + (X_L - X_C)^2}$, if $R = 5$, $X_L = 16$, and $X_C = 9$, $Z =$ __8.60__ .

    $\sqrt{25 + 16 - 9} = 5 + 4 - 3^2 = 6$
    $25 + 7^2 \sqrt{74} =$

3. In the formula $f = \dfrac{1}{2\pi\sqrt{LC}}$, if $L = 10$ and $C = 0.002$, $f =$ _____ .

(Note: π, the Greek letter pi, is a value that indicates the relationship between the diameter of a circle and its circumference, and it is approximately equal to 3.1416. Memorize this value. For most practical calculations, though, 3.14 may be used as the value of π.)

4. In the formula $I = \sqrt{\dfrac{P}{R}}$, if $P = 21$ and $R = 0.7$, $I =$ _____.

5. An electric iron which has a resistance of 60 ohms draws 1.5 kW of power. Current flow through the iron is _____ amperes.

(Hint: Use the formula $I = \sqrt{\dfrac{P}{R}}$, where I is in amperes, P is in watts, and R is in ohms.)

6. If a resistor is marked 10,000 ohms, 100 watts, it can carry _____ amperes.

ANSWERS

1. 1.16 . . . $K = \dfrac{M}{\sqrt{L_p L_s}} = \dfrac{20}{\sqrt{10 \times 30}} = \dfrac{20}{\sqrt{300}} = \dfrac{20}{17.3} = 1.16$

2. 8.60 . . . $Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{5^2 + (16 - 9)^2} = \sqrt{25 + 7^2} = \sqrt{25 + 49}$
$= \sqrt{74} = 8.60$

3. 1.13 . . . $f = \dfrac{1}{2\pi \sqrt{LC}} = \dfrac{1}{2 \times 3.14 \sqrt{10 \times 0.002}} = \dfrac{1}{6.28 \sqrt{0.02}}$
$= \dfrac{1}{6.28 \times 0.141} = \dfrac{1}{0.885} = 1.13$

4. 5.48 . . . $I = \sqrt{\dfrac{P}{R}} = \sqrt{\dfrac{21}{0.7}} = \sqrt{30} = 5.48$

5. 5 . . . 1.5kW $= 1500$ watts. Then
$I = \sqrt{\dfrac{P}{R}} = \sqrt{\dfrac{1500}{60}} = \sqrt{25} = 5$ A

6. 0.1 . . . $I = \sqrt{\dfrac{P}{R}} = \sqrt{\dfrac{100}{10,000}} = \sqrt{\dfrac{1}{100}} = \dfrac{1}{10} = 0.1$ A

6 THE RIGHT TRIANGLE . . . The triangle in Fig. 1 is called a *right triangle* because one of its sides, a (the line extending between points B and C), is perpendicular to one of the other sides, b (the line extending between points A and C). That is, side b is "square" to side a. The angle at C is 90° and is called a *right angle*.
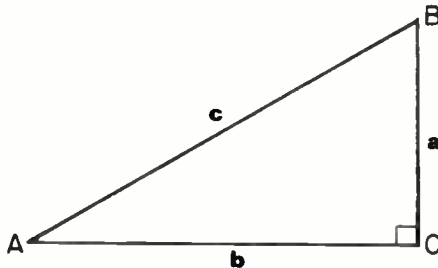
Fig. 1   A right triangle

10 The longest side of a right triangle is called its *hypotenuse.* The hypotenuse is always opposite the right angle. The other two sides are called the *legs.* In Fig. 1, *c* is the hypotenuse and *b* and *a* are the legs.

WHAT HAVE YOU LEARNED?

1. A right angle contains __90__ degrees.

2. There are __2__ legs in a right triangle.

3. The hypotenuse is always located opposite the __right__ angle.

ANSWERS

1. 90   2. 2   3. right

7 FINDING THE HYPOTENUSE . . . In practical electronics problems it is often necessary to find the length of the hypotenuse when the lengths of the other two sides of the triangle are known.

Rule . . . *The hypotenuse of a right triangle is equal to the square root of the sum of the squares of the other two sides,* or

$$c = \sqrt{b^2 + a^2}$$

where *c*, *b*, and *a* are all sides of the triangle as shown in Fig. 1.

Example . . . In Fig. 1, if *a* = 32 and *b* = 21, *c* = _____.

Solution . . . $c = \sqrt{21^2 + 32^2}$
$= \sqrt{441 + 1024}$
$= \sqrt{1465} = 38.3$, *ans.*

Right angles find much use in electronics calculations as applied to AC circuits. A typical circuit with resistance *R*, reactance *X*, and impedance *Z* and its representation by a right triangle are shown in Fig. 2.
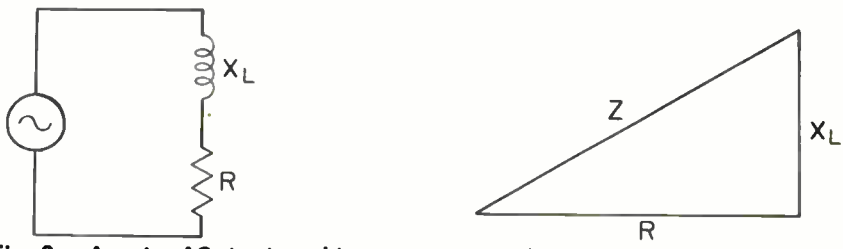
Fig. 2   A series AC circuit and its representation by a right triangle.

Example . . . In the formula $Z = \sqrt{X^2 + R^2}$, if $X = 120$ ohms and $R = 160$ ohms, $Z =$ _____ ohms.

Solution . . . $Z = \sqrt{X^2 + R^2} = \sqrt{120^2 + 160^2}$
$= \sqrt{14,400 + 25,600} = \sqrt{40,000}$
$= 200$ ohms, *ans.*

WHAT HAVE YOU LEARNED?

1. In Fig. 1, if $a = 2.1$ and $b = 1.69$, $c =$ _____. $\dfrac{2.1 + 1.69 = 3.79^2}{\sqrt{14.30}}$

2. If a room is 12 ft wide and 20 ft long, the distance between opposite corners of the room is _____ feet.

3. An AC circuit consisting of a resistor and a capacitor in parallel is shown in Fig. 3. The total current flow I_T is equal to the hypotenuse of a right triangle in which the current through the resistor I_R is equal to one leg and the current through the capacitor I_C is equal to the other leg. If $I_C = 12$ A and $I_R = 15$ A, $I_T =$ _____ amperes.

Fig. 3

4. A series AC circuit consists of an inductor and a resistor, as shown in Fig. 2. If $X_L = 25$ ohms and $R = 35$ ohms, $Z =$ _____ ohms.

ANSWERS

1. 2.70
2. 23.3 . . . $\sqrt{12^2 + 20^2} = \sqrt{144 + 400} = \sqrt{544} = 23.3$ ft
3. 19.2 . . . $I_T = \sqrt{12^2 + 15^2} = \sqrt{144 + 225} = \sqrt{369} = 19.2$ A
4. 43.0 ohms

8 MEANING OF A RATIO . . . Two quantities may be compared by dividing the magnitude of the first quantity by the magnitude of the second. The quotient obtained is called the *ratio* of the two quantities. Thus, the ratio of 8 amp to 4 amp is $\frac{8}{4}$, or 2, while the ratio of 4 amp to 8 amp is $\frac{4}{8}$, or 0.5.

If the voltage in one part of a circuit is 30 volts and the voltage in another part is 20 volts, how can we express the relationship between the two voltages? We can say that the ratio of the first voltage to the second voltage is 30 to 20. (This can also be written—not said—as 30:20.) In fractional form the ratio is $\frac{30}{20}$, or $\frac{3}{2}$.

It is much better to say that the ratio of the first voltage to the second voltage is 3 to 2 than to say 30 to 20, because the mind can more easily comprehend the exact relationship between the two values when smaller numbers are used. Since $\frac{30}{20} = \frac{3}{2} = 1.5$, we can say that the ratio of the first voltage to the second voltage is 1.5, which may also be expressed as 1.5 to 1 or 1.5:1.

In relating two numbers by a ratio, make sure they represent quantities that are measured *in the same units*. For example, the ratio of 6 in. to 2 ft is *not* $\frac{6}{2}$. We must first change 2 ft to 24 in., so that both quantities are in the same units. The ratio then is $\frac{6}{24} = \frac{1}{4}$, or 0.25.

WHAT HAVE YOU LEARNED?

1. (a) The ratio 21 to 7 is _____.
   (b) The ratio 7 to 21 is _____.

2. A man earns $500 a week and saves $50 each week. The ratio of his savings to earnings is _____.

3. Electrolyte for a bank of storage batteries consists of 5 qt of sulphuric acid mixed with 4 gal of water. The ratio of acid to water is _____. (Hint: 4 qt = 1 gal)

4. The ratio of the circumference of a circle to its diameter is 3.14, a value which is usually represented by the symbol π. If a circle has a diameter of 8 in., its circumference is _____ in.

5. If a circle has a circumference of 8 in., its diameter is _____.

1. (a) This ratio may be written as $\frac{21}{7}$, $\frac{3}{1}$, 3 to 1, 3:1, or 3.

   (b) $\frac{7}{21}$, $\frac{1}{3}$, 0.333, 1:3, or 1 to 3.

2. $\frac{50}{500}$, $\frac{1}{10}$, 0.1, 1:10, or 1 to 10

3. $\frac{5}{16}$, 5:16, 5 to 16, or 0.313 . . . 5 qt of acid is mixed with 4 gal of water. Both quantities must be in the same units before their ratio can be found. $4 \times 4 = 16$ qt. Therefore, the ratio of acid to water will be $\frac{5}{16}$, etc.

4. 25.1 in . . . $\frac{\text{circumference}}{\text{diameter}} = 3.14$. Therefore, the circumference must be 3.14 times the diameter, and $3.14 \times 8 = 25.1$ in.

5. 2.55 in . . . $\frac{8}{3.14} = 2.55$ in.

9 MEANING OF PROPORTION . . . The ratio of 10 to 5 is $\frac{10}{5}$, or 2, and the ratio of 8 to 4 is $\frac{8}{4}$, or 2. Therefore $\frac{10}{5} = \frac{8}{4}$, because each ratio is equal to 2. Such a statement of the equality of two ratios is called a *proportion. A proportion is an equation that states that two ratios are equal.*

The above proportion should be read, "10 is to 5 as 8 is to 4." The values 10, 5, 8, and 4 are called the *terms* of the proportion. *Every proportion has four terms.*

It is important to note that an equation of the form $I = \frac{E}{R}$ or $E = \frac{P}{I}$ can be written as $\frac{I}{1} = \frac{E}{R}$ or $\frac{E}{1} = \frac{P}{I}$, and therefore these equations may also be considered as proportions. Thus $\frac{I}{1} = \frac{E}{R}$ can be read as I is to 1 as E is to R.

WHAT HAVE YOU LEARNED?

1. A proportion is an equation stating that _____ ratios are equal.

2. There are _____ terms in a proportion.

3. The proportion $\frac{3}{10} = \frac{18}{60}$ is read _____.

4. The equation $E = \frac{P}{I}$, if considered as a proportion, is read _____

_____.

ANSWERS

1. two   2. 4   3. 3 is to 10 as 18 is to 60
4. E is to 1 as P is to I

LAW OF PROPORTION . . . In most practical problems, three of the four terms which make up a proportion are given and the fourth term must be found. To find this fourth term, we make use of the important principle that *in a proportion the cross products are equal.* The meaning of the term "cross products" is illustrated in Fig. 4.
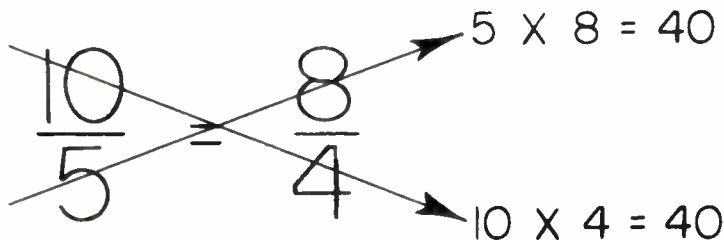
Fig. 4   In any proportion the cross products are equal.

When three terms of a proportion are known, the fourth term, or the unknown term, is represented by a symbol. If there is no standard symbol for the unknown term, the letter x is commonly used. For example, the proprtion 10 is to 5 as 8 is to *what* would be written as $\frac{10}{5} = \frac{8}{x}$.

We can find the value of the unknown term by remembering that in a proportion the cross products must be equal. In the proportion in the preceding paragraph one cross product is $5 \times 8 = 40$; therefore, the other product, $10 \times x$ must also equal 40. If x is 4, this condition will be satisfied. And we found the value 4 by dividing 40 by 10.

This leads to the following rule for finding the unknown term in a proportion.

Rule . . . To find the unknown term of a proportion, *find the cross product both terms of which are known and divide that cross product by the known value in the other cross product.*

Example . . . If $\frac{x}{11} = \frac{12}{25.3}$, $x =$ _____.

Solution . . .

$A \; 11 \times 12 = 132$

$B \; x \times 25.3 = 25.3x$

$x = \frac{132}{25.3} = 5.22$, *ans.*

Explanation . . . Both terms are known in cross product A. Their product is 132. This product is divided by the known term, 25.3, in cross product B.

In Problems 1 to 7, solve for x:

1. $\dfrac{18}{6} = \dfrac{3}{x}$

2. $\dfrac{17.5}{157.5} = \dfrac{x}{27}$

3. $\dfrac{30}{210} = \dfrac{7}{x}$

4. $\dfrac{15}{x} = \dfrac{27}{675}$

5. $\dfrac{100}{7} = \dfrac{x}{1.75}$

6. $\dfrac{x}{20} = \dfrac{30}{12}$

7. $3.25{:}4.33 = x{:}83$

8. Given the formula $E = \dfrac{P}{I}$, where E is 60 and I is 10, find the value of P.

9. Given the formula for the Q of a circuit, $Q = \dfrac{X_L}{R}$, in which X_L and R are in ohms, what value must R be to give a Q of 100 when X_L is 500 ohms?

10. In a voltage transformer, the ratio of the secondary voltage E_s to the primary voltage E_p is equal to the ratio of the number of turns on the secondary winding N_s to the number of turns on the primary winding N_p. Write this statement as a proportion.

11. A voltage transformer has 200 turns on its primary and 800 turns on its secondary. If 115 volts are applied to the primary winding of this transformer, what is the secondary voltage?

ANSWERS

1. 1 . . . $x = \dfrac{6 \times 3}{18} = 1$

2. 3   3. 49   4. 375   5. 25   6. 50

7. 62.3 . . . Before attempting to solve a proportion written in the form $A{:}B = C{:}D$, always rewrite it in the form $\dfrac{A}{B} = \dfrac{C}{D}$.

8. 600 . . . Substitute 60 for E and 10 for I in $\dfrac{E}{1} = \dfrac{P}{I}$, giving $\dfrac{60}{1} = \dfrac{P}{10}$. Then solve the proportion by cross products: $P = \dfrac{60 \times 10}{1} = 600$.

9. 5 ohms . . . By using $\dfrac{Q}{1} = \dfrac{X_L}{R}$ and substituting the given values, $\dfrac{100}{1} = \dfrac{500}{R}$. By solving the proportion for R, we have $R = \dfrac{500 \times 1}{100} = 5$.

16 10. $\dfrac{E_s}{E_p} = \dfrac{N_s}{N_p}$

11. 460 volts . . . By substituting in the proportion of Problem 10, we have

$$\dfrac{E_s}{115} = \dfrac{800}{200}$$

$$E_s = \dfrac{115 \times 800}{200} = 460 \text{ volts}$$

LESSON 2102A-1
ROOTS OF NUMBERS, RATIO, AND PROPORTION

EXAMINATION

Each examination question is followed by a number of selections. Circle the number in front of the correct selection for each question. When you have finished, transfer your answers to the Answer Sheet provided.

1. When using the square root tables, what is the most common mistake made in extracting the square root?
   (1) Confusing extracting the square root with squaring a number.
   (2) Getting the decimal point in the wrong place.
   (3) Failure to first of all, separate the number into periods of two digits each, starting at the decimal point and working out from there in each direction.

2. If the square root of 64 is 8, what is the square root of 6.4? (Don't forget to square your answer to see if it equals 6.4 as a check.)
   (1) 0.08   (2) 2.53   (3) 0.8   (4) 1.85   (5) 0.253

3. Find the square root of 27,300 to three significant figures. (Check your work.)
   (1) 165   (2) 174   (3) 510   (4) 522   (5) 529

4. With reference to ratios, which of the following statements is *not* true?
   (1) Ratios must be made between quantities measured in the same unit.

   (2) The ratio 0.2 to 1 may be written as $\dfrac{5}{1}$.

   (3) The ratio $\dfrac{6}{9}$ may be written 2:3.

   (4) By the statement "the ratio of A to B", we mean $\dfrac{A}{B}$.

5. Having worked out the value of x in a proportion, you should check your answer by seeing if
   (1) the product of the two cross products is equal to x.
   (2) one cross product divided by the other cross product gives the value of x.
   (3) the product of the numerators is equal to the product of the denominators.
   (4) the cross products are equal.

6. What is the value of y in the proportion $\frac{0.064}{4.8} = \frac{y}{0.24}$?

(Check your answer in accordance with Question 5, paying particular attention to the decimal point position.*)

(1) 0.0018   (2) 0.32   (3) 1.8   (4) 0.0032   (5) 0.18   (6) 0.018

7. The ratio of the secondary current of a transformer to the primary current is equal to the ratio of the number of turns on the primary to the number of turns on the secondary. By "ratio of the secondary current to primary current," we mean

(1) $\dfrac{\text{primary current}}{\text{secondary current}}$ (2) $\dfrac{\text{secondary current}}{\text{primary current}}$.

8. Refer to the first sentence of Question 7 and remember that a proportion is a statement that two ratios are equal. The proportion in Question 7 can be written as

(1) $\dfrac{\text{secondary current}}{\text{primary current}} = \dfrac{\text{secondary turns}}{\text{primary turns}}$.

(2) $\dfrac{\text{secondary current}}{\text{primary current}} = \dfrac{\text{primary turns}}{\text{secondary turns}}$.

9. Every proportion has
   (1) three unknown terms.   (2) four terms.   (3) three terms.
   (4) two terms.   (5) one term.

10. A vertical antenna tower is 160 ft. high. You need a wire to reach from the top of the tower to the anchor point on the ground which is 120 feet from the point where the tower rests on the ground. How long must the wire be?
   (1) 184.2 ft.   (2) 200 ft.   (3) 244.6 ft.   (4) 172.4 ft.

END OF EXAM

*Your answer may vary slightly from ours, depending upon how you rounded off. You should never be concerned about that anywhere in the course, if you use three significant figures.

EXTRACTING SQUARE ROOT ON CALCULATORS WITHOUT SQUARE ROOT KEY . . . We will find the square root of 27 to show by example how to proceed if your calculator does not have a square root key.

Step 1 . . . Make a guess as to the square root of the number, in this case an estimate of $\sqrt{27}$. Note that $5^2 = 25$, a little less than 27. Hence, we will take 5.2 as our guess of the square root. If the guess is quite a way off, it doesn't matter much—don't let it worry you.

Step 2 . . . On your calculator divide the number by its estimated square root. $27/5.2 = 5.1923$. Leave this value in the register of the calculator.

Step 3 . . . Add the square root estimate to the value that you have in the register: $5.1923 + 5.2 = 10.3923$. Leave this value in the register.

Step 4 . . . Divide the register value by 2: $10.3923/2 = 5.196$, the approximate square root.

The above value for the square root is about as accurate as you will ever need. If you want a more accurate value, just repeat the steps above, using the result in Step 4 as your new estimate of the square root. Doing this we come out with 5.196152 as the root. If your original guess as to the square root was quite a way off, it will pay you to repeat the steps that you are sure to have an answer accurate to several significant figures.

ANOTHER EXAMPLE . . . Let's find $\sqrt{2.7}$. Before you can make an intelligent guess as to the square root, you must consider the location of the decimal point. Note that $\sqrt{2.7}$ must be less than 2, because $2^2 = 4$. Let's use 1.5 as the estimate. Proceeding as previously explained, we obtain 1.65 as our first approximate root. $1.65^2 = 2.7225$. This shows that 1.65 is not a very accurate root. Hence, repeat the process using 1.65 as the estimated root. We now get 1.6432 as the estimated root. $1.6432^2 = 2.7001$. Hence, this root is quite accurate.

EXTRACTING THE SQUARE ROOT USING TABLES . . . The following examples will show how to use the square root tables. Be sure you have studied Topic 4 before you read this Appendix.

EXAMPLE 1 . . . Find $\sqrt{3.54}$

SOLUTION . . . Find 3.5 in the left vertical column of the square root table, and then move your finger horizontally to the right until you reach the column headed 4. Read 1.8815, the answer.

EXAMPLE 2 . . . Find $\sqrt{35.46}$

SOLUTION . . . Reduce 35.46 to three significant figures, which then becomes 35.5. Find 35 in the left vertical column of the square root table, and then move your finger horizontally to the right until you reach the column headed 5. Read 5.9582. This value should be reduced to three significant figures because 35.46 was reduced to three figures. Hence, 5.96, *answer*. This answer is accurate enough for most requirements in electronics.

LARGE AND SMALL NUMBERS . . . When numbers are very large or very small, it is *essential* that you first point off the number into periods of two, starting at the decimal point.

EXAMPLE 3 . . . Find $\sqrt{354000.}$

SOLUTION . . . Mark off into periods, as explained in Topic 3: 35'40'00. Think of the decimal point as being after the first period. From the table find 35.4 = 5.9498. Now the decimal point in 35.40'00 must be moved two periods to the right to get 35'40'00. Hence, move the decimal point two places to the right in 5.9498, giving 594.98, *answer*.

EXAMPLE 4 . . . Find $\sqrt{0.009}$

SOLUTION . . . Mark off into periods, as explained in Topic 3: 0.00'90. Think of the decimal point as being after the first significant period (the first period that is not all zeros). That is, consider the decimal point as being after 90. From the table, the square root of 90 is 9.4868. Now the decimal point 00'90 must be moved two periods to the left to get 0.00'90. Hence, move the decimal point two places to the left in 9.4868, giving 0.094868, *answer*.

TABLE OF SQUARE ROOTS

	0	1	2	3	4	5	6	7	8	9
1.0	1.0000	1.0050	1.0100	1.0149	1.0198	1.0247	1.0296	1.0344	1.0392	1.0440
10.	3.1623	3.1780	3.1937	3.2094	3.2249	3.2404	3.2558	3.2711	3.2863	3.3015
1.1	1.0488	1.0536	1.0583	1.0630	1.0677	1.0724	1.0770	1.0817	1.0863	1.0909
11.	3.3166	3.3317	3.3466	3.3615	3.3764	3.3912	3.4059	3.4205	3.4351	3.4496
1.2	1.0954	1.1000	1.1045	1.1091	1.1136	1.1180	1.1225	1.1269	1.1314	1.1358
12.	3.4641	3.4785	3.4928	3.5071	3.5214	3.5355	3.5496	3.5637	3.5777	3.5917
1.3	1.1402	1.1446	1.1489	1.1533	1.1576	1.1619	1.1662	1.1705	1.1747	1.1790
13.	3.6056	3.6194	3.6332	3.6469	3.6606	3.6742	3.6878	3.7014	3.7148	3.7283
1.4	1.1832	1.1874	1.1916	1.1958	1.2000	1.2042	1.2083	1.2124	1.2166	1.2207
14.	3.7417	3.7550	3.7683	3.7815	3.7947	3.8079	3.8210	3.8341	3.8471	3.8601
1.5	1.2247	1.2288	1.2329	1.2369	1.2410	1.2450	1.2490	1.2530	1.2570	1.2610
15.	3.8730	3.8859	3.8987	3.9115	3.9243	3.9370	3.9497	3.9623	3.9749	3.9875
1.6	1.2649	1.2689	1.2728	1.2767	1.2806	1.2845	1.2884	1.2923	1.2961	1.3000
16.	4.0000	4.0125	4.0249	4.0373	4.0497	4.0620	4.0743	4.0866	4.0988	4.1110
1.7	1.3038	1.3077	1.3115	1.3153	1.3191	1.3229	1.3266	1.3304	1.3342	1.3379
17.	4.1231	4.1352	4.1473	4.1593	4.1713	4.1833	4.1952	4.2071	4.2190	4.2308
1.8	1.3416	1.3454	1.3491	1.3528	1.3565	1.3601	1.3638	1.3675	1.3711	1.3748
18.	4.2426	4.2544	4.2661	4.2778	4.2895	4.3012	4.3128	4.3243	4.3359	4.3474
1.9	1.3784	1.3820	1.3856	1.3892	1.3928	1.3964	1.4000	1.4036	1.4071	1.4107
19.	4.3589	4.3704	4.3818	4.3932	4.4045	4.4159	4.4272	4.4385	4.4497	4.4609
2.0	1.4142	1.4177	1.4213	1.4248	1.4283	1.4318	1.4353	1.4387	1.4422	1.4457
20.	4.4721	4.4833	4.4944	4.5056	4.5166	4.5277	4.5387	4.5497	4.5607	4.5717
2.1	1.4491	1.4526	1.4560	1.4595	1.4629	1.4663	1.4697	1.4731	1.4765	1.4799
21.	4.5826	4.5935	4.6043	4.6152	4.6260	4.6368	4.6476	4.6583	4.6690	4.6797
2.2	1.4832	1.4866	1.4900	1.4933	1.4967	1.5000	1.5033	1.5067	1.5100	1.5133
22.	4.6904	4.7011	4.7117	4.7223	4.7329	4.7434	4.7539	4.7645	4.7749	4.7854
2.3	1.5166	1.5199	1.5232	1.5264	1.5297	1.5330	1.5362	1.5395	1.5427	1.5460
23.	4.7958	4.8062	4.8166	4.8270	4.8374	4.8477	4.8580	4.8683	4.8785	4.8883
2.4	1.5492	1.5524	1.5556	1.5588	1.5620	1.5652	1.5684	1.5716	1.5748	1.5780
24.	4.8990	4.9092	4.9193	4.9295	4.9396	4.9497	4.9598	4.9699	4.9800	4.9900

	0	1	2	3	4	5	6	7	8	9
2.5	1.5811	1.5843	1.5875	1.5906	1.5937	1.5969	1.6000	1.6031	1.6062	1.6093
25.	5.0000	5.0100	5.0200	5.0299	5.0398	5.0498	5.0596	5.0695	5.0794	5.0892
2.6	1.6125	1.6155	1.6186	1.6217	1.6248	1.6279	1.6310	1.6340	1.6371	1.6401
26.	5.0990	5.1088	5.1186	5.1284	5.1381	5.1478	5.1575	5.1672	5.1769	5.1865
2.7	1.6432	1.6462	1.6492	1.6523	1.6553	1.6583	1.6613	1.6643	1.6673	1.6703
27.	5.1962	5.2058	5.2154	5.2249	5.2345	5.2440	5.2536	5.2631	5.2726	5.2820
2.8	1.6733	1.6763	1.6793	1.6823	1.6852	1.6882	1.6912	1.6941	1.6971	1.7000
28.	5.2915	5.3009	5.3104	5.3198	5.3292	5.3385	5.3479	5.3572	5.3666	5.3759
2.9	1.7029	1.7059	1.7088	1.7117	1.7146	1.7176	1.7205	1.7234	1.7263	1.7292
29.	5.3852	5.3944	5.4037	5.4129	5.4222	5.4314	5.4406	5.4498	5.4589	5.4681
3.0	1.7321	1.7349	1.7378	1.7407	1.7436	1.7464	1.7493	1.7521	1.7550	1.7578
30.	5.4772	5.4863	5.4955	5.5045	5.5136	5.5227	5.5317	5.5408	5.5498	5.5588
3.1	1.7607	1.7635	1.7664	1.7692	1.7720	1.7748	1.7776	1.7804	1.7833	1.7861
31.	5.5678	5.5767	5.5857	5.5946	5.6036	5.6125	5.6214	5.6303	5.6391	5.6480
3.2	1.7889	1.7916	1.7944	1.7972	1.8000	1.8028	1.8055	1.8083	1.8111	1.8138
32.	5.6569	5.6657	5.6745	5.6833	5.6921	5.7009	5.7096	5.7184	5.7271	5.7359
3.3	1.8166	1.8193	1.8221	1.8248	1.8276	1.8303	1.8330	1.8358	1.8385	1.8412
33.	5.7446	5.7533	5.7619	5.7706	5.7793	5.7879	5.7966	5.8052	5.8138	5.8224
3.4	1.8439	1.8466	1.8493	1.8520	1.8547	1.8574	1.8601	1.8628	1.8655	1.8682
34.	5.8310	5.8395	5.8481	5.8566	5.8652	5.8737	5.8822	5.8907	5.8992	5.9076
3.5	1.8708	1.8735	1.8762	1.8788	1.8815	1.8841	1.8868	1.8894	1.8921	1.8947
35.	5.9161	5.9245	5.9330	5.9414	5.9498	5.9582	5.9666	5.9749	5.9833	5.9917
3.6	1.8974	1.9000	1.9026	1.9053	1.9079	1.9105	1.9131	1.9157	1.9183	1.9209
36.	6.0000	6.0083	6.0166	6.0249	6.0332	6.0415	6.0498	6.0581	6.0663	6.0745
3.7	1.9235	1.9261	1.9287	1.9313	1.9339	1.9365	1.9391	1.9416	1.9442	1.9468
37.	6.0828	6.0910	6.0992	6.1074	6.1156	6.1237	6.1319	6.1400	6.1482	6.1563
3.8	1.9494	1.9519	1.9545	1.9570	1.9596	1.9621	1.9647	1.9672	1.9698	1.9723
38.	6.1644	6.1725	6.1806	6.1887	6.1968	6.2048	6.2129	6.2209	6.2290	6.2370
3.9	1.9748	1.9774	1.9799	1.9824	1.9849	1.9875	1.9900	1.9925	1.9950	1.9975
39.	6.2450	6.2530	6.2610	6.2690	6.2769	6.2849	6.2929	6.3008	6.3087	6.3166

SQUARE ROOTS (CONTINUED)

	0	1	2	3	4	5	6	7	8	9
4.0	2.0000	2.0025	2.0050	2.0075	2.0100	2.0125	2.0149	2.0174	2.0199	2.0224
40.	6.3246	6.3325	6.3403	6.3482	6.3561	6.3640	6.3718	6.3797	6.3875	6.3953
4.1	2.0248	2.0273	2.0298	2.0322	2.0347	2.0372	2.0396	2.0421	2.0445	2.0469
41.	6.4031	6.4109	6.4187	6.4265	6.4343	6.4420	6.4498	6.4576	6.4653	6.4730
4.2	2.0494	2.0518	2.0543	2.0567	2.0591	2.0616	2.0640	2.0664	2.0688	2.0712
42.	6.4807	6.4885	6.4962	6.5038	6.5115	6.5192	6.5269	6.5345	6.5422	6.5498
4.3	2.0736	2.0761	2.0785	2.0809	2.0833	2.0857	2.0881	2.0905	2.0928	2.0952
43.	6.5574	6.5651	6.5727	6.5803	6.5879	6.5955	6.6030	6.6106	6.6182	6.6257
4.4	2.0976	2.1000	2.1024	2.1048	2.1071	2.1095	2.1119	2.1142	2.1166	2.1190
44.	6.6332	6.6408	6.6483	6.6558	6.6633	6.6708	6.6783	6.6858	6.6933	6.7007
4.5	2.1213	2.1237	2.1260	2.1284	2.1307	2.1331	2.1354	2.1378	2.1401	2.1424
45.	6.7082	6.7157	6.7231	6.7305	6.7380	6.7454	6.7528	6.7602	6.7676	6.7750
4.6	2.1448	2.1471	2.1494	2.1517	2.1541	2.1564	2.1587	2.1610	2.1633	2.1656
46.	6.7823	6.7897	6.7971	6.8044	6.8118	6.8191	6.8264	6.8337	6.8411	6.8484
4.7	2.1679	2.1703	2.1726	2.1749	2.1772	2.1794	2.1817	2.1840	2.1863	2.1886
47.	6.8557	6.8629	6.8702	6.8775	6.8848	6.8920	6.8993	6.9065	6.9138	6.9210
4.8	2.1909	2.1932	2.1954	2.1977	2.2000	2.2023	2.2045	2.2068	2.2091	2.2113
48.	6.9282	6.9354	6.9426	6.9498	6.9570	6.9642	6.9714	6.9785	6.9857	6.9929
4.9	2.2136	2.2159	2.2181	2.2204	2.2226	2.2249	2.2271	2.2293	2.2316	2.2338
49.	7.0000	7.0071	7.0143	7.0214	7.0285	7.0356	7.0427	7.0498	7.0569	7.0640
5.0	2.2361	2.2383	2.2405	2.2428	2.2450	2.2472	2.2494	2.2517	2.2539	2.2561
50.	7.0711	7.0781	7.0852	7.0922	7.0993	7.1063	7.1134	7.1204	7.1274	7.1344
5.1	2.2583	2.2605	2.2627	2.2650	2.2672	2.2694	2.2716	2.2738	2.2760	2.2782
51.	7.1414	7.1484	7.1554	7.1624	7.1694	7.1764	7.1833	7.1903	7.1972	7.2042
5.2	2.2804	2.2825	2.2847	2.2869	2.2891	2.2913	2.2935	2.2956	2.2978	2.3000
52.	7.2111	7.2180	7.2250	7.2319	7.2388	7.2457	7.2526	7.2595	7.2664	7.2732
5.3	2.3022	2.3043	2.3065	2.3087	2.3108	2.3130	2.3152	2.3173	2.3195	2.3216
53.	7.2801	7.2870	7.2938	7.3007	7.3075	7.3144	7.3212	7.3280	7.3348	7.3417
5.4	2.3238	2.3259	2.3281	2.3302	2.3324	2.3345	2.3367	2.3388	2.3409	2.3431
54.	7.3485	7.3553	7.3621	7.3689	7.3756	7.3824	7.3892	7.3959	7.4027	7.4095

	0	1	2	3	4	5	6	7	8	9
5.5	2.3452	2.3473	2.3495	2.3516	2.3537	2.3558	2.3580	2.3601	2.3622	2.3643
55.	7.4162	7.4229	7.4297	7.4364	7.4431	7.4498	7.4565	7.4632	7.4699	7.4766
5.6	2.3664	2.3685	2.3707	2.3728	2.3749	2.3770	2.3791	2.3812	2.3833	2.3854
56.	7.4833	7.4900	7.4967	7.5033	7.5100	7.5166	7.5233	7.5299	7.5366	7.5432
5.7	2.3875	2.3896	2.3917	2.3937	2.3958	2.3979	2.4000	2.4021	2.4042	2.4062
57.	7.5498	7.5565	7.5631	7.5697	7.5763	7.5829	7.5895	7.5961	7.6026	7.6092
5.8	2.4083	2.4104	2.4125	2.4145	2.4166	2.4187	2.4207	2.4228	2.4249	2.4269
58.	7.6158	7.6223	7.6289	7.6354	7.6420	7.6485	7.6551	7.6616	7.6681	7.6746
5.9	2.4290	2.4310	2.4331	2.4352	2.4372	2.4393	2.4413	2.4434	2.4454	2.4474
59.	7.6811	7.6877	7.6942	7.7006	7.7071	7.7136	7.7201	7.7266	7.7330	7.7395
6.0	2.4495	2.4515	2.4536	2.4556	2.4576	2.4597	2.4617	2.4637	2.4658	2.4678
60.	7.7460	7.7524	7.7589	7.7653	7.7717	7.7782	7.7846	7.7910	7.7974	7.8038
6.1	2.4698	2.4718	2.4739	2.4759	2.4779	2.4799	2.4819	2.4839	2.4860	2.4880
61.	7.8102	7.8166	7.8230	7.8294	7.8358	7.8422	7.8486	7.8549	7.8613	7.8677
6.2	2.4900	2.4920	2.4940	2.4960	2.4980	2.5000	2.5020	2.5040	2.5060	2.5080
62.	7.8740	7.8804	7.8867	7.8930	7.8994	7.9057	7.9120	7.9183	7.9246	7.9310
6.3	2.5100	2.5120	2.5140	2.5159	2.5179	2.5199	2.5219	2.5239	2.5259	2.5278
63.	7.9373	7.9436	7.9498	7.9561	7.9624	7.9687	7.9750	7.9812	7.9875	7.9937
6.4	2.5298	2.5318	2.5338	2.5357	2.5377	2.5397	2.5417	2.5436	2.5456	2.5475
64.	8.0000	8.0062	8.0125	8.0187	8.0250	8.0312	8.0374	8.0436	8.0498	8.0561
6.5	2.5495	2.5515	2.5534	2.5554	2.5573	2.5593	2.5612	2.5632	2.5652	2.5671
65.	8.0623	8.0685	8.0747	8.0808	8.0870	8.0932	8.0994	8.1056	8.1117	8.1179
6.6	2.5690	2.5710	2.5729	2.5749	2.5768	2.5788	2.5807	2.5826	2.5846	2.5865
66.	8.1240	8.1302	8.1363	8.1425	8.1486	8.1548	8.1609	8.1670	8.1731	8.1792
6.7	2.5884	2.5904	2.5923	2.5942	2.5962	2.5981	2.6000	2.6019	2.6038	2.6058
67.	8.1854	8.1915	8.1976	8.2037	8.2098	8.2158	8.2219	8.2280	8.2341	8.2401
6.8	2.6077	2.6096	2.6115	2.6134	2.6153	2.6173	2.6192	2.6211	2.6230	2.6249
68.	8.2462	8.2523	8.2583	8.2644	8.2704	8.2765	8.2825	8.2885	8.2946	8.3006
6.9	2.6268	2.6287	2.6306	2.6325	2.6344	2.6363	2.6382	2.6401	2.6420	2.6439
69.	8.3066	8.3126	8.3187	8.3247	8.3307	8.3367	8.3427	8.3487	8.3546	8.3606

SQUARE ROOTS (CONTINUED)

	0	1	2	3	4	5	6	7	8	9
7.0	2.6458	2.6476	2.6495	2.6514	2.6533	2.6552	2.6571	2.6589	2.6608	2.6627
70.	8.3666	8.3726	8.3785	8.3845	8.3905	8.3964	8.4024	8.4083	8.4143	8.4202
7.1	2.6646	2.6665	2.6683	2.6702	2.6721	2.6739	2.6758	2.6777	2.6796	2.6814
71.	8.4261	8.4321	8.4380	8.4439	8.4499	8.4558	8.4617	8.4676	8.4735	8.4794
7.2	2.6833	2.6851	2.6870	2.6889	2.6907	2.6926	2.6944	2.6963	2.6981	2.7000
72.	8.4853	8.4912	8.4971	8.5029	8.5088	8.5147	8.5206	8.5264	8.5323	8.5381
7.3	2.7019	2.7037	2.7055	2.7074	2.7092	2.7111	2.7129	2.7148	2.7166	2.7185
73.	8.5440	8.5499	8.5557	8.5615	8.5674	8.5732	8.5790	8.5849	8.5907	8.5965
7.4	2.7203	2.7221	2.7240	2.7258	2.7276	2.7295	2.7313	2.7331	2.7350	2.7368
74.	8.6023	8.6081	8.6139	8.6197	8.6255	8.6313	8.6371	8.6429	8.6487	8.6545
7.5	2.7386	2.7404	2.7423	2.7441	2.7459	2.7477	2.7495	2.7514	2.7532	2.7550
75.	8.6603	8.6660	8.6718	8.6776	8.6833	8.6891	8.6948	8.7006	8.7063	8.7121
7.6	2.7568	2.7586	2.7604	2.7622	2.7641	2.7659	2.7677	2.7695	2.7713	2.7731
76.	8.7178	8.7235	8.7293	8.7350	8.7407	8.7464	8.7521	8.7579	8.7636	8.7693
7.7	2.7749	2.7767	2.7785	2.7803	2.7821	2.7839	2.7857	2.7875	2.7893	2.7911
77.	8.7750	8.7807	8.7864	8.7920	8.7977	8.8034	8.8091	8.8148	8.8204	8.8261
7.8	2.7928	2.7946	2.7964	2.7982	2.8000	2.8018	2.8036	2.8054	2.8071	2.8089
78.	8.8318	8.8374	8.8431	8.8487	8.8544	8.8600	8.8657	8.8713	8.8769	8.8826
7.9	2.8107	2.8125	2.8142	2.8160	2.8178	2.8196	2.8213	2.8231	2.8249	2.8267
79.	8.8882	8.8938	8.8994	8.9051	8.9107	8.9163	8.9219	8.9275	8.9331	8.9387
8.0	2.8284	2.8302	2.8320	2.8337	2.8355	2.8373	2.8390	2.8408	2.8425	2.8443
80.	8.9443	8.9499	8.9554	8.9610	8.9666	8.9722	8.9778	8.9833	8.9889	8.9944
8.1	2.8460	2.8478	2.8496	2.8513	2.8531	2.8548	2.8566	2.8583	2.8601	2.8618
81.	9.0000	9.0056	9.0111	9.0167	9.0222	9.0277	9.0333	9.0388	9.0443	9.0499
8.2	2.8636	2.8653	2.8671	2.8688	2.8705	2.8723	2.8740	2.8758	2.8775	2.8792
82.	9.0554	9.0609	9.0664	9.0719	9.0774	9.0830	9.0885	9.0940	9.0995	9.1049
8.3	2.8810	2.8827	2.8844	2.8862	2.8879	2.8896	2.8914	2.8931	2.8948	2.8965
83.	9.1104	9.1159	9.1214	9.1269	9.1324	9.1378	9.1433	9.1488	9.1542	9.1597
8.4	2.8983	2.9000	2.9017	2.9034	2.9052	2.9069	2.9086	2.9103	2.9120	2.9138
84.	9.1652	9.1706	9.1761	9.1815	9.1869	9.1924	9.1978	9.2033	9.2087	9.2141

	0	1	2	3	4	5	6	7	8	9
8.5	2.9155	2.9172	2.9189	2.9206	2.9223	2.9240	2.9257	2.9275	2.9292	2.9309
85.	9.2195	9.2250	9.2304	9.2358	9.2412	9.2466	9.2520	9.2574	9.2628	9.2682
8.6	2.9326	2.9343	2.9360	2.9377	2.9394	2.9411	2.9428	2.9445	2.9462	2.9479
86.	9.2736	9.2790	9.2844	9.2898	9.2952	9.3005	9.3059	9.3113	9.3167	9.3220
8.7	2.9496	2.9513	2.9530	2.9547	2.9563	2.9580	2.9597	2.9614	2.9631	2.9648
87.	9.3274	9.3327	9.3381	9.3434	9.3488	9.3541	9.3595	9.3648	9.3702	9.3755
8.8	2.9665	2.9682	2.9698	2.9715	2.9732	2.9749	2.9766	2.9783	2.9799	2.9816
88.	9.3808	9.3862	9.3915	9.3968	9.4021	9.4074	9.4128	9.4181	9.4234	9.4287
8.9	2.9833	2.9850	2.9866	2.9883	2.9900	2.9917	2.9933	2.9950	2.9967	2.9983
89.	9.4340	9.4393	9.4446	9.4499	9.4552	9.4604	9.4657	9.4710	9.4763	9.4816
9.0	3.0000	3.0017	3.0033	3.0050	3.0067	3.0083	3.0100	3.0116	3.0133	3.0150
90.	9.4868	9.4921	9.4974	9.5026	9.5079	9.5131	9.5184	9.5237	9.5289	9.5341
9.1	3.0166	3.0183	3.0199	3.0216	3.0232	3.0249	3.0265	3.0282	3.0299	3.0315
91.	9.5394	9.5446	9.5499	9.5551	9.5603	9.5656	9.5708	9.5760	9.5812	9.5864
9.2	3.0332	3.0348	3.0364	3.0381	3.0397	3.0414	3.0430	3.0447	3.0463	3.0480
92.	9.5917	9.5969	9.6021	9.6073	9.6125	9.6177	9.6229	9.6281	9.6333	9.6385
9.3	3.0496	3.0512	3.0529	3.0545	3.0561	3.0578	3.0594	3.0610	3.0627	3.0643
93.	9.6437	9.6488	9.6540	9.6592	9.6644	9.6695	9.6747	9.6799	9.6850	9.6902
9.4	3.0659	3.0676	3.0692	3.0708	3.0725	3.0741	3.0757	3.0773	3.0790	3.0806
94.	9.6954	9.7005	9.7057	9.7108	9.7160	9.7211	9.7263	9.7314	9.7365	9.7417
9.5	3.0822	3.0838	3.0854	3.0871	3.0887	3.0903	3.0919	3.0935	3.0952	3.0968
95.	9.7468	9.7519	9.7570	9.7622	9.7673	9.7724	9.7775	9.7826	9.7877	9.7929
9.6	3.0984	3.1000	3.1016	3.1032	3.1048	3.1064	3.1081	3.1097	3.1113	3.1129
96.	9.7980	9.8031	9.8082	9.8133	9.8184	9.8234	9.8285	9.8336	9.8387	9.8438
9.7	3.1145	3.1161	3.1177	3.1193	3.1209	3.1225	3.1241	3.1257	3.1273	3.1289
97.	9.8489	9.8539	9.8590	9.8641	9.8691	9.8742	9.8793	9.8843	9.8894	9.8944
9.8	3.1305	3.1321	3.1337	3.1353	3.1369	3.1385	3.1401	3.1417	3.1432	3.1448
98.	9.8995	9.9045	9.9096	9.9146	9.9197	9.9247	9.9298	9.9348	9.9398	9.9448
9.9	3.1464	3.1480	3.1496	3.1512	3.1528	3.1544	3.1559	3.1575	3.1591	3.1607
99.	9.9499	9.9549	9.9599	9.9649	9.9700	9.9750	9.9800	9.9850	9.9900	9.9950

LESSON 2102B-1
INVERSE PROPORTION AND NEGATIVE NUMBERS

11 MEANING OF DIRECT PROPORTION . . . One quantity is *directly proportional* to another quantity when the ratio of any two values of the first quantity is equal to the ratio of the two corresponding values of the other quantity.

For example, in the formula $I = \dfrac{E}{R}$, let's suppose R is fixed at 10 ohms. *Then, as E increases, I increases* (see Fig. 5). Suppose first that $E = 40$ volts. We can then write

$$I_1 = \frac{E_1}{R} = \frac{40}{10} = 4 \text{ A}$$
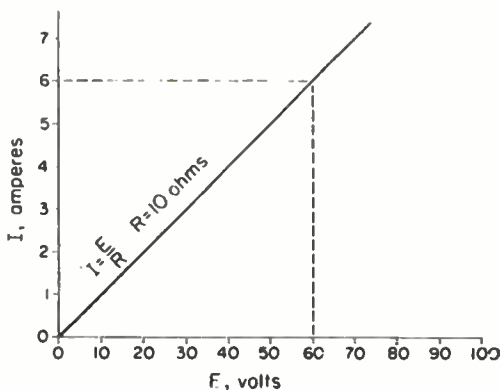
Fig. 5   Direct proportion. In the formula $I = \dfrac{E}{R}$, I is directly proportional to E: as E increases, I increases a proportional amount. The graph shows the values of I (when R is constant at 10 ohms) as E varies. For example, when E = 60 volts, I = 6 amp.

Now suppose that $E = 60$ volts, and we can write

$$I_2 = \frac{E_2}{R} = \frac{60}{10} = 6 \text{ A}$$

The ratio of the first current to the new current is

$$\frac{I_1}{I_2} = \frac{4 \text{ A}}{6 \text{ A}} = \frac{2}{3}$$

The ratio of the first voltage to the new voltage is

$$\frac{E_1}{E_2} = \frac{40 \text{ volts}}{60 \text{ volts}} = \frac{2}{3}$$

Since the ratio of the two currents is equal to the ratio of the two voltages, the current in a DC circuit, when the resistance is constant, is directly proportional to the voltage. We would write out this proportion as follows:

$$\frac{\text{first current}}{\text{second current}} = \frac{\text{first voltage}}{\text{second voltage}} = \frac{I_1}{I_2} = \frac{E_1}{E_2}$$

WHAT HAVE YOU LEARNED?

1. (a) In the equation $P = 10\ I$, P is _____ proportional to I.
   (b) As I increases, P _____.
   (c) If $I_1 = 10$, $P_1 =$ _____.
   (d) If $I_2 = 100$, $P_2 =$ _____.
   (e) $\dfrac{I_1}{I_2} =$ _____.
   (f) $\dfrac{P_1}{P_2} =$ _____.
   (g) Therefore, the ratio of values of P can be equated to the ratio of the two corresponding values of I as follows: _____ = _____.

2. The reactance of an inductor is directly proprtional to frequency. If the reactance X of a certain inductor is 100 ohms at 5 kHz, the reactance is 250 ohms at _____ kilohertz.

ANSWERS

1. (a) Directly   (b) Increases   (c) 100 . . . $P = 10 \times I = 10 \times 10 = 100$
   (d) 1000   (e) $\dfrac{1}{10}$ . . . $\dfrac{10}{100} = \dfrac{1}{10}$ (f) $\dfrac{1}{10}$ (g) $\dfrac{I_1}{I_2} = \dfrac{P_1}{P_2}$

2. 12.5 . . . $X_1 = 100$ ohms, $f_1 = 5$ kHz, $X_2 = 250$ ohms, $f_2 =$ _____ kilohertz. Then

$$\frac{X_1}{X_2} = \frac{f_1}{f_2}$$

$$\frac{100}{250} = \frac{5}{f_2}$$

The cross product with the two known terms is $5 \times 250 = 1250$. Divide this cross product by the known term, 100, in the other cross product, $100\ f_2$:

$$\frac{1250}{100} = 12.5 \text{ kHz} = f_2$$

SETTING UP PROBLEMS IN DIRECT PROPORTION . . . Following the method of Topic 10, no one has any difficulty in working out problems in proportion. Setting up problems in proportion is equally easy—but only if you go at it in the right way. The following example shows you how.

Example . . . An automobile traveling 35 miles per hour goes 150 miles in a certain length of time. If the speed of the automobile was changed to 55 miles per hour, what will be the distance covered in the same length of time?

Solution . . .

	Speed	Distance
Original Values	35 mph	150 miles
Values changed to	55 mph	x miles

$$\frac{150}{x} = \frac{35}{55}; x = 236 \text{ miles, } ans.$$

Explanation . . . You must begin every proportion problem by making a table as above. First decide what are the two types of values involved in this proportion. In this example, the two types are speed and distance. Hence, we write speed and distance as the column headings for our table, as shown. Two sets of values are involved. One set is the speed and distance first considered (35 mph and 150 miles). In the table above we have entered this set of values in the first row and called them "original values". The other set is the speed and distance after the change in speed has been made. In the table we have titled the two for these values as "values changed to". The speed for this set of values is 55 mph, and we call the distance x, since we don't as yet know its value.

Having completed the table, we can now write down the proportion directly from the table, and then find the value of x in the proportion. Since ratios must always be made from like units, the two speed values make up one of the ratios ($\frac{35 \text{ mph}}{55 \text{ mph}}$) of the proportion, and the two distance values form the other ratio ($\frac{150 \text{ miles}}{x \text{ miles}}$).

In making up the table for the above example, how do you know whether to put the speed column or the distance column on the left? It makes no difference. Similarly, it makes no difference whether you use "original values" or "values changed to" as the first row. Three other ways to make up the table of the above example are shown below. Although each table represents a different proportion, if you will work out the value for x in each of the three proportions, you will get 236 miles in each case.

	Distance	Speed
Original values	150 miles	35 mph
Values changed to	x miles	55 mph

$$\frac{150}{x} = \frac{35}{55}; x = 236 \text{ miles, } ans.$$

	Speed	Distance
Values changed to	55 mph	x miles
Original values	35 mph	150 miles

$$\frac{55}{35} = \frac{x}{150}; \; x = 236 \text{ miles, } ans.$$

	Distance	Speed
Values changed to	x miles	55 mph
Original values	150 miles	35 mph

$$\frac{55}{35} = \frac{x}{150}; \; x = 236 \text{ miles, } ans.$$

Example . . . The resistance of a copper wire is directly proportional to its length. If a 5-mile length of copper wire has a resistance of 10 ohms, what is the resistance of a 6-mile length of the same wire?

Solution . . .

	Wire length	Resistance
Shorter wire	5 miles	10 ohms
Longer wire	6 miles	x ohms

$$\frac{5}{6} = \frac{10}{x} \; ; \; x = 12 \text{ ohms, } ans.$$

Explanation . . . The two types of values in this proportion are wire length and resistance, and these form the column headings. The shorter of the two wires has a length of 5 miles and a resistance of 10 ohms, and these two values are listed in the row marked "shorter wire". In the bottom row, for the longer wire, 6 miles is listed for wire length, and x for the resistance.

WHAT HAVE YOU LEARNED?

1. The ratio of the primary to secondary voltages of a transformer varies directly with the ratio of primary to secondary turns. If the primary of a transformer has 500 turns and 110 volts are impressed across it, and if the secondary has 23,000 turns, the secondary will deliver _____ volts.

2. The reactance of an inductor is directly proportional to the frequency of the current through it. If the reactance of a certain inductor is 1500 ohms at 2100 hertz, the reactance will be _____ ohms at 10,000 hertz.

3. The reactance of an inductance at a certain frequency is 1200 ohms. If the frequency is doubled, the reactance will be _____ ohms.

4. At very high frequencies the field strength at a receiving antenna a certain distance from the transmitter will be proportional to the frequency of the signal. If the field strength at a certain receiving antenna is 8 mV (millivolts) per meter at a frequency of 100 MHz (megahertz), the field strength will be _____ millivolts per meter at a frequency of 200 MHz.

5. When resistors are connected in series, the voltage drop across each resistor is directly proportional to the applied voltage. If an applied voltage of 500 volts results in a voltage drop of 80 volts across a certain resistor, an applied voltage of 300 volts will cause a voltage drop of _____ volts across that resistor.

ANSWERS

1. 5060 volts . . .

	Voltages	Turns
Primary	110 volts	500 turns
Secondary	x volts	23,000 turns

$$\frac{110}{x} = \frac{500}{23,000} \, ; \, x = 5060 \text{ volts}$$

2. 7140 ohms . . .

	Reactance	Frequency
Lower frequency	1500 ohms	2100 hertz
Higher frequency	x ohms	10,000 hertz

$$\frac{1500}{x} = \frac{2100}{10,000} \, ; \, x = 7143 \text{ ohms,}$$

or 7140 ohms when rounded off to three significant figures.
3. 2400 ohms . . . Since reactance of an inductor is directly proportional to frequency, doubling the frequency also doubles the reactance.
4. 16 millivolts per meter
5. 48 volts

13 MEANING OF INVERSE PROPORTION . . . With direct proportion, the only kind discussed so far, an increase in one quantity brings about a corresponding increase in the other. Thus, when the circuit voltage is doubled, the circuit current also doubles, since current is directly proportional to voltage.

There is another kind of proportion, called *inverse proportion*, in which an in-
crease in one quantity results in a *decrease* in the other. An example is the state-
ment that the time required to travel by automobile between two towns is inversely
proportional to the speed of the car. If the speed is doubled, the time is reduced
to one-half that required at the original speed.

One quantity is *inversely proportional* to another quantity when the ratio of any
two values of the first quantity is the reciprocal of the ratio of any two corre-
sponding values of the second quantity.

For example, in the formula $I = \dfrac{E}{R}$ let us suppose that E is fixed at 10 volts.
Then as R increases, I decreases, as shown in Fig. 6.
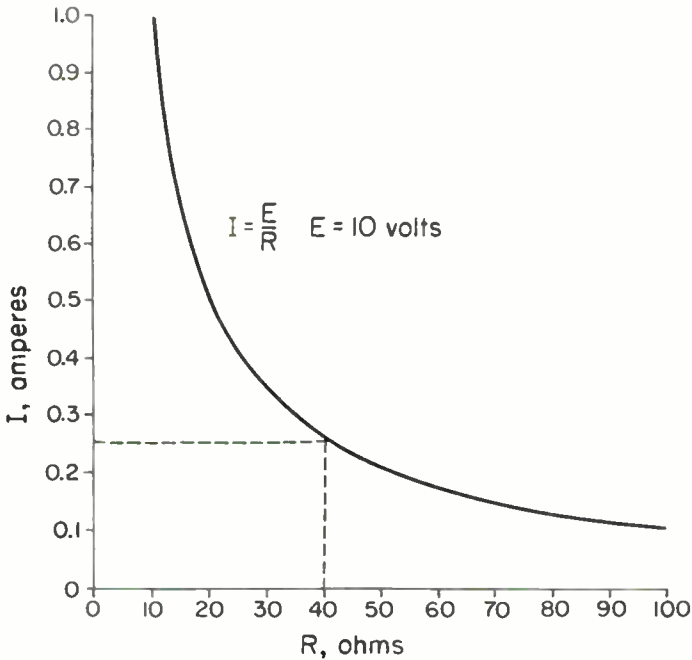
Fig. 6   **Inverse proportion. In the formula I = $\dfrac{E}{R}$, I is inversely proportional to R:**

**as R increases, I decreases in inverse proportion. The graph shows the values
of I (when E is constant at 10 volts) as R varies. For example, when R =
40 ohms, I = 0.25 amp.**

To solve a problem involving inverse proportion, set up two ratios in the same
manner as for a problem in direct proportion, as discussed in Topic 11. Now in-
vert one of the ratios, but not both, and equate them to each other. The resulting
proportion will be an inverse proportion.

32   Example . . . The resistance of a wire is inversely proportional to its cross-sectional area. If the cross-sectional area of a certain length of wire is 45 circular mils (abbreviated cir mils) and its resistance is 82 ohms, the resistance of the same length of wire with a cross-sectional area of 18 cir mils will be _____ ohms.

Solution . . .

	Area	Resistance
Smaller wire	18 cm	x ohms
Bigger wire	45 cm	82 ohms

$\frac{18}{45} = \frac{82}{x}$; $x = 205$ ohms, *ans.*

Explanation . . . Make up a table exactly as for direct proportion, and as shown above. From the table, the two ratios involved in the proportion are $\frac{18 \text{ cm}}{45 \text{ cm}}$ and $\frac{x \text{ ohms}}{82 \text{ ohms}}$.

Now we come to the only difference between working a direct proportion and an inverse proportion; in an inverse proportion, invert one of the ratios (either one, but not both). In the example above we inverted $\frac{x}{82}$ to obtain $\frac{82}{x}$. Thus the proportion becomes $\frac{18}{45} = \frac{82}{x}$.

We could just as well have inverted the ratio $\frac{18}{45}$, in which case the proportion would be $\frac{45}{18} = \frac{x}{82}$. Working out the value of x for this proportion, we get 205 ohms, the same value as obtained above.

WHAT HAVE YOU LEARNED?

1. A given circuit includes two parallel branches, as shown in Fig. 7. The current through each branch is inversely proportional to the resistance of that branch. In branch 1 the resistance is 10 ohms and current flow is 6 A. If the current in branch 2 is 2 amps, find the resistance (R_2) of branch 2.

2. In increasing one quantity to 3 times its original value causes another related quantity to also triple in value, the two quantities are in _____ proportion. If two quantities are in inverse proportion, and if the first quantity is increased to 4 times its original value, then the second quantity will change to _____ its original value.
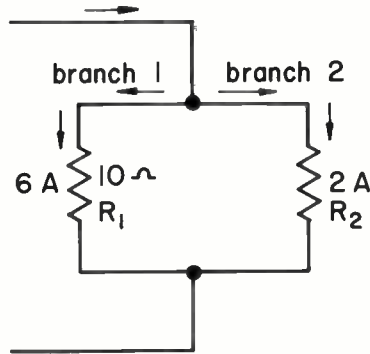
Fig. 7

3. The reactance of a capacitor is inversely proportional to the frequency. If the reactance of a certain capacitor is 1500 ohms at 2100 hertz, the reactance will be _____ ohms at 10,000 hertz.

4. The reactance of a capacitor is _____ ohms at 1200 kHz (kilohertz) if its reactance is 300 ohms at 680 kHz.

5. The reactance of a certain capacitor at a certain frequency is 4800 ohms. If the frequency is tripled, the reactance will be _____ ohms (see Problem 3).

ANSWERS

1. 30 ohms . . .

	Current	Resistance
Branch 1	6 amps	10 ohms
Branch 2	2 amps	x ohms

The two ratios are $\frac{6}{2}$ and $\frac{10}{x}$. Since an inverse proportion is involved, one of the ratios must be inverted. Inverting $\frac{6}{2}$ gives $\frac{2}{6}$. Hence the proportion is $\frac{2}{6} = \frac{10}{x}$.

2. direct; one-fourth

3. 315 . . . $\frac{1500}{X} = \frac{10,000}{2100}$ $X = 315$ ohms

4. 170 ohms . . . $\frac{X}{300} = \frac{680}{1200}$ $X = 170$ ohms

5. 1600 ohms . . . Since the reactance is inversely proportional to the frequency, making the frequency three times its original value will reduce the reactance to one-third its original value.

DIRECT OR INVERSE PROPORTION? . . . In the examples and problems so far you have been told whether the proportion is direct or inverse. When you are not this fortunate, deciding which type of proportion is involved is easy if you go about it right. In any case you start in by making up a table for the proportion just as you have been doing. You then decide whether direct or inverse proportion is involved. To do this, note the two column headings in the table (speed and distance in the example on page 28). When the value of one of these headings goes up, does the value of the other heading also go up? If so, you have a direct proportion. If the value of one of the column headings goes down when the other goes up, you have an inverse proportion. In the example on page 28, when the speed increases, the distance also increases, because you know that the faster the car goes, the more distance it will cover in a certain length of time. Hence, the proportion is a direct one.

Example . . . If a full crew of 8 workers can do a certain job in 28 days, how long would it take a short crew of 7 workers to do the same job?

Solution . . .

	Days	Workers
Full crew	28	8
Short crew	x	7

$\frac{28}{x} = \frac{7}{8}$; $x = 32$ days

Explanation . . . Is the proportion direct or inverse? The column headings are days and workers. As the number of workers increase, the number of days required to do the job will obviously go down. Hence, the proportion is inverse. Hence, of the two ratios in the table, $\frac{28}{x}$ and $\frac{8}{7}$, one must be inverted. We inverted the second, to give the proportion $\frac{28}{x} = \frac{7}{8}$.

WHAT HAVE YOU LEARNED?

1. If a train travels 378 miles in 11 hr, it will travel _____ miles in 17 hr.

2. If a ship sails 256 miles in 11½ hr, it will sail _____ miles in 179 hr.

3. If 16½ ft of coaxial cable costs $61.87, 28 ft of this same cable will cost _____.

4. A vernier dial turns 10 revolutions each time the control shaft is turned 3°. The dial will turn _____ revolutions when the shaft is turned 17°.

5. If 10 workers can do a job in 20 days, 25 workers can do the same job in _____ days.

6. If 7 workers can erect a tower in 5¼ days, 4 workers can erect the tower in _____ days.

7. You are given the formula $M = 2\pi Q^2 rh$. When h is equal to 30, then M is equal to 45. What will be the value of M when h is 72? Assume that the values of Q, π, and r do not change.

8. You are given the formula $M = \dfrac{2\pi Q^2 r}{h}$. When h is equal to 30, then M is equal to 45. What will be the value of M when h is 72? Assume that the values of Q, π, and r do not change.

ANSWERS

1. 584 miles . . .

	Distance	Time
Original values	378 miles	11 hours
Values changed to	x miles	17 hours

The two column headings are time and distance. The more time the train travels the farther it will go. Hence, as time increases, distance increases—a direct proportion. The proportion is $\dfrac{378}{x} = \dfrac{11}{17}$.

2. 3985 miles . . . A direct proportion is used.
3. $105 . . .

	Length	Cost
Short length	16.5 feet	$61.87
Long length	28 feet	x

The more you buy, the more it costs. Hence, as length increases, so does cost increase—a direct proportion $\dfrac{16.5}{28} = \dfrac{61.87}{x}$

4. 56.7 revolutions . . . A direct proportion, since the more revolutions you give the vernier dial, the further in degrees the control shaft is turned.
5. 8 days . . . An inverse proportion.
6. 9.19 days . . . An inverse proportion.
7. 108 . . .

	M	h
Original values	45	30
Values changed to	x	72

Now look at the formula carefully. Notice that the higher the value of h, the higher the value that M must be, since M is obtained by multiplying $2\pi Q^2 r$ by the value of h. Hence, the proportion involved is direct, and is $\frac{45}{x} = \frac{30}{72}$; $x = 108$.

8. 18.75 . . . The table will be identical to the one for Question 7. Studying the formula, we notice that when h becomes higher, M must become less. You are dividing $2\pi Q^2 r$ by h—the bigger the number you divide by, the lesser the quotient must be. Hence, an inverse proportion is involved. Inverting the ratio M, we have the proportion $\frac{x}{45} = \frac{30}{72}$.

15 PROPORTIONAL TO THE SQUARE OR ROOT . . . One quantity may be directly or inversely proportional to the square of some other quantity. Or one quantity may be proportional or inversely proportional to the square root of some other quantity.

Example . . . The resistance of a wire is inversely proportional to the square of the diameter of the wire. If a wire 0.15 in. in diameter has a resistance of 70 ohms, what will be the resistance of the same length of wire with a diameter of 0.25 in.?

Solution . . .

	Resistance	Diameter
Small wire	70 Ω	$(0.15)^2$ in.
Large Wire	x Ω	$(0.25)^2$ in.

$$\frac{x}{70} = \frac{(0.15)^2}{(0.25)^2}$$
$$\frac{x}{70} = \frac{0.0225}{0.0625}$$
$$x = 25.2 \text{ ohms, } ans.$$

Explanation . . . In the table, the diameter values are shown squared because the problem states that the proportion is to the square of the diameter. In setting up the proportion, the resistance ratio in the table, $\frac{70}{x}$, is inverted to give $\frac{x}{70}$ because the problem says that an inverse proportion is involved. The diameter ratios could equally well have been inverted.

WHAT HAVE YOU LEARNED?

1. The resistance of a wire is inversely proportional to the square of the diameter of a wire. If a wire 0.21 inches in diameter has a resistance of 80 ohms, what will be the resistance of the same length of wire with a diameter of 0.25 inches?

2. The power dissipated in a resistor is proportional to the square of the voltage impressed. If a voltage of 100 volts will dissipate 240 watts in a certain resistor, how much power will be dissipated if the voltage is increased to 180 volts?

3. 400 watts of power are dissipated in a certain resistor. How much power will be dissipated in this resistor if the voltage is tripled?

4. 400 watts of power is dissipated in a certain resistor. How much power will be dissipated in this resistor if the voltage is reduced to one-third of its original value?

ANSWERS

1. 56.4 ohms

2. 778 watts . . . $\frac{100^2}{180^2} = \frac{240}{x}$; $\frac{10,000}{32,400} = \frac{240}{x}$; $x = 778$ watts

3. 3600 watts . . . As no actual voltage is stated, assume the voltage is 1. The tripled voltage will then be 3. Hence, $\frac{1^2}{3^2} = \frac{400}{x}$; $\frac{1}{9} = \frac{400}{x}$; $x = 3600$ watts

4. 44.4 watts . . . The ratio of the original voltage to the new voltage will be 3 to 1. The ratio of the original power to the new power will be 400 to x. As it is a direct proportion, set these two ratios equal, but not until after the voltage ratio is squared.
$\frac{3^2}{1^2} = \frac{400}{x}$; $\frac{9}{1} = \frac{400}{x}$; $x = 44.4$ watts

16 NEGATIVE NUMBERS

MEANING OF NEGATIVE NUMBERS . . . Ordinary numbers as we commonly know them are positive although we do not usually put a plus sign in front of them. Working with only positive numbers is adequate for many people but in electronics work we must learn to use and understand negative numbers.

First of all, we must be careful about how we interpret the word negative. We often speak of a negative number as being less than zero, and many people are confused because we cannot conceive of any quantity being less than zero. Yet during the Winter season, the temperature may drop below zero. When the temperature is ten degrees below zero we write is as −10 degrees. In this case, the zero point (or reference point has been established at some point in the temperature scale.

In an electronic circuit, you must determine where the zero reference point is whenever you specify a voltage. When we specify the voltage of a battery we always use a positive number. However, if the battery is connected in a circuit we may

38 want to connect the positive battery terminal to what we call the zero reference point in which case the battery voltage measured to the other terminal would be a negative quantity since the other terminal is negative when compared to our zero reference. The reverse situation would be one in which the negative battery terminal were designated as having zero voltage and of course the voltage measured to the other terminal would be positive.

In summary, we conclude that a quantity can be either positive or negative depending on where we establish a zero reference. In electronic circuits, we frequently use ground as a reference and say that it has zero potential. A positive voltage is said to be above ground and a negative voltage is below ground. You will find many other uses of negative numbers in electronics as you progress through this course.

WHAT HAVE YOU LEARNED?

1. 14 indicates 14 units _____ than zero.

2. −14 indicates 14 units _____ than zero.

3. In a cold-climate area, the temperature varies in one day from 5°F to −15°F. _____°F is the colder temperature because _____.

4. In Fig. 8 is shown a DC circuit which uses two batteries, E_1 and E_2. The common lead between the two loops is at ground potential. The voltage at point A is _____ volts. The voltage at point B is _____ volts. Consider ground as being at zero potential.
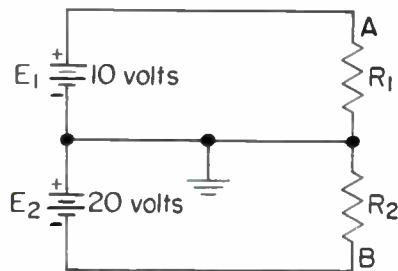
Fig. 8

1. greater . . . 14 is a positive number.   2. less
3. −15 °F is the colder temperature because it is 15° *below* zero.
4. +10; −20 . . . The negative pole of E_1 is connected to the grounded line. Because the voltage of E_1 is 10 volts, point A, connected to the positive pole of E_1, will be 10 volts above ground. The positive pole of E_2 is connected to ground. Point B connects to the negative pole of E_2, which is 20 volts below ground, or −20 volts. Therefore, the voltage at B is −20 volts.

17 ADDING POSITIVE AND NEGATIVE NUMBERS . . . While the use of + or − signs in front of numbers provides an easy shorthand method for saying "above zero" or "below zero," the real value in the use of these signs is that they make practical calculations easier. Two rules are used for adding positive and negative quantities.

Rule 1 . . . *To add two or more numbers which have the same sign, find their sum by ordinary arithmetic and prefix this sum with the common sign.*

Rule 2 . . . *To add a positive number to a negative number, find their difference by ordinary arithmetic and then prefix this difference with the sign of the number that has the greater value when the signs are ignored.*

Example . . . The sum of −7 volts and −5 is _____ volts.

Solution . . . Since a minus sign precedes both terms, Rule 1 will apply:

$$7 + 5 = 12$$

Because the common sign of the two numbers is minus, the answer is −12.

Example . . . The sum of 8 volts and −14 volts is _____ volts.

Solution . . . Since a positive number and a negative number are involved, Rule 2 will apply.

$$14 - 8 = 6$$

The number with the greater value when the sign is ignored, −14, is negative, and therefore the answer is −6 volts.

WHAT HAVE YOU LEARNED?

1. 7 + 2 = _____   3. −9 + 2 = _____

2. −6 − 8 = _____   4. 24 − 91 = _____

5. (a) The sum of 91 volts and −24 volts is _____ volts.

     (b) The sum of 91 volts and 24 volts is _____ volts.

6. (a) The sum of −10 amp and +14 amp is _____ amperes.

     (b) The sum of +14 amp and −10 amp is _____ amperes.

     (c) The sum of −14 amp and −10 amp is _____ amperes.

7. The sum of +21 decibels and −21 decibels is _____ decibels.

8. The sum of an inductive reactance of 0 ohms and a capacitive reactance of −5 ohms is _____ ohms.

9. If a −12-A current is added to another −12-A current, the result is a _____-ampere current.

10. $8 + 4 - 3 - 6 + 7 - 2 =$ _____

11. $4 - 9 - 7 + 3 - 5 - 6 =$ _____

12. $-5 - 7 + 6 - 3 =$ _____

<div align="center">ANSWERS</div>

1. 9   2. −14 . . . −6 and −8 are to be added.

3. −7 . . . Use Rule 2 to add −9 and +2.

4. −67   5. (a) 67; (b) 115   6. (a) 4; (b) 4; (c) −24   7. 0   8. −5

9. −24 . . . The negative sign preceding the current value means that current flow is opposite to the direction assumed to be positive.

10. +8 . . . Add term by term. $8 + 4 = 12$, giving $12 - 3 - 6 + 7 - 2$. Then −3 added to +12 equals +9, giving

$$9 - 6 + 7 - 2 =$$
$$3 + 7 - 2 =$$
$$10 - 2 = 8$$

11. −20   12. −9

USING PROPORTIONS TO SOLVE EQUATIONS

18 HOW IT IS DONE . . . Formulas in electronics are very often not given in a form that will allow us to directly find what we want. For example if you are given the formula $E = \dfrac{Q}{C}$, you can easily find E if you know the values of Q

and C. But suppose that it is Q that you want to find and you already know the values of E and C. By using proportion, this is nearly as easy as finding E. A few examples will show you how.

Example . . . The voltage E across a capacitor is found by the formula

$$E = \frac{Q}{C}$$

where Q is the quantity of electricity stored in coulombs and C is the capacitance in farads. What is the capacitance if 100 volts across a capacitor will store 0.02 coulombs of electricity in the capacitor?

Solution . . . Substituting the given values in the formula, we have

$$100 = \frac{0.02}{C}$$

In accordance with the upper half of page 14, this can be written as a proportion as follows:

$$\frac{100}{1} = \frac{0.02}{C}$$

Now find the value of C as you would work any other proportion.

$$C = \frac{0.02 \times 1}{100} = \frac{0.02}{100} = 0.0002 \text{ farad, } ans.$$

WHAT HAVE YOU LEARNED?

1. Using the formula in the last example, find the value of Q if $E = 500$ volts and $C = 0.004$ farads.

2. The time constant of an inductance and resistance in series is given by the formula $t = \frac{L}{R}$, where t is the time in seconds, L is inductance in henrys, and R is the resistance in ohms. What value of R should you use with an inductance of 5 henrys in order to obtain a time constant of 0.4 second?

3. Using the formula of Problem 2 above, if R is 100 ohms, what value should L be for a time constant of 0.2 second?

4. The base current of a transistor, I_B, is given by the formula $I_B = \frac{I_c}{\beta}$, where I_c is the collector current and β is the amplification factor. If β is 100, what will be the collector current if the base current is 50 milliamperes?

1. 2 coulombs . . . $E = \dfrac{Q}{C}$; $500 = \dfrac{Q}{0.004}$. Writing this as a proportion $\dfrac{500}{1} =$ $\dfrac{Q}{0.004}$; $Q = \dfrac{500 \times 0.004}{1} = 2$ coulombs

2. 12.5 ohms . . . $t = \dfrac{L}{R}$; $0.4 = \dfrac{5}{R}$. Writing this as a proportion, $\dfrac{0.4}{1} = \dfrac{5}{R}$; $R = \dfrac{5 \times 1}{0.4} = 12.5$ ohms

3. 20 henrys   4. $50 \times 100 = 5000$ mA $= 5$ A

19   MORE EXAMPLES USING PROPORTION IN EQUATIONS . . .

Example . . . Given the equation $A = \dfrac{KH}{MC}$ find the value of K if $H = 8$, $M = 12$, $A = 4$, and $C = 6$.

Solution . . . Inserting the given values

$$A = \frac{KH}{MC} \; ; \; 4 = \frac{8 \times K}{12 \times 6}$$

Writing as a proportion

$$\frac{4}{1} = \frac{8 \times K}{12 \times 6}$$

To find K in this proportion (or the unknown in any similar proportion) first find the cross products.
$$4 \times 12 \times 6 = 1 \times 8 \times K$$
Now take the cross product in which all the terms are known (in theis example $4 \times 12 \times 6$) and divide it by the known terms in the other cross product (1×8). This is a slight extension to the Rule on page 15 for solving a proportion.

$$\frac{4 \times 12 \times 6}{1 \times 8} = K$$

$$\frac{\overset{6}{\cancel{4}} \times \cancel{12} \times 6}{\underset{2}{1 \times \cancel{8}}} = K$$

$$36 = K, \text{ ans.}$$

Mathematically $\dfrac{4 \times 12 \times 6}{1 \times 8} = K$ is the same as $K = \dfrac{4 \times 12 \times 6}{1 \times 8}$.

Example . . . At what frequency will an inductance of 5 henrys have a reactance of 1000 ohms? The formula to use is $X_L = 2\pi f L$, where $2\pi = 6.28$, X_L is the reactance in ohms, f if the frequency in hertz, and L is the inductance in henrys.

Solution . . . Substituting in the formula
$$X_L = 2\pi fL$$
$$1000 = 6.28 \times f \times 5$$

Writing as a proportion, $\dfrac{1000}{1} = \dfrac{6.28 \times f \times 5}{1}$

Solving, $\qquad\qquad 1000 \times 1 = 1 \times 6.28 \times f \times 5$

$$f = \dfrac{\overset{200}{\cancel{1000} \times 1}}{1 \times 6.28 \times \cancel{5}}$$

$$= \dfrac{200}{6.28} = 31.8 \text{ Hz, } ans.$$

WHAT HAVE YOU LEARNED?

1. Given the formula $Q = \dfrac{0.4\ Aw}{mpH}$, find A if $w = 12$, $m = 9$, $p = 15$, $H = 10$, and $Q = 20$.

2. Using the formula of Problem 1, find H if $Q = 200$, $A = 3$, $w = 12$, $m = 9$, and $p = 15$.

3. Given the formula $X_c = \dfrac{1}{2\pi fc}$, find C if $Xc = 500$, and $f = 2000$.

4. Given the formula $W = \dfrac{E^2C}{2}$, find C if $W = 4$ and $E = 30$.

5. Using the formula of Problem 4, find E if $W = 4$ and $C = 0.08$. (Hint: First find E^2, and remember that E is the square root of E^2.)

6. Given the formula $P = I^2R$, where P is power in watts, I is current in amperes, and R is the resistance in ohms, find the current in *milliamperes* if $P = 5$ watts, and $R = 400$ ohms.

7. Given the formula $M = \sqrt{L_1L_2}$, find L_1 if $M = 40$ and $L_2 = 16$. (Hint: Rewrite $\sqrt{L_1L_2}$ as $\sqrt{L_1} \times \sqrt{L_2}$, find the value of $\sqrt{L_1}$, and then square to get L_1.)

8. Given the formula $f = \dfrac{1}{2\pi\sqrt{LC}}$, find the value of C if $f = 6$ and $L = 25$.

1. 5625 . . . $Q = \dfrac{0.4\ Aw}{mpH}$; $20 = \dfrac{0.4 \times A \times 12}{9 \times 15 \times 10}$

$\dfrac{20}{1} = \dfrac{0.4 \times A \times 12}{9 \times 15 \times 10}$; $20 \times 9 \times 15 \times 10 = 1 \times 0.4 \times A \times 12$

$A = \dfrac{9 \times 15 \times 10 \times 20}{0.4 \times 12} = 5625$

2. 0.000533 . . . $\dfrac{200}{1} = \dfrac{0.4 \times 3 \times 12}{9 \times 15 \times H}$

$H = \dfrac{1 \times 0.4 \times 3 \times 12}{200 \times 9 \times 15} = 0.000533$

3. 0.000000159 . . . $\dfrac{500}{1} = \dfrac{1}{6.28 \times 2000 \times C}$

$C = \dfrac{1 \times 1}{500 \times 6.28 \times 2000} = 0.000000159$

4. 0.00889 . . . $\dfrac{4}{1} = \dfrac{(30)^2 \times C}{2}$; $C = \dfrac{4 \times 2}{1 \times (30)^2} = \dfrac{8}{900} = 0.00889$

5. 10 . . . $\dfrac{4}{1} = \dfrac{E^2 \times 0.08}{2}$; $E^2 = \dfrac{2 \times 4}{1 \times 0.08} = 100$; $E = \sqrt{100} = 10$

6. 112 mA . . . $5 = I^2 \times 400$; $\dfrac{5}{1} = \dfrac{I^2 \times 400}{1}$; $I^2 = \dfrac{5 \times 1}{1 \times 400} = 0.0125$ amp;

$I = \sqrt{0.0125} = 0.112$ amp $= 112$ mA. Note that 0.112 A is multiplied by 1000 to obtain 112 mA.

7. 100 . . . $400 = \sqrt{L_1} \times \sqrt{16}$; $\dfrac{40}{1} = \dfrac{\sqrt{L_1} \times 4}{1}$; $\sqrt{L_1} = \dfrac{40 \times 1}{1 \times 4} = 10$; $L_1 = 10^2 = 100$

8. 0.0000282 . . . $f = \dfrac{1}{6.28 \times \sqrt{L} \times \sqrt{C}}$; $6 = \dfrac{1}{6.28 \times \sqrt{25}\ \sqrt{C}}$

$6 = \dfrac{1}{6.28 \times 5 \times \sqrt{C}}$; $\sqrt{C} = \dfrac{1 \times 1}{6 \times 6.28 \times 5} = 0.00531$

$C = (0.00531)^2 = 0.0000282$

INVERSE PROPORTION AND NEGATIVE NUMBERS

EXAMINATION

Each examination question is followed by a number of selections. Circle the number in front of the correct selection for each question. When you have finished, transfer your answers to the Answer Sheet provided. Then use the special envelope provided to mail the examination to the school as soon as it is completed.

1. In the formula $A = \dfrac{B}{C}$, A is

   (1) directly proportional to C.
   (2) directly proportional to B.
   (3) inversely proportional to B.

2. In the formula $A = \dfrac{B}{C}$

   (1) as B increases, A increases.
   (2) as B decreases, A increases.
   (3) as B increases, A decreases.

3. If the current in a transformer primary is constant, the current output from the secondary is inversely proportional to the number of turns in the secondary. If the secondary current output is 150 mA when there are 500 turns on the secondary, what would be the secondary current output if there were only 100 turns on the secondary? Don't forget to make a table first.
   (1) 0.200 mA   (2) 0.213 mA   (3) 0.750 mA
   (4) 200 mA   (5) 750 mA

4. We frequently use ground as a reference in electronics, and say it has
   (1) zero potential.
   (2) a negative potential.
   (3) a positive potential.

5. The sum of −9 V and −3 V is
   (1) 12 V.   (2) −12 V.   (3) 6 V.   (4) −6 V.

6. The resistance of a wire is
   (1) directly proportional to the square of its diameter.
   (2) inversely proportional to the square of its diameter.
   (3) inversely proportional to its length.
   (4) directly proportional to its diameter.

7. If increasing one quantity to twice its original value causes another related quantity to double also, the two quantities are
   (1) inversely proportional.
   (2) indirectly proportional.
   (3) directly proportional.

8. The sum of +15 V and −7 V is
   (1) −22 V.   (2) 8 V.   (3) 22 V.   (4) −8 V   (5) −105 V.

9. The voltage E across a capacitor is found by the formula

$$E = \frac{Q}{C}$$

where Q is the quantity of electricity in coulombs, and C is the capacitance in farads. What is the capacitance if 5 volts across the capacitor will store 0.01 coulombs of electricity in the capacitor? (Insert the given values and set up a proportion.)
   (1) 0.02 F   (2) 0.002 F   (3) 0.05 F   (4) 0.5 F   (5) 2 F

10. The reactance of an inductor is directly proportional to the frequency. If the reactance of a certain inductor is 200 Ω at 2500 Hz, what is the correct *proportion* for finding the reactance at 5000 Hz? (Make a table. Note that the proportion is a direct one.)
   (1) $\dfrac{2500}{x} = \dfrac{5000}{200}$ (2) $\dfrac{200}{2500} = \dfrac{5000}{x}$

   (3) $\dfrac{200}{x} = \dfrac{2500}{5000}$

END OF EXAM

No matter how complicated an electronics sytem may be, it is made up largely of rather simple series and parallel circuits. If you understand those circuits well, all of electronics becomes easy to understand. Hence, with the next lesson you will begin to study some of the most important material in your training program.
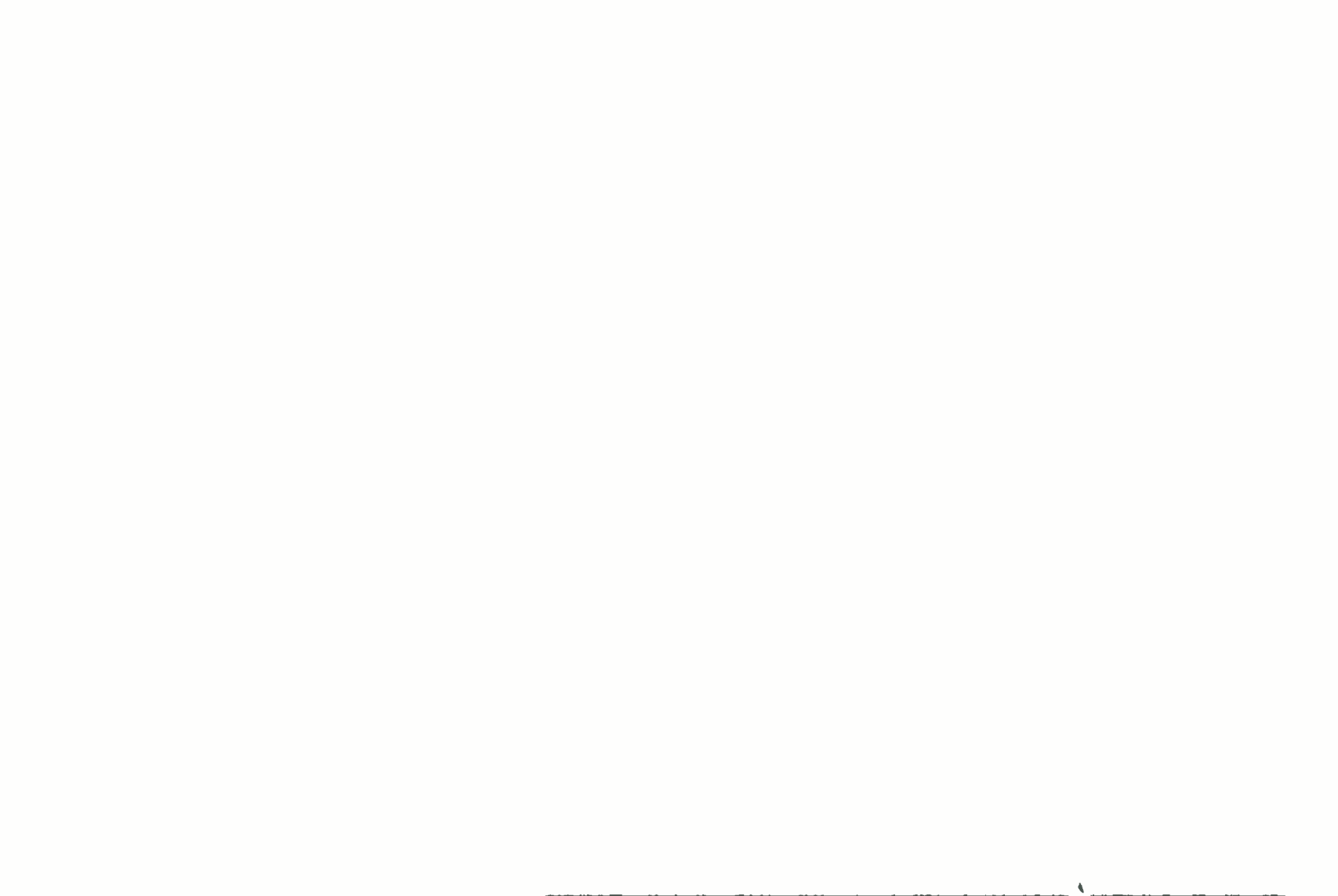
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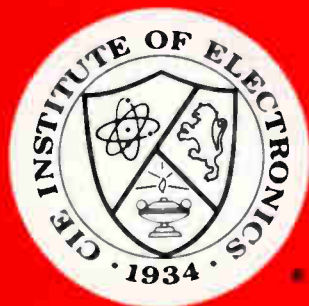
electronics

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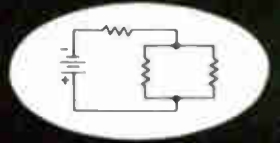
Lesson 2323A-7
Parallel Circuits

Lesson 2323B-7
Equivalent Circuits

Lesson 2323C-7
Applications of Kirchhoff's Laws

AUTO-PROGRAMMED® Lessons

ABOUT THE AUTHOR

In the course of over 30 years' experience helping students learn through home study, Darrell Geiger has obtained an intimate understanding of the unique problems facing home-study students. He has used this knowledge to make many improvements in our teaching methods. Mr. Geiger believes that students learn fastest when they actively participate in the lesson, rather than just read it.

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Lesson 2323A-7
Parallel Circuits

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Applications of Kirchhoff's Laws

By DARRELL GEIGER
Technical Staff
Cleveland Institute of Electronics, Inc.

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Lesson 2323A-7
Parallel Circuits

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Equivalent Circuits

Lesson 2323C-7
Applications of Kirchhoff's Laws

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There are two basic types of DC circuits: series and parallel. This volume is devoted to understanding and working with the currents, voltages, and resistances associated with these two circuit types. Although the volume is about DC circuits, the principles—with certain modification—apply equally to the AC circuits you'll study later.

The principles taught in this volume are basic to the operation of practically all electronic equipment. Therefore, the better you understand these principles, the easier and the faster you will go through your training program—and the more you will learn. So be sure to write for help (using the Request for Assistance sheets provided) on any points in the volume that you can't fully understand.

Never forget that your success depends to a great extent upon regular study: one or two hours a day, five days a week, should bring excellent results. If you haven't yet set aside a definite time each day for study, now's the time to do so.

Lesson 2323A-7
Parallel Circuits

CURRENTS IN PARALLEL CIRCUITS

Components in a circuit are hooked to each other, and to the power source, in two basic arrangements: *series* and *parallel*. In the series arrangment, there's only one current, but there are several voltages. In the parallel arrangement, there's only one voltage, but there are several current values, the laws that determine these current values are the subject of this part of the lesson.

SERIES AND PARALLEL CIRCUITS . . . In a *series circuit,* such as that shown in Fig. 1, there is only one path for the current to follow. Battery voltage E pushes electrons from the negative terminal of the battery through the ammeter, resistor R_2, resistor R_1, and the lamp, and finally back to the positive terminal of the battery. It is called a series circuit because every electron moving around the circuit must pass through *every component* in the circuit.

(a) Pictorial diagram   (b) Schematic diagram
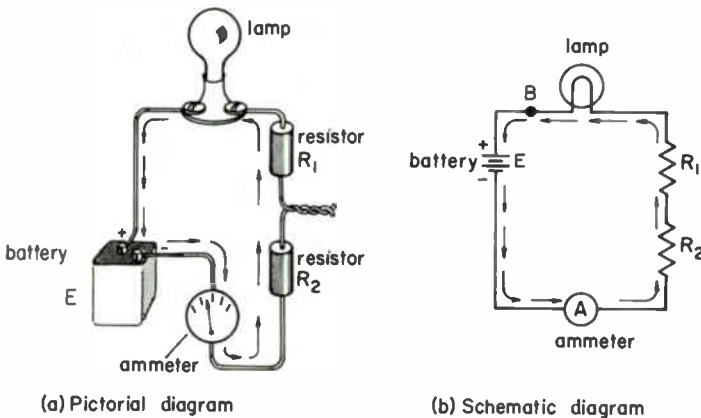
Fig. 1   In a series circuit, current flowing from the negative terminal of the battery must pass through every element of the circuit before returning to the positive terminal. (Arrows show direction of electron flow.)

Since all the electrons that form the current must pass through every component, *the amount of current flowing through each element of a series circuit is the same.* In Fig. 1, for example, if the current through resistor R_2 is 300 mA (milliamperes), then the current through R_1, the lamp, the ammeter, and the battery itself must also be 300 mA.

We can learn the current strength in Fig. 1 by reading the ammeter. All the current flowing around the circuit must pass through the ammeter, and this current swings the meter pointer along the scale. The stronger the current, the farther the pointer swings. Ammeters for measuring low-current strengths (less than one ampere) are often called *milliammeters,* but in this lesson we'll call them ammeters, too.

In a *parallel circuit,* such as that shown in Fig. 2, there are several paths—or *parallel branches*—that the current may follow. The battery voltage E pushes electrons from the negative terminal of the battery through ammeter A to point B. At point B, however, the electrons divide. Some take the path through the lamp, some go by way of resistor R_1, and the rest go through R_2. All the electrons meet again at point C, and from there return to the positive terminal of the battery. This is called a parallel circuit because an electron, in going once around the circuit, must pass through the lamp, *or* resistor R_1, *or* resistor R_2—*but it can't go through more than one of these components on a single trip around the circuit.* Contrast this to Fig. 1, in which every electron going through the circuit passed through all three components.

(a) Pictorial diagram   (b) Schematic diagram
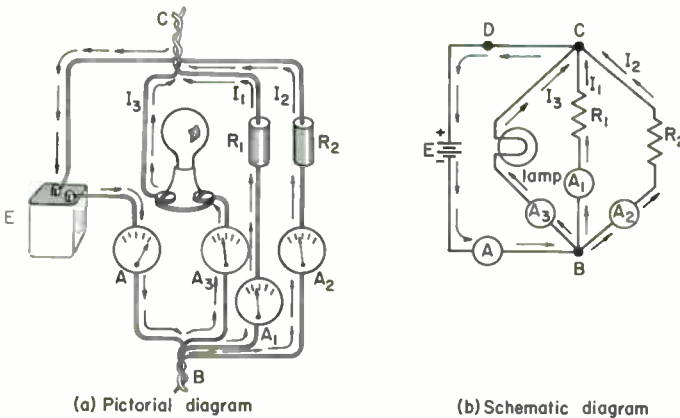
Fig. 2   **In this parallel circuit, current flowing from the negative terminal of the battery to the positive terminal divides into three parts. One part I_1, flows through R_1; another part, I_2, flows through R_2; and the third part, I_3, flows through the lamp.**

Note that the circuit in Fig. 2 includes four ammeters: ammeter A measures the current going from the negative terminal of the battery to point B; ammeter A_1 reads the amount of current passing through R_1; ammeter A_2 reads the amount of current passing through R_2; and ammeter A_3 reads the amount of current passing through the lamp. Since the electrons upon reaching point B divide and go in three different ways, the reading of any one of the ammeters—A_1, A_2, or A_3—must be less than the reading of ammeter A. In other words, the current in any branch of a parallel circuit must be less than the total current supplied by the battery or other power source.

4   Since all the electrons upon reaching point B must also leave B by one or another of the three paths, the sum of the three branch currents must equal the current supplied by the battery. Thus, if the lamp draws 1 A (ampere), resistor R_1 draws 2 A, and resistor R_2 draws 3 A, the current I flowing from the battery is equal to 1 A + 2 A + 3 A = 6 A.

Kirchhoff's current law summarizes what happens to the current at branch points in a circuit:

> *Kirchhoff's current law*   The sum of all the currents flowing away from a point in a circuit must equal the sum of the currents flowing to that point.

As we have found, 6 A flows away from point B (1 A to the lamp, 2 A to R_1 and 3 A to R_2), so 6 A must flow to point B from the negative battery terminal. The sum of the currents flowing to point C is $I_3 + I_1 + I_2 = 1$ A + 2 A + 3 A = 6 A. Hence, the current flowing away from point C to the positive terminal of the battery must also be 6 A.

WHAT HAVE YOU LEARNED?

1. If the current at any point in a *(series) (parallel)* circuit is 7 A, then the current in any other part of the circuit is also 7 A.

2. If the ammeter in Fig. 1 reads 450 mA, then the current through the lamp is *(more than) (less than) (equal to)* 450 mA.

3. If we remove the ammeter in Fig. 1(b) from the position shown, and insert it in the circuit at point B, will it show the same current value as before?

4. If the current through the lamp in Fig. 2 is 750 mA, then the current flowing through ammeter A_3 *(is) (isn't)* equal to 750 mA.

5. If ammeter A_1 in Fig. 2 reads 200 mA, ammeter A_2 reads 400 mA, and ammeter A_3 reads 700 mA, then ammeter A must read _____ mA, or _____ A.

6. Find the current flowing through the lamp in Fig. 2 if ammeter A_1 reads 300 mA, ammeter A_2 reads 150 mA, and ammeter A reads 700 mA.

7. (Refer to Problem 6.) If ammeter A_3 is removed from where it is shown in Fig. 2 and inserted in the circuit at point D, what will it read?

8. Certain circuits must be able to perform properly despite changes in the temperature of the environment. To test such circuits, you place them in a chamber where the temperature can be controlled by an electronic thermostat. Assume that one such chamber contains four heaters, and that the technician can connect the heaters in either of the two ways shown in Fig. 3(a) and (b). In Fig. 3(a), the heaters are connected in *(series) (parallel)*. If each heater requires 200 mA, the switch in the thermostat must be able to handle _____ mA.
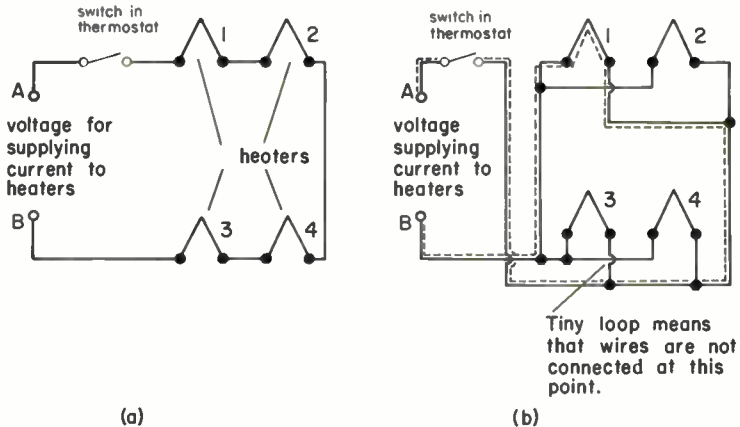
Fig. 3

9. To see how the heaters in Fig. 3(b) are connected, start at voltage-source terminal *A* and—with your pencil point—try to trace a path that will take you through heater 1 and back to voltage-source terminal *B*. The dashed line shows the path you'll have to take. (Note that you didn't trace through any of the other heaters.) Now, trace from *A* through heater 2 back to *B* in a similar manner. Do the same thing with heaters 3 and 4. If, in every case, you are able to go from *A* through the heater being considered and back to *B* without passing through any other heater, then you know that the heaters are connected in *(series) (parallel)*.

10. If, in Fig. 3(a), you trace from *A* through heater 1 and back to *B*, you *(must)* *(must not)* also pass through heaters 2, 3, and 4. This verifies that the heaters of Fig. 3(a) are connected in _____.

11. Since each heater in Fig. 3(b) requires a current of 200 mA, how much current will the switch in the thermostat have to handle?

12. The household appliances of Fig. 4 are connected in *(series) (parallel)*. Assuming that all of them may be in use at the same time, would you use a 10-A, a 15-A, or a 20-A fuse to protect this circuit?

6
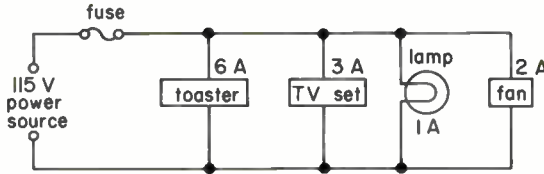
Fig. 4

ANSWERS

1. series   2. equal to   3. yes . . . since the current is the same in all parts of a series circuit, the ammeter will read the same no matter where it is placed in the circuit.
4. is . . . All the electrons passing through the lamp must also pass through A_3 (since ammeter A_3 is in series with the lamp). Hence, the reading of A_3 is the current drawn by the lamp.
5. 1300 mA, or 1.3 A . . . To change milliamperes to amperes, divide by 1000.
6. 250 mA . . . Since ammeter A reads 700 mA, the current flowing into point B is 700 mA. By Kirchhoff's current law, the sum of the currents leaving point B must also be 700 mA. 300 mA + 150 mA = 450 mA leaves by way of R_1 and R_2. This means that 700 mA − 450 mA = 250 mA must leave by the path through the lamp. Check: 300 mA + 150 mA + 250 mA = 700 mA, which is the current coming into point B as read on ammeter A.
7. 700 mA . . . The ammeter will read the current leaving point C and going to the positive terminal of the battery. The current entering point C is $I_1 + I_2 + I_3$ = 300 mA + 150 mA + 250 mA = 700 mA. Hence, the current *leaving* point C is also 700 mA.
8. series; 200 mA . . . Since the current is the same in all parts of a series circuit, the current drawn from the voltage source *must* be the same as the current through any one of the heaters.
9. parallel   10. must; series   11. 800 mA . . . In a parallel circuit, the total current is the sum of the currents taken by the components connected in parallel.
12. parallel; 15 A . . . You'd select a fuse rated a little higher than the maximum current through the fuse. The fuse current will be 6 A + 3 A + 1 A + 2 A = 12 A. Hence, a 15-A fuse should be satisfactory.

2 FINDING THE CURRENT IN A PARALLEL CIRCUIT . . . The parallel circuit of Fig. 2 is redrawn in Fig. 5 with the resistance and voltage values shown, and with a couple of switches added. Let's find the readings of the ammeters, both with the switches open and with one or both switches closed.
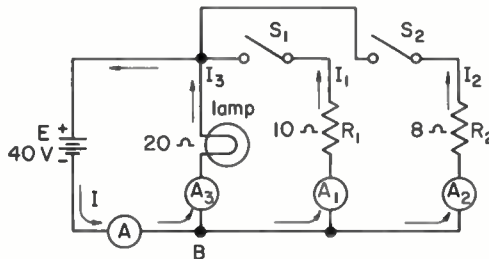
Fig. 5   The current through any branch of a parallel circuit across a constant voltage doesn't change if additional parallel branches are added or removed.

When switches S_1 and S_2 are open, R_1 and R_2 are disconnected from the battery. As a result, the circuit is reduced to a lamp connected across the battery. By Ohm's law, the lamp current is

$$I_3, \text{ in amperes (A)} = \frac{E, \text{ in volts (V)}}{R_3, \text{ in ohms } (\Omega)}$$
$$= \frac{40 \text{ V}}{20 \text{ } \Omega}$$
$$= 2 \text{ A}$$

Thus, A_3 reads 2 A when both switches are open. However, even if we close switch S_1, we don't change the fact that the lamp is connected directly across the 40-V electrical "pressure" put out by the battery. With or without switch S_1 closed, the 40 V of the battery is pushing electrons against the 20 Ω of opposition that is the lamp resistance. Hence, by Ohm's law, the current through the lamp is 2 A, no matter whether S_1 is open or closed. Similarly, if *both* S_1 and S_2 are closed, the current will continue to be 2 A. As long as the battery voltage stays constant at 40 V, opening or closing one or both switches will *not* change the reading of ammeter A_3.

When S_1 is closed, R_1 is connected directly to the two battery terminals. The current is found by Ohm's law, and its value stays the same whether or not the lamp—or R_2—or also connected to the battery:

$$I = \frac{E}{R_1}$$
$$= \frac{40 \text{ V}}{10 \text{ } \Omega}$$
$$= 4 \text{ A}$$

Similarly, the reading of ammeter A_2 is

$$I_2 = \frac{E}{R_2}$$
$$= \frac{40}{8}$$
$$= 5 \text{ A}$$

We find the reading of ammeter A (which is the total current furnished by the battery) by using Kirchhoff's current law. The current entering point B from the battery must equal the sum of the currents leaving point B and going through the three parallel branches. In other words, $I = I_3 + I_1 + I_2 = 2 \text{ A} + 4 \text{ A} + 5 \text{ A} = 11 \text{ A}$. Thus, ammeter A reads 11 A when both switches are closed.

8 To summarize our findings in this topic: Each of the components in a parallel circuit is connected directly across the battery (or other power source). Since the current through any one component does *not* pass through any other component, the current taken by that component is completely independent of all other components in parallel. As long as the battery voltage doesn't change, the current through that component won't change—even though you add more parallel components, change their value, or take away some components. That component is connected directly across the battery, and its current is always given by $I = \dfrac{E}{R}$, where R is the resistance of that component. The total current supplied by the battery is the sum of the currents drawn by the components in parallel.

> *The voltage is always the same across every component in parallel.*

When all switches in Fig. 5 are closed, each one of the three components is connected directly across the battery. Therefore, the voltage across each one must be 40 V.

WHAT HAVE YOU LEARNED?

1. In Fig. 6 a light, a power saw, and a TV set are operating from the 110-V house wiring. The three devices are connected in *(series) (parallel)*. Turning any one of the devices on or off *(does) (doesn't)* affect the operation of the other two devices—which proves that the current drawn by a device is unaffected by other devices connected in *(series) (parallel)* with it. Hence, to find the current taken by a component or device connected across a constant-voltage source, such as a battery of the 110-V main, you *(have to consider) (don't have to consider)* the current taken by other components or devices in parallel.
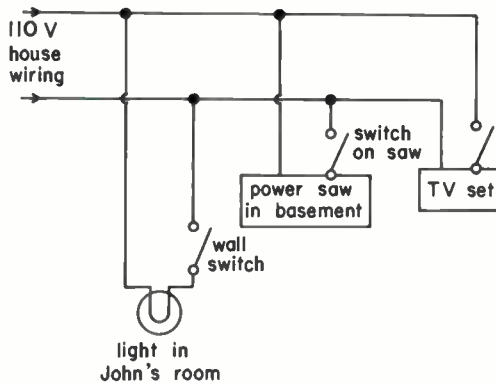
Fig. 6

2. If the TV set in Fig. 6 has an equivalent resistance of 55 Ω, then the set draws a current of _____ amperes. If the power saw has an equivalent resistance of 20 Ω, it draws _____ amperes from the 110-V supply. If the lamp filament has a resistance of 110 Ω, it draws _____ ampere(s) from the line. The total current drawn from the house line in Fig. 6 when all three devices are in use, therefore, is _____ amperes.

3. The ammeter in Fig. 7 reads _____ amperes.
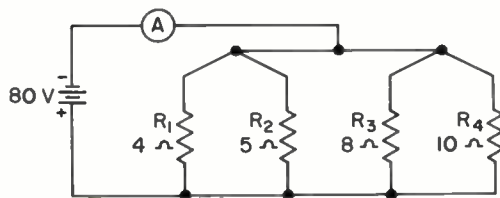
Fig. 7

4. In Fig. 7, the voltage across R_1 is _____ volts; the voltage across R_2 is _____ volts; the voltage across R_3 is _____ volts; and the voltage across R_4 is _____ volts.

5. The voltage applied to R_2 in Fig. 8 *(is) (isn't)* the battery voltage. The current through R_2 is _____ amperes, and the resistance of R_2 is _____ ohms. Using Ohm's law, then, the battery voltage must be _____ volts.
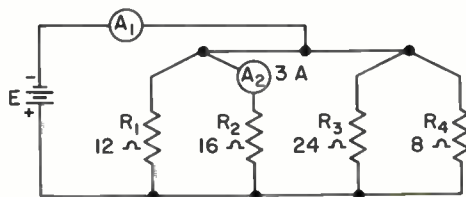
Fig. 8

ANSWERS

1. parallel; doesn't; parallel . . . We'll soon see that components do affect each other when connected in series; don't have to consider.
2. 2; 5.5; 1; 8.5   3. 54 . . . The current through R_1 is 20 A; through R_2, 16 A, through R_3, 10 A, and through R_4, 8 A. The ammeter reads the sum of these currents.
4. 80; 80; 80; 80 . . . The voltages across components in parallel are always equal.
5. is; 3 . . . Ammeter A_2 reads the current through R_2; 16; 48 . . . How this value is obtained is discussed in the next topic.

3 ADDITIONAL PARALLEL CIRCUIT PROBLEMS . . . In the preceding topic, we practiced finding the total current when we knew the battery voltage and the resistance of each component. Now we'll see how to solve parallel-circuit problems no matter what information we have to start with (providing it's adequate). No new principles are involved: solving any parallel circuit problem involves nothing more than using Ohm's law and Kirchhoff's current law.

Example 1 . . . Find the voltage (E) of the battery and the reading of the ammeter (A_1) in Fig. 8.

Solution . . . Studying the circuit, we note that both the current through R_2 and the resistance of R_2 are known. When we know both current and resistance, we can always find the voltage using the Ohm's law formula $E = I \times R$. Note that the voltage found is the battery voltage, because R_2 is connected directly across the battery terminals.

$$\begin{aligned} E &= I_2 \times R_2 \\ &= 3 \text{ A} \times 16 \text{ } \Omega \\ &= 48 \text{ V} \end{aligned}$$

Hence, the battery voltage must be 48 V.

The reading of the ammeter A_1 is the sum of the currents through the four parallel branches. Hence, we must first find the unknown branch currents—which is easy now that we know the battery voltage.

$$\begin{aligned} I_1 &= \frac{E}{R_1} \\ &= \frac{48 \text{ V}}{12 \text{ } \Omega} \\ &= 4 \text{ A} \end{aligned}$$

$$\begin{aligned} I_3 &= \frac{E}{R_3} \\ &= \frac{48 \text{ V}}{24 \text{ } \Omega} \\ &= 2 \text{ A} \end{aligned}$$

$$\begin{aligned} I_4 &= \frac{E}{R_4} \\ &= \frac{48 \text{ V}}{8 \text{ } \Omega} \\ &= 6 \text{ A} \end{aligned}$$

The reading of the ammeter, then, is

$$\begin{aligned} I_1 + I_2 + I_3 + I_4 &= 4 \text{ A} + 3 \text{ A} + 2 \text{ A} + 6 \text{ A} \\ &= 15 \text{ A} \end{aligned}$$

Example 2 . . . Find the resistance of R_3 in Fig. 9.
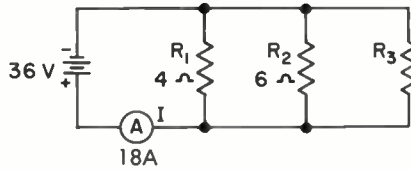
Fig. 9

Solution . . . First, we'll find the current through R_3, using Kirchhoff's current law. Then, we'll find the resistance of R_3 using Ohm's law. However, before we can use Kirchhoff's current law, we must first know the value of the current through R_1 and through R_2.

$$I_1 = \frac{E}{R_1}$$
$$= \frac{36 \text{ V}}{4 \text{ }\Omega}$$
$$= 9 \text{ A}$$

$$I_2 = \frac{E}{R_2}$$
$$= \frac{36 \text{ V}}{6 \text{ }\Omega}$$
$$= 6 \text{ A}$$

According to Kirchhoff's law, the total current I (which the ammeter shows to be 18 A) is equal to the sum of the three branch currents. The sum of I_1 and I_2 is 9 A + 6 A = 15 A. The current through R_3, then, must be 18 A − 15 A = 3 A.

Check . . . $I = I_1 + I_2 + I_3 = 9 \text{ A} + 6 \text{ A} + 3 \text{ A} = 18$ A—which is the reading of the ammeter.

Now we're ready to find the resistance of R_3:

$$R_3 = \frac{E}{I_3}$$
$$= \frac{36 \text{ V}}{3 \text{ A}}$$
$$= 12 \text{ }\Omega, \text{ } ans.$$

WHAT HAVE YOU LEARNED?

1. Ammeter A in Fig. 10 reads _____ amperes.
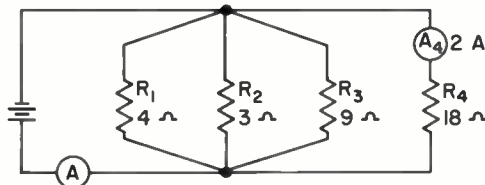
Fig. 10

2. The three resistors in Fig. 11 are in *(parallel) (series)*. Note: They are in parallel if—and *only* if—you can take each resistor in turn, trace through that resistor starting at point B, and return to point C without passing through either of the other two resistors.
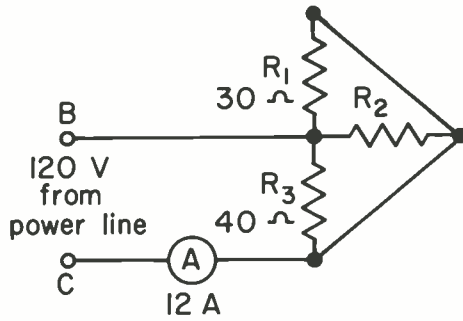
Fig. 11

3. The resistance of R_2 in Fig. 11 is _____ ohms.

4. The voltage of the battery in Fig. 12 is _____ volts.
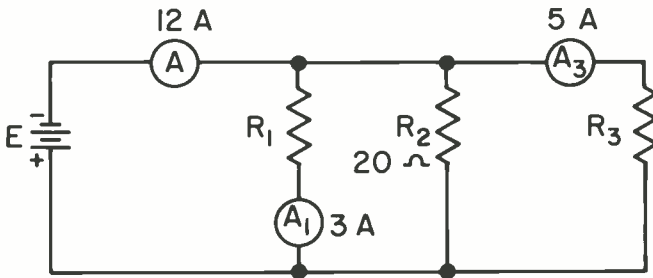
Fig. 12

5. The switch in Fig. 13 is called a double-pole double-throw (DPDT) switch. It has two switch blades B and E, which always move together. When the switch is thrown to the right, blade B makes an electrical connection with contact C and blade E makes a connection with contact F. When the switch is thrown to the left, B makes contact with A and E makes contact with D. Trace around the circuit to find the current path or paths when the switch is thrown to the right, and again when the switch is thrown to the left. Start at the negative battery terminal, and—for each switch position—find all the paths that can be followed that will bring you back to the positive battery terminal.

(a) What lights are on when the switch is to the right?

(b) When the switch is to the right, are the "on" lights connected in series or in parallel?

(c) What lights are on when the switch is to the left?

(d) When the switch is to the left, are the "on" lights in series or in parallel?

Dashed line means that
the switch blades move
in unison.

Fig. 13

Fig. 14

(a)   (b)
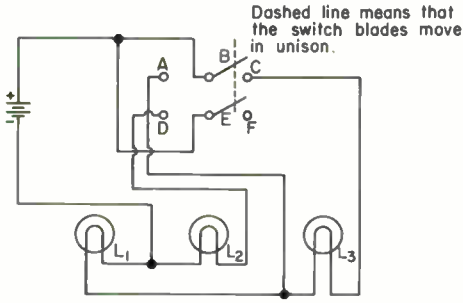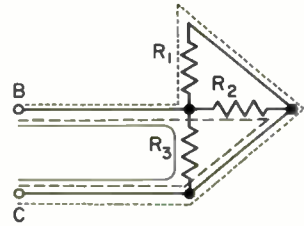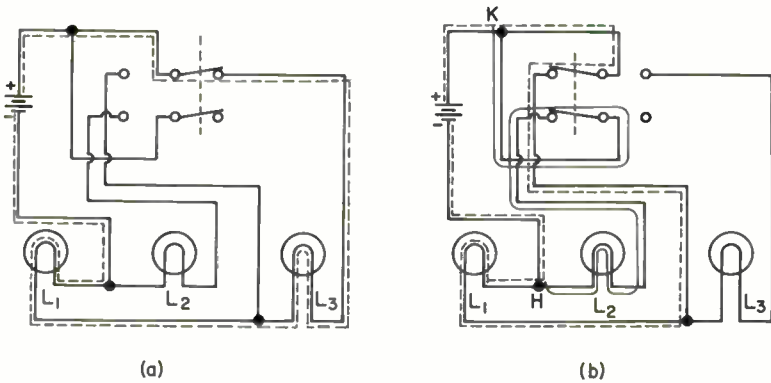
Fig. 15

ANSWERS

1. 27 A . . . The battery voltage is 36 V (2 A $\times$ 18 Ω); I_1 is 9 A; I_2 is 12 A and I_3 is 4 A. In finding the total, don't forget the 2 A of I_4.

2. parallel . . . Each of the three paths in Fig. 11 passes through one and only one resistor. See Fig. 14.

3. 24 . . . R_1 draws 4 A, and R_3 draws 3 A, for a total of 7 A for the two. Hence, R_2 must draw 12 A $-$ 7 A = 5 A. $R_2 = E/I_2 = $ 120 V $\div$ 5 A = 24 Ω.

4. 80 . . . R_1 and R_3 together draw 8 A. Hence, R_2 must draw 4 A so the total of the branch currents will be 12 A. $E = I \times R = $ 4 A $\times$ 20 Ω = 80 V.

5. (a) L_1 and L_3 will be on . . . See Fig. 15(a) for the current path. Note that the path shown by the dashed line is the only possible way to trace around the circuit from negative battery terminal to positive terminal.   (b) series   (c) L_1 and L_2 . . . See Fig. 15(b) for current paths. Tracing from the negative battery terminal, upon reaching point H there are two paths we can follow that will bring us back to K and the positive battery terminal. One path is shown by the dashed line, the other by the solid line.   (d) parallel

4 ELECTRON MOVEMENT IN THE CIRCUIT . . . In the preceding pages, we've analyzed series and parallel circuits by tracing the path taken by electrons leaving the negative plate of the battery until they get back to the positive plate. This is the usual method of circuit tracing, because it's convenient—but some additional explanation is needed so you won't be misled about the nature of electron action when current flows.

If you suppose that electrical action literally starts at the negative battery terminal, you must assume in Fig. 16(a) that—after switch S is closed—light L_1 won't come on until the electrons leaving the negative terminal have time enough to travel to L_1. You would assume that L_2 won't come on until a fraction of a second after L_1 comes on. As it happens, this idea of how current works is all wrong! For one thing, electrons move along a wire very slowly—seldom more than an inch a minute. Thus, if L_1 were 20 ft (feet) away from the battery, say, if we had to wait for the electrons to get from the negative terminal to L_1, it would be several hours after the switch was closed before the light came on!
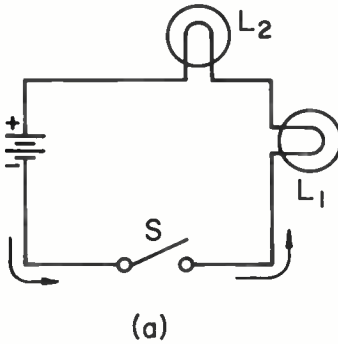
Fig. 16   **(a)**

What actually happens when the switch is closed, is that the electrons start moving in *all* parts of the circuit almost instantly. The action is much like that of the bicycle chain in Fig. 16(b). Although the chain may be pulled slowly, the links start moving everywhere in the chain almost the moment the operator starts pulling (not instantly, because the slack must first be taken out from between the links). Note that the chain has no beginning and no end.
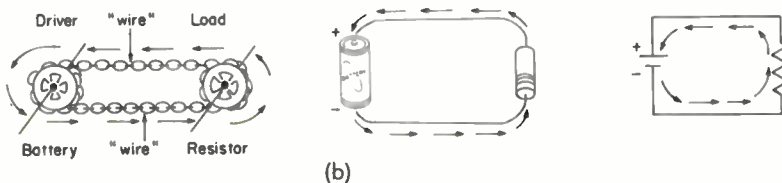
(b)

Fig. 16   The flow of current is like the movement of a continuous chain.

The flow of current acts in much the same way. Whether the switch in Fig. l6(c) is open or closed, there are free electrons everywhere in the wire and in the conducting parts of the components. (These electrons correspond to the links of the chain.) When the switch is closed, all the free electrons start moving almost at once, forming an endless chain of electrons moving slowly around the circuit. An important thing to note in Fig. l6(c) is that there's neither a beginning nor an end to the moving chain of electrons—in other words, you can't put your finger on a particular spot in the circuit and say that this is where the current starts. Only for convenience do we start tracing through a circuit at the negative battery terminal—*not* because the current starts there.
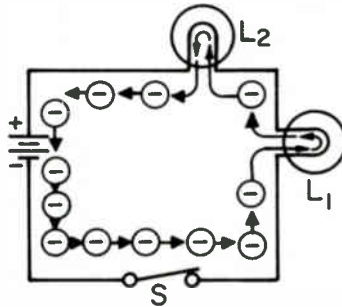
Fig. 16   **(c)**

To see why the free electrons are "hooked" together like the links in a chain (so that one can't move along the wire without the rest moving, too), consider the short section of wire diagrammed in Fig. l6(d). Since every electron has a negative charge, all electrons repel one another; therefore, they try to get as far away from each other as they can. It follows, then, that they're farthest away from each other when they're equally spaced along the wire. Suppose that electron *C* in Fig. l6(d) is pushed to the right from its normal position, as shown—say, by the battery pumping action. That will make all the other electrons in the wire also move, and here's why. Electron *C* moving over closer to *D* greatly increases the repulsive force between *C* and *D*: the closer like electric charges are to each other, the stronger the force of repulsion between them. Consequently, electron *D* is pushed over toward *E*, which in turn repels *E* to the right, and so on.
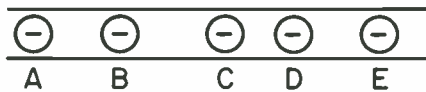
Fig. 16   **(d)**

16 Looking at the electrons to the left of C, you can see that the distance between B and C has increased as C has moved to the right. That reduces the repulsion between B and C. As a result, electron A is pushing harder in its efforts to move B to the right than C is pushing in its efforts to push B to the left. Consequently, electron B moves to the right, which in turn weakens the repulsion between B and A, and in turn allows A also to be pushed to the right by the electron to *its* left.

Because of the time required for all of this electron jockeying to take place, there is a slight time delay after the switch is closed before all the electrons in the circuit are in motion. This delay corresponds to the time required to get the slack out of the chain in Fig. 16(b) before all the links move. The delay in a typical electrical circuit is extremely slight—a few millionths of a second, or even less. But slight as it is, it can be important, as you'll see in later lessons.

LESSON 2323A-7
PARALLEL CIRCUITS

EXAMINATION

1. If there's only one possible path for current to take in flowing around a circuit, the circuit is
   (1) a low-current circuit.   (3) a high-voltage circuit.
   (2) a parallel circuit   (4) a series circuit.

2. An engineer is designing a system that will enable an aircraft to indicate an emergency condition. The system is supposed to turn on a red lamp in the cockpit whenever the landing gear fails to come down and lock. Because an LED (light-emitting diode) may not be bright enough, the engineer must use incandescent (filament-type) lamps. The engineer decides that since an incandescent lamp may fail, he will have to include, another lamp as a backup. If the lamp fails by open-circuiting, should the two lamps be wired
   (1) in series—so that if one lamp fails, the other will still work?
   (2) in parallel—so that if one lamp fails, the other will still work?

3. In the series circuit shown in Fig. 17,
   (1) the current is the same in the lamp and both resistors, and can be read on the ammeter.
   (2) the current is greatest in the lamp.
   (3) the current is greatest in R_2.
   (4) the current is greatest in R_1.
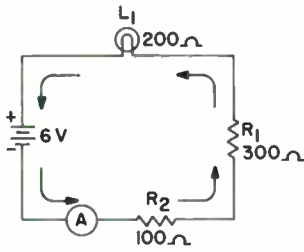
Fig. 17
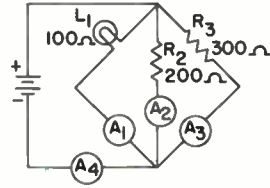
Fig. 18

4. The current flowing *into* R_1 in Fig. 17 is 10 mA. How much current is flowing *out of* R_1?
   (1) 20 mA   (2) 5 mA   (3) 10 mA   (4) 15 mA

5. Which ammeter in Fig. 18 will read the least current?
   (1) A_4 (2) A_3 (3) A_2 (4) A_1

6. If in the circuit of Fig. 18, A_1 reads 30 mA; A_2 reads 15 mA; and A_4 reads 55 mA, then A_3 reads
   (1) 45 mA.   (2) 30 mA.   (3) 20 mA.   (4) 10 mA.

7. If the voltage across the 300-Ω resistor in Fig. 18 is 3 V, the voltage across the lamp is
   (1) 4.5 V.   (2) 3 V.   (3) 2 V.   (4) 1 V.

8. If another parallel branch were added to the circuit of Fig. 18 by connecting another 300-Ω resistor as shown in Fig. 19, the current read on A_4 would
   (1) not change.   (2) increase.   (3) decrease.
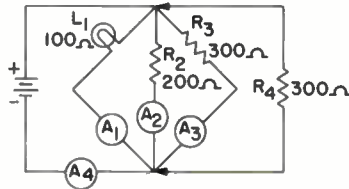
Fig. 19

9. Referring to question 8, the current read on A_3 would
   (1) not change.   (2) increase.   (3) decrease.

10. The best way to tell a series circuit from a parallel circuit is to trace around the circuit by all possible paths that make a complete loop.
    (1) If there is only one such path, it is a parallel circuit; if more than one, it is a series circuit.
    (2) If there is only one such path, it is a series circuit; if more than one, it is a parallel circuit.

END OF EXAM

Lesson 2323B-7
Equivalent Circuits

COMBINED RESISTANCE IN SERIES AND PARALLEL CIRCUITS

A circuit can often be simplified and made easier to understand if it is redrawn with several components replaced by a single *equivalent* component. The principle of equivalent components will be used in this part of the lesson to find the combined resistance of circuit components in series or parallel.

5 HOW EQUIVALENT CIRCUITS MAKE ELECTRONICS EASY . . . The series circuit of Fig. 1 is redrawn in Fig. 20 with resistance and voltage values shown. It's hard for current to get through the extremely fine wire that forms the filament in a light bulb. Therefore, a light bulb has resistance (that is, opposes current) just as regular resistors do. In this case, the filament resistance is 6 Ω.
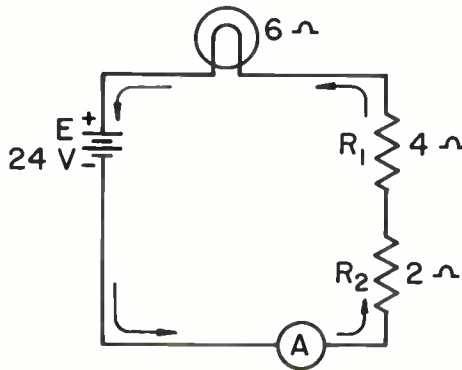
Fig. 20 **The current in a series must make its way through all the resistances in the circuit.**

Let's find out what the ammeter *A* in Fig. 20 will read. Since this is a series circuit, every electron going around the circuit must pass through the 2-Ω, the 4-Ω, and the 6-Ω resistors. Each one of these resistances opposes (tries to stop) the current. Since the electrons must struggle through all three resistors, the going is a lot harder (which means that the resistance is higher) than if the electrons had but one resistance to go through—which is only natural, if you think about it: the more obstacles there are in an obstacle course, the tougher it is to get around the course.

Since the electrons in Fig. 20 must first make their way through 2 Ω of opposition, then through 4 Ω of opposition, and finally through 6 Ω of opposition, the total opposition to current is 2 Ω + 4 Ω + 6 Ω = 12 Ω. If we had one 12-Ω resistor in the circuit, then, instead of the three smaller resistances shown, the current read by ammeter *A* would be the same as it is in the actual circuit. That being the case, we can draw an *equivalent circuit* in which the three actual resistances are replaced by a 12-Ω equivalent resistance. See Fig. 21.

An equivalent circuit is a simplified circuit that has the same performance—at least in regard to the aspects in which we're interested—as the original circuit. We use equivalent circuits to help us solve problems and to help us understand circuit operation.

For example, Fig. 21(b) is equivalent to Fig. 21(a) (and to Fig. 20) as far as voltage, current, and resistance are concerned. Each circuit has a source voltage of 24 V and a total resistance of 12 Ω. By using Ohm's law, we can find at once the reading of ammeter *A* in Fig. 21(b):

$$I = \frac{E}{R}$$
$$= \frac{24 \text{ V}}{12 \text{ Ω}}$$
$$= 2 \text{ A}$$

Since the ammeter in Fig. 21(b) reads 2 A, the ammeter in (a) will read the same thing. (If the two ammeters didn't read the same thing, the circuits wouldn't be equivalent with regard to current.)

(a) Actual circuit   (b) Equivalent circuit
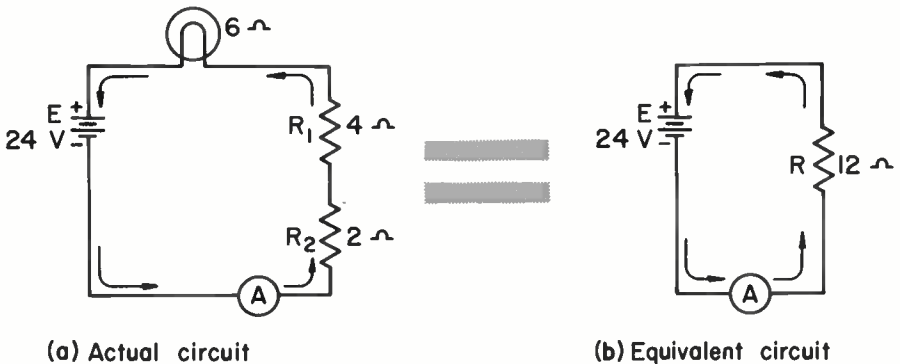
Fig. 21   Simplifying a circuit by the use of an equivalent circuit.

6 FINDING CURRENT AND TOTAL RESISTANCE IN A SERIES CIRCUIT
. . . The total (combined) resistance of two or more resistances is a single resistance of such value that, when used in place of the original resistances, it will keep the circuit current the same. In other words, the total, or combined, resistance is the *equivalent* resistance of the circuit resistances. The total resistance in Fig. 21(a) is 12 Ω, for example, because if we replace the three resistances with a 12-Ω resistance, as in (b), the circuit current remains the same.

When resistances are in series, the total resistance is easy to find: it's simply the sum of the individual resistances.

Example 1 . . . In Fig. 22(a), the three resistors R_1, R_2, and R_3—shown connected in series—have values of 20, 30, and 40 Ω respectively. Find their total resistance.

(a)   (b)
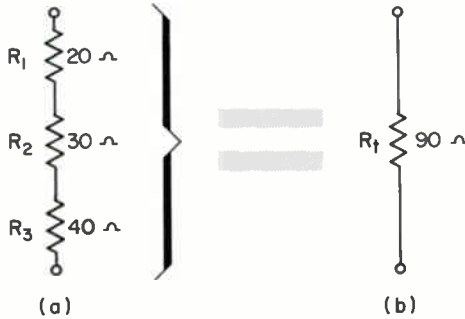
Fig. 22   The total resistance of resistors in series equals the sum of the resistance of the individual resistors.

Solution . . . $R_t = R_1 + R_2 + R_3$
$= 20 \text{ Ω} + 30 \text{ Ω} + 40 \text{ Ω}$
$= 90 \text{ Ω}$

Explanation . . . The answer shows that the three resistors in series could be replaced by a single 90-Ω resistor, as shown in Fig. 22(b).

Example 2 . . . If the three resistors in Fig. 22(a) are connected across a 9-V battery, the total current is _____ amperes.

Solution . . . The total current is found using Ohm's law:

$$I = \frac{E}{R}$$
$$= \frac{9 \text{ V}}{90 \text{ Ω}}$$
$$= 0.1 \text{ A}$$

Explanation . . . Since the current through each element in a series circuit is the same, the current through R_1, R_2, R_3, and the battery is 0.1 A.

Example 3 . . . A lamp filament is connected in series with a resistor. The color code on the resistor, green-blue-black, shows that the resistance R_r of the resistor is 56 Ω. By measuring with an ohmmeter, you find that the total resistance of the filament and resistor in series is 87 Ω. The resistance R_f of the filament, then, is _____ ohms.

Solution . . . $R_t = R_f + R_r$
$\quad\quad\quad 87\ Ω = R_f + 56\ Ω$
$\quad\quad\quad\quad R_f = 31\ Ω$

Explanation . . . Since 87 Ω is the combined resistance of the filament and resistor in series, 87 Ω minus the resistance of the resistor (56 Ω) is the resistance of the filament.

Check . . . 31 Ω + 56 Ω = 87 Ω.

WHAT HAVE YOU LEARNED?

1. Three resistors with values of 15, 22, and 19 Ω are connected in series to an 84-V battery.
(a) Draw the circuit, and mark the voltage and resistance values on it. (That's the way to start working *any* electronics problem.)
(b) Find the total resistance.
(c) Draw the equivalent circuit. (Electronics gets easy when you get in the habit of drawing equivalent circuits.)
(d) Use Ohm's law to find the circuit current.

2. If a relay coil has a resistance of 20 Ω, how much resistance must you connect in series with it so that the total circuit resistance is 50 Ω?

3. A series circuit is operated from an 80-V power source. If we want the circuit current to be 4 A, what total value of resistance do we need in the circuit?

4. If a relay coil that requires a current of 1.5 A for proper operation is to be operated from a 24-V battery, what should the relay resistance be in order for the relay to draw the correct current?

5. If the resistance of the relay coil in Problem 4 were actually only 10 Ω, the relay would draw *(too much) (too little)* current when operated from a 24-V battery.

6. Referring to Problem 5, you could decrease the current through the relay down to what it should be by *(increasing) (decreasing)* the total circuit resistance. To do so, you'd connect a resistor in *(series) (parallel)* with the relay coil.
(a) Draw a diagram of the circuit, indicating battery voltage and coil resistance.
(b) Draw an equivalent circuit, showing the proper value of equivalent (total) resistance for the circuit current to be the correct value of 1.5 A.
(c) What must be the value of the resistance placed in series with the relay coil?

7. Three resistors are connected in series. One resistor is color-coded brown-black-brown, so you know it to be rated at _____ ohms. The second resistor is color-coded brown-brown-brown, so its value is _____ ohms. The third resistor isn't color-coded. You measure the total resistance of the circuit, which is 340 ohms. The resistance of the unmarked resistor is therefore _____ ohms. The correct color code for this resistor is _____.

8. In Fig. 1 (page 2), if R_1 is 10 Ω, R_2 is 20 Ω, and the lamp is 50 Ω, the combined resistance of the circuit is _____ ohms. If the battery voltage E is 160 V, the circuit current is _____ amperes. The current through R_1 is _____ amperes; the current through R_2 is _____ amperes; and the current through the lamp is _____ amperes.

9. Show by a diagram how to connect three equal resistors in such a way that the combined resistance of the three is equal to 3 times the resistance of each.

10. A fixed resistor of 10,000 Ω is connected in series with a variable resistor with a minimum value of 100 Ω and a maximum of 5000 Ω. The minimum resistance this combination can have is _____ ohms, and the maximum value it can have is _____ ohms. If this combination is connected across a 250-V power supply, the minimum possible current is _____ milliamperes and the maximum possible current is _____ milliamperes.

ANSWERS

1. (a) See Fig. 23(a).   (b) 56 Ω (c) See Fig. 23(b).
(d) 1.5 A . . . $I = \dfrac{E}{R} = \dfrac{84 \text{ V}}{56 \text{ }\Omega} = 1.5$ A
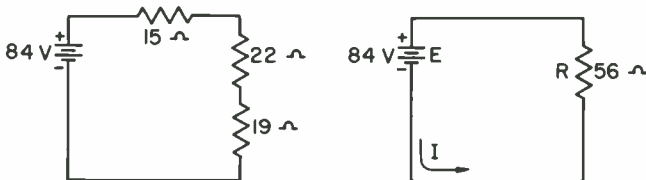
Fig. 23   original circuit   equivalent circuit

2. 30 Ω . . . See Fig. 24.

Fig. 24 actual circuit equivalent circuit

3. 20 Ω . . . Use the Ohm's law formula: $R = \dfrac{E}{I} = \dfrac{80 \text{ V}}{4 \text{ A}} = 20 \ \Omega$.

4. 16 Ω . . . $R = \dfrac{E}{I} = \dfrac{24 \text{ V}}{1.5 \text{ A}} = 16 \ \Omega$.

5. too much . . . The less the resistance, the more the current, because resistance opposes current.

6. increasing; series; (a) See Fig. 25(a); (b) See Fig. 25(b); (c) 6 Ω . . . R_1 and the relay coil must have a total resistance of 16 Ω, as shown in the equivalent circuit. $R_1 = 6 \ \Omega$, since 10 Ω + 6 Ω = 16 Ω.

(a) actual circuit (b) equivalent circuit

Fig. 25

7. 100; 110; 130 . . . The combined resistance of the known resistors is 210 Ω. Since the total resistance is 340 Ω, the resistance of the unmarked resistor is 340 − 210 = 130 Ω; brown-orange-brown.

8. 80; 2; 2; 2; 2 . . . In a series circuit, the current through one component is equal to the current through each of the other components.

9. -WW-WW-WW- . . . If the value of each resistor is 10 Ω, the total resistance is 30 Ω or 3 times the resistance of each individual resistor.

10. 10,100; 15,000; 16.7 . . . Remember that the current is least when the resistance is highest, which is when the resistance is 15,000 Ω. Then the current is $I = \dfrac{E}{R} = \dfrac{250 \text{ V}}{15,000 \ \Omega} =$ 0.0167 A = 16.7 mA. (We multiply by 1000 to change amperes to milliamperes.); 24.8 . . . The current is greatest when the resistance is least. Thus:

$$I = \frac{E}{R}$$
$$= \frac{250 \text{ V}}{10100 \ \Omega}$$
$$= 0.0248 \text{ A}$$
$$= 24.8 \text{ mA}.$$

7 RESISTANCE IN PARALLEL CIRCUITS . . . The combined or joint resistance of two or more resistances in parallel is a single resistance of such value that, when it's used in place of the original resistances, it will keep the circuit current the same. In other words, it's the equivalent resistance of the circuit resistances.

To find the combined resistance of the three branches in Fig. 5 (page 6) with all switches closed, we can use Ohm's law to find what equivalent resistance to use in place of the three resistances so that the reading of ammeter *A* won't change. (Ammeter *A* reads 11 A.)

$$R = \frac{E}{I}$$
$$= \frac{40 \text{ V}}{11 \text{ A}}$$
$$= 3.64 \text{ } \Omega$$

Thus, we can replace the three resistances of Fig. 5 with an equivalent resistance, as shown in Fig. 26(b). The value of this combined resistance is 3.64 Ω.

original circuit   equivalent circuit
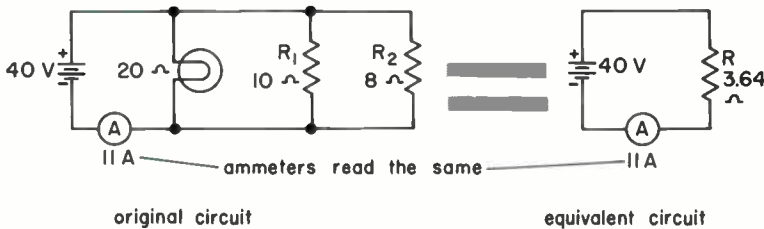
Fig. 26   The combined resistance of 20, 10 and 8 Ω in parallel is 3.64 Ω.

We'll next see how changes in individual resistance values affect the combined resistance. We've learned that, in series circuits, the combined resistance is the sum of the resistances of the individual components. In other words, in the series circuit Fig. 27(a), adding resistive components *increases* the amount of opposition, or resistance, to current flow.

(a) Series circuit   (b) Parallel circuit
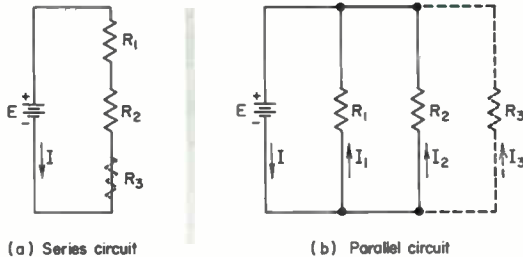
Fig. 27   Effect of adding resistance in series and parallel circuits. In the series circuit (a), adding resistor R_3 increases opposition, or resistance, to the flow of current. In the parallel circuit (b), adding the branch with resistor R_3 adds another path along which current can flow, and thereby decreases opposition (or resistance) to the flow of current.

In parallel circuits, though, the situation is quite different. In such a circuit, each additional branch, as shown in Fig. 27(b), is another path along which current can flow. Thus, adding resistance in parallel *decreases* the total resistance of the circuit.

Example . . . In Fig. 28, five resistive components are shown connected in parallel. R_1 = 5 Ω, R_2 = 8 Ω, R_3 = 10 Ω, R_4 = 16 Ω, and R_5 = 20 Ω. Is the combined resistance of the circuit, as measured between points A and B, more or less than 5 Ω?
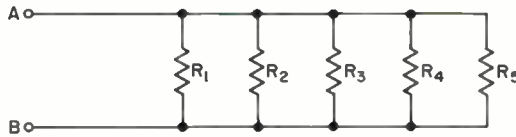
Fig. 28 **Circuit with five resistive parallel branches. The total resistance of a parallel circuit is always less than the resistance of the branch that has the lowest resistance.**

Solution . . . The combined resistance is less than 5 Ω.

Explanation . . . In this example, the lowest resistance is 5 Ω. Each resistor connected in parallel across the 5-Ω resistor is another path along which current can flow, and each resistor therefore decreases the total resistance below 5 Ω. You can always be sure, without even performing any calculations, that the combined resistance of a parallel circuit is less than the resistance of the branch that has the lowest resistance.

(o)   (b)
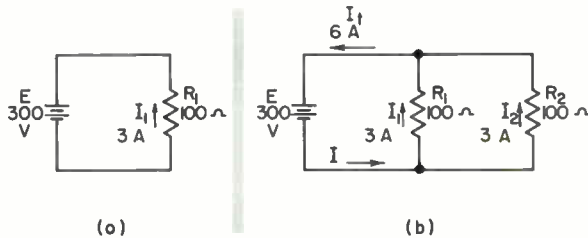
Fig. 29 **When a parallel resistor is added to the circuit in (a), total current increases as shown in (b).**

Now let's see what happens in a circuit when one resistor is connected in parallel with a second, equal resistor. In Fig 29(a) a 100-Ω resistor is connected across a 300-V battery. The current is found as follows:

$$I_1 = \frac{E}{R_1}$$
$$= \frac{300 \text{ V}}{100 \text{ Ω}}$$
$$= 3 \text{ A}$$

26 In Fig. 29(b), a second 100-Ω resistor (R_2) is connected in parallel with the first. Note that this second resistor is connected across the battery terminals in the same way as the first resistor. In other words, the voltage across R_2 is 300 V. The current I_2 through R_2 is

$$I_2 = \frac{E}{R_2}$$
$$= \frac{300 \text{ V}}{100 \text{ Ω}}$$
$$= 3 \text{ A}$$

Remember that the total current is the sum of the branch currents. In this case, the total current I_t is

$$I_t = I_1 + I_2$$
$$= 3 \text{ A} + 3 \text{ A}$$
$$= 6 \text{ A}$$

Thus, placing the second resistance in parallel with the first increases the amount of current drawn by the circuit from 3 to 6 A. In this particular example, where the resistances of the two branches are equal, adding the second equal resistor *doubles* the total current.

What happens to the combined resistance? Using Ohm's law for resistance, we find in Fig. 29(a):

$$R = \frac{E}{I_1}$$
$$= \frac{300 \text{ V}}{3 \text{ A}}$$
$$= 100 \text{ Ω}$$

Similarly, in Fig. 29(b):

$$R = \frac{E}{I_t}$$
$$= \frac{300 \text{ V}}{6 \text{ A}}$$
$$= 50 \text{ Ω}$$

Thus, adding the second equal resistor in parallel with the first *halves* the total resistance while it *doubles* the total current.

> Rule: *To find the combined resistance of equal resistances in parallel, divide the value of a single resistance by the number of resistors.*

Example . . . In Fig. 30, four 100-Ω resistors are in parallel across a 200-V supply. The
combined resistance of the circuit is (a) _____ ohms. The total circuit current I is
(b) _____ amperes. If the four resistors were in series rather than in parallel, the
combined resistance would be (c) _____ ohms, and the total current would be (d)
_____ amperes. When the resistors are connected in parallel, the current through
any one of the four resistors is (e) _____ amperes. When the resistors are connected
in series, the current through any one of the four resistors is (f) _____ amperes.
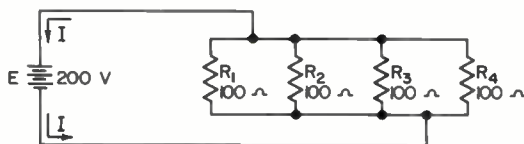
Fig. 30

Solution . . . (a) $R_t = \dfrac{100\ \Omega}{4} = 25\ \Omega$

(b) $I = \dfrac{E}{R_t} = \dfrac{200\ V}{25\ \Omega} = 8\ A$

(c) $R_t = R_1 + R_2 + R_3 + R_4 = 4 \times 100\ \Omega = 400\ \Omega$

(d) $I = \dfrac{E}{R_t} = \dfrac{200\ V}{400\ \Omega} = 0.5\ A$

(e) Since the total current (8 A) divides evenly among the four equal resistors, the current
through any one of the resistors is $8 \div 4 = 2\ A$
(f) From (d), the current is 0.5 A.
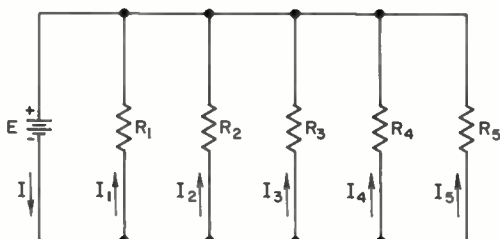
Fig. 31   Parallel circuit containing five resistive branches.

When a number of unequal resistances are in parallel, as in Fig. 31, the combined
resistance is found using the formula

$$R = \cfrac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \dfrac{1}{R_4} + \dfrac{1}{R_5}}$$

Thus, *the resistance of a parallel circuit is equal to the reciprocal of the sum of
the reciprocals of the resistances of the individual branches.* (The quantity $1/X$
is the reciprocal of X.)

Example 1 . . . A parallel circuit consists of four resistive branches: $R_1 = 3\ \Omega$, $R_2 = 5\ \Omega$, $R_3 = 20\ \Omega$ and $R_4 = 50\ \Omega$. The total resistance of the circuit is _____ ohms.

Solution . . .
$$R_t = \cfrac{1}{\cfrac{1}{R_1} + \cfrac{1}{R_2} + \cfrac{1}{R_3} + \cfrac{1}{R_4}}$$

$$= \cfrac{1}{\cfrac{1}{3} + \cfrac{1}{5} + \cfrac{1}{20} + \cfrac{1}{50}}$$

$$= \cfrac{1}{0.333 + 0.2 + 0.05 + 0.02}$$

$$= \cfrac{1}{0.603}$$

$$= 1.66\ \Omega$$

Explanation . . . Four resistive components are in parallel. Therefore, there are four terms in the denominator of the equation for resistance. To solve, we substitute numerical values into the equation, convert to decimals, and complete the operations indicated.

Example 2 . . . In Fig. 31, if $E = 22$ V, $R_1 = 2\ \Omega$ $R_2 = 4\ \Omega$ $R_3 = 5\ \Omega$, $R_4 = 10\ \Omega$, and $R_5 = 20\ \Omega$, $I =$ _____ amperes.

Solution . . .
$$R_t = \cfrac{1}{\cfrac{1}{R_1} + \cfrac{1}{R_2} + \cfrac{1}{R_3} + \cfrac{1}{R_4} + \cfrac{1}{R_5}}$$

$$= \cfrac{1}{\cfrac{1}{2} + \cfrac{1}{4} + \cfrac{1}{5} + \cfrac{1}{10} + \cfrac{1}{20}}$$

$$= \cfrac{1}{0.5 + 0.25 + 0.2 + 0.1 + 0.05}$$

$$= \cfrac{1}{1.10}$$

$$= 0.909\ \Omega$$

For the circuit, $I = \dfrac{E}{R_t} = \dfrac{22\ V}{0.909\ \Omega} = 24.2$ A

For the special case of two resistive components in parallel, we can use a simpler formula:

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

That is, *the resistance of a circuit consisting of two resistances in parallel is equal to the product of the two resistances divided by their sum.*

Example 1 . . . A parallel circuit consists of a 5-Ω resistance in parallel with a 20-Ω resistance. The resistance of the parallel combination is _____ ohms.

Solution . . . Using the formula $R_t = \dfrac{R_1 R_2}{R_1 + R_2}$,

$$R_t = \dfrac{5 \times 20}{5 + 20}$$
$$= \dfrac{100}{25}$$
$$= 4 \; \Omega$$

Example 2 . . . Three resistors with values of 5, 20, and 50 Ω are connected in parallel. By using the special parallel resistance formula for two resistors, find the total resistance of the three resistors.

Solution . . . The parallel resistance of the 5-Ω and the 20-Ω resistors is equal to

$$R = \dfrac{5 \times 20}{5 + 20}$$
$$= \dfrac{100}{25}$$
$$= 4 \; \Omega$$

We can now consider the circuit as having only two resistors in parallel. One resistor is the 50-Ω resistor, and the other the 4-Ω equivalent resistor. Applying the special parallel resistor formula for two resistors, we have

$$R_t = \dfrac{4 \times 50}{4 + 50}$$
$$= \dfrac{200}{54}$$
$$= 3.70 \; \Omega$$

WHAT HAVE YOU LEARNED?

1. Three resistors with values of 5, 7.5, and 15 Ω are connected in parallel. Their combined resistance is less than (a) _____ ohms. Calculation shows the combined resistance to be (b) _____ ohms.

2. Two resistors with values of 10 and 30 Ω are connected in parallel. By using the formula for resistance of two resistors in parallel ($R = $ (a) _____), you find their combined resistance is (b) _____ ohms. As a quick check, you realize that the resistance must be less than (c) _____ ohms; therefore, the answer to (b) is reasonable.

3. Two 100-Ω resistors are connected in parallel. Their resistance is (a) _____ ohms. Three 100-Ω resistors are connected in parallel. Their combined resistance is (b) _____ ohms. Four 100-Ω resistors are connected in parallel; their combined resistance is (c) _____ ohms.

E
120 V

R_1
5 Ω

R_2
14 Ω

R_3
21 Ω

R_4
25 Ω

R_5
100 Ω
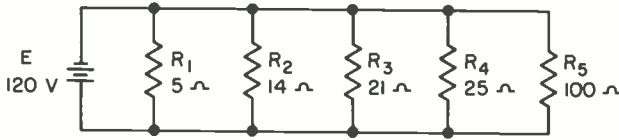
Fig. 32

4. Figure 32 shows five resistors connected in parallel. Use the general formula for resistors in parallel to find the combined resistance of the parallel combination of resistors:

$\frac{1}{R_1}$ = (a) _____ $\frac{1}{R_2}$ = (b) _____ $\frac{1}{R_3}$ = (c) _____

$\frac{1}{R_4}$ = (d) _____ $\frac{1}{R_5}$ = (e) _____

Therefore R_t = (f) _____ = (g) _____ ohms.

5. The total current through the parallel combination in Problem 4 is _____ amperes. (Use the combined resistance and Ohm's law for current.)

6. The total current through the parallel combination to Problem 4 is _____ amperes. (First determine the current through each individual resistor and then sum up the individual currents.

7. Four light bulbs, each with a resistance of 160 Ω, are connected in parallel across a 120-V source. Their combined resistance is (a) _____ ohms. The current drawn by each light bulb is (b) _____ amperes, and the total current is (c) _____ amperes.

8. Two resistors, 40 and 80 Ω, are connected in parallel. Their combined resistance is less than (a) _____ ohms. The combined resistance is (b) _____ ohms.

9. Three resistors, 40, 90, and 75 Ω, are connected in parallel. Their combined resistance is (a) _____ ohms. If connected across a potential of 100 V, the parallel combination will draw (b) _____ amperes.

10. When charging a storage battery, it is necessary to insert a resistance of 20 Ω in series with the battery to limit current to the proper value. The resistance is made up of light bulbs, each with a resistance of 140 Ω, connected in parallel. How many bulbs should be used to produce the required resistance?

1. (a) 5 . . . Combined resistance is always less than the least of the resistances.

(b) 2.5 . . . $R_t = \dfrac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}}$

$= \dfrac{1}{\dfrac{1}{5} + \dfrac{1}{7.5} + \dfrac{1}{15}}$

$= \dfrac{1}{0.2000 + 0.1333 + 0.0667} = \dfrac{1}{0.4000} = 2.5\ \Omega$

2. (a) $\dfrac{R_1 \times R_2}{R_1 + R_2}$; (b) 7.5; (c) 10   3. (a) 50; (b) 33⅓; (c) 25

4. (a) 0.2; (b) 0.0714; (c) 0.0476; (d) 0.04; (e) 0.01; (f) $\dfrac{1}{0.369}$; (g) 2.71

5. 44.3 . . . 120 V ÷ 2.71 Ω = 44.3 A.

6. 44.3 . . . $I_1 = 24$ A, $I_2 = 8.57$ A, $I_3 = 5.71$ A, $I_4 = 4.8$ A, $I_5 = 1.2$ A; then 24 + 8.57 + 5.71 + 4.8 + 1.2 = 44.3 A.

7. (a) 40; (b) 0.75; (c) 3   8. (a) 40; (b) 26.7   9. (a) 20.2; (b) 4.95

10. seven . . . $\dfrac{140\ \Omega}{7} = 20\ \Omega.$

8 CONDUCTANCE . . . So far in our discussion of DC circuits, we've studied only *resistance*, which is a measure of the *opposition* of a circuit to the flow of the current. Resistance is, of course, usually represented by the letter R, and is measured in ohms (Ω).

Now, let's turn our attention to a new quantity, *conductance*. Conductance is a measure of *how easy* it is for a current to flow through a circuit. Conductance is usually represented by the letter G, and is measured in *mhos*.* (Note that "mho" is "ohm" spelled backwards.) An inverted capital omega ($\mho$) is sometimes used to represent mhos.

Conductance (G) is the reciprocal of resistance (R). That is,

$$G = \frac{1}{R}$$

Thus, the conductance of a 100-Ω resistor, for example, is found as follows:

$$G = \frac{1}{R}$$
$$= \frac{1}{100}$$
$$= 0.01\ \text{mho}$$

*More recently, the IEEE has adopted the term *siemens* (S) as the unit of conductance.

32   Since conductance is the reciprocal of resistance, it follows that resistance is the reciprocal of conductance—in other words, $R = \frac{1}{G}$. This means that we can easily convert from conductance back to resistance. For example, if $G = 0.01$ mho,

$$R = \frac{1}{G}$$
$$= \frac{1}{0.01 \ \text{mho}}$$
$$= 100 \ \Omega$$

—which proves our previous calculation.

WHAT HAVE YOU LEARNED?

1. The unit of conductance is the _____, and the symbol for conductance is _____. Since conductance is the reciprocal of _____, the formula for conductance is _____.

2. The greater the conductance, the easier it is for a current to flow through a circuit. Therefore, a circuit with a conductance of 0.05 mho will have *(more) (less)* current for a given voltage than a circuit with a conductance of 0.5 mho. The greater the circuit resistance, the _____ the circuit conductance. The greater the circuit conductance, the _____ the circuit resistance.

3. If the resistance of a circuit is 25 Ω, its conductance is _____ mho. If the resistance of a circuit is 10 Ω, its conductance is _____ mho. If the conductance of a circuit is 0.02 mho, the resistance of the circuit is _____ ohms.

4. Suppose 12 V is applied to a circuit with a current of 6 A. The circuit conductance is _____ mhos.

ANSWERS

1. mho; G; resistance; $G = \frac{1}{R}$ 2. less; less; less

3. 0.04 . . . $\frac{1}{25} = 0.04$ mho; 0.1; 50 . . . $\frac{1}{0.02} = 50 \ \Omega$

4. 0.5 . . . $R = \frac{E}{I} = 2 \ \Omega$; $G = \frac{1}{R} = \frac{1}{2} = 0.5$ mho

EXAMINATION

1. *Conductance* is
   (1) the change in voltage accompanied by a change in resistance.
   (2) the change in current accompanied by a change in voltage.
   (3) the ability of a circuit to resist current.
   (4) the ability of a circuit to conduct current.

2. The unit of conductance is the
   (1) coulomb.   (2) mho.   (3) volt.   (4) ohm.

3. The conductance of a circuit in which 9 A flows when 12 V is applied is
   (1) 0.75 mho.   (3) 9 mhos.
   (2) 8 mhos.   (4) 108 mhos.

4. If several resistors are connected in parallel,
   (1) the equivalent resistance is less than that of the resistor with the highest resistance, but greater than that of the resistor with the lowest resistance.
   (2) the equivalent resistance is less than that of the resistor with the least resistance.
   (3) the equivalent resistance is the sum of the individual resistance values.

5. The equivalent resistance of a parallel circuit consisting of one branch of 12 Ω resistance and one branch of 6 Ω resistance is
   (1) 18 Ω.   (3) 4 Ω.
   (2) 9 Ω   (4) 3 Ω.

6. What is the total resistance in the circuit of Fig. 33?
   (1) 6.86 Ω   (2) 20 Ω   (3) 28 Ω   (4) 16 Ω   (5) 24 Ω
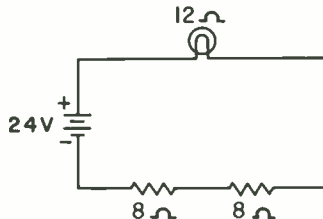
Fig. 33

7. Figure 34(b) shows an equivalent circuit of Fig. 34(a). What's the value of R in the equivalent circuit?
   (1) 20 Ω   (2) 15 Ω   (3) 12 Ω   (4) 10 Ω   (5) 7 Ω

8. If A_1 in Fig. 34(a) has a reading of 3 A, what is the reading of A_2 in Fig. 34(b)?

    (1) 5 A   (2) 3 A   (3) 2 A   (4) 1.5 A   (5) 1 A
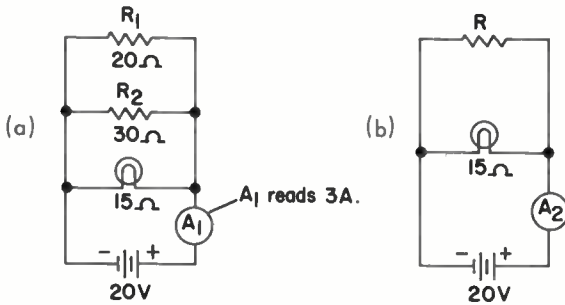
Fig. 34

9. You need a 5-Ω resistor, but all you have are three 10-Ω resistors. To obtain the required 5-Ω resistance, you could connect

    (1) two 10-Ω resistors in parallel.

    (2) two 10-Ω resistors in series.

    (3) three 10-Ω resistors in parallel.

    (4) three 10-Ω resistors in series.
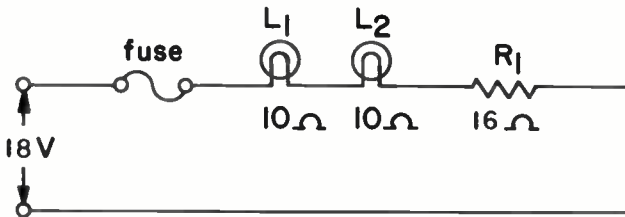
Fig. 35

10. Suppose you wish to determine the proper size of fuse to use in the circuit of Fig. 35. The size of a fuse is simply the number of amperes it can carry without melting and opening the circuit. So, to determine proper fuse size, you must first determine the normal current that flows in the circuit. You then choose a fuse with a little larger current rating than the normal circuit current. A suitable size of fuse to use in Fig. 35, therefore, would be a

    (1) 0.25-A fuse.   (4) 1.5 A fuse.

    (2) 0.5-A fuse.   (5) 2.5-A fuse.

    (3) 0.75-A fuse.

END OF EXAM

Don't let up! You should be proud of the progress you've made in your training program. Let that success be an inspiration to move on, and not to "rest on your laurels." At CIE, your progress isn't our most important product: it's our only product!

Lesson 2323C-7
Applications of
Kirchhoff's Laws

VOLTAGES IN SERIES CIRCUITS

The voltage across any one component of a series circuit is *not* equal to the circuit power-source voltage. Likewise, the voltages of the series components are generally not equal to each other. Series circuits are much used in electronics where a voltage lower than the power-supply voltage is needed. Connecting components in series will never produce a voltage higher than the power-supply voltage in a DC circuit (In an AC circuit, however, it sometimes will, as you'll see in a later lesson.)

9 VOLTMETERS AND THEIR USE . . . As you've seen in preceding illustrations, an ammeter is connected in series, so that the current being measured must pass through the ammeter. The needle deflection of the ammeter is proportional to the amount of current passing through the meter. In other words, we hook up the ammeter in Fig. 36(a) the same way we hook up the water-flow meter in Fig. 36(b). The water in (b) must flow through the flow meter, just as the current in (a) must flow through the ammeter.

(b)　　　　　　　　　　(a)
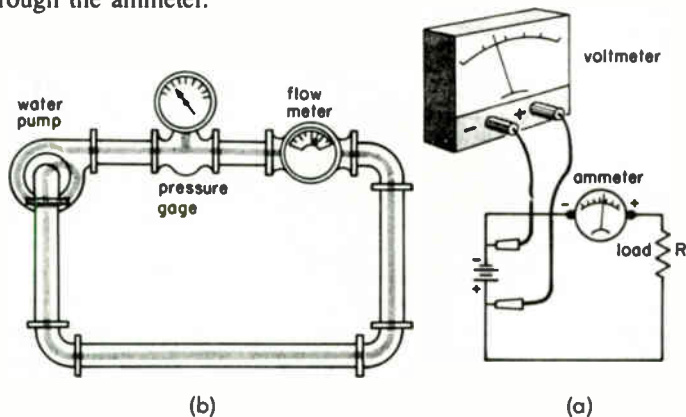
Fig. 36　Electrical measurements and corresponding water-flow measurements.

However, note that in Fig. 36(b) the water-pressure gage is connected in such a way that no water flows through it. If we tried to do that, no water could flow, since water can't get through a pressure gage. The gage consists of a diaphragm that is distended by the water pressure. This bulging out of the diaphragm pushes against the pressure-indicating needle.

36   Since a voltmeter measures the electrical equivalent of pressure, it can't be connected in series, like an ammeter. If it were connected in series, only a negligible current would get through, since a voltmeter has an extremely high resistance. As Fig. 36(a) shows, a voltmeter must be connected in parallel with the voltage to be measured. That is, one of the voltmeter test leads is connected to each side of the voltage being measured. In Fig. 36(a), we connected the leads to the two battery terminals, which enables us to measure the battery voltage.

When using an ammeter, therefore, be extremely careful that you don't connect it as you would a voltmeter. An ammeter has a very low resistance, and so it would draw a huge current if connected across a voltage source. As a result, the ammeter would burn out instantly. (Fig. 37). When the ammeter is properly connected, as in Fig. 36(a), the resistance of the load R limits the current from the battery so that the ammeter will not burn out—unless, of course, the current taken by the load is greater than the meter is designed to measure.
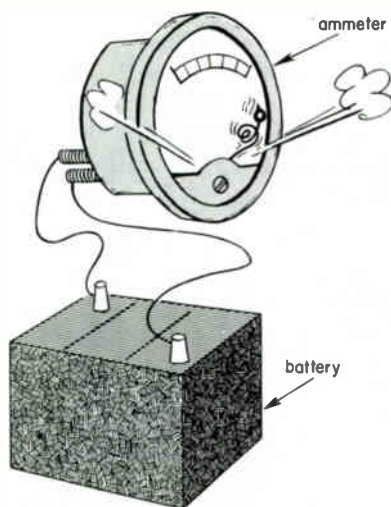
Fig. 37   **If this were a voltmeter, it would be connected correctly. However, an ammeter connected this way would burn out at once.**

By "load" (a term you'll hear frequently in electronics) we mean the device to which the voltage source is furnishing power. Although we represent the load in Fig. 36(a) by a resistance, it could just as well be a toaster, an amplifier, a transistor, or anything at all that you are using the battery to supply current to. The value of the resistance R is the equivalent resistance of the actual load, whatever that load might be.

10 A RESISTOR CAN HAVE A VOLTAGE . . . A voltmeter connected across the power source in a circuit, such as the battery of Fig. 38(a), reads the voltage of that source. What may come as a surprise is the fact that a circuit component that is not generating electricity can also have a voltage! For example, if the voltmeter is connected across R_1, as in Fig. 38(b), it will read 11 V—although the resistor is obviously not a source of power.
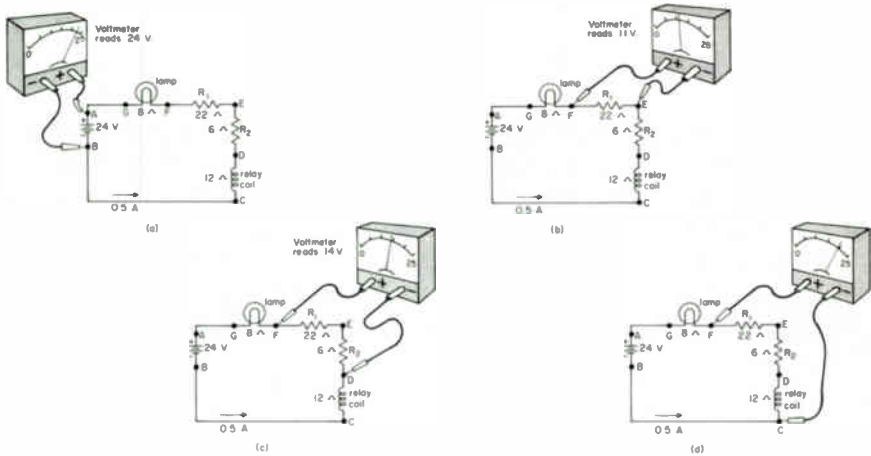
Fig. 38   **Although there's only one voltage source, many different voltages exist in this circuit.**

This brings us again to the idea of an equivalent circuit. The resistor R_1 in Fig. 38(b) is equivalent to an 11-V battery, because the voltmeter reading is the same as it would be if we replaced R_1 with an 11-V battery. The lamp, the relay, and R_2 also have voltages across them, and therefore can be regarded as equivalent voltage sources.

You don't need a voltmeter to find out what the voltage is across R_1—just use Ohm's law. $E = I \times R = 0.5$ A $\times 22$ $\Omega = 11$ V. Ohm's law tells you what ingredients you must have to get a voltage across a component or part of a circuit that doesn't have a battery or other power source in it: the ingredients are current and resistance. Any component or part of a circuit that has resistance will have a voltage across it if current flows through it.

The voltmeter in Fig. 38(c) is connected to points F and D. Therefore, it measures the voltage across R_1 and R_2 in series. Since resistances in series add, the R_1-R_2 combination is equivalent to a single resistor of 28 Ω connected between F and D in place of R_1 and R_2. By Ohm's law, the voltmeter will read $E = I \times R = 0.5$ A $\times 28$ $\Omega = 14$ V.

38 A *voltage divider*, much used in electronics, makes practical use of the fact that a resistor can be used as an equivalent voltage source. A voltage divider consists of two or more resistors in series across a power supply. It's used to obtain a voltage lower than that of the power supply. If we had a 24-V battery but needed only 12 V to power a transistor, we could use the voltage-divider circuit of Fig. 39(a) to get the needed 12 V. The equivalent circuit in (b) shows that the voltage across R_2 is equivalent to a 12-V battery, so that the transistor operates as if it were actually used across a real 12-V battery. It's easy to figure this equivalent voltage: simply multiply $I \times R_2 = 0.5$ A $\times$ 24 Ω = 12 V.

You should know that an equivalent circuit is often equivalent only under specified conditions. In the equivalent circuit of Fig. 39(b), for example, it's assumed that the current drawn by the transistor is small compared with the 0.5 A through R_1. If the transistor draws only 0.01 A, this requirement is adequately met. A more elaborate equivalent circuit is needed if a heavy current is to be taken from the voltage-divider output. However, you're not far along enough in your studies to get into such elaborate circuits. This discussion is only a preview of voltage dividers; later lessons will explain them in detail.

(a) Voltage - divider circuit

(b) Equivalent circuit, assuming transistor draws only a small current
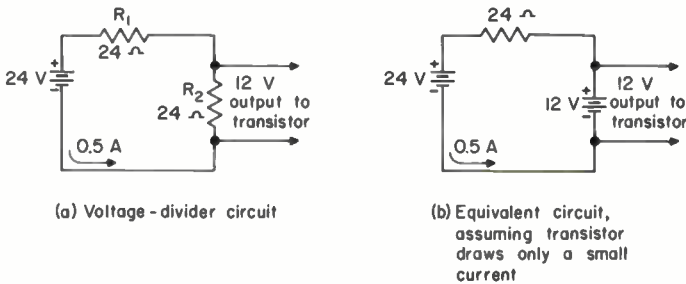
Fig. 39   A voltage divider for obtaining a 12-V output from a 24-V battery.

WHAT HAVE YOU LEARNED?

1. Even though the load on a circuit might be a transmitter, it can be represented by a resistance, such as R on Fig. 36(a). The value of R is the _____ resistance of the transmitter. If the load were six lamps connected in parallel, each with a resistance of 18 Ω, then the value to show for the load resistance R would be _____ ohms.

2. The voltmeter in Fig. 38(d) reads _____ volts.

3. If the voltmeter leads in Fig. 38 are connected to points D and E, the voltmeter will read _____ volts.

4. If the voltmeter is connected to points E and C, it will read _____ volts.

5. The voltage across the lamp in Fig. 38 is _____ volts.

6. If the voltmeter is connected to points B and C in Fig. 38, it will read _____ volts.

7. Add the voltages found across each of the four components in Fig. 38. Is the sum equal to the battery voltage?

8. In Fig. 40, voltmeter V_1 reads _____ volts; voltmeter V_2 reads _____ volts; and voltmeter V_3 reads _____ volts.
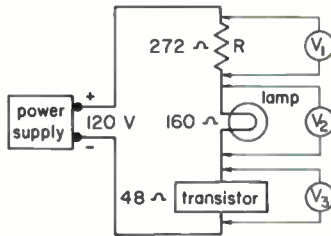
Fig. 40

9. Add the voltmeter readings in Fig. 40. Is the sum equal to the supply voltage?

10. The lamp in Fig. 40 will burn at proper brilliancy if it is manufactured to be used on _____ volts.

ANSWERS

1. equivalent; 3 . . . The combined (or equivalent) resistance of six 18-Ω resistors in parallel is 18/6 = 3 Ω.

2. 20 . . . The equivalent resistance between points F and C is 22 Ω + 6 Ω + 12 Ω = 40 Ω. $E = I \times R = 0.5\ A \times 40\ Ω = 20\ V$.

3. 3   4. 9 . . . The equivalent resistance between points E and C is 6 Ω + 12 Ω = 18 Ω. $E = I \times R = 0.5\ A \times 18\ Ω = 9\ V$.

5. 4   6. 0 . . . To have a voltage between points B and C, you must have a current flowing between the points, and you must have resistance between the points. You have current, but no resistance. (It's true that the wire connecting point B to point C would have a slight resistance, but this can be neglected.)

7. Yes . . . The sum is 24 V, which is the same as the battery voltage. The voltage across the lamp is 4 V; the voltage across R_1 is 11 V; the voltage across R_2 is 3 V; and the voltage across the relay coil is 6 V. 4 V + 11 V + 3 V + 6 V = 24 V. In any series circuit, the sum of the voltages must equal the supply voltage.

8. 68 . . . First find the circuit current. 272 Ω + 160 Ω + 48 Ω = 480 Ω, the total resistance, $I = E/R = $ 120 V/480 Ω = 0.25 A. V_1 reads the voltage across R, which will be $E = I \times R = $ 0.25 A × 272 Ω = 68 V; 40; 12

9. Yes . . . 68 V + 40 V + 12 V = 120 V. (See the discussion of Problem 7, above.) Seeing if the sum is equal to the supply voltage is a good way to check your work.

10. 40 . . . Even though the power supply is 120 V, a 120-V bulb would burn dimly here because the voltage across the lamp is only 40 V.

11 POLARITY OF SERIES CIRCUIT VOLTAGES . . . We'll now take a look at the polarity of the voltages connected with a series circuit. DC voltmeters always have their leads marked (+) and (−). To read the voltage of a battery (or other voltage source), the (+) lead of the voltmeter must connect to the positive battery terminal and the negative lead to the negative terminal, as in Fig. 38(a). If the voltmeter is connected with the leads reversed, the meter needle will try to swing backwards—which it can't do—and no meter reading will be obtained. When using a voltmeter, you can determine the polarity of any circuit voltage. Simply connect the voltmeter, and—if no reading is obtained—reverse the leads. When a reading is obtained, the (+) and (−) markings on the meter indicate the polarity of the voltage being measured.

In Fig. 38(b), the polarity of the voltage across R_1 is left-end positive and right-end negative (as you can determine at once by merely looking at the voltmeter). The polarity of the voltage between points F and D in Fig. 38(c) is point F positive with respect to point D, which is negative.

You don't have to use a voltmeter to find the polarity of the voltages across the components in Fig. 38: simply note which way the current flows through the components. *The current always enters a passive component at the negative terminal, and leaves at the positive terminal.* A *passive component* is one that's not actually a voltage source, although it may have a voltage across it and therefore be equivalent to a voltage source. A resistor is an example of a passive component. The lamp, the relay coil, R_1, and R_2 in Fig. 41 are passive components. The current enters the relay coil at the bottom, and leaves at the top. Therefore, the bottom of the coil is negative with respect to the top, as indicated in Fig. 41. Similarly, the polarities of the lamp and R_1 and R_2 are as marked.
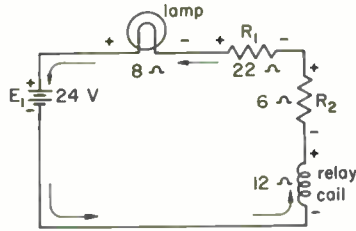
Fig. 41   Polarity of components in a series circuit.

An *active component*, on the other hand, is one that directly supplies operating power to the circuit. Batteries, generators, power supplies, and wall outlets are examples of active components. There would be no current in Fig. 41 if it weren't for the battery. Hence, the battery is an active component, while all the other components (which would have no voltages of their own if it weren't for the battery) are passive components.

Since an active component is a voltage source, it has its own polarity, as determined by its design. Also, its polarity—unlike the polarity of a passive device—doesn't depend on the direction of current. The current direction determines the polarity of a passive device, but the polarity of an active device determines the current direction. If there's only one active component in the circuit, the current direction (as you've previously learned) is from the negative terminal through the rest of the circuit and back to the positive terminal, as shown in Fig. 41.

If there's more than one active circuit component, however, the current doesn't always flow in the direction indicated in the preceding paragraph. In Fig. 42(a), for example, an additional battery (E_2) has been added to the circuit. Battery E_2 is pushing the current clockwise around the circuit, while E_1 is pushing in the opposite direction. The higher voltage, of course, wins out in this tug-of-war, so that the current direction is as shown. Although the current through E_1 is opposite in direction to that of Fig. 41, the battery polarity doesn't change.

(a) Actual circuit   (b) Equivalent circuit
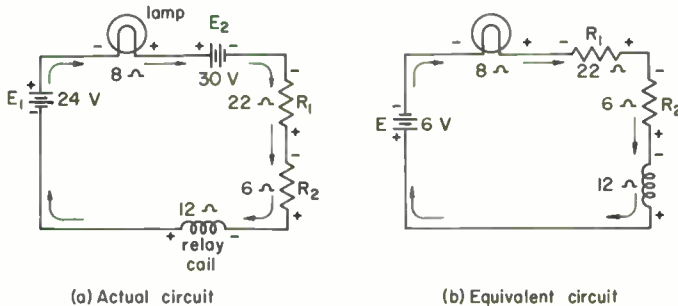
Fig. 42   When voltage sources "buck", the polarity of the higher active voltage determines the current direction.

The result of active voltage E_1 in Fig. 42(a) "bucking" active voltage E_2 is a net voltage of 30 V − 24 V = 6 V. Hence, the circuit of Fig. 42(a) can be simplified by replacing the two batteries with a single equivalent voltage source of 6 V—E in Fig. 42(b).

If we were to reverse the polarity of E_1 in Fig. 42(a), the two battery voltages would add. Then, the voltage of the equivalent battery E in Fig. 42(b) would be 30 V + 24 V = 54 V. You can easily tell if the voltages of two active components add or subtract: just note which way each active voltage is trying to push the current. If both voltages are pushing in the same direction, the two voltages add; if they are pushing in opposite directions, they subtract. Another way to tell is to remember that, in order for the voltages to add, the positive terminal of one cell must be connected to the negative terminal of the other cell. In making this check, you ignore all passive components between the terminals. For example, in Fig. 42(a) you can see that the (+) terminal of E_1 connects to the (+) terminal of E_2. (Pay no attention to the lamp in between.) Hence, the two cells are bucking each other.

WHAT HAVE YOU LEARNED?

1. In Fig. 43(a), the voltmeter reads _____ volts. The voltage across the light bulb is _____ volts.

Fig. 43   (a)   (b)
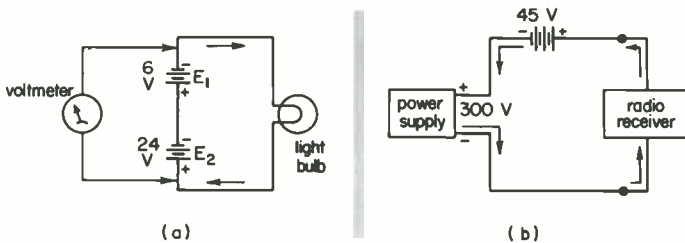
2. In the circuit shown in Fig. 43(b), the total circuit voltage is _____ volts. The voltage to the radio receiver is _____ volts.

3. To connect two voltages in series so that the voltages add, connect the positive terminal of one of the voltages to the _____ terminal of the other.

4. If the battery shown in Fig. 43(b) had its leads reversed, the voltage to the radio receiver would be _____ volts.

5. If the resistance of the light bulb in the circuit in Fig. 43(a) is 10 Ω, the current drawn by the bulb is _____ amperes.

6. If you had a 250-V power supply, you could connect in series another power supply with an output of _____ volts in order to operate a 400-V transmitter.

7. The current direction in Fig. 44(a) is as shown. Mark on the drawing the polarity of the power supply and the polarity of each of the passive components. In Fig. 44(b), determine the current direction and mark it on the drawing. Also, mark the polarity of the voltage across each of the passive components.

Fig. 44   (a)   (b)
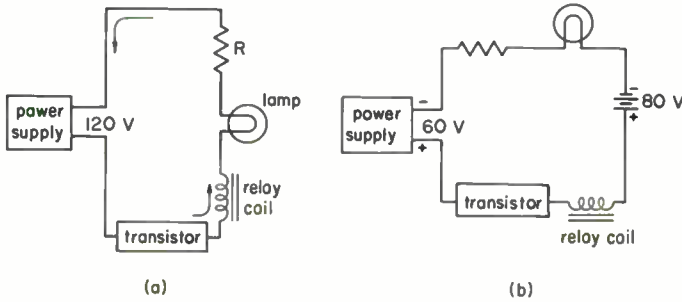
8. Draw an equivalent circuit for Fig. 44(b) in which the voltage sources are replaced by an equivalent voltage source. Show current direction and all polarities, and show the equivalent voltage in the circuit where the power supply is now located.
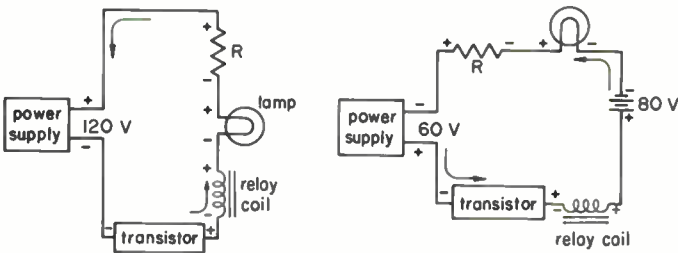
Fig. 45

ANSWERS

1. 30; 30   2. 345; 345 . . . The entire voltage of the two voltages sources in series is applied to the radio receiver.

3. negative   4. 255 . . . 300 V − 45 V = 255 V.

5. 3 . . . Use the formula $I = \dfrac{E}{R}$, where E is the voltage actually applied to the bulb, which is 30 V. $I = \dfrac{30}{10} = 3$ A.

6. 150 . . . 400 V − 250 V = 150 V.

7. See Fig. 45(a); see Fig. 45(b).   8. See Fig. 46.

Fig. 46

relay coil
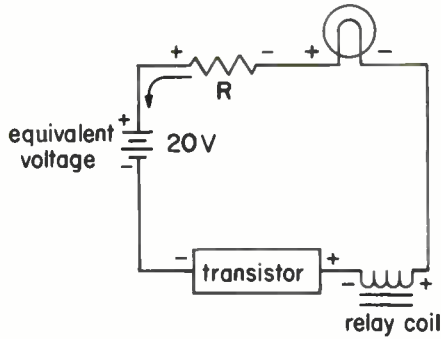
12 KIRCHHOFF'S VOLTAGE LAW . . . The voltages across the components in a series circuit can be classified as *voltage drops* and *voltage rises*. Suppose we trace or walk around a circuit in the direction of current. Whenever we come to a component across which the voltage acts to boost the circuit current up to a higher value, we say the voltage across that component is a voltage rise. Conversely, if the voltage across the component acts to decrease current, we refer to the voltage across that component as a voltage drop.

If we come to a resistor while walking around the circuit in the direction of current, the voltage across that resistor will be a voltage drop. Resistors act to decrease the flow of current, since resistance is opposition to current. The voltage across any passive component that you come to while walking around a circuit in the current direction will be a voltage drop, because all passive components oppose the flow of current.

To understand a little better why voltage drops are so named, suppose we want to operate a 6-V lamp from a 9-V battery. We can do so by connecting in series with the lamp a resistor of such value that the voltage across it is 3 V, as shown in Fig. 47. The resistor drops the battery voltage 3 V, bringing the 9 V of the battery down to the desired 6 V required for operating the lamp. However, the 6 V across the lamp is also a voltage drop, since the lamp is a passive component.
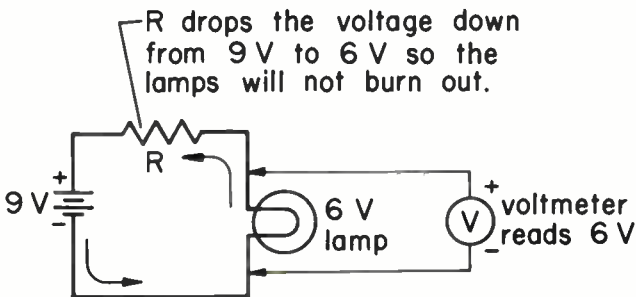
Fig. 47   Operating a 6-V lamp from a 9-V battery.

As we walk around a series circuit in the direction of current, any active component
we come to would ordinarily be a voltage rise—*but not always*. Consider the cir-
cuit of Fig. 48: The 100 V of the power supply pushes current around the circuit
in the direction shown, and it is therefore a voltage rise. If we start at the negative
terminal of this power supply and walk around the circuit, we come first to another
active component, the 20-V battery E_2. Now, E_2 is connected "bucking," so that
it is trying to push current in an opposite direction to the way we're walking.
Because of the way it's connected, it reduces the circuit current instead of increasing
it. Battery E_2 is therefore a voltage drop. If we were to reverse its polarity, battery
E_2 would then be a voltage rise.
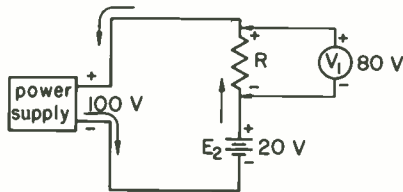
Fig. 48   Both the resistor and E_2 are voltage drops.

When you have a series circuit in which two active components are connected
in such a way that they oppose each other and are trying to force the current in
opposite directions, you may wonder which way the circuit current will flow. The
direction is determined by the source with the higher voltage, since it overpowers
the other voltage source. Thus, in Fig. 48 the 100-V source, and *not* the 20-V source,
determines the direction in which the current will flow.

The voltage developed by an active voltage source, such as a battery or a generator,
is often called an *electromotive force*, abbreviated *emf*. It's also called the battery
or generator *potential*. For practical purposes, you can consider voltage, poten-
tial, and emf as meaning the same thing (except that voltage across a passive com-
ponent isn't usually called an emf). A voltage drop is sometimes also called an
IR drop, since its value is equal to $I \times R$.

Now we get to Kirchhoff's voltage law, which says that *the sum of the voltage
drops in a series circuit must equal the voltage rises*. For example, in Fig. 48,
the sum of the voltage drops is 80 V + 20 V = 100 V, which is equal to the
voltage rise.

When there's only one active voltage in a series circuit (which is most often the
case), we can reduce Kirchhoff's voltage law to simpler English by stating that
the sum of the voltage drops must equal the supply voltage. In Fig. 47, for in-
stance, the sum of the voltage drops is 3 V + 6 V = 9 V, which equals the supply
voltage.

1. What must the power supply voltage be in Fig. 49?

2. What voltage rating should the bulb in Fig. 49 have in order to operate at normal brilliancy?

3. The relay used in the circuit of Fig. 49 should have a coil designed to operate at _____ volts.
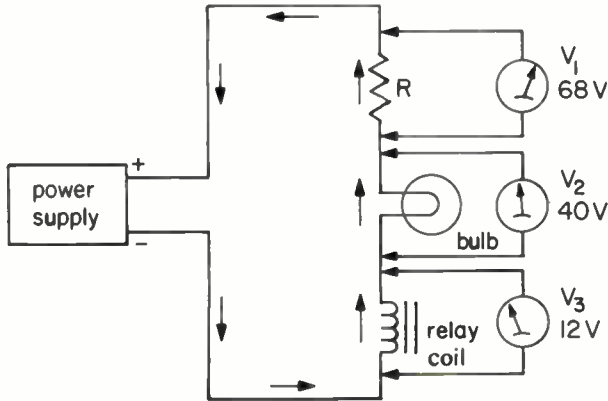
Fig. 49

4. If two resistances of equal value are in series across a voltage source, the voltage across one resistor is the same as that across the other. If $R_1 = R_2$ in Fig. 50, and if the voltage across R_1 is 15 V, then the voltage across R_2 is _____ volts, and the voltage of battery E is _____ volts. If two identical light bulbs, each rated at 15 V, are connected in series, the battery furnishing current to the bulbs should have a voltage of _____ volts if the bulbs are to light at normal brilliancy.
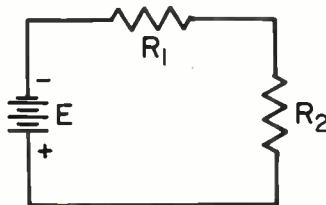
Fig. 50

5. Two identical light bulbs, each rated at 115 V, are connected in series. The voltage applied to this circuit should be _____ volts if the bulbs are to burn at normal brilliancy.

6. Lamp filaments are often operated in series. Figure 51(a) shows four identical filaments, F_1, F_2, F_3, and F_4, in series. If the proper operating voltage for each filament is 6.3 V, then the proper power-supply voltage E is _____ volts. If the actual power-supply voltage is greater than this value (which is often the case), a resistor R, as shown in Fig. 51(b), can be connected in series to provide proper operation. If the voltage across R is 20 V, then the power-supply voltage E should be _____ volts for proper voltage on the lamp filaments. If the power-supply voltage is 30 V, then the value of R should be adjusted until the voltage across it is _____ volts for proper voltage on the lamp filaments.

Fig. 51   (a)   (b)
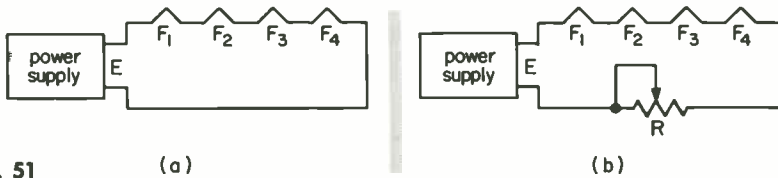
7. In Fig. 52, the collector-to-emitter circuit of a transistor is shown in series with R and across the 40-V battery. Voltmeter V reads the collector-emitter voltage. If the voltage across R is 12 V, the voltage between collector and emitter is _____ volts.

Fig. 52   40 V
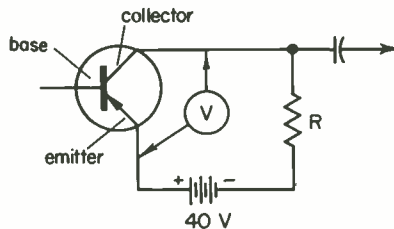
ANSWERS

1. 120 V . . . The sum of the voltage drops is 68 V + 40 V + 12 V = 120 V. Since this must equal the source voltage, the power-supply voltage must be 120 V.
2. 40 V . . . The voltage rating of the bulb should be that of the actual voltage across the bulb, and *not* the voltage of the power supply.
3. 12   4. 15; 30; 30
5. 230 . . . The applied voltage must be the sum of the voltages across the components, or 115 V + 115 V = 230 V.
6. 25.2 . . . Applied voltage must be the sum of the voltages across the components: 4 × 6.3 V = 25.2 V; 45.2 . . . The power-supply voltage must equal the voltage across the filaments, plus the voltage across R: 25.2 V + 20 V = 45.2 V; 4.8 . . . 30 V − 25.2 V = 4.8 V.
7. 28 . . . The sum of the voltages around the series circuit must equal the supply voltage: 40 V − 12 V = 28 V.

13 FIGURING VOLTAGES IN SERIES CIRCUITS . . . No new principles are involved in this topic. As a matter of fact, the only "tools" needed for the problems that follow are Ohm's law and Kirchhoff's voltage law. But tools are useless until you develop the skill to use them properly and that is the purpose of the examples and problems that follow.

Example 1 . . . If R in Fig. 51(b) is 80 Ω, and the current through filament F_1 is 0.5 A, the voltage drop across R is _____ volts.

Solution . . . Since the current through all parts of a series circuit is the same, the current through R is also 0.5 A. Then:

$$E = I \times R$$
$$= 0.5 \text{ A} \times 80 \text{ }\Omega$$
$$= 40 \text{ V}$$

Example 2 . . . Assuming a current of 0.5 A, what value should R in Fig. 51(b) have in order that the voltage across it will be 20 V?

Solution . . .

$$R = \frac{E}{I}$$
$$= \frac{20 \text{ V}}{0.5 \text{ A}}$$
$$= 40 \text{ }\Omega$$

Example 3 . . . In order to function properly, a certain light bulb filament must operate at 6.3 V and 300 mA. You want to operate the filament from a 12.3-V supply. To apply the correct voltage across the filament, you would connect a resistance of _____ ohms in series with the filament.

Solution . . . $R_r = E_r/I$. To find E_r:

$$E_r = 12.3 - 6.3$$
$$= 6 \text{ V}$$

To convert I to amperes:

$$I = 300 \text{ mA}$$
$$= 0.3 \text{ A}$$

Therefore:

$$R_r = \frac{E_r}{I}$$

$$= \frac{6 \text{ V}}{0.3 \text{ A}}$$
$$= 20 \text{ }\Omega$$

Explanation . . . Since the current in all parts of a series circuit is of the same value, the current through the resistor is 300 mA. The voltage across the filament should be 6.3 V; therefore, voltage across the resistor should be 12.3 V − 6.3 V = 6 V. The value of the resistor is calculated from Ohm's law.
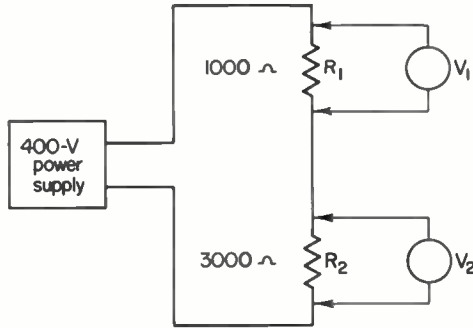
Fig. 53

Example 4 . . . A 1000-Ω resistor R_1 is connected in series with a 3000-Ω resistor R_2, and the combination is placed across a 400-V source as shown in Fig. 53. Current in the circuit is (a) _____ milliamperes. Voltmeter V_1 reads (b) _____ volts, and voltmeter V_2 reads (c) _____ volts.

Solution . . . $R = R_1 + R_2 = 1000\ \Omega + 3000\ \Omega = 4000\ \Omega$.

(a) $I = \dfrac{400\ V}{4000\ \Omega} = 0.1\ A = 100\ mA$

(b) Voltage across R_1 is $E_1 = IR_1 = 0.1\ A \times 1000\ \Omega = 100\ V$

(c) Voltage across R_2 is $E_2 = IR_2 = 0.1\ A \times 3000\ \Omega = 300\ V$

Explanation . . . The total resistance in a series circuit is equal to the sum of the resistances. Ohm's law for current gives us 0.1 A as the current through the circuit. Ohm's law for voltages gives the voltage drop across each resistor. Notice that the ratio of the voltages across the two resistors (100 to 300, or 1 to 3) equals the ratio of the values of the two resistors (1000 to 3000, or 1 to 3). Note also that the sum of the voltage drops across the two resistors equals the supply voltage (100 V + 300 V = 400 V).
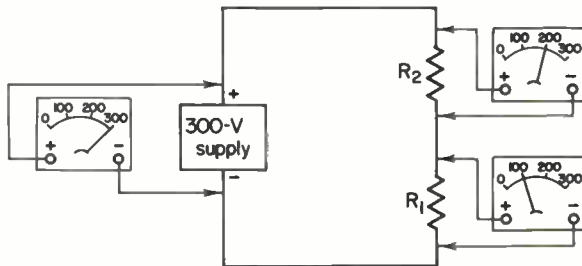
Fig. 54   The sum of the voltage drops across R_1 and R_2 equals the supply voltage.

50　Example 5 . . . Figure 54 shows two resistors in series across a 300-V source. Circuit voltages are indicated by the three voltmeters. Since the voltage drop across R_2 is greater than the drop across R_1, the resistance of R_2 is (a) _____ than the resistance of R_1. If the current through R_2 is 100 mA, the resistance of R_2 is (b) _____ ohms. The resistance of R_1 is (c) _____ ohms.

Solution . . . (a) greater

(b) $R_2 = \dfrac{E_2}{I} = \dfrac{200 \text{ V}}{100 \text{ mA}} = \dfrac{200 \text{ V}}{0.1 \text{ A}} = 2000 \ \Omega$

(c) $R_1 = \dfrac{E_1}{I} = \dfrac{100 \text{ V}}{0.1 \text{ A}} = 1000 \ \Omega$

Explanation . . . The resistance of R_2 is greater because the voltage drop across it is greater: the resistance of a component in a series circuit is directly proportional to the voltage drop across it. The resistance of R_2 is found using the formula $R_2 = \dfrac{E_2}{I}$. Because I is the same value for R_1, we are able to determine the resistance of R_1 also.

WHAT HAVE YOU LEARNED?

1. Three resistors—R_1, R_2, and R_3, of 10, 30, and 20 Ω, respectively—are connected in series across a 240-V supply. The current through R_1 is _____ amperes; that through R_2 is _____ amperes; and that through R_3 is _____ amperes. The voltage drop across R_1 is _____ volts; that across R_2 is _____ volts; and that across R_3 is _____ volts. The total voltage drop across the three resistors, _____ volts, equals the _____ voltage.

2. A light bulb with 200 Ω resistance is designed to operate at 115 V. We want to operate the bulb from a 230-V line. To prevent the bulb from burning out, a 300-Ω resistor is connected in series with it, to drop the voltage across it to a lower value. (a) Draw a diagram of the circuit. (b) What's the voltage drop across the resistor? (c) What's the voltage across the bulb? (d) Will the bulb burn normally, burn dimly, or burn out?

3. In problem 2, what value of resistance can be used to set the voltage drop across the bulb at 115 V?

4. Three identical light bulbs are operated in series across 120 V. What's the voltage across each bulb?

5. Two light bulbs, one with a resistance of 140 Ω and one with a resistance of 200 Ω, are connected in series across a 240-V line. The voltage across the bulb with a resistance of 140 Ω is _____ volts, while the voltage across the other bulb is _____ volts.

6. Five identical heating elements are connected in series. Each element requires 6.3 V for proper operation. What voltage is required to operate the group of elements?

7. Each of the elements described in problem 6 draws 0.3 A. If the required voltage is obtained from a 110-V line by using a dropping resistor, what value of resistance is required?

8. Heater *A* operates at 50 V, and draws 150 mA. Can it be operated in series with heater *B*, which also draws 150 mA, but at only 12.6 V? _____ If so, what voltage is required across the two heaters in series? _____ What is the value of the dropping resistor required if operation is from a 110-V line?
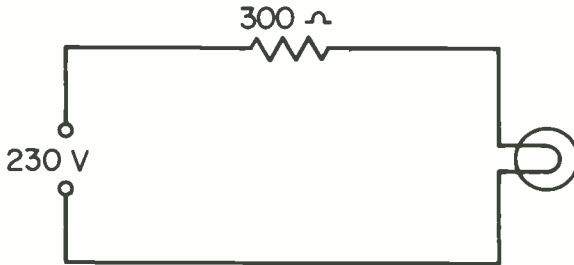
Fig. 55

ANSWERS

1. 4; 4; 4; 40; 120; 80; 240; source
2. (a) See Fig. 55; (b) 138 V; (c) 92 V; (d) burn dimly . . . The bulb will burn dimly because the voltage across it is less than 115 V.
3. 200 Ω . . . Since we want half of the supply voltage across the bulb, the resistance of the dropping resistor should equal the resistance of the bulb.
4. 40 V   5. 98.8; 141   6. 31.5 V
7. 262 Ω . . . The voltage must be dropped from 110 V down to 31.5 V—a drop of 78.5 V. The value of resistance is $R = E/I = 78.5$ V/0.3 A $= 262$ Ω.
8. Yes . . . In a circuit with 150 mA flowing, the current voltage appears across each element; 62.6 V; 316 Ω . . . The voltage must be dropped 110 V − 62.6 V = 47.4 V:

$$R = \frac{E}{I}$$
$$= \frac{47.4 \text{ V}}{0.15 \text{ A}}$$
$$= 316 \text{ Ω}$$

LESSON 2323C-7
APPLICATIONS OF KIRCHHOFF'S LAWS

EXAMINATION

Send in the examinations for this volume promptly. Then start on the next lesson.

1. Which one of the following is an example of a passive component?
   (1) Generator   (3) Wall outlet
   (2) Resistor   (4) Battery

2. Which one of the following instruments is used to measure battery or generator potential?
   (1) Amp meter   (3) Ohmmeter   (5) Resistor
   (2) Ammeter   (4) Voltmeter

3. Which one of the following is an example of an active component?
   (1) Heating element   (3) Lamp
   (2) Relay coil   (4) Power supply

4. In the circuit of Fig. 56, the voltage rise is 30 V. One of the two voltage drops is known: it is 10 V, as shown. Given these facts (and the fact that this is a series circuit), the unknown voltage drop across the 40-Ω resistor R_1 is
   (1) 40 V.   (2) 30 V.   (3) 20 V.   (4) 10 V.
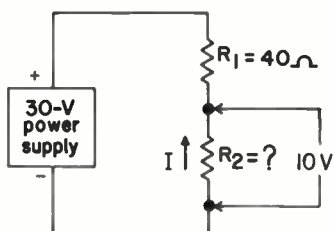
Fig. 56

5. Now that you know the voltage across R_1, you can use Ohm's law to calculate the current through R_1. Since this is a series circuit, the current through R_2 and the resistance of R_2 are
   (1) $I = 0.25$ A, $R_2 = 80$ Ω.
   (2) $I = 0.5$ A, $R_2 = 20$ Ω.
   (3) $I = 0.5$ A, $R_2 = 40$ Ω.
   (4) $I = 0.25$ A, $R_2 = 40$ Ω.

6. In the case of a passive component, electrons
   (1) enter at the positive lead.
   (2) enter at the negative lead.
   (3) sometimes enter at the negative lead, and sometimes enter at the positive lead.

7. As we walk around a series circuit in the direction of electron flow, any *active* component we would come to would
   (1) be a voltage drop.
   (2) ordinarily be a voltage rise, although not always.
   (3) always be a voltage rise.

8. Most multimeters don't have AC current ranges, although they do have AC voltage ranges. Given the circuit of Fig. 57, you can nevertheless determine the motor current by measuring the voltage across the 2-Ω resistor. All you have to do is use Ohm's law, and keep in mind the fact that this is a series circuit. There is one voltage rise (115 V) and there are two voltage drops (one given and one unknown). Given this information, you can calculate the motor current to be
   (1) 57 A.   (2) 4 A.   (3) 2 A.   (4) 1 A.   (5) 0.5 A.
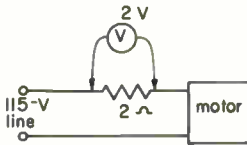
Fig. 57
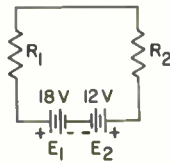
Fig. 58

9. In which direction are the electrons flowing around the circuit of Fig. 58? (Hint: Note that E_2 bucks E_1, also, refer to Topic 11.)
   (1) Counterclockwise
   (2) Clockwise

10. In which one of the drawings in Fig. 59 are the meters connected correctly?
    (1) a   (2) b   (3) c   (4) d
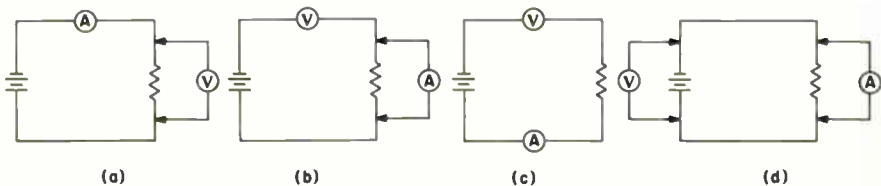
Fig. 59

END OF EXAM

Now, on to the next lesson. Remember that every lesson completed brings you that much closer to your goals: a better job and a better life.
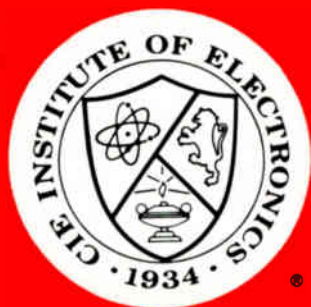
electronics
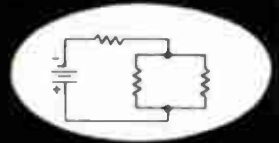
Lesson 2324A-8
Series-Parallel Circuits

Lesson 2324B-8
Voltage and Power

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ABOUT THE AUTHOR

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Lesson 2324A-8
Series-Parallel Circuits

Lesson 2324B-8
Voltage and Power

By *DARRELL L. GEIGER*
Technical Staff
Cleveland Institute of Electronics, Inc.

A Chat with Your Instructor

You've already learned the relationship between voltage, current, and resistance in both series and parallel circuits. In this volume, we'll continue to explore this relationship—particularly as it applies to circuits made up of a combination of series and parallel circuits.

One of the key purposes of this volume is to give you a better understanding of the meaning of *voltage* (or *potential*). You need this extra training, since it's not as easy to understand voltage as it is to understand current and resistance. In addition, *voltage* is far and away the term most commonly used in electricity and electronics, so the better you understand it, the easier the study of electronics will be for you.

Since this volume is a continuation of your study of DC circuits that began with Volume 2323, you may want to review that volume, either before starting this one or while studying it. In any case, when you have finished this volume, your study of DC circuit theory will be complete, and you'll be ready for new areas of learning in electronics.

Lesson 2324A-7
Series-Parallel Circuits

SERIES-PARALLEL CIRCUITS

You already know how to figure the voltage, current, and resistance values associated with series circuits and with parallel circuits. Very often, however, a circuit is neither all series nor all parallel, but rather a combination of the two. If you go about it right, though, analyzing such a circuit is practically as easy as analyzing a simple series or parallel circuit (although more steps are required). The proper procedure is to progressively *simplify* the circuit by replacing the various series and parallel branches within the complex circuit with equivalent values.

1 SERIES-PARALLEL CIRCUIT WITH RESISTANCE VALUES GIVEN . . . Figure 1(a) shows a series-parallel circuit in which resistors R_1 and R_2 are connected in parallel, and this combination is connected in series with R_3. To find the total resistance of the circuit, first find the combined resistance of R_1 and R_2 (shown in Fig. 1(b) as R_a), and then find the total series resistance (R_a plus R_3).

(a) Series parallel circuit

(b) Equivalent circuit (R_a is the combined resistance of R_1 and R_2)
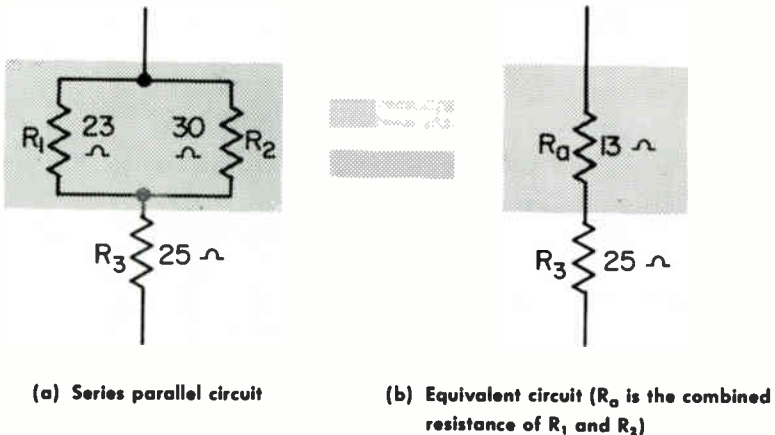
Fig. 1   Series-parallel circuit with equivalent circuit.

Example 1 . . . In Fig. 1(a), if R_1 is 23 Ω (ohms), R_2 is 30 Ω, and R_3 is 25 Ω, what is
the total resistance of the circuit?

Solution . . .

$$
\begin{aligned}
R_a &= \frac{R_1 R_2}{R_1 + R_2} \\
&= \frac{23 \times 30}{23 + 30} \\
&= \frac{690}{53} \\
&= 13\ \Omega
\end{aligned}
$$

$$
\begin{aligned}
R_a + R_3 &= 13\ \Omega + 25\ \Omega \\
&= 38\ \Omega
\end{aligned}
$$

Example 2 . . . In Fig. 2(a), the total current I_t is (a) _____ A (amperes); voltmeter V_{12}
reads (b) _____ V (volts); voltmeter V_3 reads (c) _____ V; the voltage across R_1 is (d)
_____ V, and the voltage across R_2 is (e) _____ V. The current I_1 through resistor R_1
is (f) _____ A, and current I_2 is (g) _____ A.
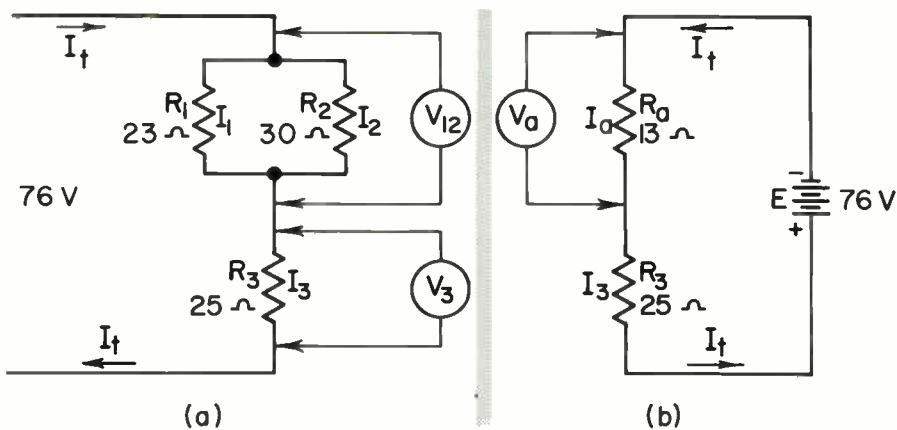
Fig. 2 **Voltmeters V_{12} and V_a read the same, because the two circuits are
equivalent to R_a (equal to R_1 and R_2 combined).**

Solution . . . The resistance values are the same as in Example 1, where the total resistance
was found to be 38 Ω.

(a) Total current $I_t = \dfrac{\text{supply voltage } E}{\text{total resistance}}$

$\qquad\quad = \dfrac{76\ \text{V}}{38\ \Omega}$

$\qquad\quad = 2\ \text{A}$

(b) Figure 2(b) shows the equivalent circuit to the circuit in Fig. 2(a). Now, since R_a is equal in value to R_1 and R_2 combined, voltmeters V_{12} and V_a will read the same, since they're across equivalent values. By Ohm's law then, the voltage E_a (which is the reading of V_a) is

$$
\begin{aligned}
E_a &= I_a \times R \\
&= 2 \text{ A} \times 13 \text{ }\Omega \\
&= 26 \text{ V}
\end{aligned}
$$

(c) E_3, the voltage across R_3, is found as follows:

$$
\begin{aligned}
E_3 &= I_3 \times R_3 \\
&= 2 \text{ A} \times 25 \text{ }\Omega \\
&= 50 \text{ V}
\end{aligned}
$$

Check . . . By Kirchhoff's voltage law, the sum of the voltage across R_a and R_3 should equal the supply voltage:

$$
\begin{aligned}
E_a + E_3 &= 26 \text{ V} + 50 \text{ V} \\
&= 76 \text{ V}
\end{aligned}
$$

which is the supply voltage.

(d), (e) The reading of V_{12} is the voltage across R_1, and is also the voltage across R_2. Hence, the voltage across each is 26 V.

(f) Since the voltage across R_1 is 26 V, the current through R_1 is

$$
\begin{aligned}
I_1 &= \frac{E_1}{R_1} \\
&= \frac{26 \text{ V}}{23 \text{ }\Omega} \\
&= 1.13 \text{ A}
\end{aligned}
$$

(g)

$$
\begin{aligned}
I_2 &= \frac{E_2}{R_2} \\
&= \frac{26 \text{ V}}{30 \text{ }\Omega} \\
&= 0.87 \text{ A}
\end{aligned}
$$

Check . . . By Kirchhoff's current law, the total current I_t should equal the sum of the currents in the parallel branches:

$$
\begin{aligned}
I_1 + I_2 &= 1.13 \text{ A} + 0.87 \text{ A} \\
&= 2 \text{ A}
\end{aligned}
$$

which is the same as I_t.

A summary of the proper use of Ohm's law may be useful at this point. You've seen that Ohm's law can be used for *parts* of a circuit, as well as for the entire circuit. The important thing to remember when applying Ohm's law to a part of a circuit is that the voltage, current, and resistance used with the formula must be the voltage across that part of the circuit, the current through that part of the circuit, and the resistance of that part of the circuit. For example, in finding I_1—the current through R_1 in part (f) of Example 2—we used the voltage across R_1 and the resistance of R_1.

2 HINTS ON SOLVING SERIES-PARALLEL CIRCUITS . . . Sometimes, the
easiest way to analyze a series-parallel circuit is to redraw it. For example, the
circuit shown in Fig. 3(a) contains four resistors in series-parallel. The circuit
is redrawn in Fig. 3(b), with resistors R_1 and R_2 in parallel, and resistors R_3 and
R_4 also in parallel. The two parallel combinations are in turn connected together
in series.

(a) Resistors in series-parallel   (b) Same circuit redrawn   (c) Equivalent circuit
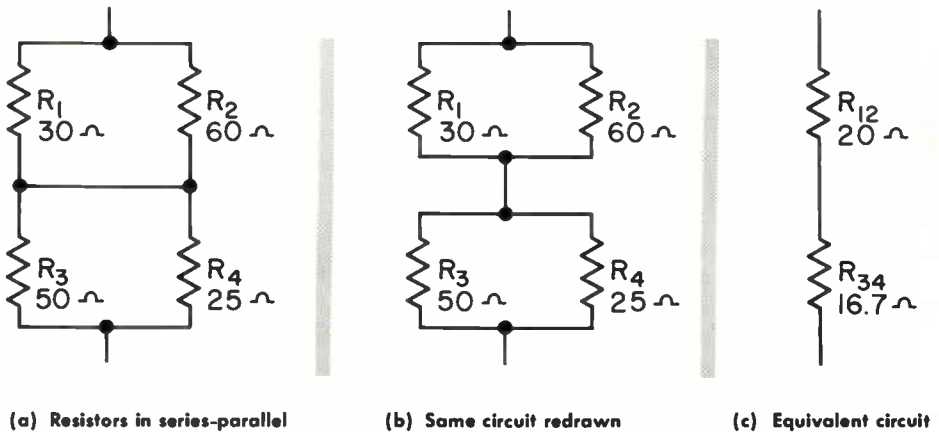
**Fig. 3   Four resistors in series-parallel. In the equivalent circuit, R_{12} is the combined
resistance of R_1 and R_2, and R_{34} is the combined resistance of R_3 and R_4.**

To solve for the total resistance of such a circuit, first solve for the resistance of
each parallel combination and then solve for the resistance of the series
combination.

Example . . . In Fig. 3(a), if $R_1 = 30\ \Omega$, $R_2 = 60\ \Omega$, $R_3 = 50\ \Omega$, and $R_4 = 25\ \Omega$, what
is the total resistance of the circuit?

Solution . . . The combined resistance R_{12} of R_1 and R_2 can be found using the following
formula:

$$R_{12} = \frac{R_1 R_2}{R_1 + R_2}$$
$$= \frac{30 \times 60}{30 + 60}$$
$$= \frac{1800}{90}$$
$$= 20\ \Omega.$$

Similarly the value R_{34} of R_3 and R_4 in parallel is 16.7 Ω. Thus, in Fig. 3(c), R_{12} = 20 Ω and R_{34} = 16.7 Ω. The total circuit resistance, therefore, is 20 Ω + 16.7 Ω = 36.7 Ω.

In the example on Page 3 you were asked to find all the currents and voltages associated with the circuit. Often, though, you'll be asked to find just a single voltage or current at some point in the circuit. Oddly enough, the beginner is apt to find such a problem more difficult than if he or she were asked to find all the voltage and current values. The reason is that he or she looks for some shortcut to find the value asked for, without bothering to find those voltages and currents that the problem does *not* ask for. However, when finding a specific voltage or currents, too. And in any event, whether absolutely necessary or not, this kind of work provides valuable experience using Kirchhoff's voltage and current laws to check your work.

In working a series-parallel circuit, then, don't concentrate at first on the specific current or voltage asked for. Instead, study the circuit to see what voltage or current value you can readily find. After you find that value, mark it on your circuit drawing. This additional piece of information may lead you to some other value that's easily found. Proceeding in this way, you'll soon have all the voltage and current values—including the value specified in the problem.

Don't forget to use equivalent circuits whenever applicable, since they can often make even the hardest-looking circuit really simple. Finally, after you've found all the circuit values, check them for consistency using Kirchhoff's voltage and current laws (or by some other means suitable to the problem).

Example . . . Find the current I_4 through R_4 in Fig. 4.
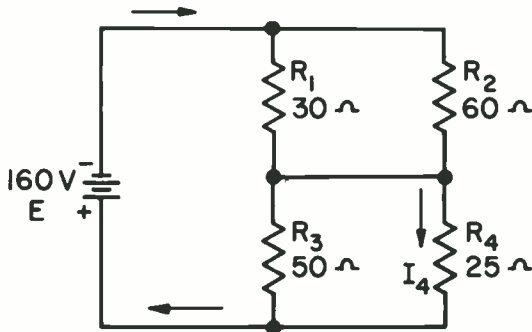
Fig. 4   Circuit of Fig. 3 with voltage source added.

Solution . . . Find all current and voltage values. You'll then have I_4, and will also be able to check your work. You've already found the combined resistance and equivalent circuits in the previous example, so the next step is to find the total current I:

$$I = \frac{E}{R_t}$$
$$= \frac{160 \text{ V}}{36.7 \text{ }\Omega}$$
$$= 4.36 \text{ A}$$

This value of I is marked on the equivalent circuit shown in Fig. 5(a). The voltages across R_{12} and R_{34} can now be found as follows:

$$E_{12} = I \times R_{12}$$
$$= 4.36 \text{ A} \times 20 \text{ }\Omega$$
$$= 87.2 \text{ V}$$

$$E_{34} = I \times R_{34}$$
$$= 4.36 \text{ A} \times 16.7 \text{ }\Omega$$
$$= 72.8 \text{ V}$$

Check . . . $E_{12} + E_{34} = 87.2 \text{ V} + 72.8 \text{ V}$
$$= 160 \text{ V}$$

which equals the supply voltage.

(a)

(b)
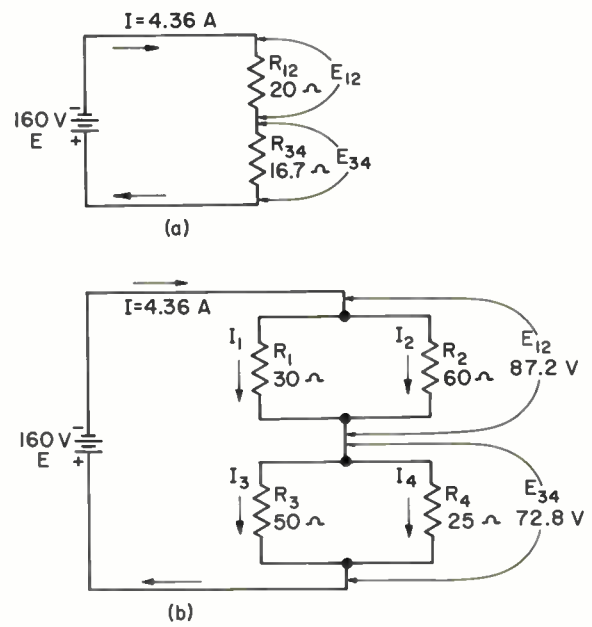
Fig. 5   Steps in the solution of the circuit of Fig. 4.

Since R_{12} is equivalent to R_1 and R_2 in parallel, the voltage across R_1 and R_2 is E_{12} (the voltage across R_{12}). We can now draw the diagram of Fig. 5(b), showing all currents and voltages known so far. Since this new diagram gives the voltages across R_1, R_2, R_3, and R_4, the current through each of these resistors can now be found.

$$I_1 = \frac{E_1}{R_1}$$
$$= \frac{E_{12}}{R_1}$$
$$= \frac{87.2 \text{ V}}{30 \text{ }\Omega}$$
$$= 2.91 \text{ A}$$

$$I_2 = \frac{E_2}{R_2}$$
$$= \frac{E_{12}}{R_2}$$
$$= \frac{87.2 \text{ V}}{60 \text{ }\Omega}$$
$$= 1.45 \text{ A}$$

$$I_3 = \frac{E_3}{R_3}$$
$$= \frac{E_{34}}{R_3}$$
$$= \frac{72.8 \text{ V}}{50 \text{ }\Omega}$$
$$= 1.46 \text{ A}$$

$$I_4 = \frac{E_4}{R_4}$$
$$= \frac{E_{34}}{R_4}$$
$$= \frac{72.8 \text{ V}}{25 \text{ }\Omega}$$
$$= 2.91 \text{ A}$$

Check . . . Note that the current from the negative side of the battery divides upon reaching R_1 and R_2, as shown in Fig. 5(b)—part of the current going through R_1, and part through R_2. Hence, the sum of I_1 and I_2 should equal the current coming from the battery. Similarly, the sum of I_3 and I_4 should equal the battery current.

$$I_1 + I_2 = 2.91 \text{ A} + 1.45 \text{ A}$$
$$= 4.36 \text{ A}$$
$$= I$$

$$I_3 + I_4 = 1.46 \text{ A} + 2.91 \text{ A}$$
$$= 4.37 \text{ A}$$
$$= I \text{ (approximately)}$$

The reason that I_3 and I_4 do not *exactly* add up to 4.36 A (the value of I) is that slight errors are made in rounding off values to three significant figures while working the problem. A slight discrepancy in the third significant figure often occurs in checking.

1. We wish to operate the two 6.3-V lamps in Fig. 6(a) in series. One lamp requires 0.3 A, and the other requires 0.4 A. Would the two lamps operate properly in series across 12.6 V? (a) _____ The resistance of the first lamp is (b) _____ Ω; that of the second is (c) _____ Ω. The total resistance of the two in series is (d) _____ Ω. When the two lamps are connected across 12.6 V, the current through them is (e) _____ A. By Ohm's law, the voltage across the first lamp is (f) _____ V, and that across the second is (g) _____ V. To make these lamps operate correctly, a resistor can be placed in parallel with one lamp as shown in Fig. 6(b). The resistor must draw (h) _____ A at (i) _____ V. Therefore, the value of the resistor should be (j) _____ Ω.
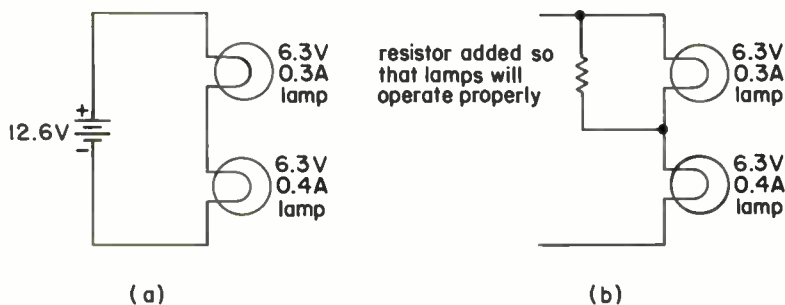
Fig. 6

2. If several lamps are to be operated in parallel, each of them must require the same _____. To be operated in series, each of them should require the same _____.

3. Figure 7 shows four methods of connecting three identical resistors to get four different total resistances. Suppose that all resistors are 100 Ω. The total resistance in Fig. 7(a) is (a) _____ Ω; in Fig. 7(b), (b) _____ Ω; in Fig. 7(c), (c) _____ Ω; and in Fig. 7(d), (d) _____ Ω. Therefore, to connect three resistors of equal value in such a way that the total resistance is one-third the resistance of any one of them, you'd connect them as shown in (e) _____; if one and one-half times the value of one, as shown in (f) _____; if two-thirds the value of one, as shown in (g) _____; and if three times the value of one, as shown in (h) _____.

*If you're using a calculator, remember that CIE's answers are usually rounded to three figures.

10

(a) (b) (c) (d)
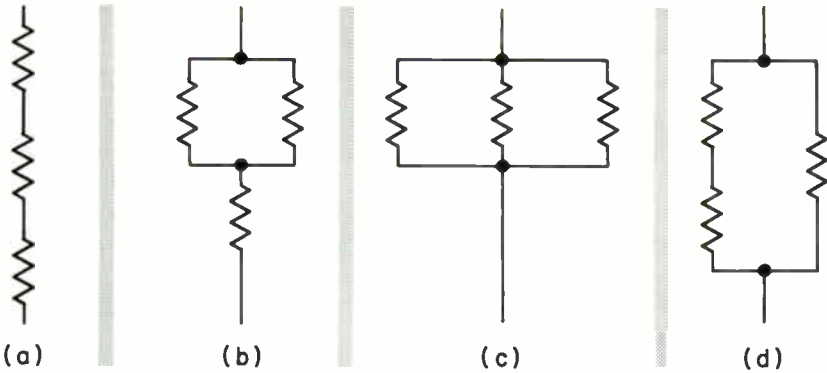
Fig. 7

4. Suppose that the values of R_1, R_2, and R_3 in Fig. l(a) are l4, l8, and 22 Ω, respectively. Suppose also that this series-parallel circuit is connected to a 90-V source. The combined resistance of R_1 and R_2 is (a) _____ Ω. The combined resistance of R_1, R_2, and R_3 is (b) _____ Ω. The 90-V source supplies (c) _____ A to the circuit. The current through R_3 is (d) _____ A. The voltage drop across R_3 is (e) _____ V; that across R_1 is (f) _____ V; and that across R_2 is (g) _____ V. The current through R_1 is (h) _____ A, and that through R_2 is (i) _____ A.

5. Suppose, in Fig. l(a), that the value of R_1 is 27 Ω, the value of R_2 is 34 Ω, and the value of R_3 is 58 Ω. If the circuit is connected to a l00-V source, the current through R_3 is _____ A, the current through R_1 is _____ A, and the current through R_2 is _____ A.

6. In Fig. l(a), the value of R_1 is 5 Ω; R_2 is 20 Ω; and R_3 is 6 Ω. The circuit is connected to a voltage source. The current through R_1 is 3 A. The voltage across R_1 is (a) _____ V, and the voltage across R_2 is (b) _____ V. The current through R_2 is (c) _____ A, and the current through R_3 is (d) _____ A. The voltage across R_3 is (e) _____ V, and the source voltage is (f) _____ V.

7. In Fig. l(a), R_1 is 240 Ω, R_2 is 80 Ω, and R_3 is 650 Ω. The circuit is connected to a voltage source. The current through R_1 is 30 mA (milliamperes), or (a) _____ A; the current through R_2 is (b) _____ mA; and the current through R_3 is (c) _____ mA. The voltage across R_1 is (d) _____ V; across R_2, (e) _____ V; and across R_3, (f) _____ V.

8. Suppose that a resistor of 32 Ω is in parallel with a resistor of 36 Ω, and that a 54-Ω resistor is in series with the pair. When 350 V is applied to the combination, the current through the 54-Ω resistor is _____ A, and the voltage drop across the 54-Ω resistor is _____ V.

9. A 242-Ω resistor is in parallel with a 180-Ω resistor, and 420-Ω resistor is in series with the combination. A current of 22 mA flows through the 242-Ω resistor. The current through the 180-Ω resistor is _____ mA.

10. Two 24-Ω resistors are in parallel, and a 42-Ω resistor is in series with the combination. When 78 V is applied to the three resistors so connected, the voltage drop across the 42-Ω resistor is _____ V.

11. A 19-Ω resistor is in parallel with an 18-Ω resistor, and a 14-Ω resistor is in series with the two. When 70 V is applied to this combination, the current through the 19-Ω resistor is _____ A.

ANSWERS

1. (a) No . . . One lamp requires more current than the other. If the two lamps were connected in series, the current would have to be the same in both.

(b) 21 . . . Naturally, we use Ohm's law ($R = E/I$) to find the resistance. Since it's the resistance of the first lamp we want to know, make sure that the value you use for E in the formula is the voltage across the first lamp (6.3 V), and that the value you use for I is the current required by the first lamp (0.3 A). So:

$$R = \frac{E}{I}$$
$$= \frac{6.3\text{ V}}{0.3\text{ A}}$$
$$= 21\ \Omega$$

(c) 15.75 ... You may prefer to round this off to three significant figures, calling it 15.7 or 15.8 Ω, and it's OK to do so. However, when the first significant figure is a 1, you'll increase your accuracy a little if you keep four significant figures. But as long as you keep at least three significant figures, your answers will be accurate enough for practical purposes, and would certainly never be considered wrong.

(d) 36.8 . . . 21 Ω + 15.75 Ω = 36.75 Ω. Now, you can use this value if you want to, but you'll save yourself some work in the following steps if you round it off to three significant figures, which would make it 36.7 or 36.8. Of course, this will make your final answer less accurate, but the difference is so slight that it's not worth the extra work involved in using four significant figures.

(e) 0.342 . . . Since we want to find the current through the two lamps if connected in series, the formula to use is $I = E/R$. The voltage to use in this formula is 12.6 V, since that's the voltage across the two lamps in series. Now, since we use the voltage across the two lamps for E, we must use the resistance of the two lamps from part (d) that is 36.8 Ω. Never forget that the values you use for both E and R must refer to the same part of the circuit. For example, if you use the voltage across both lamps for E, you can't use the resistance of only one of the lamps for R. Remembering this will spare you a lot of mistakes in using Ohm's law.

$$I = \frac{E}{R}$$
$$= \frac{12.6\text{ V}}{36.8\ \Omega}$$
$$= 0.342\text{ A}$$

If you use 36.7 or 36.75 for R, you'll get 0.343 A, and that answer is just as good as 0.342. Two persons won't generally get exactly the same answer to a problem with several steps, because they won't round off in exactly the same manner as they proceed. Consequently, don't expect the answers you get to agree exactly with our answers (although they should always be *close* to ours).

(f) 7.18 . . . In using the formula $E = IR$, keep in mind that you can't use just any values for I and R. We want to find the voltage across the *first lamp*. That means we must use for I the current through the *first lamp* (0.342 A), and we must use for R the resistance of the *first lamp* (21 Ω): $E = IR = 0.342 \times 21 = 7.18$ V. Now, maybe you got 7.16, 7.17, or 7.19 V, because you rounded off a little differently and so used a slightly different value for I. If so, don't let that worry you. Those values are close enough that any of them can be considered correct. When you went to school, you may have learned that if, say, 86.5 was the book answer, then 86.4 or any other close value was dead wrong. As engineers and technicians see it, however, all answers near 86.5 (say 86.3, 86.4, 86.6, and 86.7) are equally correct.

(g) 5.4 . . . Because the voltage across this lamp is less than the 6.3 V required for proper operation, the filament won't reach a high enough temperature, and the lamp will be too dim. You found in part (f) that the first lamp has 7.18 V across it. Thus, the first lamp will get too hot, and will eventually burn out.

(h) 0.1 . . . Looking at Fig. 6(a), we can see that our basic problem is that the lower lamp needs 0.4 A for proper operation, while the upper lamp needs only 0.3 A. We can lick this problem by connecting a resistor across the upper lamp as shown in Fig. 6(b), and giving it the necessary resistance value to draw 0.1 A. The resistor and the upper lamp together use 0.3 A + 0.1 A = 0.4 A. Thus, this parallel combination can be used properly in series with the lower lamp, since the current requirements are now the same. Remember that the flow of current is similar to water flow. Suppose the lower lamp was a water pipe capable of carrying 0.4 gal of water per minute, and that the upper lamp was a pipe that could carry only 0.3 gal per min. In order to keep the flow of water (current) through the lower pipe at 0.4 gal per min, we'd have to put an additional pipe across the first one to carry the additional 0.1 gal per min. All of the water through the first two pipes would then flow through the lower pipe. Similarly, all of the current through the two upper resistances must flow through the lower resistance.

(i) 6.3 . . . The voltage across the resistor will be the same as the voltage across the lamp, because the two are in parallel. Using the resistor has equalized the voltages across the lamps, so that each is now 6.3 V.

(j) 63 . . . $R = \dfrac{E}{I}$

$$= \frac{6.3}{0.1}$$
$$= 63\ \text{Ω}$$

Remember, to find the current through the resistor R, we must use the current through R for I in the formula. We can't use 0.3 A or 0.4 A for I because the current through the resistor is 0.1 A.

2. voltage; current

3. (a) 300; (b) 150; (c) 33.3; (d) 66.7; (e) c; (f) b; (g) d; (h) a

The circuit of Fig. 8(a) is as described in Problem 4. To find the combined resistance of R_1 and R_2 in parallel, we have

$$R_e = \frac{R_1 \times R_2}{R_1 + R_2}$$
$$= \frac{14 \times 18}{14 + 18}$$
$$= 7.88 \ \Omega$$
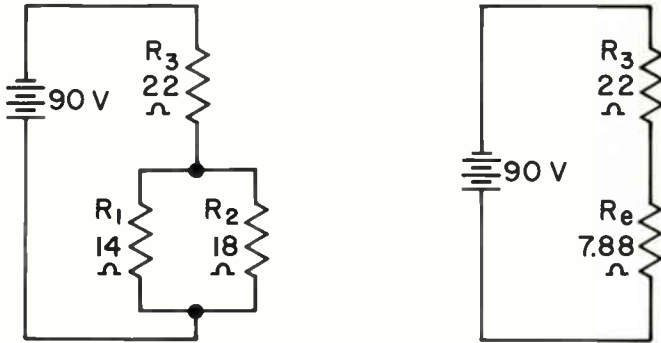
Fig. 8

where R_e is the equivalent resistance of the two. We can now draw the equivalent circuit, replacing the parallel combination of R_1 and R_2 with a single resistor of 7.88 Ω ,as shown in Fig. 8(b). Since R_e is in series with R_3, the combined resistance is $R_t = R_e + R_3 = 7.88 + 22 = 29.9 \ \Omega$, where R_t is the total resistance of the circuit. To find the current supplied by the source, we use Ohm's law: $I = E/R_t = 90/29.9 = 3.01$ A. The current through R_3 is, of course, the total current from the source—that is, 3.01 A. The voltage drop across R_3 is determined by Ohm's law to be $E = IR_3 = 3.01 \times 22 = 66.2$ V. The voltage drops across R_1 and R_2 are equal, because the two resistors are in parallel; they can be found by subtracting the drop across R_3 from the source voltage: $90 - 66.2 = 23.8$ V. Finally, by using the voltage drop across each resistor, we can compute the current through each: $I_1 = E_1/R_1 = 23.8/14 = 1.70$ A; $I_2 = E_2/R_2 = 23.8/18 = 1.32$ A.

5. 1.37; 0.763; 0.606 . . . The first thing to do when a circuit is involved is to draw the circuit. Then, add to the drawing all pertinent data given. This was done in Fig. 9. There are various ways to solve this problem, but we'll show only one.
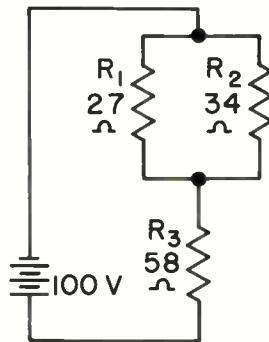
Fig. 9

First,

$$R_e = \frac{R_1 \times R_2}{R_1 + R_2}$$
$$= \frac{27 \times 34}{27 + 34}$$
$$= 15.05 \; \Omega$$

$R_t = 15.05 \; \Omega + 58 \; \Omega = 73.05 \; \Omega$, or 73.0 to three significant figures. Next, find the total current through the circuit. To do this, divide the total voltage by the total resistance:

$$I_t = \frac{100 \text{ V}}{73 \; \Omega}$$
$$= 1.37 \text{ A}$$

Now, find the voltage across the parallel combination. The total current is flowing through R_3. The voltage drop across R_3 is $E = 1.37 \text{ A} \times 58 \; \Omega = 79.4 \text{ V}$. Hence, the voltage across the parallel combination is $100 \text{ V} - 79.4 \text{ V} = 20.6 \text{ V}$. The current through the resistors, then, is

$$I_{R_1} = \frac{20.6 \text{ V}}{27 \; \Omega}$$
$$= 0.763 \text{ A}$$

and

$$I_{R_2} = \frac{20.6 \text{ V}}{34 \; \Omega}$$
$$= 0.606 \text{ A}$$

As a check, the sum of the currents through R_1 and R_2 should equal the current through R_3: $0.763 \text{ A} + 0.606 \text{ A} = 1.369 \text{ A}$. Rounded off to three significant figures, this becomes 1.37 A, which is the same as the value found above for I_t. Since it's not likely that you rounded off exactly as we did at every step in the solution, your figures may vary slightly from ours. Don't waste time worrying about that. (Remember what we said about significant figures in the answer to Problem 1.) Also, in checking your answer, the sum of the two branch currents may not be precisely the same as the current through R_3 because of slight errors in rounding off.
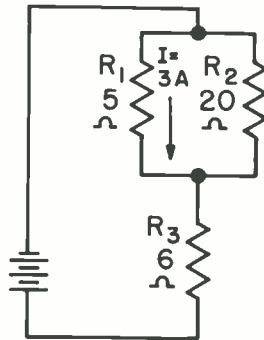
Fig. 10

6. (a) 15; (b) 15; (c) 0.75; (d) 3.75; (e) 22.5; (f) 37.5 . . . Refer to Fig. 10. The voltage across R_1 is found in Ohm's law to be $E = IR = 3 \text{ A} \times 5 \, \Omega = 15$ V. Since R_2 is in parallel with R_1, the voltage across it is also 15 V. The current through R_2 is $I = E/R = 15 \text{ V}/20\Omega = 0.75$ A. The current through R_3 must be the sum of the currents through R_1 and R_2, or 3 A + 0.75 A = 3.75 A. Since we know the current through R_3 and the resistance of R_3, we can find the voltage across R_3: $E = IR = 3.75 \text{ A} \times 6 \, \Omega = 22.5$ V. Finally, the source voltage is the sum of the voltages across the parallel branch and the series branch, or 15 V + 22.5 V = 37.5 V.

7. (a) 0.03; (b) 90; (c) 120; (d) 7.2; (e) 7.2; (f) 78   8. 4.94; 267

9. 29.6 . . . Refer to Fig. 11. First find the voltage drop across the 242-Ω resistor: $E = IR = 0.022 \text{ A} \times 242 \, \Omega = 5.324$ V. The same voltage must appear across the 180-Ω resistor, so the current through the 180-Ω resistor is $I = E/R = 5.324 \text{ V}/180 \, \Omega = 0.0296$ A. In this problem, we don't have to consider the value of the series resistor, because we know the voltage across the resistor in parallel with the 180-Ω resistor.
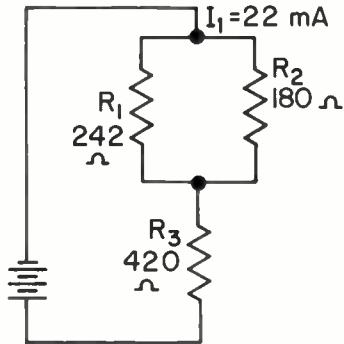
Fig. 11

10. 60.5

11. 1.46 . . . See Fig. 12.

$$R = \frac{19 \times 18}{19 + 18}$$
$$= 9.243 \, \Omega$$

$$R_t = 14 \, \Omega + 9.243 \, \Omega$$
$$= 23.243 \, \Omega$$

$$I_t = \frac{70 \text{ V}}{23.24 \, \Omega}$$
$$= 3.012 \text{ A}$$
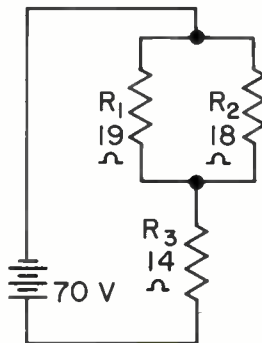
Fig. 12

Voltage drop across the 14-Ω resistor is

$$E = 3.012 \text{ A} \times 14 \text{ Ω}$$
$$= 42.168 \text{ V}$$

Voltage drop across the parallel resistor is

$$E = 70 \text{ V} - 42.170 \text{ V}$$
$$= 27.830 \text{ V}$$

The current through the 19-Ω resistor is

$$I = \frac{27.83 \text{ V}}{19 \text{ Ω}}$$
$$= 1.46 \text{ A}$$

3 SERIES-PARALLEL CIRCUITS WITH MANY COMPONENTS . . . A series-parallel circuit can have more branches than the circuits we've studied so far, but it's "worked" following the same general method. The examples below illustrate the procedure.
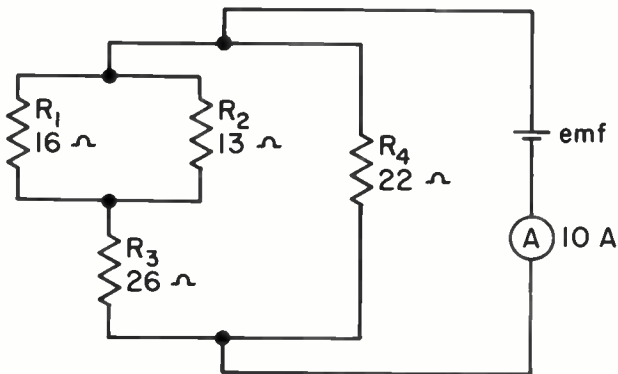
Fig. 13   Diagram of four-component series-parallel circuit.

Example 1 . . . What's the combined resistance of the network of Fig. 13?

Solution . . . Since R_1 and R_2 are in parallel with each other, their combined resistance is

$$R_{12} = \frac{R_1 R_2}{R_1 + R_2}$$
$$= \frac{16 \times 13}{16 + 13}$$
$$= 7.17 \text{ Ω}$$
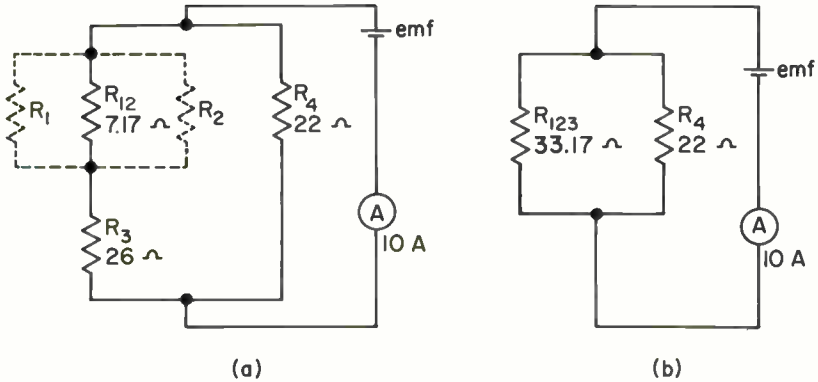
Fig. 14   Equivalent circuits for Fig. 13.

In Fig. 14(a), the circuit is redrawn with R_1 and R_2 replaced by the equivalent resistor R_{12}. R_{12} is seen to be in series with R_3, so that the combined resistance of these two is 7.17 Ω + 26 Ω = 33.17 Ω. An equivalent circuit is again drawn [see Fig. 14(b)]; in it, R_{123} replaces R_{12} and R_3 of Fig. 14(a). Figure 14(b) is a simple parallel circuit, the combined resistance of which is

$$R = \frac{R_{123}R_4}{R_{123} + R_4}$$
$$= \frac{33.17 \times 22}{33.17 + 22}$$
$$= 13.23\Omega$$

Example 2 . . . In Fig. 13, the total current flowing through the combination, as shown by the ammeter A, is 10 A. (a) How much is the impressed voltage (emf)? (b) What's the current through R_1? (c) through R_2? (d) through R_3? (e) through R_4? (f) what's the voltage drop across R_1? (g) across R_3?

Solution . . . (a) 132.3 V . . . The combined resistance from Example 1 is 13.23 Ω, so—since the current is 10 A—the impressed voltage is 10 A $\times$ 13.23 Ω = 132.23 V.
(b) 1.79 A . . . In Fig. 14(b), the current through R_{123} is 132.3 V/33.17 Ω = 4 A. In Fig. 14(a), the voltage drop across R_{12} is 4 A $\times$ 7.17 Ω = 28.7 V. In Figure 13, the current through R_1 is 28.7 V/16 Ω = 1.79 A.
(c) The current through R_2 is 28.7 V/13 Ω = 2.21 A.
(d) The current through R_3 is the same as the current through R_{123} (4 A).
(e) The current through R_4 is 132.3 V/22 Ω = 6.01 A.

Check on Current Distribution . . . The 10 A from the source must pass through R_1, R_2, and R_4. Hence, the sum of the currents through these three resistors should equal the total current: 1.79 A + 2.21 A + 6.01 A = 10.01 A. The slight discrepancy is due to the calculations being accurate to only three significant figures.

(f) The voltage across R_1 is 1.793 A × 16 Ω = 28.7 V.
The voltage across R_2 is 2.21 A × 13 Ω = 28.7 V. (This is a check on E_1, since E_1 and E_2 should be equal.)
(g) The voltage across R_3 is 4 A × 26 Ω = 104 V.

Voltage Check . . . The voltage across R_1 plus the voltage across R_3 should equal the impressed voltage: 28.7 V + 104 V = 132.7 V. (This is close enough to verify the accuracy of the computations.)

WHAT HAVE YOU LEARNED?

1. Two resistances of 28 Ω and 25 Ω are connected in parallel; a 38-Ω resistance is connected in series with this combination; a 24-Ω resistance is connected in parallel with this total combination. The total current flowing through the combination is 75 mA. What's the current value in the 25-Ω resistance?

ANSWERS
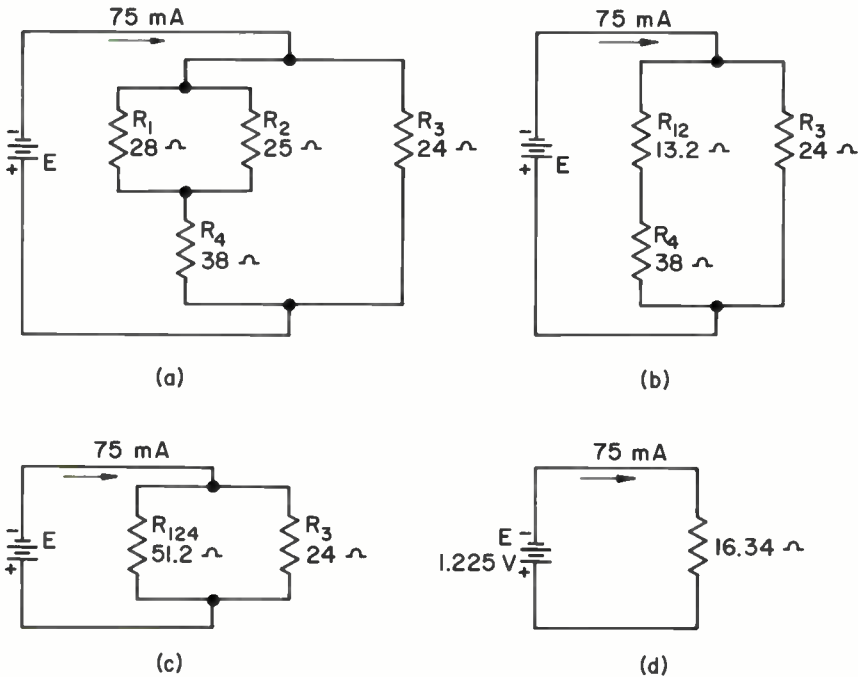
Fig. 15

1. 12.6 mA . . . Figure 15 shows the progressive steps to follow in working out the problem. Part (a) shows the circuit. In parts (b), (c), and (d), the components have been combined to form simpler and simpler equivalent circuits, until in (d) the entire resistance network has been reduced to the single equivalent 16.34-Ω resistance. Now, Ohm's law can be used to find the battery E voltage (1.225 V). Part (e) is part (c) redrawn, but—since E is now known—the currents through R_{124} and R_3 can now be found. (They are as shown.) At this point, make your first check by adding the two branch currents: 23.9 mA + 51.0 mA = 74.9 mA. Although this sum doesn't *exactly* equal the total current of 75 mA, it's close enough. Again, the discrepancy results from rounding off in the calculations.
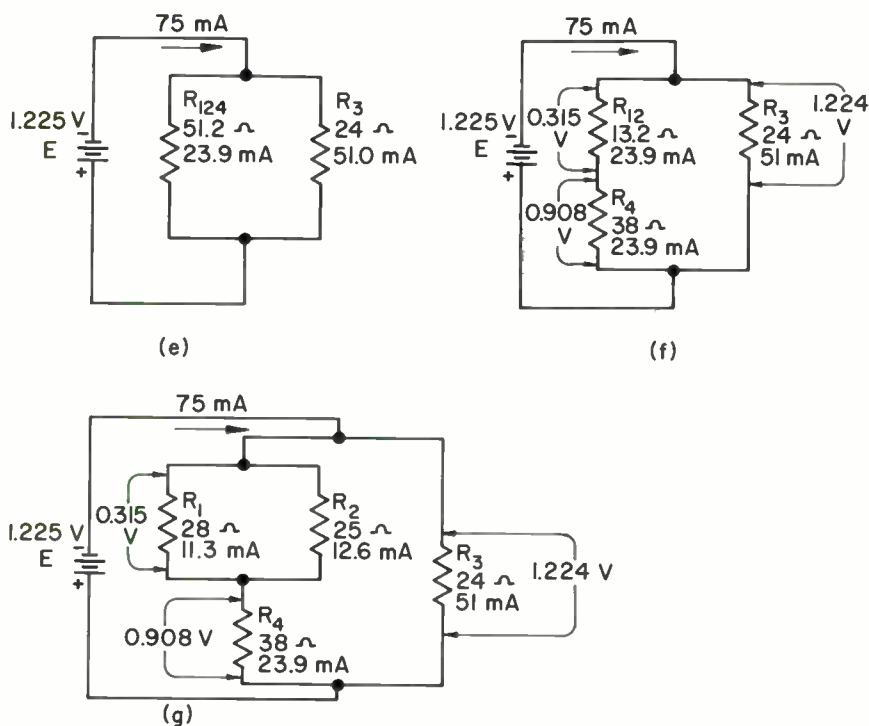
Fig. 15 cont'd.

Fig. 15(f) is part (b) redrawn, with the information in parts (d) and (e) added. The voltage drops across the resistances are calculated by $E = I \times R$, and the results are marked on the figure. We can now make our next check by seeing if the sum of the voltages across R_{12} and R_4 equals the applied voltage E: 0.315 V + 0.908 V = 1.223 V. The slight difference between this sum and 1.225 (the value of E) is, again, due to rounding off.

Part (g) of Fig. 15 is the original drawing with all known values added. All that remains is to find the value of the currents through R_1 and through R_2. The sum of these two currents should equal the current through R_4—so, as your last check, see if it does.

Most of the wire used for electrical conduction is made of copper. You should be familiar with how various wire sizes are designated, and with the use of a wire table to answer copper-wire problems.

4 COPPER WIRE SIZES . . . Copper wire intended for use as a conductor is sized in accordance with American Wire Gage (AWG) numbers. Some sizes commonly used in electronics applications are shown in actual size in Fig. 16. Note in particular that the larger the gage number, the smaller the wire. Although wires as small as No. 40 (0.003 in.) are commonly used in electronics, they're not shown in Fig. 16 because they're too small to distinguish in type.

A popular size of hookup wire for electronics circuitry is No. 22. (See Fig. 16) It's large enough to have adequate mechanical strength, but is easy to handle. In compact transistor circuitry, where space is limited, wire as small as No. 32 (not shown) is used. Wire smaller than that would be too fragile for hookup or other unprotected use. Most of the hookup wire used today has plastic insulation.
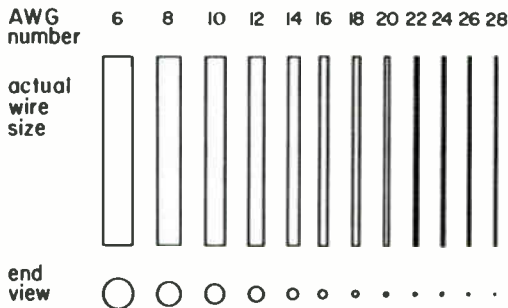
Fig. 16   Actual sizes of copper wire conductors.

Although No. 22 hookup wire can carry a current of 1 A or more without damage to the insulation, larger wire is often used for currents over 100 mA, in order to keep the power and the voltage loss in the wire low. Of course, the less protected the wire is, the larger it must be. For example, a wire smaller than No. 18 is unsuitable for a power cord that is to carry more than 3 A.

The National Electrical Code doesn't allow the use of wire smaller than No. 14 for building or workshop wiring. Wire of this size should never be fused for more than 15 A. Number 12 workshop wiring can be fused for 20 A, and No. 10 can be fused for 30 A. Good technicians see to it that their workshop wiring is never overfused.

Wire intended for coil winding is called *magnet* wire. Since such wire isn't sub-
ject to physical damage, the insulation can be thin (so that it doesn't take up valuable
coil space). For insulation, magnet wire is commonly coated with either enamel
or a thin film of some plastic material, such as polyester. Magnet wire sizes from
No. 20 to No. 40 are in common use.

5 COPPER WIRE TABLE . . . Some useful reference material on copper wire is
given in Table 1. Wire diameter is usually given in *mils*, a mil being one-thousandth
of an inch. Thus, the diameter of a No. 18 wire, given in the table as 40.3 mils,
is 0.0403 in. In winding a coil, it's necessary to know how long a winding form
is needed to hold the desired number of turns. The column headed *Turns per Linear
Inch* gives this information. For example, a form 2 in. long will hold a single-
layer winding of 2 × 37 = 74 turns of No. 22 enamel-covered wire.

Since the resistance of wire is inversely proportional to its cross-sectional area,
the cross-sectional area of wire is obviously of particular interest. If we double
the cross-sectional area of a conductor, we halve the resistance of the conductor;
if we reduce the cross-sectional area to one-third of its original value, we increase
the resistance to three times its original value; and so forth.

Be careful not to confuse cross-sectional area with diameter. The cross sections
of two conductors are shown in Fig. 17. Note that the conductor in (b) has twice
the diameter of the conductor in (a). But the area of the end of (b) is *four* times
the area of the end of (a). The cross-sectional area of a conductor varies with
the square of the diameter: if, for example, the diameter is tripled, the area becomes
nine times its previous value. This is because the area of any circle is equal to
one-fourth of π (pi) times the square of its diameter.

the area is the
amount of surface
inside the circle

0.785
sq. in.
area

3.14
sq. in.
area

— 1 in. —
diameter
(a)

— 2 in. —
diameter
(b)
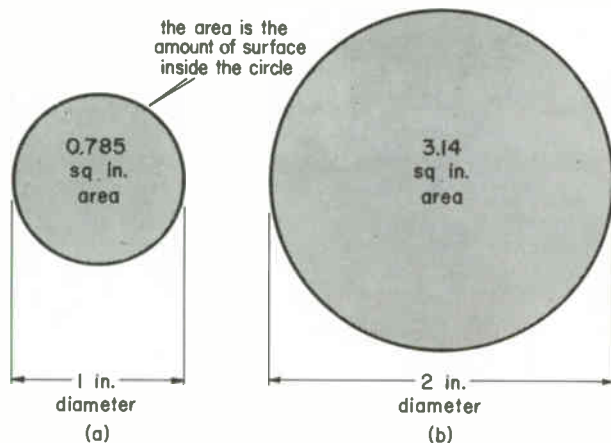
**Fig. 17   Although the diameter of the circle in (b) is only twice that of the circle
in (a), the area of the circle in (b) is four times that of the circle in (a).**

22   The square of the diameter of a wire, in mils, is called the *circular-mil* (CM) area of the wire. If the diameter of a wire is 42 mils, for example, its area will be $42 \times 42 = 1764$ CM. The resistance of a conductor is inversely proportional to its circular-mil area.

Example . . . A certain wire with a diameter of 204 mils has a resistance of 18 Ω. What will be the resistance of another wire the same length and of the same material, but with a diameter of 74 mils?

Solution . . .
$$204^2 = 41{,}600 \text{ CM}$$
$$74^2 = 5480 \text{ CM}$$
$$\frac{41{,}600}{5480} = \frac{R}{18}$$
$$R = 136.8 \ \Omega$$

Explanation . . . The diameters are squared in order to obtain the circular-mil cross-sectional area of the wire. An inverse proportion is then formed and solved. An inverse proportion is used because the resistance varies inversely as the cross-sectional area.

Since magnet wire is used for winding coils in which the closeness of the turns prevents free dissipation of heat, the current-carrying capacity of magnet wire is much less than that of hookup wire or other wire whose surface is exposed to the air. A rule of thumb for determining the current-carrying capacity of wire wound into a multilayer coil is one ampere per 1500 CM. For example, Table 1 shows the circular-mil area of No. 18 wire as 1625 CM. Therefore, 1.1 A is a reasonable estimate of the maximum current that a coil wound with No. 18 wire can carry.

It's also useful to remember that wire area doubles for every three gage numbers. Thus, a No. 20 wire has twice the circular-mil area of a No. 23 wire—and therefore half the resistance.

TABLE 1   23

Copper Wire Table

Gage No. (AWG)	Diameter (mils*)	CM (Circular-Mil Area)	Turns per Linear Inch† (enamel-covered wire)	Feet per lb (bare wire)	Ohms per 1000 ft. 25 C°	Current-carrying capacity at 1500 CM per A‡
1	289.3	83690	—	3.947	0.1264	55.7
2	257.6	66370	—	4.977	.1593	44.1
3	229.4	52640	—	6.276	.2009	35.0
4	204.3	41740	—	7.914	.2533	27.7
5	181.9	33100	—	9.980	.3195	22.0
6	162.0	26250	—	12.58	.4028	17.5
7	144.3	20820	—	15.87	.5080	13.8
8	128.5	16510	7.6	20.01	.6405	11.0
9	114.4	13090	8.6	25.23	0.8077	8.7
10	101.9	10380	9.6	31.82	1.018	6.9
11	90.74	8234	10.7	40.12	1.284	5.5
12	80.81	6530	12.0	50.59	1.619	4.4
13	71.96	5178	13.5	63.80	2.042	3.5
14	64.08	4107	15.0	80.44	2.575	2.7
15	57.07	3257	16.8	101.4	3.247	2.2
16	50.82	2583	18.9	127.9	4.094	1.7
17	45.26	2048	21.2	161.3	5.163	1.3
18	40.30	1624	23.6	203.4	6.510	1.1
19	35.89	1288	26.4	256.5	8.210	0.86
20	31.96	1022	29.4	323.4	10.35	.68
21	28.46	810.1	33.1	407.8	13.05	.54
22	25.35	642.4	37.0	514.2	16.46	.43
23	22.57	509.5	41.3	648.4	20.76	.34
24	20.10	404.0	46.3	817.7	26.17	.27
25	17.90	320.4	51.7	1031	33.00	.21
26	15.94	254.1	58.0	1300	41.62	.17
27	14.20	201.5	64.9	1639	52.48	.13
28	12.64	159.8	72.7	2067	66.17	.11
29	11.26	126.7	81.6	2607	83.44	.084
30	10.03	100.5	90.5	3287	105.2	.067
31	8.928	79.70	101	4145	132.7	.053
32	7.950	63.21	113	5227	167.3	.042
33	7.080	50.13	127	6591	211.0	.033
34	6.350	39.75	143	8310	266.0	.026
35	5.615	31.52	158	10480	335.0	.021
36	5.000	25.00	175	13210	423.0	.017
37	4.453	19.83	198	16660	533.4	.013
38	3.965	15.72	224	21010	672.6	.010
39	3.531	12.47	248	26500	848.1	.008
40	3.145	9.88	282	33410	1069	0.006

*A mil is 1/1000 (one thousandth) of an inch.
†The figures given are approximate only, since the thickness of the insulation varies with the manufacturer.
‡The current-carrying capacity at 1000 CM per ampere is equal to the circular-mil area (column 3) divided by 1000.

1. Table 1 shows that the diameter of No. 24 wire is 20.1 mils. What's the diameter of the wire in inches?

2. Having found the diameter of No. 24 wire in Problem 1, find the circular-mil area of the wire. (Compare your answer with the value given in Table 1.)

3. You must run hookup wire between two points in a circuit that are 5 ft apart. The wire will be carrying 0.2 A, and the voltage loss in the wire must not exceed 5 mV. What's the smallest size of wire you can use? (Hint: Use the column *Ohms per 1000 ft* in Table 1 to find the resistance of various sizes of wire.)

ANSWERS

1. 0.0201 in.   2. 404.01 CM . . . 20.1² = 404.01. This is the same as the value given in Table 1.

3. No. 16 . . . By Ohm's law, the maximum resistance the 5-ft length of wire can have would be

$$R = \frac{E}{I}$$
$$= \frac{0.005 \text{ V}}{0.2 \text{ A}}$$
$$= 0.025 \ \Omega$$

The maximum resistance per foot would be 0.025/5 = 0.005 Ω or 1000 × 0.005 = 5 Ω per 1000 ft. Looking in Table 1, we find that No. 16 is the smallest wire with a resistance not exceeding 5 Ω per 1000 ft.

LESSON 2324A-7
SERIES-PARALLEL CIRCUITS

EXAMINATION

Each examination question is followed by a number of selections. Circle the number in front of the correct selection for each question. When you have finished, transfer your answers to the Answer Sheet provided.

1. In which network of Fig. 18 is the total resistance equal to 1½ times the resistance of one resistor? (Hint: Assume each resistance to be 1 Ω—or some other convenient value—and work out total resistance for each network.)

   (1) (a)   (2) (b)   (3) (c)   (4) (d)

2. In which network of Fig. 18 is the total resistance equal to two-thirds the resistance of one resistor? (Each resistance has the same value.) Select your answer from among the choices given for Question 1.

(a)

(b)

(c)

(d)
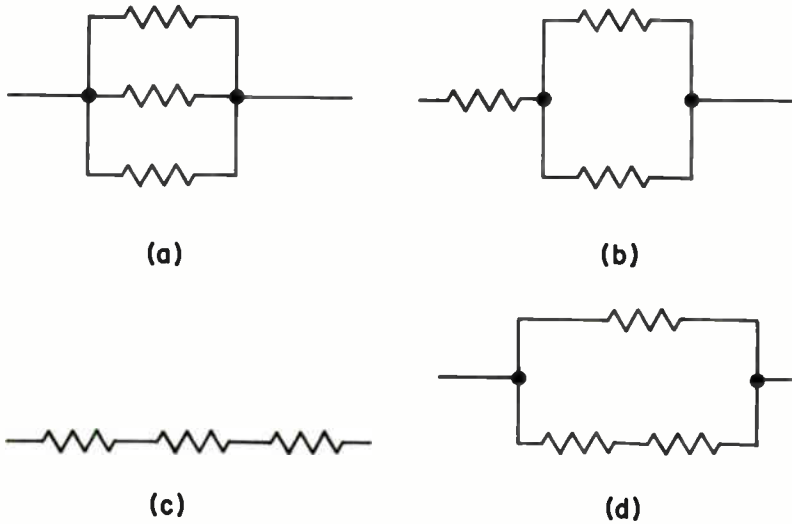
Fig. 18

3. In which network of Fig. 18 is the total resistance equal to three times the resistance of one resistor? Select your answer from among the choices given for Question 1.

4. In which network in Fig. 18 is the total resistance equal to one-third the resistance of one resistor? Select your answer from among the choices given for Question 1.

5. Figure 19 shows a series-parallel circuit with ammeters and voltmeters connected to measure current and voltage in various parts of the circuit. Voltmeter V_2 reads 36 V, and ammeter A_1 reads 4 A. What does ammeter A_4 read?
   (1) 2 A   (3) 4 A   (5) 8 A
   (2) 3 A   (4) 6 A
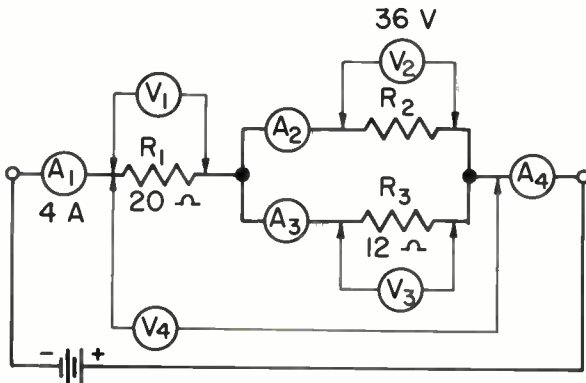
Fig. 19

6. What does voltmeter V_3 in Fig. 19 read?
   (1) 18 V   (2) 36 V   (3) 48 V   (4) 72 V
   (5) Can't be determined based on information given

7. What does ammeter A_3 in Fig. 19 read?
   (1) 1 A   (3) 3 A   (5) 6 A
   (2) 2 A   (4) 4 A

8. You want to replace the four resistors of Fig. 20 with a single resistor. What
   value should it be? (It will be helpful to redraw this circuit, so that the com-
   ponents in series and those in parallel will be more readily apparent.)
   (1) 20.8 Ω   (3) 25.0 Ω   (5) 100 Ω
   (2) 21.8 Ω   (4) 26.6 Ω
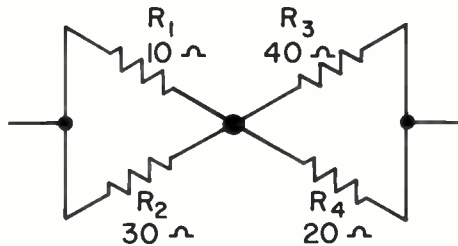
Fig. 20

9. A good wire size for general use in hooking up electronic components is
   (1) No. 14. (2) No. 16. (3) No. 19. (4) No. 22. (5) No. 28.

10. You have wound a coil using 50 ft of No. 24 wire. Measuring the resistance,
    you find it's twice the value you want. What size wire should be used in order
    to get the desired resistance (assuming that 50 ft is still needed)?
    (1) No. 21   (2) No. 22   (3) No. 23   (4) No. 25   (5) No. 27

END OF EXAM

Regular daily study is your key to fast
progress. Start tomorrow on your next
lesson.

Lesson 2324B-7
Voltage and Power

UNDERSTANDING POTENTIAL

6 INTRODUCTION . . . Until you get a firm mental grip on the meaning of *potential* or *voltage*, you can't clearly understand electronic circuits. Since every electronic circuit involves voltage, it's not hard to see why this is true.

To begin with, measuring voltage is a lot like measuring distance. When you use a ruler to measure distance, you put the "zero" mark at one point and determine the distance to the other point by noting the reading on the ruler. Similarly, when we measure voltage with a voltmeter, we also have two points: one point where we put the *ground* (or reference) probe, and another point where we put the *hot*, or measurement, probe. Just as there can be no ruler without at least two points, there can be no voltmeter without having two leads. And just as we can't specify a distance without having two points to compare, we can't have a voltage without two points to compare.

Many students seem to get confused when we introduce the concept of *ground*. Actually, ground is simply a common reference point, just as the term *ground level* is used when specifying the height of a building, or *sea level* when specifying the elevation of a mountain.

Taking the latter as an example, suppose we were considering the elevation of a mountain on an island in the ocean. If the top of the mountain were 1000 feet above sea level, we'd say that the elevation of the top of the mountain was +1000 feet. However, if there were a mine shaft on the same island, and the bottom of the shaft were 100 feet below sea level, then the elevation of the bottom of the mine shaft would be −100 feet. In a similar way, you can have *voltages* that are both positive and negative in relation to ground, such as +1000 V and −1000 V.

Now, let's suppose that a canary flies from the bottom of the mine shaft to the top of the mountain. How high would the bird have flown? Of course, the total distance would be the sum of 100 feet and 1000 feet, or 1100 feet. Now, suppose you had an electric current flowing from −100 V to +1000 V, and that the current flowed through a resistor. The total voltage across the resistor would be 100 V plus 1000 V, or 1100 V.

28 Another area that seems to bother a lot of students concerns the determination of the polarity of a voltage. The key here is that polarity is determined by the direction that current would flow through a resistor if it were going from one point to another, *even though there may be no such resistor and no such current flowing in the circuit.* If you have a waterfall with a 200-foot drop, that 200-foot drop remains even if there happens to be no water flowing over the fall at some point in time. We could dam up the water, and stop the waterfall, but the drop would still remain—and it's the same way with voltage. There may actually be no current path through a resistor (or other component), but the difference between −100 V and +1000 V would still be there, with the first point being 1100 V more negative than the other.

Now, let's consider that mountain on the island again: Suppose you were standing at a point on the mountain that was 125 feet above sea level. Suppose that you then climb to a point 750 feet above sea level. How far up would you have climbed? Of course, the answer is the difference between +125 feet and +750 feet, or 625 feet. So, at the end of the climb you'd be standing 625 feet above the point where you began, and you'd also be 750 feet above sea level. Further, you'd be at −250 feet in relation to the top of the 1000-foot mountain.

Similarly, you could have a circuit powered from 1000 V, but you might be interested in the voltage between two points that were at, say, +125 V and +750V in relation to ground. The voltage between these two points would be 625 V, of course. If a resistor were connected between them, it would have 625 V across it. One end of the resistor would be at +125 V measured from ground, and the other end would be at +750 V. If you connected a voltmeter between the ends of a resistor, you'd read 625 V. Furthermore, the voltmeter would read the same, regardless of whether the resistor were actually there or not.

Finally, when you're tracing circuits, remember that for every electron leaving the − terminal of the battery, another electron enters the + terminal at the same time. This means that all the current flowing out of the − terminal of a battery must return to the + terminal of that same battery: it won't stop simply because it has reached the + terminal of another battery. There can be no current unless there's a complete circuit from the − to the + end of the battery.

7 VOLTAGE IS ALWAYS RELATIVE . . . What's the voltage point *F* in Fig. 21? To find out, we use a voltmeter—one lead of which is, of course, connected to point *F*, as shown. But a voltmeter has *two* leads—so where do we connect the other lead? If we connect it to point *E*, the voltmeter will read 11 V; if we connect it to point *D*, the meter will read 14 V; if we connect it to point *C*, 20 V; and so on. In other words, to ask what the voltage is at point *F* is meaningless unless we specify the other point of measurement.

For all practical applications, voltage (or potential) is a *relative* matter; that is, we can state the voltage at some point in a circuit only by comparing that point

with some other point. In Fig. 21, we can say that the voltage at point F is 14
V *with respect to point* D; 20 V *with respect to point* C; or 11 V *with respect to point* E. To say that the voltage at point F is so many volts means nothing at all unless a reference point is stated or implied.
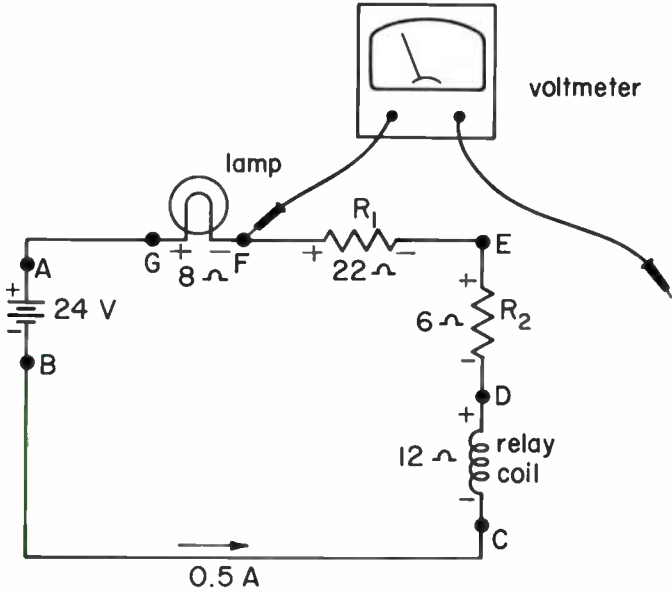
Fig. 21   The voltmeter reading depends upon where the meter is connected.

When we say that the voltage across R_1 in Fig. 21 is 11 V, we mean that the voltage at point F with respect to point E is 11 V (or the voltage at point E with respect to F is 11 V). When we say that the voltage of the battery in Fig. 21 is 24 V, we mean that the voltage at point A with respect to point B is 24 V. However, you shouldn't say that the voltage at point A is 24 V unless you're sure the person you're talking to understands that you mean the voltage at point A with respect to point B, the negative battery terminal. For example, the votlage at point A with respect to point D is *not* 24 V, but 18 V.

8 POLARITY WITH RESPECT TO REFERENCE POINT . . . More often than not, you'll want to know not only the numerical value of the voltage between two points, but also the polarity of that voltage. A voltage at a given point in a circuit is positive if it's more positive than the reference point. The voltage at point F in Fig. 21 is +14 V with respect to point D. We can tell this by the fact that the positive lead of the voltmeter must be connected to the point at which we want the voltage, point F, in order that the voltmeter will read forward. The voltage at point D is −14 V with respect to point F, because to measure the voltage at

30 point D you must connect the negative voltmeter lead to point D in order to get a forward reading.

The voltage at a given point in a circuit can be either positive or negative, depending upon what's used as the reference point. Point F is $+14$ V with respect to point D, but point F is -4 V with respect to point G. Not only voltage but also polarity at a point is meaningless unless the reference point with which a comparison is being made is specified or otherwise understood.

9 GROUND AS THE REFERENCE POINT FOR VOLTAGE MEASUREMENTS
. . . As we'll see in the next topic, most practical electronic equipment has some point in the circuitry grounded. Very frequently, the metal chassis to which the ground connection is made is used as the reference point to which voltage measurements are made. For example, the voltage with respect to ground at point F in Fig. 22 is $+20$ V. Similarly, the voltage to ground at point D is $+6$ V.
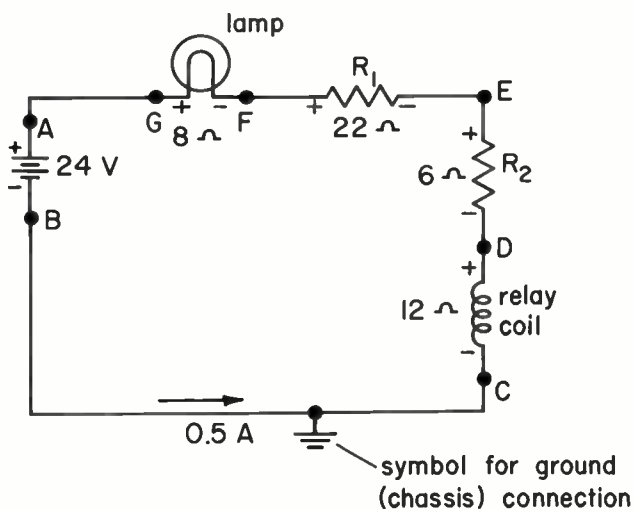
Fig. 22   **Voltage measurements often use ground as the reference point.**

The voltages marked on a manufacturer's circuit diagram can usually be assumed to be with respect to ground if not otherwise stated. However, always check the corner of the drawing for a legend that gives the reference point used for the voltage measurements.

1. In Fig. 2l, the voltage and polarity at point E with respect to point C are _____.

2. In Fig. 2l, the voltage and polarity at point C with respect to point D are _____. The voltage across the relay coil is __ V. The voltage and polarity at point D with respect to point C are _____.

3. In Fig. 2l, the voltage at point B with respect to point C is _____ V.

4. In Fig. 2l, the voltage and polarity of point A with respect to point E are _____.

5. In Fig. 22, the voltage and polarity to ground of the positive terminal of the battery are _____, and the voltage and polarity to ground of the negative battery terminal are _____.
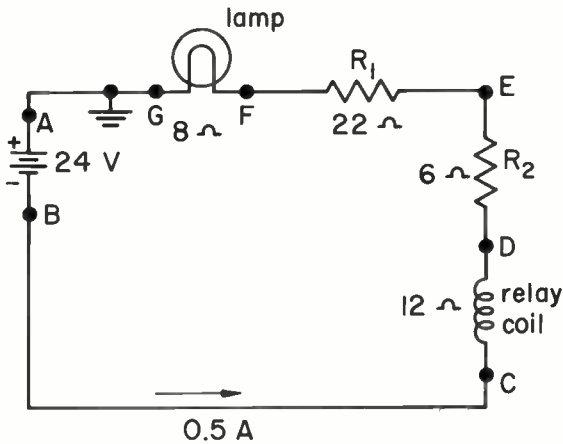
Fig. 23

6. In Fig. 23, the voltage and polarity to ground of the positive terminal of the battery are _____. The voltage and polarity to ground of the negative battery terminal are _____. The voltage across the battery in both Fig. 22 and Fig. 23 is _____ V.

7. In Fig. 23, the voltage and polarity to ground at point F are _____; at point E, they're _____; at point D, they're _____; and at point C, they're _____ V.
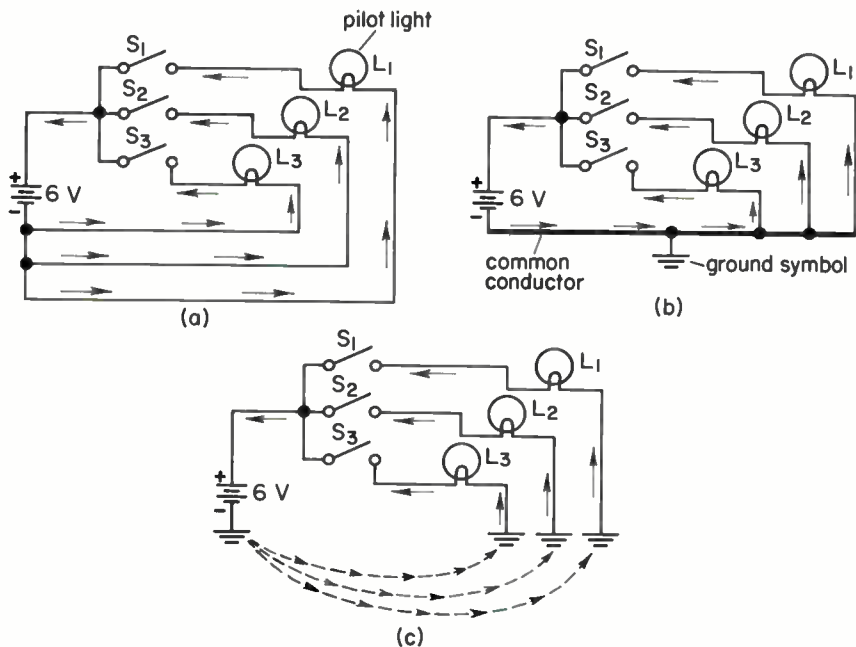
Fig. 24   Use of grounding to reduce the amount of wiring.

ANSWERS

1. +9 V . . . The resistance between points E and C is 18 Ω. $E = I \times R = 0.5 \times 18\Omega$ = 9 V. To find the polarity, remember that the end of a passive component from which the current leaves is positive with respect to the end the current enters. Hence, to get a forward reading with the voltmeter, the positive lead of the meter must be connected to point E. Hence, point E is 9 V positive with respect to C.

2. −6 V; 6 . . . We have no basis for calling this voltage either positive or negative, since nothing is said about which end of the relay is the reference end. However, if we're in terested in polarity, we can say that "the voltage across the relay coil is 6 V, end D being positive with respect to end C"; +6 V

3. 0   4. +15 V   5. +24 V; 0 V

6. 0 V; −24 V . . . Your voltmeter is, of course, measuring the voltage across the battery when the leads are connected at point B and at ground in Fig. 23. For a forward meter reading, the negative lead of the voltmeter must be connected to point B, the negative battery terminal. Hence, point B is −24 V with respect to ground; 24

7. −4 V . . . The current direction through the lamp is from F to ground. Since the lamp is a passive component, the current enters at the negative side (point F) and comes out at the positive side, which is connected to ground. Hence, point F is negative with respect to ground; −15 V; −18 V; −24 V

10 THE USE OF GROUNDS IN ELECTRONICS . . . Most electronic circuitry is built up on a metal chassis. Some of the wiring leads are usually soldered—or

otherwise connected—directly to the chassis. Such leads are said to be *grounded*. Grounding is used for one or both of two reasons: (1) to reduce the amount of wiring, by using the metal chassis itself as a conductor; and/or (2) to reduce noise or hum and prevent interaction with nearby circuits, and thus improve performance.

The simple circuitry of Fig. 24 illustrates the use of grounds to reduce the amount of wiring required. The three pilot lights L_1, L_2, and L_3 are turned on and off by the three associated switches S_1, S_2, and S_3. In Fig. 24(a), each of the three lamps has its own independent wiring. In (b), the amount of wiring required has been reduced to just a single wire that carries all three currents from the negative side of the battery to the lamps. A conductor used as a path for a number of different currents is called a *common conductor*. It's sometimes drawn heavier than the other wiring (as it is here), both because it's easily identifiable and because a heavier wire, is actually sometimes used as the common conductor. Such a wire is often referred to as the *ground bus*.

(a)   (b)
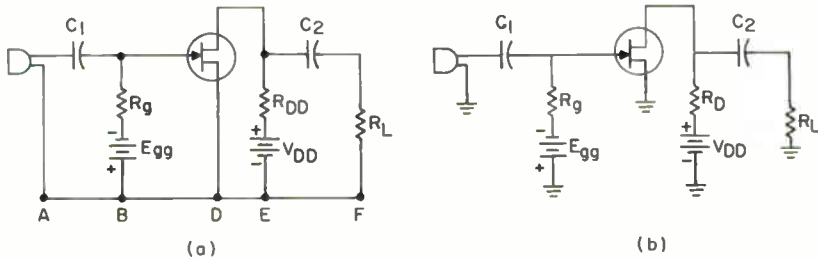
Fig. 25   Two electrically identical circuits.

In Fig. 24(b), the common conductor is shown grounded. In this particular circuit, the ground serves no purpose whatever: none of the currents associated with the operation of this circuit flow through the ground connection. However, if this were an amplifier circuit, the ground would probably be useful. Circuits are seldom in a world all by themselves. They're likely to be close to other circuits, from which they pick up unwanted voltages—or they may pick up static from electrical equipment operating elsewhere in the room. True, these pick-up voltages are very weak at the moment they're picked up. However, after being amplified by the amplifier, they can become strong enough to be heard in the output, thereby reducing the quality of reception. If the common conductor is grounded, the shielding action of the metal chassis will reduce such pickup of stray signals.

In Fig. 24(c), the common conductor is eliminated and the metal chassis is used instead to carry the current from the negative side of the battery to the lamps. (The dashed arrows show the current path through the chassis.) This technique requires minimum wiring, and is therefore widely used. In some cases, as in a high-fidelity audio amplifier, the use of the chassis to carry signal currents may

cause instability. In those cases, a common conductor—grounded at a single point, as in (b)—is used instead.

Figure 25(a) shows a simple circuit drawn without using a ground. Points A, B, D, E, and F are all connected together by the bottom horizontal wire. If we solder points A, B, D, E, and F to the chassis, however, they will all be electrically connected without the need for the horizontal wire. The circuit will then be as shown in Fig. 25(b), which is electrically identical with (a). We sometimes draw circuits without a ground, as in (a), to make it easier for you to trace the circuit action. The practical version of such circuits is likely to have one or more grounds, as in Fig. 25(b).

When voltages are marked as in Fig. 26, we often want to know the voltage drop across a certain component. We find it by subtracting the voltage shown for one end of the component from the voltage shown for the other end. Thus, in Fig. 26(a), the voltage drop across R_2 is simply 9 V − 6 V = 3 V. The top of R_2 will be positive, because the voltage at E is more positive than at D. To find the voltage drop across R_2 using the voltages in Fig. 26(b), we have 0 V − (−3) V = 3 V. (Remember, to subtract a negative number, we change its sign and then add.) The voltage across R_2 from Fig. 26(c) is (−15 V) − (−18 V) = −15 V + 18 V = 3 V. Hence, no matter where the reference point is, the voltage drop across R_2 is 3 V. (We can, of course, further check this voltage drop value using Ohm's law: $E_2 = I \times R_2 = 0.5$ A $\times$ 6 Ω = 3 V.)
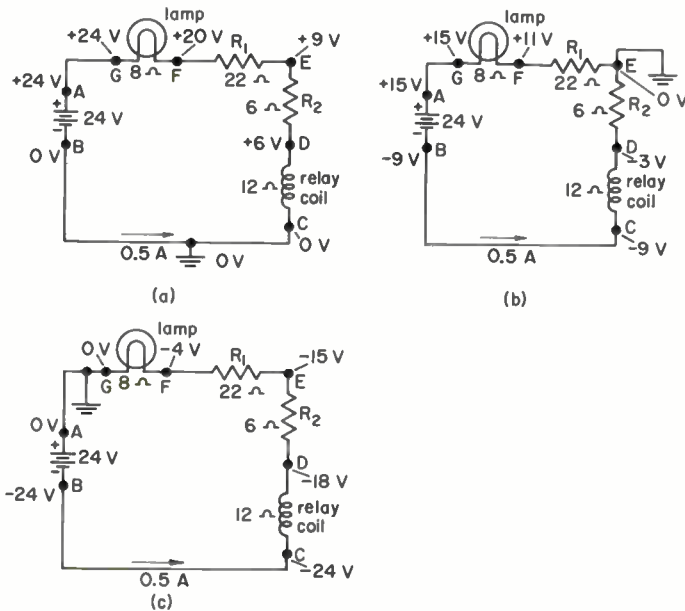
Fig. 26   Ground (or other reference point) is always considered as zero voltage.

The voltage between points F and D in Fig. 26 is, from part (a) of the figure, 35
20 V − 6 V = 14 V. From (b), this voltage drop is (+11 V) − (−3 V) = +11
V + 3 V = 14 V. By means of part (c), we get the same 14-V drop, as follows:
(−4 V) − (−18 V) = −4 V + 18 V = 14 V.

We can easily see from Fig. 26(a) that, for the 14-V drop between points F and
D, point F is positive with respect to D, since F is at a higher (+20 V) potential
than D (+6 V). Part (b) of the figure also shows point F at a higher potential
than point D. In part (c), however, it may not be so clear that point F is at a higher
potential than point D—but, mathematically, it is. With negative numbers, the value
nearest zero is the greater; hence −4 is a greater number than −18. Think of a
thermometer and you won't get mixed up on this: −4° is higher up the scale than
−18°, right?

WHAT HAVE YOU LEARNED?

1. Figure 27 is Fig. 15(g) redrawn with a ground added. Indicate on the figure
the voltages with respect to ground at points A, B, C, D, F, G, and H. Be sure
to show the polarity of each voltage. (*Note:* We know that voltages across parallel
paths are equal; the discrepancies in the figure are due to rounding off the
calculations.)
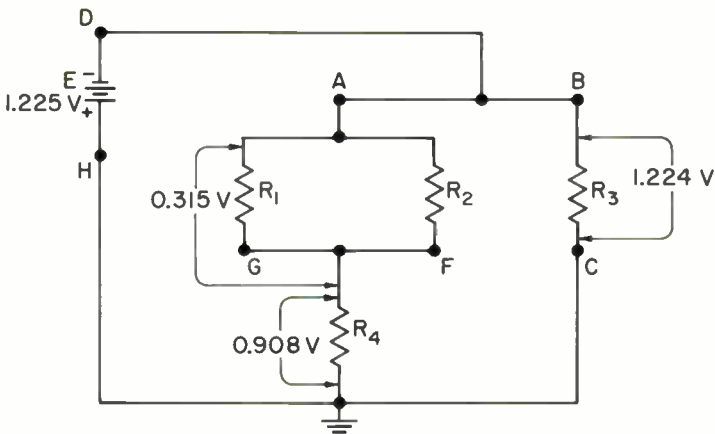
Fig. 27

2. Figure 28 is the same as Fig. 27, except that the ground has been changed to
a different place. Mark on the figure the voltages with respect to ground at points
A, B, C, D, F, G, and H, being sure also to mark the polarity of each voltage.
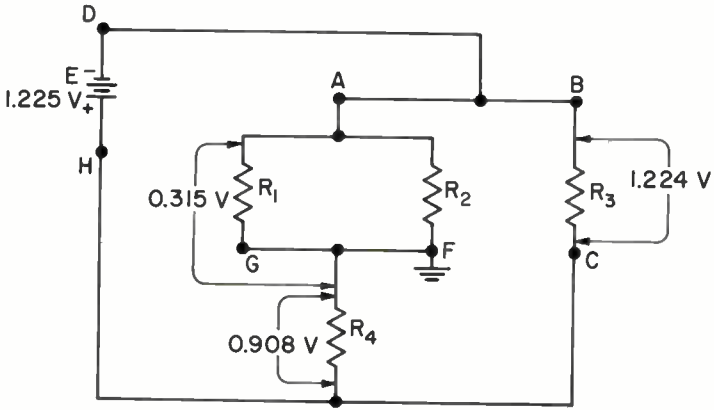
Fig. 28

ANSWERS

1. See Fig. 29   2. See Fig. 30.
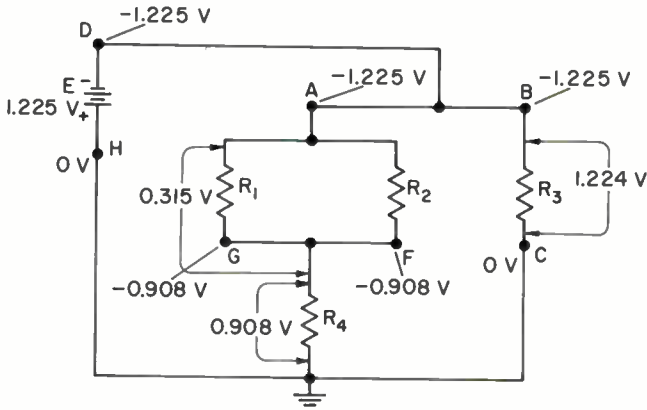
Fig. 29
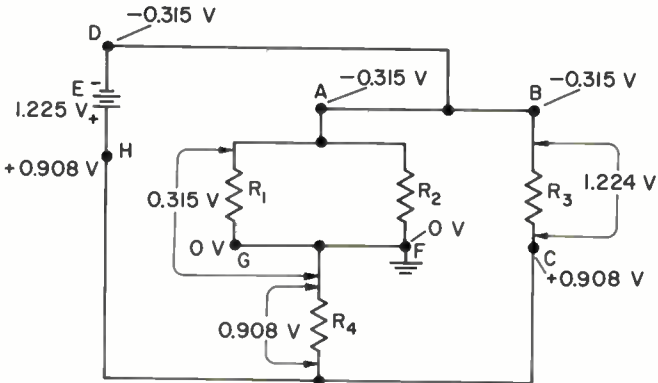
Fig. 30

11 VOLTAGES MEASURED TO THE SAME REFERENCE POINT . . . It's often
useful to measure all voltages in an electronic circuit with respect to the same
reference point, in which case ground is generally the reference point used. The
common reference point is always considered as being at zero voltage. The voltages
at other points are either positive or negative, depending on whether they're higher
(that is, more positive) or lower (less positive, or more negative) than the reference
point.

Figure 26 shows the voltage across a circuit measured to ground for three dif-
ferent positions of ground. Note that, regardless of the circuit point that's ground-
ed, ground is considered as at zero volts. Note also that the marked voltage values
are different all in three circuits (because different points are grounded). When
the reference point is changed, as by grounding a different point, all voltage values
measured to the reference point will be changed. Note finally that a point that's
positive when measured to one reference point may be negative when the reference
point is changed. Thus, point D is positive in Fig. 26(a), and negative in (b) and (c).

12 READING VOLTAGE AND POLARITY MARKINGS ON DIAGRAMS . . .
The circuit diagram of Fig. 31 has some voltages and polarities shown on it just
as might be found on an actual manufacturer's diagram. Our purpose in this topic
is to clarify the meaning of these voltage and polarity markings.
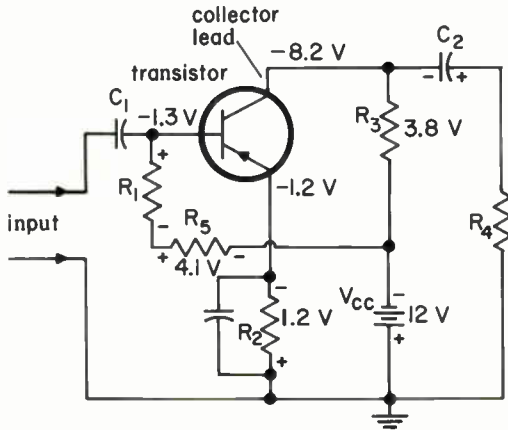
Fig. 31   Typical electronic diagram, with some of the voltages and polarities
marked.

Since voltages and polarities mean nothing except with respect to some other point
in the circuit, you must be able to recognize the intended reference point or points
before you can make any use of the voltage values included on schematic diagrams.
When one lead of a component is marked with a plus sign and the other lead

38   has a minus sign, the side of the component marked + is at a higher potential than the side marked −. For example, the upper end of R_1 in Fig. 31 is at a higher potential (that is, is more positive) than the lower end of that resistor—or, to put it another way, the upper end of R_1 is positive with respect to the lower end. Looking at the other components, we can see that the right end of R_5 is negative with respect to the left end; that the right plate of capacitor C_2 is positive with respect to the left plate; and that the top lead from the power supply V_{CC} is negative with respect to the bottom lead.

Note also in Fig. 31 that the left end of R_5 (marked +) is connected to the bottom end of R_1 (marked −). This doesn't mean that the left end of R_5 is positive with respect to the bottom end of R_1, however: since the two points are only separated by hookup wire, they must be at the same potential. The + and − markings refer only to the components to which they're attached, and have no meaning with respect to any other component.

A voltage value marked in the center of a component refers to the *voltage drop* across that component. For example, Fig. 31 shows the voltage drop across R_3 to be 3.8 V. Note that this voltage has neither a + or a − sign in front of it, since polarity has no meaning unless we know which end of the component is considered to be the reference end. The voltage drop across R_5 is shown as 4.1 V, and the polarity markings show that the left end of the resistor is 4.1 V positive with respect to the right end. Similarly, Fig. 31 shows the upper end of V_{CC} to be 12 V negative with respect to the bottom end.

Voltages marked at points on the wiring (rather than in the middle of a component) refer to voltage readings with respect to some common reference point. This common reference point may be considered to be ground if there's no information to the contrary. Thus, in Fig. 31, the −1.3 V value means that, at the point where this voltage value is shown, the voltage with respect to ground is −1.3 V. Similarly, the −8.2 V value indicates that the collector lead of the transistor is −8.2 V with respect to ground.

13 VOLTAGES BETWEEN UNCONNECTED POINTS ARE MEANINGLESS . . .
We've emphasized that voltage at a given point can have meaning only with respect to another point. However, there must be an electrical path between the two points involved for the voltage to have meaning. In Fig. 32(a), for example, there's no electrical connection between the left and right circuits. Consequently, to speak of the voltage at point A with repect to point B has no meaning. The voltmeter shown connected between these two points will either read zero, or—if it's an extremely sensitive meter—some random value.
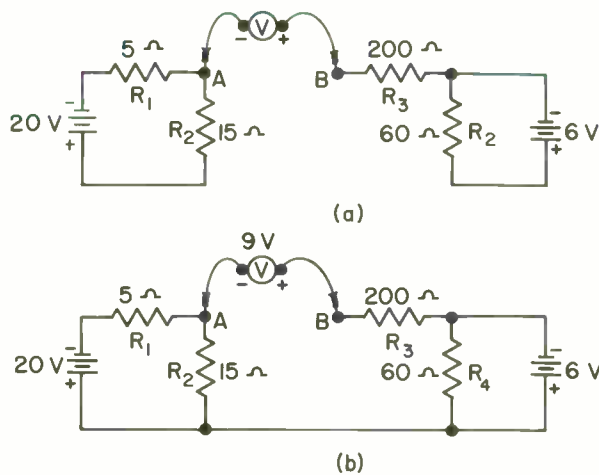
Fig. 32   **Voltage between two points has no meaning unless the two points are somehow connected.**

In Fig. 32(b), a wire has been added at the bottom to connect the two parts of the circuit together. Now we can properly speak of the potential between points *A* and *B*, and the voltmeter will read 9 V.

In a MOSFET transistor like the one in Fig. 33(a), the gate is electrically insulated from the rest of the MOSFET elements. Therefore, the shaded area isn't electrically connected to the rest of the circuitry. For the MOSFET to operate properly, the voltage on the gate with respect to the source must be −6 V. But if there's no electrical path between gate and source gate voltage with respect to source voltage is meaningless. Hence, when the MOSFET is connected as in Fig. 33(a), it can't be expected to work correctly.

In Fig. 33(b), a wire has been added at the bottom to connect the circuit in the shaded area with the source. Now the voltage on the gate is −6 V with respect to source, and the requirement for proper operation has been met.

WHAT HAVE YOU LEARNED?

1. The voltage of +17 V on the drain on Fig. 34 means that *(the voltage drop across R_4 is 17 V) (the drain is +17 V with respect to ground)*.

2. The voltage from point *B* to ground in Fig. 34 is *(17 V) (8 V)*.

(a)

(b)
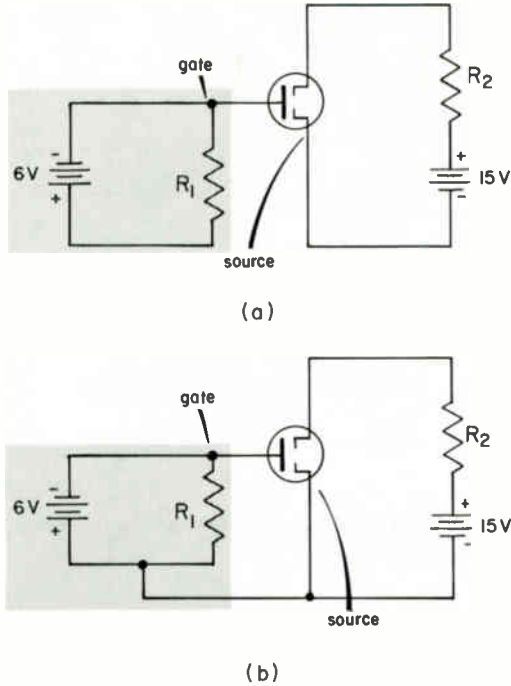
Fig. 33   Gate voltage in a MOSFET transistor circuit.
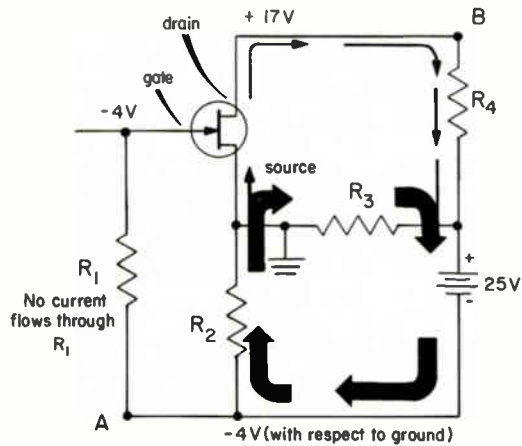
Fig. 34

3. The voltage at the positive terminal of the battery in Fig. 34 is *(+25 V with respect to ground) (+25 V with respect to the negative terminal of the battery).*

4. With respect to ground, the positive terminal of the battery in Fig. 34 is at *(+25 V) (+17 V) (+21 V)*.

5. The voltage on the gate in Fig. 34, measured in relation to ground, is *(+4 V) (−4 V)*.

6. The voltage on the negative terminal of the battery, measured with respect to ground, is *(−25 V) (−17 V) (−4 V)*.

7. Figure 35 *(does) (doesn't)* show that point B is positive with respect to point A.
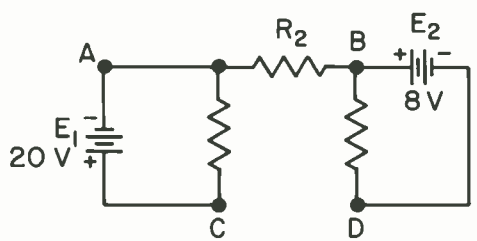
Fig. 35

8. Does any current flow through R_2 in Fig. 35?

ANSWERS

1. the drain is +17 V with respect to ground.
2. 17 V
3. +25 V with respect to the negative terminal of the battery . . . Note that current flows out of the negative terminal of the battery, through R_2, through R_3, and back to the positive terminal of the battery. Thus, R_2 and R_3 function as a voltage divider, and ground is connected to the output of the voltage divider formed by these two resistors.
4. +21 V . . . This is because the ground is at +4 V in relation to the negative terminal of the battery.
5. −4 V . . . Since there's no current through R_1, there's no voltage across R_1. Thus, the gate is at the same potential as the negative terminal of the battery, which is −4 V in relation to ground.
6. −4 V . . . Because of the voltage-divider action of R_2 and R_3, the negative terminal of the battery is at −4 V in relation to ground.
7. doesn't . . . The − sign at point A and the + sign at point B refer to the polarity of batteries E_1 and E_2, respectively, and don't in any way suggest that point B is positive with respect to point A.
8. No . . . For current to flow through R_2, there would have to be a complete electrical loop (so that the current flowing through R_2 could return to its starting point). If a wire were run between points C and D, current would then flow through R_2.

An ideal power source has no resistance, but every practical power source, such as a battery or generator, has resistance. Although the resistance of a power source can sometimes be safely neglected, it's often of great importance, since it affects the performance of the circuit using the power supply.

14 EQUIVALENT CIRCUIT FOR A VOLTAGE SOURCE . . . The value of the resistance of a power source can range from negligibly low to very high. It's frequently useful to represent a practical source of power by an equivalent circuit made up of a perfect voltage source with a resistance in series—the value of the series resistance being the internal resistance of the power source.

Figure 36 is a representation of a battery by an equivalent circuit. The materials from which a battery are constructed, like all other conducting materials, have resistance. (This resistance is shown as R_i in the equivalent circuit of Fig. 36. The 12 V shown for the perfect battery in the equivalent circuit is the voltmeter reading when no current is being drawn from the battery. Because of the internal resistance R_i, the voltage of a practical battery always goes down a little when current is drawn from the battery.

voltmeter
12 V

12 V battery

a voltage source has voltage (desirable) and also resistance (undesirable)

12 V R_i
perfect   resistance
battery   within battery
(no resistance)

equivalent circuit
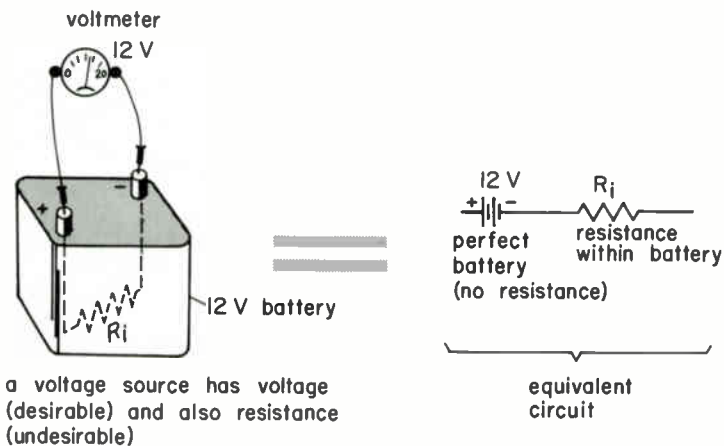
Fig. 36   Equivalent circuit for a power source—a perfect battery with a resistance in series to represent the internal resistance of the power source.

When we measure battery voltage with a voltmeter across the battery terminals as in Fig. 37, we measure the true battery voltage E less any voltage loss across the internal resistance R_i. If the switch S is open, so that there's no current drain from the battery (and therefore no current through R_i), the voltage drop across

within the battery.
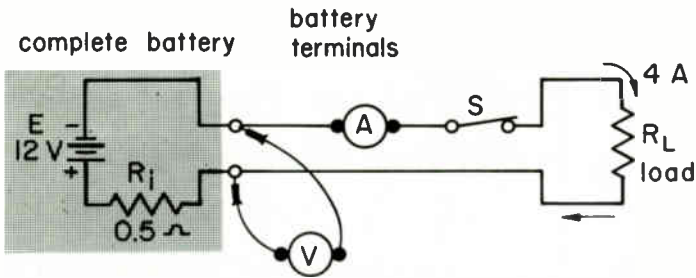
Fig. 37   Because of the voltage loss across R_i, the reading of the voltmeter is less than 12 V when switch S is closed.

Suppose, however, that when switch S is closed in Fig. 37, the load R_L to which the battery is connected draws 4 A. Then 4 A flows through the internal resistance R_i. The voltage drop across R_i is $E = I \times R = 4 \text{ A} \times 0.5 \text{ }\Omega = 2 \text{ V}$. The voltmeter reads the voltage E minus the voltage drop across R_i, or 12 V $-$ 2 V $=$ 10 V. Thus, the effect of the internal resistance is to cause the battery voltage to drop when the battery is loaded. The greater the current taken from the battery, the more this voltage drop will be.

15 CHECKING BATTERY CONDITION . . . As ordinary dry cells or storage batteries become discharged, their internal resistance increases. With continued discharge of a dry cell, the internal resistance eventually becomes so high that the cell is useless and must be replaced. Storage batteries must be recharged before they reach this degree of discharge; otherwise, they'll be damaged.

The beginning of the end of the useful life of those dry cells used to power electronic equipment, such a portable radios, is often indicated by noisy reception. As the internal resistance increases, battery-generated noise increases. This noise is caused by small random variations in the internal resistance. If the internal resistance is high, the varying voltage drop across the small resistance changes may be loud enough to be heard in the receiver.

You check a battery using a voltmeter to read the battery voltage *while the battery is delivering normal current to its load*. If the voltage you read is considerably lower than what you would expect from a new battery, the battery should be replaced (or recharged, if of the storage type). *Don't waste your time trying to find the condition of a battery by reading its open-circuit voltage.* The open-circuit voltage is the voltage when the battery is furnishing no current, which is why open-circuit voltage readings are useless for determining the condition of a battery.

44 Consider the circuit of Fig. 37. If the switch S is open (so that the voltmeter is reading the open-circuit voltage of the battery), the meter reading will be the same, regardless of the internal resistance R_i. (Remember, there's no voltage loss across R_i unless the battery is delivering current.) When S is open, the voltmeter is reading the generated voltage E, which is 12 V. As the battery becomes discharged, this voltage usually doesn't change. Thus, the voltmeter is apt to read 12 V, regardless of the condition of charge of the battery, as long as switch S is open. When switch S is closed, the greater the R_i, the less the voltmeter will read. As a result, the voltmeter reading *then* reliably indicates the charge condition of the battery.

16 HIGH-IMPEDANCE AND LOW-IMPEDANCE SOURCES . . . Batteries, generators, and 115-V building outlets are all sources of electric power for operating electronic equipment. Part of this power is converted within the electronic equipment to other voltages. For example, many types of electronic gear include one or more *oscillators,* which convert the DC voltage from the battery (or other original power source) into an alternating voltage of the desired frequency. Since the oscillator is generating something *different,* we tend to look at an oscillator as still another power—or voltage, or signal—source.

A *transistor* takes a very weak signal, such as one picked up by a receiving antenna, and makes it into a much stronger signal. We therefore consider transistors— when used in this manner—as signal or voltage generators, since they replace the weak original signal with a much stronger one. So, as you can see, there are a number of signal or voltage sources in electronic equipment.

Signal sources are often classified as either "high impedance" or "low impedance," and you should know the difference between the two. Figure 38 shows equivalent circuit diagrams for both DC and AC voltage sources. Note that although a battery is used to represent the voltage E in Fig. 38(a), this doesn't imply that a battery is actually used. There are equivalent circuits, and a battery with suitable resistance in series is equivalent to any DC voltage source.
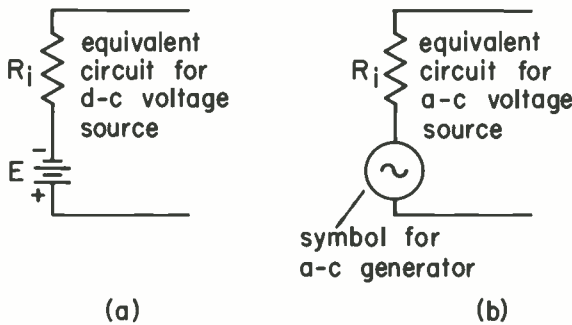
Fig. 38   Equivalent circuits for DC and AC sources.

If the internal resistance R_i in either Fig. 38(a) or Fig. 38(b) is low, the circuit represented is said to be a *low-resistance,* or *low-impedance* source. If R_i is high, the circuit represented is a high-resistance, or *high-impedance*, source. Of course, the source doesn't have to be either high-resistance or low-resistance: it can very well be some value in between. Perhaps the first question to come to mind about high- and low-resistance sources is what value of R_i represents a high resistance and what value a low resistance. A voltage source is a high-resistance source if a great drop in voltage occurs when an attempt is made to draw appreciable current from the source. A low-resistance source is one whose voltage does *not* change very much when it's furnishing current.

Some characteristics of high- and low-resistance sources are shown in Fig. 39. In the high-resistance source (a), note that the source voltage drops from an open-circuit value of 12 V down to only 0.571 V when furnishing current to a 10,000-Ω load. For the same load, the voltage of the low-resistance source (b) drops very little—from 12 V down to 11.76 V. Note also the much lower current delivered to the load by the high-resistance source: 0.0571 mA, as compared to 1.176 mA for the low-resistance source.

(a) High impedance source

(b) Low impedance source

(c) High impedance source shorted

(d) Low impedance source shorted
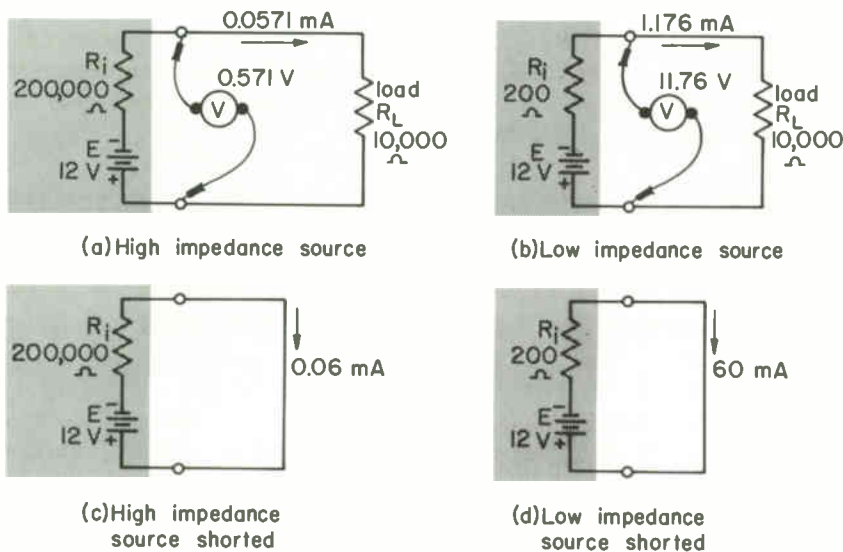
Fig. 39   Effects of high- and low-source impedances on voltages and currents.

46 Varying the load resistance doesn't affect the current from a high-resistance source very much. Note in Fig. 39(c) that short-circuiting the high-resistance source produces a current of only 0.06 mA, which is only slightly more than the current of 0.0571 mA required for a load of 10,000 Ω. Shorting a low-resistance source, as in Fig. 39(d), greatly increases the current—from 1.176 mA in Fig. 39(b) to 60 mA in (d).

A source of power should be considered as being of low resistance unless otherwise stated (or unless you know from its nature that the supply would be of high resistance). Specifically, you should assume that the supply resistance is so low that the voltage drop due to current drawn from the supply is negligible. That's not to say that high-resistance sources are unimportant: you'll encounter them from time to time throughout your study of—and career in—electronics. If you don't understand what's meant by a high-resistance supply, you won't be able to understand many important circuit principles.

POWER IN DC CIRCUITS

17 WORK, POWER, AND ENERGY . . . Before we discuss the next important part of this lesson—power in DC circuits—it's essential you know the difference between work, power, and energy. So to make sure let's look at each of these vital concepts in turn.

In a scientific sense, *work* is the overcoming of opposition. You do work when you lift a *crated* television set from the warehouse platform into a truck, or when you drag the crate along the platform. But you do no work at all, in the scientific sense of the word, no matter how hard you push or pull, unless you lift or move the crate. Unless the resistance offered by the crate to being moved is overcome, no work is done.

Work is measured by the product of a force times the distance through which the force moves. In a mechanical system, the most common unit of work is the *foot-pound*. In an electrical system, work is measured in *watthours* or *kilowatt-hours*. One kWh (kilowatt-hour) of work in an electrical system equals approximately 2,660,000 ft-lb (foot-pounds) of work.

The work you do carrying a 50-lb audio amplifier up a flight of stairs 12 ft high is 50 lb × 12 ft = 600 ft-lb. Note that from the standpoint of work done, it makes no difference whether you do the job in an hour or in a minute. However, the amount of *power* required to do a job does depend on time. The amount of power required to do a job in one minute is 60 times the power required to do it in one hour. The term *power* includes the idea of time, since power is the speed, or rate, of doing work. So:

$$power = \frac{work}{time}$$

or

$$work = power \times time$$

The common unit for measuring power in mechanical systems is the *horsepower*. If a machine can do 33,000 ft-lb of work in one minute, its power is 1 hp (horsepower). The practical units of power in electrical circuits are the *watt* and *kilowatt*. One kilowatt (abbreviated kW) equals 1000 watts (abbreviated W). Horsepower and watts are related as follows: 1 hp = 746 W; 1 kW = 1.34 hp.

The work done in an electrical circuit, in kilowatt-hours, equals the power in kilowatts times the number of hours. For example, if the power required to operate a motor is 2 kW and the motor operates for 7 hr, the work done is $2 \times 7 = 14$ kWh (kilowatt-hours).

Energy is the capacity to do work. For example, if a battery is able to do 1 kWh of work before it must be recharged, the energy stored by the battery is 1 kWh. The difference between work and energy is that work is what has been done by a device, while energy indicates the amount of work that a source of energy is able to do. There are many types of energy: a moving car, for example, has mechanical energy; a charged battery has chemical energy; a hot stove has heat energy.

An important point about energy is that, when work is done, the energy used to do the work is never used up: it is simply changed from one form to another. For example, suppose a charged battery causes current to flow in a circuit. The chemical energy of the battery has changed to electric energy in the circuit. Suppose the electric energy of the circuit causes a lamp filament to heat up; now the electric energy has changed to heat energy. When someone talks into a microphone, and thereby generates an input signal to an amplifier, the acoustic energy of the sound waves is changed into electric energy.

18 POWER IN ELECTRIC CIRCUITS . . . As stated earlier, the units of power in electric circuits are the watt and the kilowatt. (One kilowatt equals 1000 W.) Power, in watts, is the product of the voltage, in volts, times the current, in amperes. The basic formulas for power follow:

$$P = EI$$
$$E = \frac{P}{I}$$
$$I = \frac{P}{E}$$

48 However, two other formulas derived from Ohm's law are also very useful for calculating power. According to Ohm's law, $E = IR$. Therefore, by substituting for E in the basic power formula, we get

$$\begin{aligned} P &= EI \\ &= (IR) \times I \\ &= I^2R \end{aligned}$$

Ohm's law for current is $I = E/R$. By substituting for I in the basic power formula, we get

$$\begin{aligned} P &= EI \\ &= E \times \left(\frac{E}{R}\right) \\ &= \frac{E^2}{R} \end{aligned}$$

Remember these three formulas: they're the three essential formulas for calculating power.

$$\begin{aligned} P &= EI \\ P &= I^2R \\ P &= \frac{E^2}{R} \end{aligned}$$

19 POWER CALCULATIONS IN DC CIRCUITS . . . The total power in a circuit can be calculated easily if any two of three quantities—voltage, current, and resistance—are known. For example, if a motor draws 3 A at 30 V, the power furnished by the power supply can be calculated by using the formula $P = EI$:

$$\begin{aligned} P &= EI \\ &= 30 \times 3 \\ &= 90 \text{ W} \end{aligned}$$

Example . . . A 30-Ω resistor is connected in series with the collector of a transistor. The power source delivers 50 V at 0.5 A to the combination. The power used by the resistor is (a) _____ W. The voltage across the resistor is (b) _____ V. The voltage drop across the transistor is (c) _____ V. The power used by the transistor is (d) _____ W.

Solution . . . (a) 7.5 W . . .

$$P = I^2R$$
$$= (0.5)^2 \times 30$$
$$= (0.25) \times 30$$
$$= 7.5 \text{ W}$$

(b) 15 V . . .

$$E = IR$$
$$= (0.5) \times 30$$
$$= 15 \text{ V}$$

(c) 35 V . . . 50 V − 15 V = 35 V
(d) 17.5 W . . .

$$P = EI$$
$$= 35 \times 0.5$$
$$= 17.5 \text{ W}$$

Explanation . . . Always be careful to use only quantities that apply specifically to the component. In this example, the current of 0.5 A does flow through the resistor, but the entire 50 V doesn't appear across the resistor. Therefore, we use the formula $P = I^2R$ to calculate the power used by the resistor. Suppose 100 V is applied across a 5000-Ω resistor. We'd simply use the formula $P = E^2/R$:

$$P = \frac{E^2}{R}$$
$$= \frac{100 \times 100}{5000}$$
$$= \frac{10,000}{5000}$$
$$= 2 \text{ W}$$

WHAT HAVE YOU LEARNED?

1. A light bulb is used across a 120-V line and draws 60 mA. The power used by the light bulb is _____ W.

2. A 120-V light bulb is stamped "60 W." This bulb normally draws _____ A from the line.

3. The filament of a #47 lamp is operated at 6.3 V, and draws 0.15 A. The power used for lighting this lamp is _____ W.

4. The current through a 15,000-Ω resistor is 7 mA. The voltage across the resistor is _____ V. The power dissipated by the resistor is _____ W.

5. A certain computer operates on a 5-V power supply. You wish to operate a light-emitting diode (LED) from this supply to indicate when the computer is on. The LED is rated at 20 mA, and—at this current—the voltage across the LED is 2.1 V. By connecting a dropping resistor in series with the LED, you can operate the LED off the 5-V supply. The voltage across the dropping resistor will be (a) _____ V. The current through the dropping resistor will be (b) _____ mA. Using Ohm's law, the value of the dropping resistor is (c) _____ Ω. The power dissipated in the dropping resistor will be (d) _____ W.

6. In Fig. 40, the voltage across R_1 is (a) _____ V. Since R_1 and R_2 are in parallel, the voltage across R_2 is (b) _____ V. The current through R_2 is (c) _____ A, and the current through R_3 is (d) _____ A. Power dissipated by R_1 is (e) _____ W; that by R_2 is (f) _____ W; and that by R_3 is (g) _____ W. Voltage supplied by the battery is (h) _____ V. Power supplied by the battery is (i) _____ W.
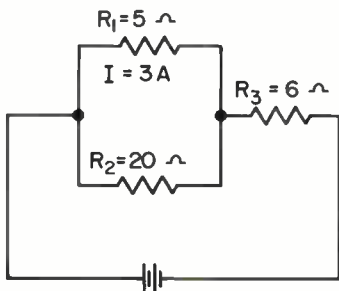
Fig. 40

7. A television set is rated at 115 V, 450 W. A check with an ammeter shows that the set is drawing 2.8 A from the line. Is this normal? If not, what current should the set draw?

ANSWERS

1. 7.2 . . . $P = EI$
   $= 120 \text{ V} \times 0.06 \text{ A}$
   $= 7.2 \text{ W}$
2. 0.5 . . . $I = \dfrac{P}{E}$
   $= \dfrac{60 \text{ W}}{120 \text{ V}}$
   $= 0.5 \text{ A}$
3. 0.945 W . . . $P = EI$
   $= 6.3 \text{ V} \times 0.150 \text{ A}$
   $= 0.945 \text{ W}$

4. 105; 0.735 . . . You can use $P = I^2R$, $P = IE$, or $P = E^2/R$.

5. (a) 2.9 V . . . Since 5 V is the rise, and the voltage across the LED and resistor are the drops, the unknown drop across the resistor is the 5-V rise minus the 2.1-V drop, which is 2.9 V.

(b) 20 mA . . . The resistor is in series with the LED, so the same current must flow through the resistor and through the LED.

(c) 145 Ω . . . $R = E/I$

$= 2.9$ V/0.02 A

$= 145$ Ω

(d) 58 mW . . . $P = E \times I$

$= 2.9$ V $\times$ 0.02 A

$= 0.058$ W (or 58 mW)

6. (a) 15; (b) 15; (c) 0.75; (d) 3.75; (e) 45; (f) 11.25; (g) 84.4; (h) 37.5; (i) 141

7. No; 3.91 A

20 WATTAGE RATINGS OF RESISTORS . . . Resistors are rated not only for resistance value, but also for how much power they can dissipate safely. When current flows through a resistor, heat is generated at a rate proportional to the power dissipated in the resistor. This heat must be carried off by the surrounding air as fast as it's generated or the resistor will overheat and may burn up! The maximum amount of power that a resistor can handle without excessive heating is called the *wattage rating* of the resistor. The wattage rating of any resistor must, of course, be at least as great as the actual wattage being dissipated by the resistor.

However, the wattage rating of a resistor and the actual wattage being dissipated by the resistor are two entirely different things. For example, consider a resistor that has a wattage rating of 10 W. This means that the resistor is *capable of* dissipating 10 W. It does *not* mean that the resistor necessarily *is* dissipating 10 W. For example, if a 20-Ω resistor is carrying 300 mA, the actual power dissipated is only $0.3^2 \times 20 = 1.8$ W. Since this is much less than its wattage rating, the resistor will not overheat.

Ratings assume ideal ventilation, which is seldom found in practice. Therefore, it's a good idea to calculate the power that the resistor in question must dissipate, and then use a resistor rated to dissipate 1½ to 2 times that much power. For example, if calculations show that a resistor must dissipate ½ W in a certain application, select a 1-W resistor.

The formula $P = I^2R$ indicates that the power dissipated varies as the square of the current. Thus, if the resistance in a certain circuit is held constant and the current is doubled, power will increase up to 4 times its original value. If the current increases by just 20 per cent, wattage increases not just by 20 per cent but by 44 per cent. If a resistor is subject to overcurrent in a certain application, the resistor must have a sufficient wattage rating to stand the highest wattage to be dissipated. The formula $P = E^2/R$ shows that the power dissipated by a resistor also varies as the square of the voltage. If the voltage increases by 20 per cent,

power increases by 44 per cent. Again, this must be taken into consideration when selecting a resistor. For small increases in current and voltages (not over 20 per cent), you can assume the percentage increase in wattage to be twice the percentage increase in current or voltage. Thus, a resistor subject to a 10 per cent overcurrent needs a 20 per cent larger wattage than would otherwise be the case.

Identical resistors may be connected either in series or in parallel to increase their power-dissipation capability. Whether connected in series or in parallel, however, the wattage rating of the group is equal to that of a single resistor multiplied by the number of resistors. Thus, two 10-W, 50-Ω resistors connected in series will be equivalent to a 20-W, 100-Ω resistor. When the same two resistors are connected in parallel, they will be equivalent to a 20-W, 25-Ω resistor.

WHAT HAVE YOU LEARNED?

1. You want to charge a 25-V battery at a 5-A rate from a 100-V DC line. you connect a resistor in series with the battery, in order to drop the line voltage down to the 25 V required to charge the battery. The voltage across the resistor is (a) _____ V, and the resistor should have a resistance of (b) _____ Ω. The power dissipated in the resistor is (c) _____ W. You should use a resistor with a rating of about (d) _____ W.

2. If 3 A flows through a 10-Ω resistor, the power dissipated in the resistor is (a) _____ W. If the current is now doubled to 6 A, the power dissipated is (b) _____ W. When the current is doubled, the power increases to (c) _____ times the original value. If the current is tripled, the power will increase to (d) _____ times its original value. If the current is cut in half, the power will reduce to (e) _____ its original value.

3. If 3 A flows through a 10-Ω resistor, the voltage across the resistor is (a) _____ V. If this voltage is doubled, the current will (b) _____. We found in Problem 2 that doubling the current increases the power dissipation by 4 times. Since doubling the voltage doubles the current, doubling the voltage also increases the power dissipation by (c) _____ times. If the voltage is reduced to one-third its original value, the power dissipation will be reduced to (d) _____ of its original value.

4. If 3 A flows through a 10-Ω resistor, the power dissipation has been found in problem 2 to be 90 W. If the resistance is doubled to 20 Ω but the current is kept at 3 A, the power dissipated will be (a) _____ W. Hence, doubling the resistance (b) _____ the power dissipated. If the resistance is reduced to one-third its original value and the current is held constant, the power dissipated will be reduced to (c) _____ its original value.

5. If 30 V is connected across a 10-Ω resistor, the power dissipated is (a) _____
W. If the resistance is doubled to 20 Ω, the power dissipated will be (b) _____
W, assuming the voltage stays at 30 V. If the voltage doesn't change, reducing
the resistance by one-half will (c) _____ the power dissipated.

ANSWERS

1. (a) 75 . . . 100 V − 25 V = 75 V (the amount that the voltage is dropped); (b) 15
. . . $R = E/I$ = 75 V/5 A = 15 Ω; (c) 375; (d) between 560 and 750
2. (a) 90; (b) 360; (c) four; (d) nine; (e) one-quarter
3. (a) 30; (b) double; (c) four; (d) one-ninth
4. (a) 180; (b) doubles; (c) one-third   5. (a) 90; (b) 45; (c) double

LESSON 2324B-7
VOLTAGE AND POWER

EXAMINATION

**Each examination question is followed by a number of selections. Circle the
number in front of the correct selection for each question. When you have
finished, transfer your answers to the Answer Sheet provided. Then use the
special envelope provided to mail the examination to the school as soon
as it is completed.**

1. The difference between electric power and electric energy is that
   (1) power is expressed in watts, energy in kilowatts.
   (2) energy is work that is done, while power is the ability to do work.
   (3) energy is the capacity to do work, while power is the rate of doing work.
   (4) power is the capacity to do work, while energy is the rate of doing work.

2. What is the unit of electric power?
   (1) Ohm   (2) Siemens   (3) Ampere   (4) Volt   (5) Watt

3. Which is the formula for determining the power in a DC circuit when only
   the current and voltage are known?
   (1) $P = \dfrac{E^2}{R}$ (2) $P = IR$ (3) $P = I^2R$
   (4) $P = \dfrac{E^2}{I}$ (5) $P = EI$

4. If two 10-W 500-Ω resistors are connected in parallel, the power-dissipation
   capability of the combination is
   (1) 10 W.   (2) 100 W.   (3) 5 W.   (4) 20 W.

5. One reason for using a chassis ground in the construction of electronic equipment is
   (1) that otherwise there would be no reference point to which voltage measurements could be made.
   (2) to increase the life of the battery used to power the circuit.
   (3) to reduce the amount of chassis wiring required.
   (4) to make it possible to use a lower-voltage source of power.

6. To check the condition of a dry cell, you should
   (1) disconnect the battery from its load and measure its voltage.
   (2) measure the voltage while the battery is delivering normal load current.
   (3) measure the load current.
   (4) divide the battery voltage by the load current. (If this quotient is less than 10, the battery is near the end of its life.)

7. As a dry cell nears the end of its useful life.
   (1) its open-circuit voltage decreases.
   (2) its internal resistance decreases.
   (3) its internal resistance increases.
   (4) its open-circuit voltage goes down and its internal resistance remains the same.

8. If the voltage of a source drops greatly when the source is supplying appreciable current, then
   (1) the source is a high-resistance type.
   (2) the source is a low-resistance type.
   (3) the source is probably short-circuited.

9. In Fig. 41, the voltage at point A with respect to point B is
   (1) +20 V.   (2) +30 V.   (3) +40 V.   (4) +50 V.
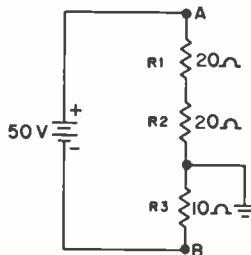
Fig. 41

10. What's the voltage at point A with respect to ground in Fig. 41? (Select your answers from among the choices given for Question 9.)

END OF EXAM

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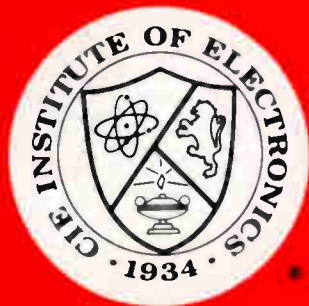
electronics

Lesson 2330A-5
Current and Voltage

Lesson 2330B-5
Controlling Current and Voltage

AUTO-PROGRAMMED® Lessons

ABOUT THE AUTHOR

Wayne Lemons has had almost forty years of practical experience in the electronics field. During World War II, he served in the U.S. Air Force as a loran and radar technician. After his discharge, in 1946, he went into radio and TV servicing. His success was such that, in 1958, he was one of ten men in the country to receive the coveted All-American Technician Award.

Mr. Lemons' experience includes many years of teaching electronics to high school students. He founded station KBFL, Missouri's first and most powerful public high school radio station. In addition, he has written seven books and more than 250 magazine articles on radio and TV servicing and other practical aspects of electronics.

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Frontispiece: *An engineer takes required meter readings of a 1000 watt FM transmitter. Power output readings, final tube plate voltage and current readings, as well as frequency deviation must be made by an FCC licensed operator.* Photo: Courtesy, Station KBFL, Missouri.

CLEVELAND INSTITUTE OF ELECTRONICS, INC.

Lesson 2330A-5
Current and Voltage

Lesson 2330B-5
Controlling Current and Voltage

by WAYNE LEMONS
Technical Staff
Cleveland Institute of Electronics, Inc.

How to Start TODAY Toward a Top Job Tomorrow

There are two lessons in this volume. You should complete the first one today—it will take you only an hour or two. Then you will be on your way to more interesting work, security, and better pay. Just follow the simple instructions below. But remember: START RIGHT NOW.

1. Start at the beginning and read through the first of the two lessons in this volume—that is, read to page 23. *A Chat with Your Instructor,* which you will read first, introduces you to the lesson—makes the lesson easier to learn. In some lessons, the chat may contain the answer to an exam question, too.

2. Answer the What Have You Learned? questions as you come to them. They are there to make the lesson easy for you—to help you learn more, learn it faster, and remember it better.

3. After you have read through the lesson, return to any sections that you did not completely understand and read them again. Keep in mind, though, that these first few lessons are only introductory. The subjects will be discussed thoroughly and completely later on—so don't worry if these first lessons don't tell you everything you would like to know, or if you don't understand something as well as you would like. CIE will take you step by step, deeper and deeper into the mysteries of electronics, until they are no longer mysteries—and you have the background to become an electronics expert.

4. As soon as you complete reading and briefly reviewing the lesson, answer the examination questions on pages 21 and 22. Do this TODAY.

5. Copy your answers to the examination questions on one of the *Answer Sheets* provided, and mail it to CIE as soon as it is ready. TODAY. This is important. If you have time to also complete the second lesson in this volume today, you may mail both exams on the same Answer Sheet. But don't hold up your report on the first lesson while you work on the second. Your instructor wants to see your report for the first lesson as soon as possible.

6. Once you have completed your first lesson and the examination is in the mail, you can be proud of your progress. But there is still something important to do. Set aside a time for studying the next lesson NOW. We call that *scheduling,* and it is most important for your success.

A Chat with Your Instructor

Welcome to the exciting and profitable world of electricity and electronics. You could not have chosen a field in which there is greater expansion, or greater need for well-trained people. Note that "well-trained," however. The people who have the really good jobs to offer you are looking for a person who has a strong basic knowledge of electricity and electronics. No matter what position you finally accept, mastering the *fundamentals* is essential. There are thousands of specialized jobs in electronics, but every one of them requires that you be well grounded in the basics you will be studying in this first volume, and will continue to see in the remainder of your CIE course. So make up your mind right now that you are going to get these abc's down pat.

This volume is intended to give you a preview of some of the terms and concepts that are of great importance in electronics. Keep in mind as you study this volume that it is intended to do no more than introduce you to a few of the principles upon which electronics is built. And although we do want you to study the volume with care, don't be concerned if you only partly understand some of the subjects discussed. Later lessons will go into these subjects thoroughly and completely, and you will then acquire a good understanding. CIE will take you step by step into the exciting and rewarding world of electronics, until you will feel that you belong there.

If you need assistance or advice, don't hesitate to write; everyone at CIE will be more than glad to help. To make it easy, CIE has provided you with some "Request for Assistance" sheets.

When to study, how much to study, and where to study are important elements of your progress, Here are some tips that will help you to understand, retain, and enjoy what you study.

1. *When to study* . . . Determine *now* the hours in which you are going to study. Set aside a certain time each day when you will be free from interruption or distraction for an hour or two. Plan the hours and the days in which you will be able to do this, and then stick to it. A planned schedule always produces better results than working haphazardly. If you need a short break during your study period, fine: take one. Don't keep going when a short break will do you good.

2. *How much to study* . . . An hour or two is usually plenty for one sitting. When you do study, study hard and thoroughly—but don't make those study periods excessively long. Don't skip over part of the lesson just because you studied the subject before. Study it again—get that better understanding. Remember, a command of the basic theory of electronics is a must for a good technician.

3. *Where to study* . . . If possible, find yourself a place where you can keep all of your study materials together. That way, once you begin to work you won't have to stop two or three times to get something you need. To get the most out of your study time, have everything ready to go. Then *go*—but don't try to go too fast. If you hurry through the first lessons, the later lessons will be that much harder for you. This course is designed in careful layers, so that understanding one part will help you understand the next.

Lesson 2330A-5
Current and Voltage

1 STUDYING BY THE CIE METHOD . . . There are some things that you, as a new CIE student, should know as you begin your study of electronics. The first thing is that reading a CIE lesson is not the same kind of reading that you did in school. There, the text was only a classroom aid: the teacher did most of the explaining, correcting, and evaluating. With CIE, however, your lessons are not only textbooks, they are the classroom and the teacher as well. They have been written especially for the home-study method, and are much more than mere textbooks. CIE lessons are meant not only to inform, but to guide as well.

The most important part of a CIE lesson is that it is meant to be *read more than once.* Accordingly, all the exams in the lessons are meant to be taken "open book." Of course, this means that the exam questions may be more penetrating than the questions you might face in a residence school. Sometimes, the answer to a CIE exam question isn't even in the lesson you are studying, but comes from an earlier lesson. And there's a very good reason why we include such questions: Studies have shown—and our experience at CIE confirms—that people remember better and for longer periods of time when they are provided opportunities for review. Accordingly, you may find yourself re-reading a CIE lesson in order to answer a particular question.

All CIE lessons include important self-tests called "What Have You Learned?" exams. It is important that you complete all of these tests as you work your way through the material. They not only give you an opportunity for on-the-spot review, but also give you the facts—and sharpen the skills—you need to complete the more comprehensive exams that conclude each CIE lesson.

"What Have You Learned?" exams are self-tests; in other words, you don't send in your answers for CIE to grade them. You grade the WHYL exams yourself. If you see that you have made an error (or if you have misunderstood something),

4   you simply go back to the lesson material to find the answer or the needed information. Sometimes you may have to *reason* your way through a WHYL exam, for the answer may be included in the test itself, rather than in the lesson. Keep in mind that CIE lessons are not just collections of random facts: on the contrary, they are intended to give you the skills you will need to solve actual electronics problems in real-life situations. Thus, some "What Have You Learned?" questions may confront you with a simulation of a real-life problem, giving you only the information you'd have in those circumstances and requiring you to figure out the answer based on what you've learned in your CIE studies.

To get you started in the practice of taking What Have You Learned exams, here's one for you to try your hand at.

WHAT HAVE YOU LEARNED?

1. After you take a "What Have You Learned?" exam, you *(do)* *(do not)* send your answers in to CIE for grading.

2. People remember better and for longer periods when there are opportunities for   *Review* .

3. CIE lessons are intended to be read *(once)* *(more than once)*.

4. Ohm's law is an important principle that you will soon learn. It is important to know Ohm's law *(just for that lesson)* *(because Ohm's law is used repeatedly in electronics)*.

5. Would you think it likely that an advanced CIE lesson might include an exam question that refers back to your earliest lessons on Ohm's law? *(yes)* *(no)*

6. When you find an exam question that puzzles you, you should stop immediately and write a Request for Assistance to your CIE instructor. *(True)* *(False)*

7. There are one thousand millivolts to a volt. How many milliamperes do you suppose there are in one ampere? *(.001)* *(1)* *(1000)*

8. Since all of the material you need to learn is in the lesson text, you really don't need to do the "What Have You Learned?" exams unless you feel like doing them. *(True)* *(False)*

1. do not . . . "What Have You Learned?" exams are self-tests. Their purpose is mainly for review. The only exam you send to CIE for grading is the one at the end of the lesson.
2. review
3. more than once . . . You do *not* read a CIE lesson from cover to cover and then forget it, the way you might read a novel.
4. because Ohm's law is used repeatedly in electronics . . . Just as the most experienced engineer needs to remember that 6 times 7 is 42, anyone involved in electronics needs to know Ohm's law—and to know it just as automatically as "6 times 7."
5. Yes . . . While the exam question probably would not simply ask you to state Ohm's law, knowing Ohm's law could very well be essential to solving the problem.
6. False . . . Often, an instructor can do no more with such an inquiry than simply refer you to the page and sentence where the answer is to be found. This wastes your time. Of course, don't hesitate to write us when your search for the answer turns up nothing. Sometimes you really should ask for help—and that's what we're here for!
7. 1000 . . . This is an example of a question that isn't answered in the text. The question itself gives you a clue to the correct answer.
8. False . . . As the question above demonstrates, you can miss something important if you skip the "What Have You Learned?" exams!

ELECTRICITY—PAST AND PRESENT

2 A LITTLE BIT OF HISTORY . . . Electricity as a natural phenomenon has been around as long as there has been a universe. As a science, however, electricity and electronics have been around for less than a century—although the first recorded electrical experiment took place more than twenty-six centuries ago. Since then, thousands of experiments by hundreds of different people have fit the pieces of the puzzle together, but many pieces still remain to be supplied. Sometimes, it seems that the picture is complete—but then the puzzle enlarges again. Even so, it is now possible, if we understand the fundamentals, to predict what will happen when we generate, transport, and use electricity.

Back all those twenty-six centuries ago, a Greek named Thales found a clear yellowish stone that had washed ashore from the sea. He discovered that if he rubbed this stone—it was actually a material called *amber*—it would attract bits of straw or lint from his robe. He called the stone *elektron,* a Greek word from which our terms *electron, electronics,* and *electricity* come.

Thales also studied another kind of stone known as a *magnes stone* or *lodestone.* This natural stone would attract bits of iron. (It's from the magnes stone that we get our present-day word *magnet.*) Thales thought that the amber and magnes stones were the same kind of thing, and it was a long time before anyone discovered his error.

6   It wasn't until 1600 or so that an English physician named William Gilbert discovered a number of important facts that we take for granted today. In his book *On the Magnet*, Gilbert noted that the world itself is a giant magnet, with *poles*— points of concentrated magnetism, as at the ends of a bar magnet—one called the *south pole* and the other the *north pole*.

The kind of electricity that Thales discovered by rubbing the piece of amber is called *static electricity*—that is, electricity that does not move. You can generate this kind of electricity by rubbing a comb or a glass rod vigorously with a piece of silk, or moving the comb through your hair. If you now hold the comb near some tiny bits of paper, you will find that it attracts the scraps of paper to it. (See Fig. 1.)

(a)   **(b)**

(c)   **(d)**
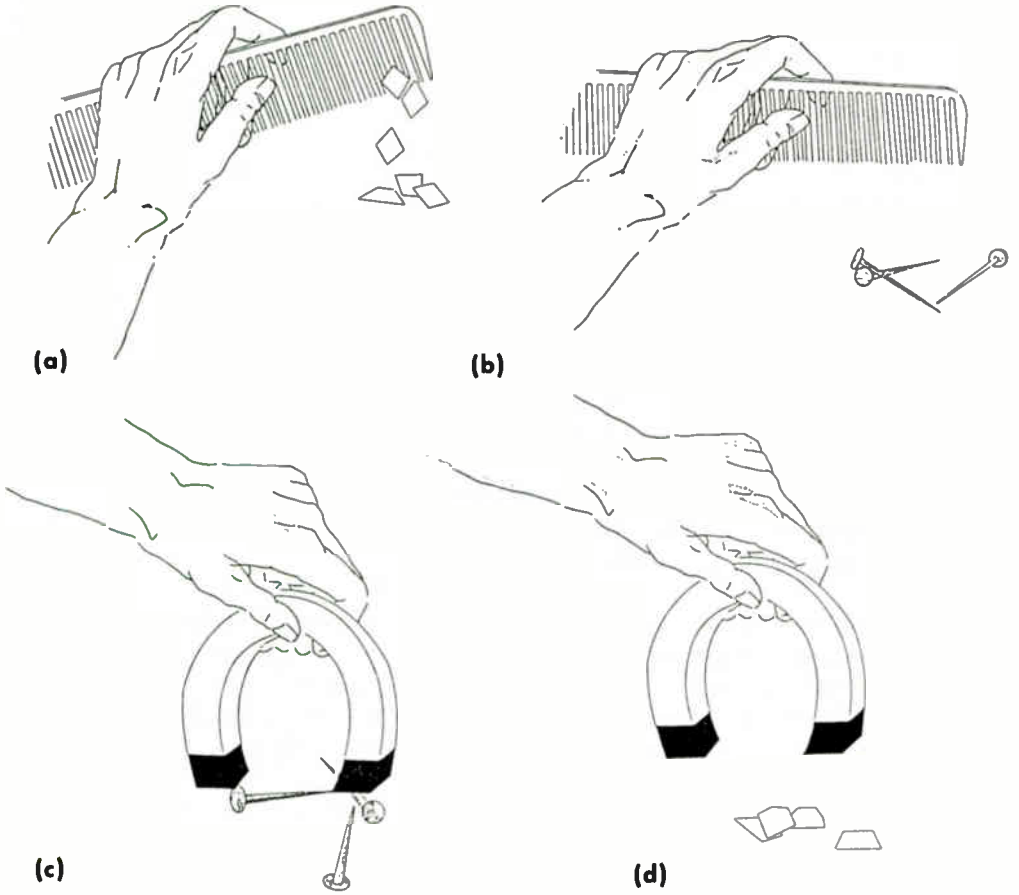
Fig. 1   The charged comb attracts pieces of paper (a), it also attracts iron nails but the force is not great enough to move the nails (b). By comparison, the magnet attracts nails (c), but not bits of paper (d). This is the basis for our understanding of electric and magnetic fields.

A magnet, on the other hand, does not have to be rubbed to attract pieces of iron; but try as you may, you can't get a magnet to attract pieces of paper (see Fig. 1). Based on these conclusions, Gilbert fit some of the puzzle together. Whereas Thales had thought that electric force and magnetic force were the same, Gilbert proved that they are entirely different and separate. (Subsequent discoveries, however, have proved that although they are indeed different, you can't produce one without producing the other.)

3 ELECTRIC AND MAGNETIC FIELDS . . . Any time there is a flow of electric current in a piece of wire, there is also a magnetic force (which we usually call a *magnetic field*) around the wire. That is, a piece of iron near the wire will be acted on by the magnetic force; if it is small enough, it will even move. On the other hand, if we move a magnet past a wire loop, we will find that a tiny current will flow in the loop. In all of electronics, there is nothing more important than the facts that a moving electric current will produce a magnetic field, and a moving magnetic field will produce an electric current. It took the early experimenters a long time to discover these facts, and it will take a while for you to understand their significance. All we want to do in this lesson is establish that there is an interaction between electricity and magnetism that is of tremendous importance.

We say that there is a magnetic field in the space near a magnet because iron (and to a lesser extent a few other materials) are attracted within that area. Similarly, we say that there is an electric field near an electrically charged body because things near the body are attracted to it. Thus, there are two different types of fields: the magnetic field and the electric field. That they are not the same is obvious from the fact that one acts on only a few things (mainly iron), while the other acts on everything.

WHAT HAVE YOU LEARNED?

1. Which one of the following statements is correct? (a) Electricity behaves in accordance with rules that are now well known, so that it is usually possible to predict what it will do; (b) The study of electricity is made difficult by the fact that we can seldom predict what it is going to do.

2. Current is electricity on the move. Electricity that does not move, such as that produced when you rub a comb through your hair, is called _STaTic_ electricity.

3. An electric field and a magnetic field are the same thing. *(True) (False)*

4. A body charged with static electricity will attract *(only a few different materials, mainly iron) (any type of material)*.

ANSWERS

1. (a) ... We *can* predict what electricity will do.
2. static
3. False
4. any type of material.

THE ELECTRICAL AND ELECTRONIC LANGUAGE

Even if you haven't had much experience with electricity or electronics, you probably know that they have a language of their own. You will master this language as you go along, using it to communicate with other people in the field. However, when you use electrical terms, be sure you know what you are talking about. For example, the catchall phrase "short" or "short circuit" is often used by the novice to explain just about any electrical trouble. You've no doubt heard someone with no knowledge of electricity whatsoever say, "It's probably a short" when an appliance doesn't work. As a matter of fact, more electrical troubles are caused by opens than by shorts (see Fig. 2). You'll learn in the next few pages the meaning of both of these terms, and a couple of others that you may have wondered about.
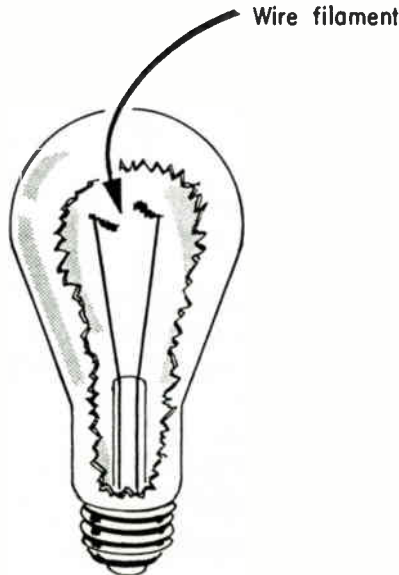
Wire filament

Fig. 2 A burned-out light bulb is an example of an "open". The filament is "open" because it is broken, and therefore cannot conduct electricity. Most electrical problems are caused by such opens, not by shorts.

4 WHAT IS VOLTAGE? . . . You probably know that some things operate on 120 volts, such as your home appliances, lights, and TV set. Still other things operate on other voltages. For example, a two-cell flashlight operates on 3 volts and a small transistor radio usually operates on from 3 volts to 9 volts (See Fig. 3). Large motors and machines used in industry often require 220 volts, 440 volts, or even more.
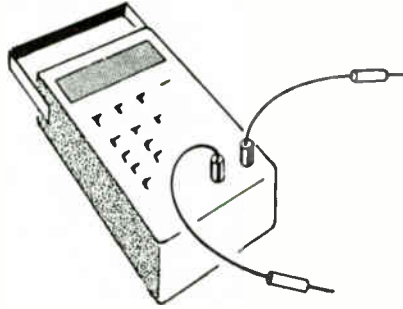
(a) Digital multimeter uses two 1.5-V cells for a total of 3 volts.
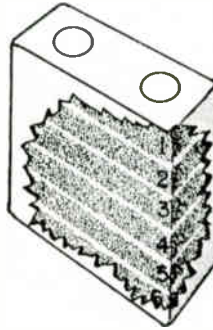
(b) Standard 9-volt battery is made of 6 1½-V cells, for a total of 9 volts.
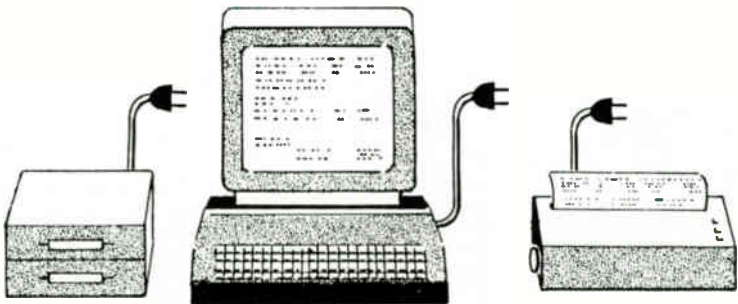
(c) Most personal computers operate on 120-V power (as do the peripheral devices).

Fig. 3

10

(d) Most microprocessor "chips" operate on only 5 volts.
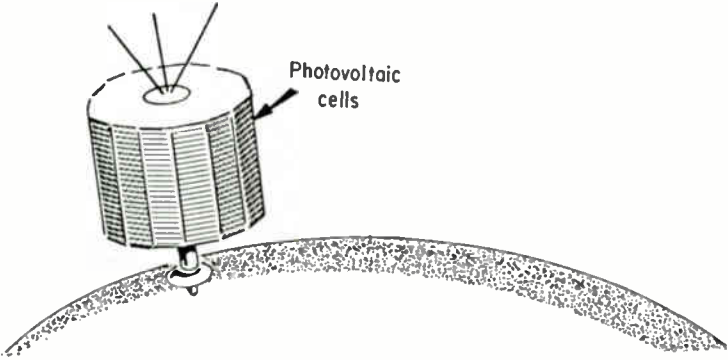
(e) Communications satellites are powered by many photovoltaic cells connected in series. Like the 9-V battery, they produce direct current (DC).

Fig. 3 Voltages used by various electrical/electronic devices.

What do we really mean when we say *voltage*? We mean the amount of electrical pressure that pushes the electric current through an electrical device. This pressure is somewhat like the pressure on the water in your home that forces the water out of an opened faucet. (See Fig. 4.) It is *not* the pressure that washes your hands, waters your plants, or whatever, it is the water that does that, but it is the pressure that forces the water out of the pipes.
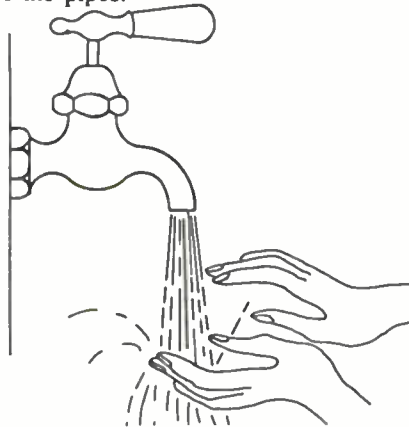
Fig. 4 The more pressure in a water system, the more water that flows when the tap is opened—and the same is true of electricity; the more voltage in a given circuit, the more electric current that will flow.

As with the water, in electricity it is *not* the pressure that actually lights a lamp
(though the lamp wouldn't light without it), turns a motor, or makes the toast:
it is the pressure (voltage) that forces the electric *current* to flow and do the work
and, as Figure 5 suggests, the more voltage, the more current.
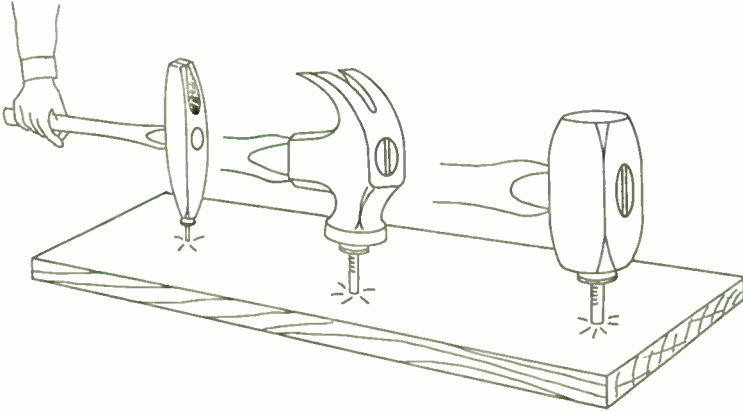
**Fig. 5   Just as it takes a bigger hammer to drive a larger nail in the same material,
so it takes more voltage to force more current through a given circuit.**

Voltage can be compared with the pressure in a U-shaped tube with a valve at
the bottom as shown in Fig. 6. As more fluid is poured into the tube, the pressure
(voltage) builds up against the valve at the bottom; however, there is no fluid (cur-
rent) flow. If we now open the valve, the fluid will flow, and continue to flow
until the pressures in the two arms equalize, as in Fig. 6(b). Voltage, then, can
be explained as a condition of *unequal* pressures. The electrons inside the electric
wires will move so long as the pressure is not equalized. Once the pressure ceases,
current also ceases.

Think of Fig. 6(a) as a fully charged battery, and Fig. 6(b) as a fully *dis*charged
battery. How long it would take to discharge the battery would depend on how
far the valve was open. If the valve were opened only a tiny amount, current would
be small and the battery would last a long time. On the other hand, if the valve
were opened full (representing a short circuit), there would be an extremely heavy
current but only for a short time. A fully opened valve would be something like
placing a piece of wire across the terminals of a flashlight battery, as in Fig. 7(a):
the battery would be discharged very quickly. On the other hand, if the battery
were used to light a small lamp that restricted the flow of current, as in Fig. 7(b),
the battery would last for several hours.
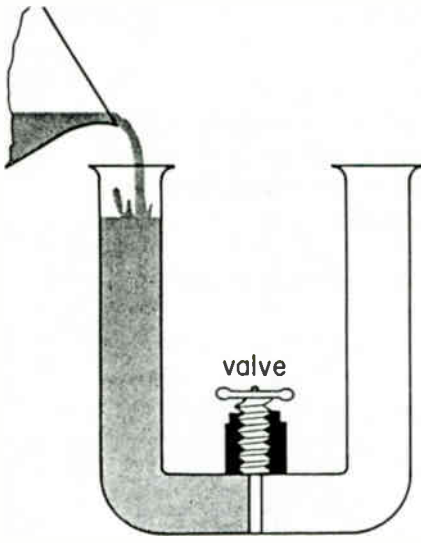
(a) Pressures in the arms are unequal
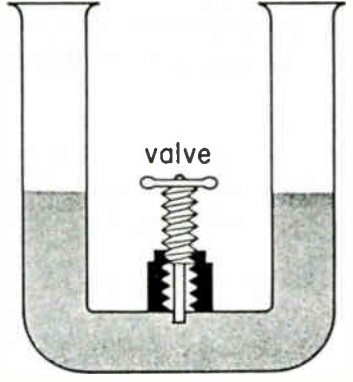
(b) Pressures in the arms are equal

Fig. 6   If there is more water on one side of the valve in the U-shaped tube than on the other, water pressure is developed. Similarly, an unequal distribution of electrons in a battery (more on one plate than on the other) develops an electrical pressure, which we call voltage.
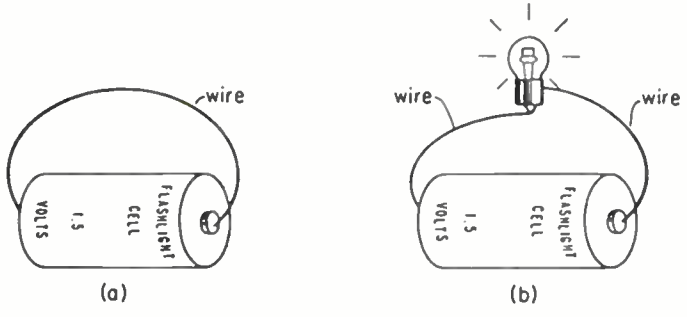
Fig. 7   A short circuit (a) runs a battery down very quickly, but a normal circuit (b) will do useful work for quite a while before the battery is discharged.

Note that every battery has two terminals. That includes a flashlight cell, although you may say that you see only one. One terminal is the center post shown in Fig. 7, and the second terminal is the bare metal bottom of the battery case. Unless there is a connection to both of these terminals there will be no current.

Electrical pressure or voltage is measured in *volts*. A circuit with 100 volts has twice the pressure of a circuit with 50 volts, or—to put it another way—a circuit with 50 volts has half the pressure of a circuit with 100 volts. Other things being equal, a circuit with twice the voltage of another circuit will have twice as much current flowing through it.

Every electrical device is designed to operate on some particular voltage. If you attempt to operate it on a considerably different amount or type of voltage, either the device won't work at all or it will be severely damaged. For instance, if you were to put 120 volts on a 9-volt radio, all you would get would be a puff of smoke and a gravely damaged radio. See Fig. 8(a). On the other hand, if you connected a 9-volt battery to the 220-volt clothes dryer in Fig. 8(b), there would be no damage—but there would be no dry clothes, either!
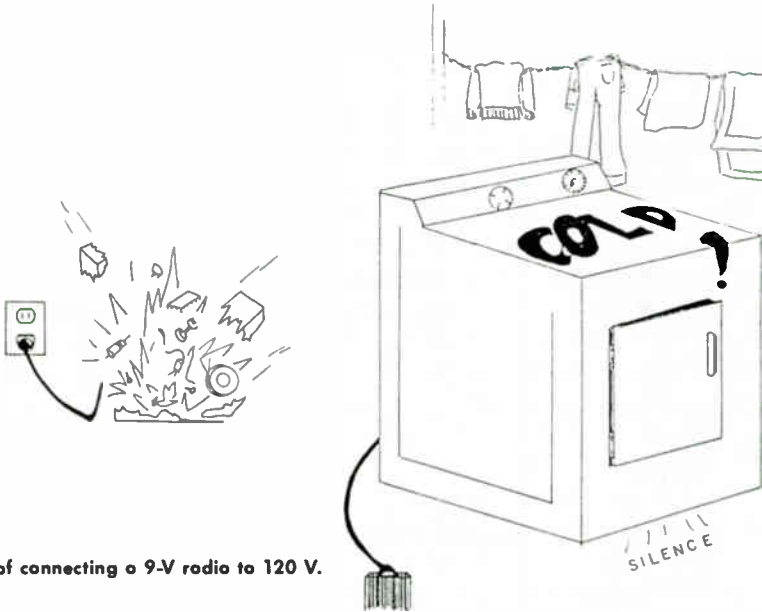
(a) Result of connecting a 9-V radio to 120 V.

(b) Result of connecting a 220-V electrical clothes dryer to a 9-V battery.

Fig. 8   It is essential that you respect the manufacturer's recommendations for any electrical device.

5 WHAT IS CURRENT? . . . Current is the movement of electricity through wires and electrical devices; it is similar to the flow of water through a pipe. The fact that we can't see the electricity as we can see the water does not make it any less real. But although it is easy to see how water can flow through a hollow pipe, how can anything flow through a solid wire? The answer is that what we call a solid wire consists mostly of wide open space. If metal were actually solid, a piece of it the size of the head of a pin would weigh nearly a million tons! A piece of metal—or any other substance—is made up of extremely tiny atoms which, in comparison with their size, are widely separated from each other. If you could enlarge a piece of metal until each of the atoms was the size of the earth, for example, the atoms would be as far distant from each other as the earth is from the sun.

Electricity is made up of electrons, which are still smaller than atoms. So, as you can see, with all that Texas-style space between the atoms, the electrons don't have much trouble getting through.

It is easy for someone with just a casual acquaintance with electricity to get voltage and current confused. Although, like the car and the motor, they are intimately associated with each other, they are not the same thing. The motor moves the car and the voltage moves the electricity. We don't have a current unless the electricity is moving. Electricity that isn't moving is *static* electricity, which we have already talked about. Static electricity makes your clothes stick together when you take them out of the dryer, and it can provide you with unpleasant shocks on dry days. Static electricity is frequently an annoyance, and sometimes it is even dangerous. Although static electricity has a few useful applications, moving electricity—what we usually call *electric current*— is the electricity responsible for the electrical world of today. For that reason, we will give nearly all of our attention to electric current.

It is electric current that lights the lamp, heats the oven, and runs the motor. However, in order to make the electricity move so that we have a current to flow, there must be a voltage behind it. Thus, *both* voltage and current are needed to get the job done. To be more technical, we say that both voltage and current are needed to produce *power.* In fact, electric power, which is measured in *watts,* is found by multiplying the voltage by the current.

As stated earlier, voltage is measured in volts. Current is measured in *amperes,* which is often shortened to *amps.* "Ampere" is pronounced AM-peer.

1. Voltage is to electricity as _pressure_ is to the water system in your home.

2. An electrical pressure of 90 volts is _Three_ times as much pressure as 30 volts.

3. Electrical appliances *(do)* *(don't)* all work on the same voltage.

4. Before you can do work with electricity, you must have *(voltage) (current)* *(both voltage and current)*.

5. The amount of electric current in a circuit is measured in *(volts)* *(amperes)* *(watts)*.

6. If you connected 120 volts to the battery leads of a 9-volt radio, the radio would *(play normally)* *(not play, but otherwise would not be affected)* *(be severely damaged, and probably go up in smoke.)*

ANSWERS

1. pressure
2. three
3. don't
4. both voltage and current . . . Unless you have voltage pushing the electricity, the electricity will stop flowing and no work will get done.
5. amperes.
6. be severely damaged, and probably go up in smoke . . . If you use double the voltage an appliance is rated for, you will double the current. But remember we said that the electric power in a circuit is found by multiplying the voltage by the current. Even doubling the voltage increases the electric power in the circuit 4 times (2 × 2). In this example, the voltage would be increased over 13 times, as would the current, making the increase in electric power more than 169 times (13 × 13). Something has to give in such a situation, and that something would be the radio.

6 WHAT IS A SHORT? . . . A *short* or *short circuit* occurs when two or more wires in a circuit accidently get together, metal to metal. For example, if the two wires in the power cord of a table lamp became frayed, so that the insulation of both wires wore through, and the two wires then came together, that would be a short.

If you plugged in a lamp that had a shorted cord, you would likely get sparks and flashes where the two wires were shorting together (see Fig. 9). If it were a "dead short," the fuse in the power line would blow or the circuit breaker would trip. There might not be any sparking, since a dead short is one that is very secure—the wires not just rubbing together but actually twisted or held so tightly together that there is no chance for sparking between them. The simple short is most apt to start a fire, because it will sometimes spark and burn for several seconds before the wire burns itself in two or the short blows a fuse.

However, you can have shorts where there is no sparking or burning, regardless of whether the short is a dead one or not. If the voltage is low, or the available current is low, then you won't have a visible spark. For example, the wires in a turntable cable can and often do short together as shown in Fig. 10. This prevents the stereo from working, but it presents absolutely no fire hazard. As you proceed in this CIE course, you will learn about the many different degrees of shorts that can occur in electric circuits.
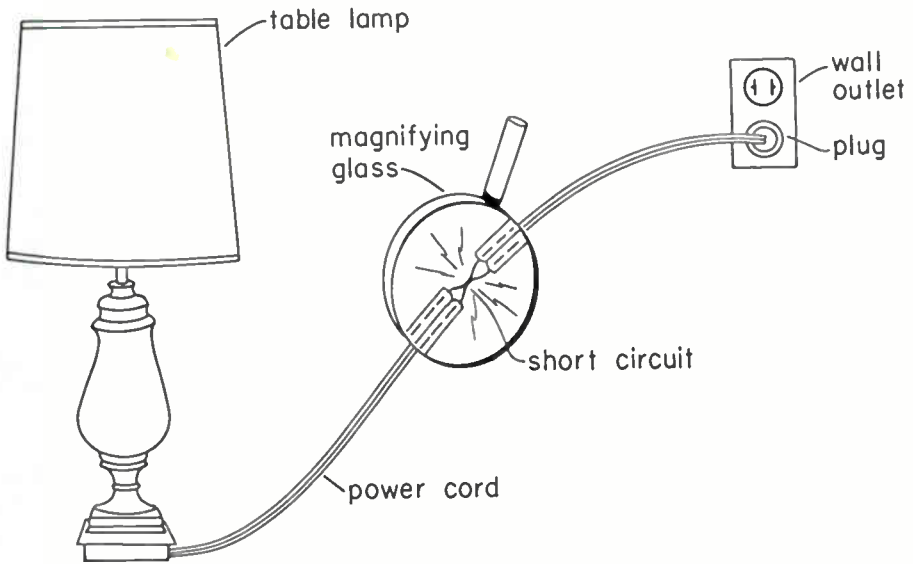
Fig. 9 **If the two wires get together (metal to metal) in a lamp cord, the result is a short circuit.**
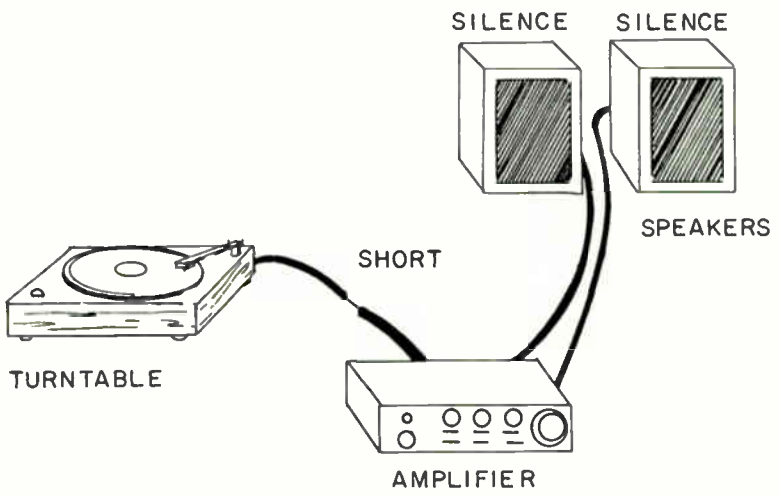
Fig. 10 If two bare wires in the turntable cable short together, there is no sound from the speakers. In this case, since the power from the tonearm pickup is very low, there is no arcing or sparking if the bare wires get together. (Compare with Fig. 9).

7 WHAT IS AN OPEN? . . . Open circuits occur more often than short circuits in most electric circuits. As Fig. 11 shows an open circuit is like an open drawbridge: traffic (current) simply stops. Similarly, if a wire breaks in a power cord to the lamp in Fig. 12, no electric current can flow. This is called an *open*, or an *open circuit*.
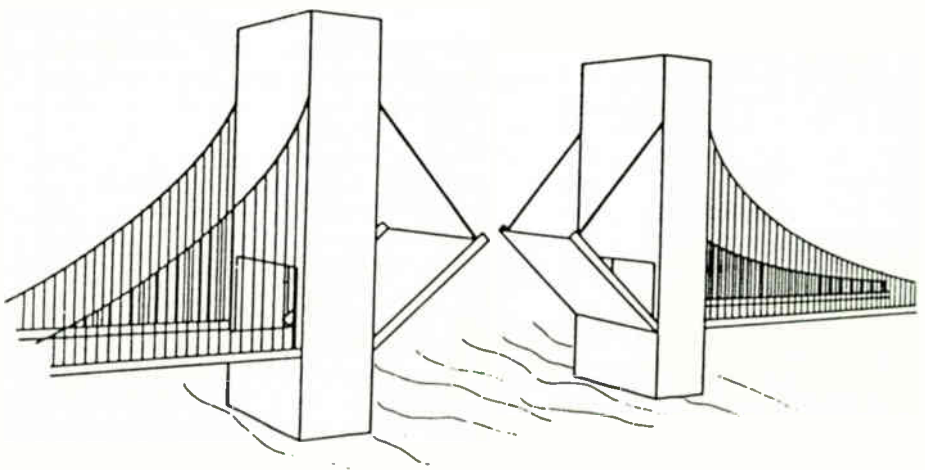
Fig. 11 An open circuit, like an open drawbridge, stops the flow of traffic (electrical current).

18
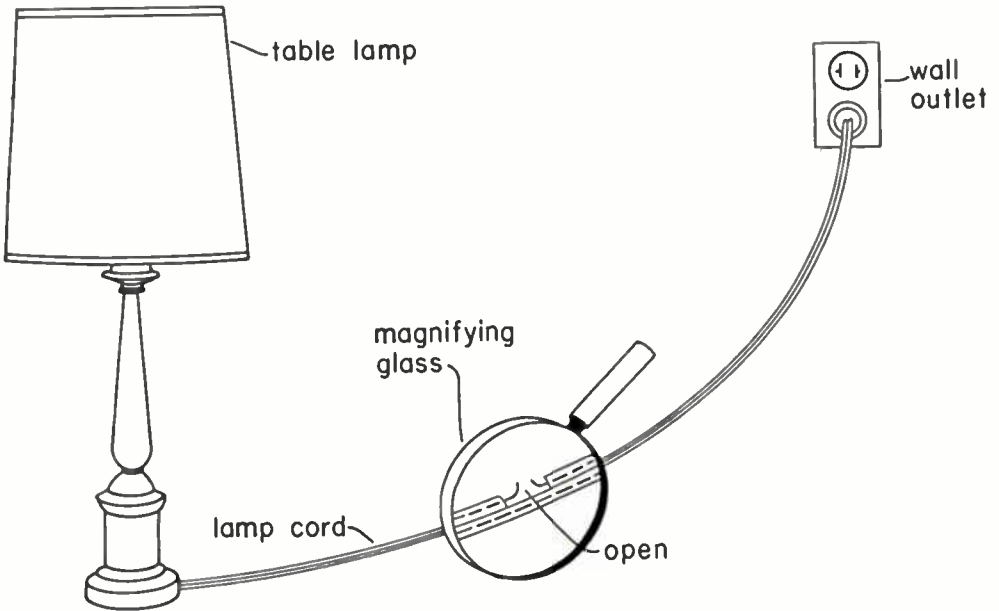
Fig. 12 If one the the wires inside this cord breaks in two, that is an "open cir-
cuit." If you pull the plug or turn off the lamp switch, the result is also
an open circuit. Therefore, an open circuit is any circuit in which, for any
reason, there is no electrical connection.

Any circuit that is not complete for any reason can be called an open circuit. For
example, if you turn off a light switch, you have *opened* the circuit. If a light bulb
burns out, it is because the tiny filament wire inside has burnt in two, as we saw
in Fig. 2. So we could say that the light bulb is *open*.

WHAT HAVE YOU LEARNED?

1. If the bare wires in a lamp cord should lose their insulation and touch together,
the circuit would have a(n) *(open)* *(short)*.

2. When you turn a wall switch off in your home, you have *(opened)* *(shorted)*
the circuit.

3. In regard to short and open circuits, ___Short___ circuits are more likely
to cause fires than ___open___ circuits.

4. In Fig. 13(a), if a wire were connected between points *A* and *B*, you would say the circuit was *(shorted)* *(open)*.

5. In Fig. 13(b), the circuit is *(open)* *(shorted)* and the lamp *(will)* *(will not)* light.

6. Figure 13 (c) *(is)* *(isn't)* a short circuit.

7. Which one of the following statements is true of Fig. 13(d): The circuit is shorted, and the lamp will not light; The circuit is open, and the lamp will not light; The circuit is open and the lamp will light; or The circuit is okay, and the lamp will light?

LANTERN BATTERY

(a)

LAMP
FILAMENT
BROKEN

LANTERN BATTERY

(b)

NO CONNECTION
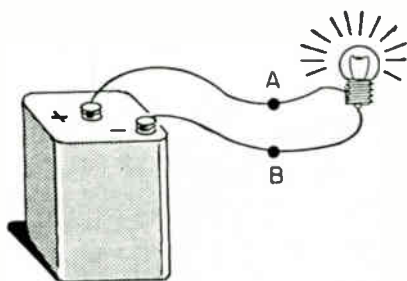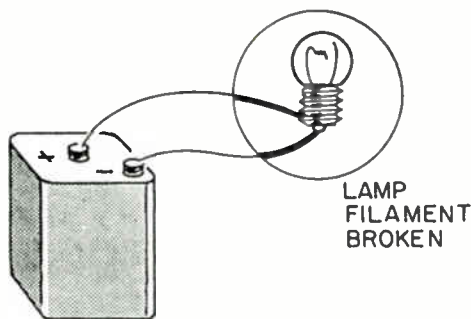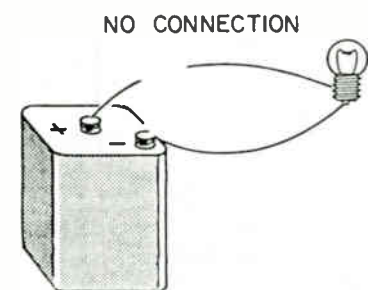
LANTERN BATTERY

(c)
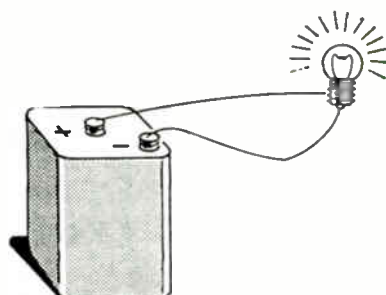
LANTERN BATTERY

(d)

Fig. 13   Circuits for WHYL questions 4 through 7.

1. short . . . The circuit is actually "shortened," since there is an easier (shorter) path for the current to follow than the path through the lamp.

2. opened . . . Any circuit through which current will not flow is an open circuit, so when you turn a switch off, you open the circuit. The light in the switched circuit then has no current through it, and so goes out.

3. short; open . . . In a short circuit there is heavy current, and this can cause a fire—especially in a high-voltage circuit. With an open there is no current, so the chances of fire are negligible.

4. shorted . . . Tieing together the two wires that are connected to the battery causes a short circuit. Have you ever touched a pair of open pliers between the posts of a car battery and touched off an array of sparks? That is a short. (Note that both terminals of this type of battery are at the same end of the battery.)

5. open; will not . . . Here, the open circuit is the filament wire inside the lamp bulb. You can usually tell if a clear-glass bult is defective by looking carefully at the filament wire to see whether or not it is open.

6. isn't . . . Here, the wire is open.

7. the circuit is okay, and the lamp will light . . . This is a good circuit. Note that one wire goes from one battery post to one side of the bulb, and the other wire goes to the other side of the bulb: no breaks and no shorts.

8 COMPLETING YOUR EXAMINATION . . . Now that you have read through the lessons and answered the *What Have You Learned?* questions, you will probably find the following examination questions fairly easy. So answer them at once. Don't hesitate to check back in the lesson for information you need to answer any questions on which you are in doubt.

Be sure to mail your completed examination promptly. It will usually be graded and returned the day it is received, so that you will know as soon as possible how you made out. If your grade is 70 or higher, you are doing OK. A grade below 70 is a warning signal, however. Restudy the lesson with the low grade carefully, and resolve to study the following lessons more thoroughly. You will have to redo any lesson in which your grade is below 70.

If you are able to do the following lesson at this time, you may mail both exams together, using the same *answer sheet.*

Discussion sheets explaining each examination question will be returned to you with the last examination in each volume. Although a volume may have two or three lessons, they are always on the same subject matter. Therefore, we have a single discussion sheet for a volume, so that the subject matter can be discussed in a unified manner.

LESSON 2330A-5
CURRENT AND VOLTAGE

EXAMINATION

Each examination question is followed by a number of selections. Circle the number in front of the correct selection for each question. When you have finished, transfer your answers to the Answer Sheet provided.

1. What is a good description of voltage?
   (1) The amount of resistance to current.
   (2) The amount of current that flows in an electric circuit.
   (3) The amount of electrical pressure that pushes electric current through an electrical device.

2. What is the normal voltage you can expect in your home at a wall outlet where you might plug in your radio, TV set, or table lamp?
   (1) About 120 volts   (3) About 12 volts
   (2) About 60 volts

3. An electric circuit that has 120 volts has how many times as much electrical pressure as a circuit having 40 volts?
   (1) One   (2) Two   (3) Three   (4) Four

4. Electricity that flows in an electric circuit is called
   (1) voltage.   (3) resistance.
   (2) current.   (4) pressure.

5. What is the name of the unit we use to measure current in an electric circuit?
   (1) Volt   (2) Ampere   (3) Ohm   (4) Watt

6. What is the name of the unit we use to measure the electrical pressure in a circuit?
   (1) Volt   (2) Ampere   (3) Ohm   (4) Watt

7. If a light in your home blows fuses all the time, you would say the lamp cord was probably
   (1) shorted.   (2) open.

22

8. In Fig. 14(a), the lamp
   (1) would be lit.   (2) would not be lit.

9. In Fig. 14(b), the circuit is
   (1) open   (2) shorted   (3) closed.

10. In Fig. 14, which sketch indicates a short?
    (1) (a)   (2) (b)   (3) (c)

(a)

AUTOMOBILE   TAIL
LIGHT

table lamp

wall outlet
plug
120 VOLTS

BARE WIRES
TOUCHING

(b)

120 VOLT
WALL OUTLET

3 VOLT
FLASHLIGHT

(c)

(batteries removed)
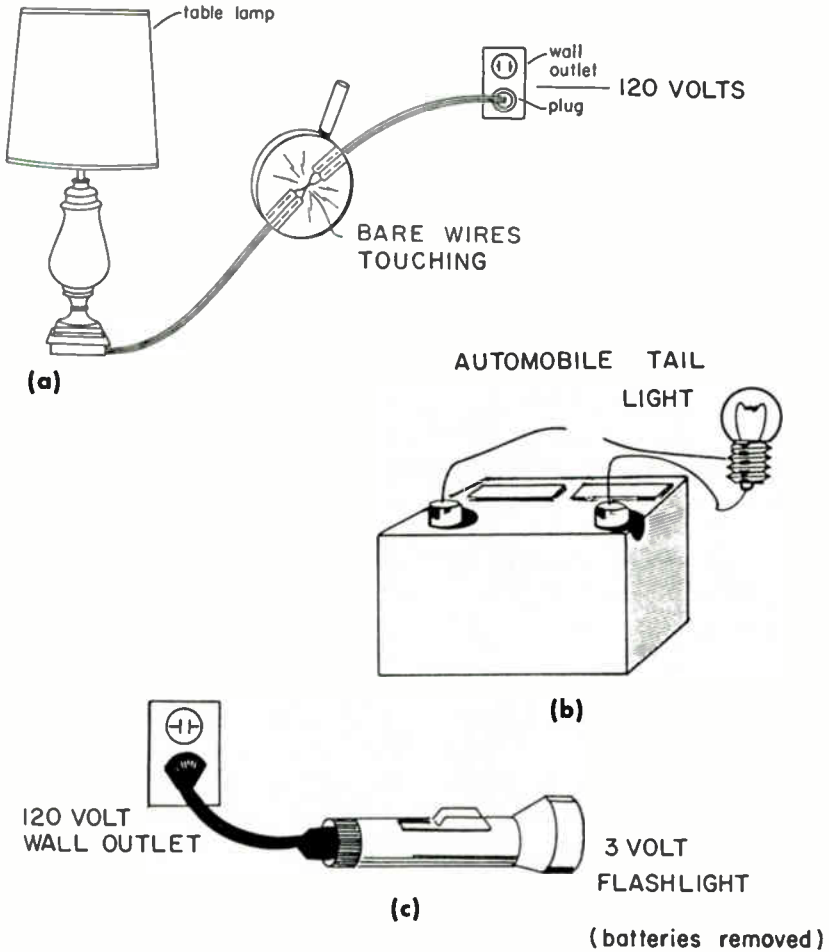
Fig. 14

END OF EXAM

9 HOW TO CONTINUE ON TOWARD YOUR GOAL . . . You will find the second lesson in this volume as easy to complete as the first, and it won't take you any longer. You can finish it, including the examination, TODAY.

After you complete this lesson you may prefer to take a one day rest before going on to the next volume. Fine. But first plan the time and place for studying the next lesson. Never set your lessons aside until you have planned when to study again. There is nothing more important than *planning* your study hours. Planning makes you a doer, it is the doers who get the top jobs.

Successful study tip: Keep all your lesson material, pencils and pens, scratch paper, and envelopes—everything you need for your studies—together in a package, so that whatever you need is instantly available. That is good time-saving organization.

Lesson 2330B-5
Controlling Current
and Voltage

THE MOVEMENT OF ELECTRICITY

10 WHAT IS A CONDUCTOR? . . . A conductor is any material through which electricity can flow. All metals and many liquids are conductors. Silver is the best conductor, but it is too expensive to be widely used for that purpose. Copper is the second best conductor, and is by far the most widely used material for wire for electric circuits. Aluminum is also a good conductor and is inexpensive, but its use is limited because it is difficult to solder.

Absolutely pure water—such as double-distilled water—will not conduct electricity, but most water, including common drinking water, contains enough dissolved minerals and salts to make it at least a fair conductor and often a fairly good one. Salt water is an excellent conductor. Since even a poor conductor can provide a severe electric shock, you must take extreme care when you work with electricity in damp areas. Avoid contact with damp ground and concrete by standing on dry boards. Anyone who touches an electrical appliance or radio powered from the house mains while taking a bath is looking to commit suicide.

11 WHAT IS INSULATION? . . . Just as we must have conductors to carry electricity, so we must have insulators and insulation to prevent the conductors from getting together and causing a short circuit.

Many materials make good insulators—paper, fiber, plastic, rubber, glass, and—the most common of all—air. Some materials are better insulators than others. Some work better for certain kinds of electric current than for others. Some are better suited to a particular job than to others. For example, a lamp cord usually has plastic or rubber insulation, since it must be flexible. Glass or porcelain is often used for the insulators on electric light poles, where rigidity is essential (Fig. 15).
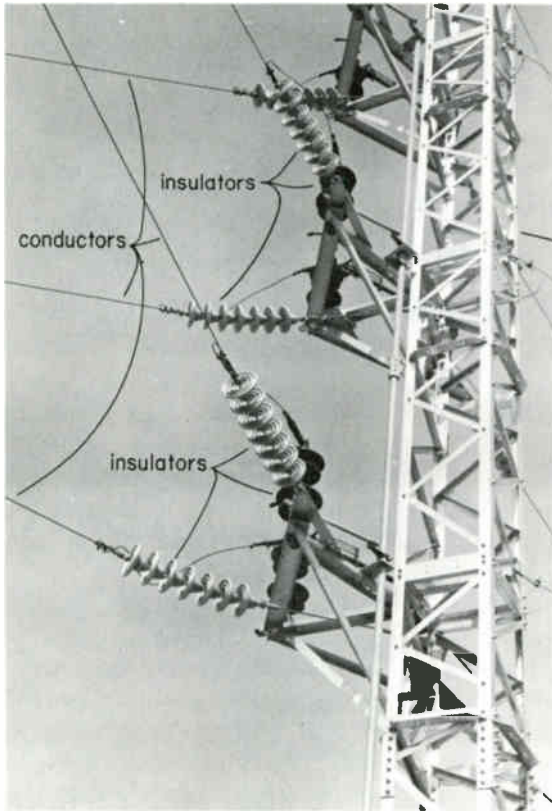
Fig. 15   The tower would "conduct" electricity to ground if it were not for the insulators, since the tower is made of metal. Some power-line porcelain insulators are suitable for 50,000 volts.

Paper is a good insulator for power-line voltages, but it is not nearly as good an insulator between the elements of a TV antenna. Paper would be useless where there is a lot of heat, so insulators of asbestos, mica, and ceramic are used as insulation in electric stoves, irons, toasters, and the like.

An insulator, then, is any material through which electricity will not flow easily. (No insulation material is perfect, and all insulations will break down if sufficient voltage is applied to them.)

WHAT HAVE YOU LEARNED?

1. In Fig. 16(a), the copper penny _(is)_ _(isn't)_ conducting.
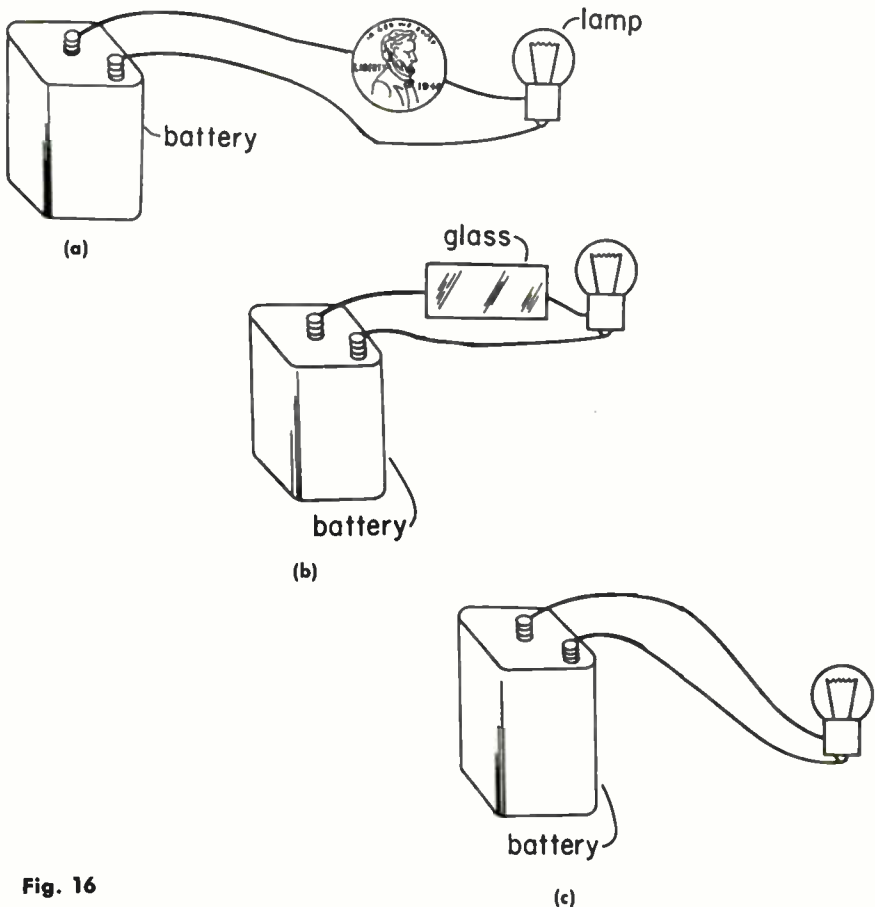
Fig. 16

2. A conductor is *(always some type of wire)* *(not necessary in a practical circuit)* *(something able to carry electric current)*.

3. If your hands are damp with perspiration, is there more danger from shock than if your hands were dry? yes

4. In Fig. 16(b), the glass *(is)* *(isn't)* conducting.

5. In Fig. 16(c), the wires from the battery to the lamp are covered with some type of _insulation_ —possibly _rubber_ .

6. An insulator is any material through which electricity *(will)* *(won't)* flow easily. A conductor is any material through which electricity *(will)* *(won't)* flow easily or fairly easy.

ANSWERS

1. is . . . The penny is part of the electrical path to the lamp. Since copper is a conductor, the current going to the lamp passes through it.
2. something able to carry electric current.
3. Yes . . . Most nonmetallic materials are better conductors when damp. Dry skin is a poor conductor, and so it helps prevent shock. The inside of your body is a good conductor, so that the skin is the only natural protection the body has against shock. The skin cannot be relied upon to protect us safely even from regular household voltage (115 volts), which many technicians who should know better consider "safe." Although most shocks from this voltage produce nothing worse than an uncomfortable feeling, the fact is that more people are killed by regular household voltage than by any other voltage.
4. isn't . . . The current would have to pass through the glass to get to the lamp, and that is not possible because glass is an insulator. Therefore, the circuit is open.
5. insulation; rubber or plastic.
6. won't; will . . . There is no perfect insulator or perfect conductor. No conductor passes electricity without at least some slight loss, and no insulator is so good that it will not eventually pass current if enough voltage is applied. However, at normally encountered voltages and currents, conductors conduct with minimum losses and insulators insulate with an unmeasurably low current through them.

12 WHAT IS A SWITCH? . . . A switch is a device that provides a convenient means of turning electricity on and off. To understand how a basic switch works, let's consider the simple lamp-and-battery circuit of Fig. 17. As long as the two wires from the lamp are connected to the battery as shown in Fig. 17(a), the lamp glows. Electrical current is constantly flowing from the negative end of the battery, through the negative wire to the lamp, through the lamp filament, and back again to the positive terminal of the battery. As long as the circuit is complete, so that current can get from the battery to the lamp and back to the battery again, current will flow and will make the lamp shine. But if there is an open *anywhere* along the circuit path, no current will flow anywhere in the circuit and the lamp will go out.
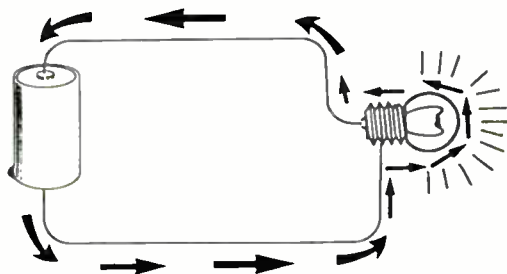
(a) As long as both wires are connected to the lamp and battery, the circuit is complete, current will flow, and the lamp will glow.
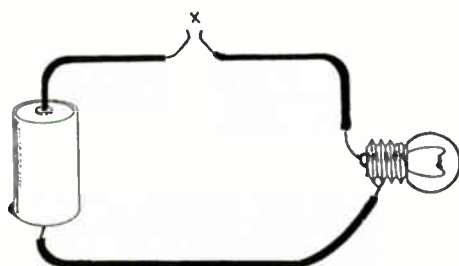
(b) When we touch the bare wire ends together, the circuit is complete, current can flow, and the lamp glows. When the wires are separated as shown, the circuit is broken, no current can flow, and the lamp is out.
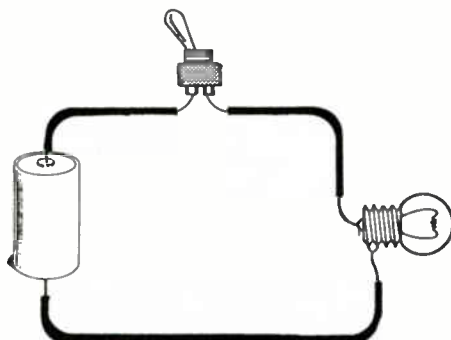
(c) The switch does the same thing we did with the bare wire ends in (b), but is safer and more permanent.

Fig. 17   Lamp-and-battery circuit.

You could "break" the circuit at any point—say, by disconnecting the wire from one end of the battery—and the lamp would go out. As soon as you restored the connection and made the circuit once more complete, the lamp would again shine. You could even solder the wires to the lamp and the battery, and then cut either wire at any point: as soon as you cut the wire, the circuit would be broken and the lamp would go out.

Now, suppose that we did just that—soldered the wires to the lamp and the battery, and then cut one wire in the middle. Further suppose that we took the ends where we cut the wire and skinned off some of the insulation, as shown in Fig. 17(b). You would then have the crudest kind of electrical switch—two bare wire ends. When you touched the wires together, the current would flow and the lamp would shine. When you separated the wire ends, the current would immediately stop and the lamp would go out.

Figure 17(c), finally, shows how a switch does the same thing that we do with the wire ends in Fig. 17(b). However, with the switch we have a much more permanent arrangement—as well as protection from possible shock.

Figure 18 shows what's inside a typical switch of the kind used to turn lamps on and off. Note the two *contacts*—conductors made specifically to close and open circuit connections without wearing out quickly. As you can see, there is also a spring and a lever on a pivot. When you push the lever one way, the force overcomes the spring, and the contacts come together. When you push the lever the other way, the spring pulls the contacts apart quickly, and the circuit is broken.

The switch is usually made in such a way that the spring holds the lever and contacts either in the open or closed position unless a firm force is applied to the lever. When the lever is moved from one position to another, there is an audible "snap." This snapping action is refered to as *detent* (de-TENT).

Switches like the one in Figure 18 are commonly called *toggle switches*. The schematic diagram for a toggle switch (and others like it) is shown in Fig. 19. The arrowhead is usually omitted for simplicity, and the switch is normally illustrated in its open position. This is true even though the switch is designed to be closed. (In the same fashion, the schematic diagram of a television receiver will show all the circuit voltages and signals when the set is turned on, but the power switch may be drawn in the open [Power Off] condition.)

switch handle

circuit terminals

toggle switch

switch handle pushed to OFF

pivot

mounting bushing

plunger spring

switch contacts open

spring-loaded plunger

circuit terminal

toggle switch

switch handle pushed to ON

pivot rivet

Notch causes switch contacts to close and open open rapidly when handle is pushed ON and OFF.

switch contacts closed

spring contact lever

Fig. 18   Operation of one kind of toggle switch.

30

OPEN   CLOSED
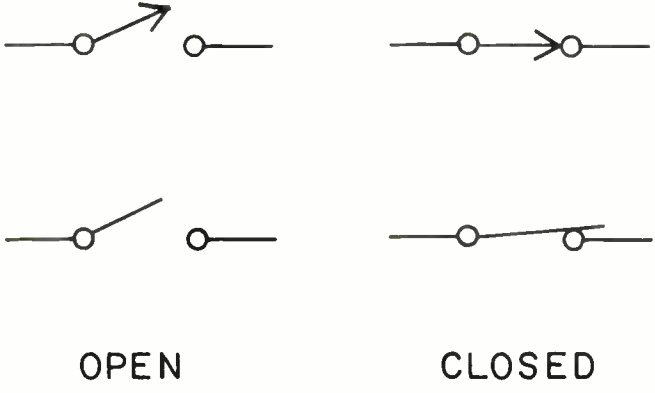
Fig. 19   Schematic symbols commonly used for toggle and similar switches.
           Usually, the switch is drawn in the open position with the arrow head
           omitted.

flexible wires

metal contact electrodes

glass tube

mercury

(a) Off

Mercury covers contact
electrodes and makes
electrical contact
between them

(b) On
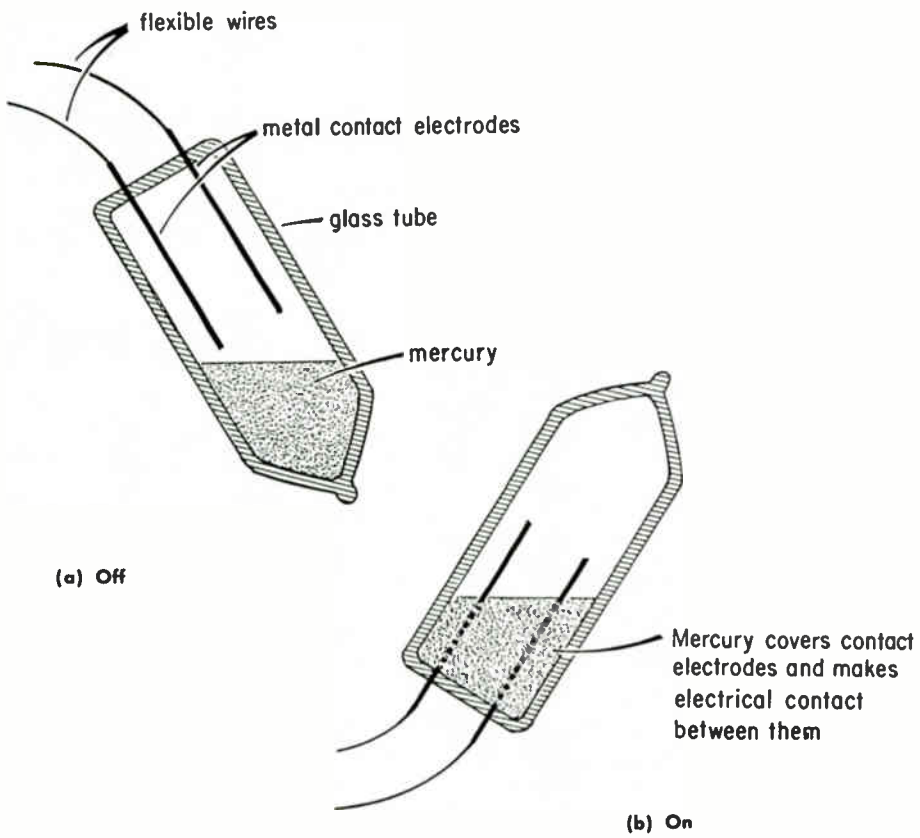
Fig. 20   Operation of mercury switch.

You've probably used switches in newer buildings that have a much less pronounced detent "snap" to them. These were probably *mercury switches.* Figure 20 illustrates the basic principle behind the operation of a mercury switch. In (a), you can see the basic parts of the switch. Two contact electrodes (bare wire ends) are positioned in one end of a sealed glass container that holds a small amount of the liquid metal, mercury. When the tube is tilted as in (a), the mercury switch is open, because there is no connection between the contact electrodes. When the tube is tilted as in (b), however, the mercury rolls down over the contacts and makes an electrical connection between them. To reopen the switch, you simply tilt the tube back to the (a) position.

Mercury switches last much longer than ordinary metal-contact switches because there is little contact burning or chemical deterioration. The glass tube is usually filled with a chemically inert gas such as argon or nitrogen, to prevent oxidation of the mercury and the contact electrodes. Since the oxides of most metals— mercury included—are insulators, the inert gas in the tube keeps the mercury from oxidizing into a non-conducting red powder.

The *slide switch* is often used in electronic equipment where economy and small size are important. Figure 21 shows both the internal construction and the common schematic symbol for a slide switch. The slide switch contains a metal strip that performs basically the same function that the mercury does in a mercury switch. When the handle is pushed one way, the metal strip slides up over two contacts and makes a connection between them, thus closing the switch. Pushing the handle the other way slides the metal strip off the contacts, and opens the switch. In the schematic symbol of Fig. 21(b), the rectangle represents the metal strip, and the circles represent the contacts.

Slide switches usually have a detent mechanism, too, so they remain in one position unless the handle is used to change the position. While there are many ways to obtain the detent in a slide switch, the usual way is to make the sliding strip out of a metal that is not only a good conductor, but also has some natural springiness. Bumps in the strip and on the housing of the switch are arranged to produce the desired detent.

(a) Internal view

(b) Schematic symbol
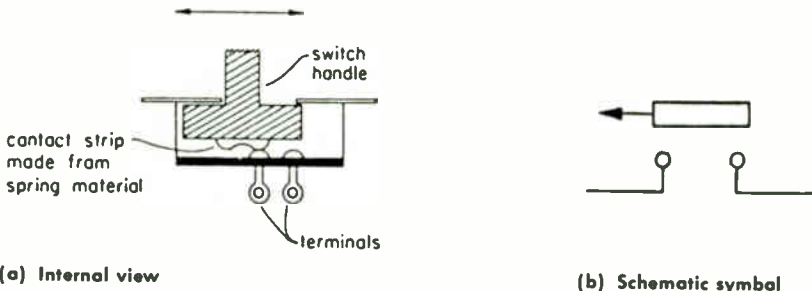
Fig. 21   Slide switch.

32 *Pushbutton switches* are used in some of today's most advanced electronics equipment, including computers. There are countless other uses for pushbuttons, down to the humble doorbell.

Figure 22 shows the workings of an ordinary pushbutton. The pushbutton differs from other kinds of switches we've considered in one important respect: most pushbuttons are *momentary*, meaning that they're closed only when the button is pushed. Otherwise, they're open, as the one in Figure 22 is. Normally, the return spring inside the switch holds the shorting bar away from the fixed contacts. When the actuator (button) is pushed down, the force overcomes the spring. The shorting bar is pushed against the two fixed contacts, making connection between them and closing the switch. As soon as the button is released, the spring pushes the shorting bar up from the contacts and the switch opens again.

Some types of pushbuttons contain detent mechanisms that give them a snap action. You'll often find this type on calculator keyboards, for example. Pushbutton switches used for turning power on and off often have mechanisms that close the switch and open it on alternate applications of pressure. These types are commonly called *push-on/push-off* switches.

The *rotary switch* is also very popular in electronic equipment. Instead of pushing a handle or pressing a button, you actuate a rotary switch by turning the knob attached through its shaft.
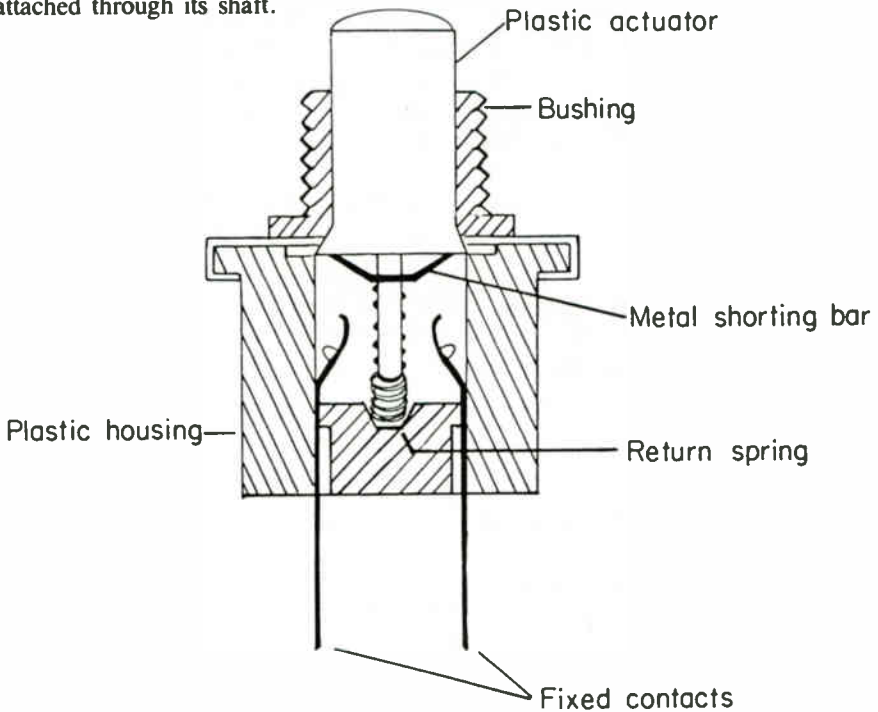
Fig. 22   Internal view of typical pushbutton switch

Figure 23 shows a typical rotary switch and its various parts. One contact on the rotary switch is arranged so that it always touches a circular metal strip called the *wiper*. As the shaft of the switch is turned, the wiper connects this contact to one or more stationary contacts on the (insulating) switch wafer. The switch in Fig. 23 is shown with only one stationary contact on the wafer, but there are holes on the wafer where other stationary contacts can be riveted in place. That way, the wiper contact can be connected first to one stationary contact and then to another as the shaft is turned.

An arrangement like the one just described provides a *selector switch*. Your stereo probably has such a selector switch that enables you to choose whether you get the phonograph, AM, FM, or tape audio through the amplifier. It may also include another selector switch that lets you switch on another pair of speakers in another room. Older and less expensive television receivers have elaborate selector switches that tune the set to different channels—the familiar "channel selector" switch on the front of the set.
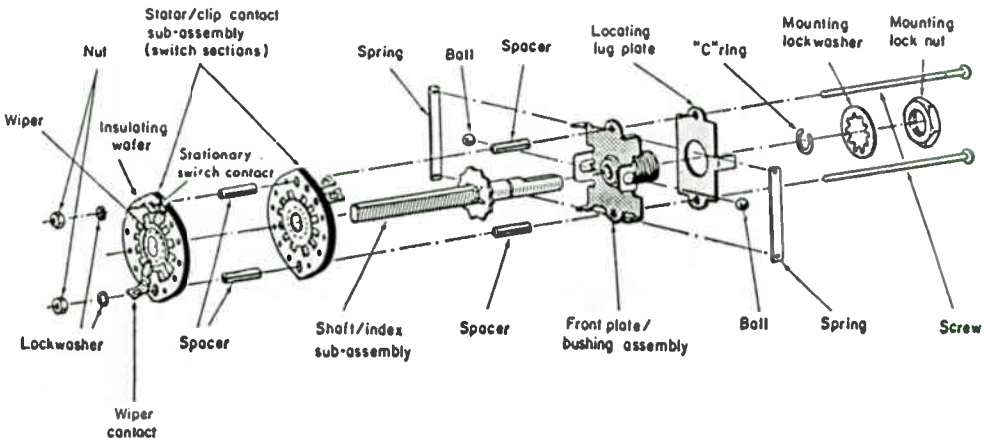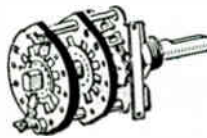
Fig. 23   Construction of a typical rotary switch

34 Many other kinds of switch arrangements can be built into rotary switches besides selectors. Rotary switches perform complicated "on" and "off" functions on oscilloscopes and other kinds of electronic equipment. When servicing a piece of equipment that includes such a complicated switch, you may find it necessary to draw a separate diagram for each position of the switch so that you can figure out precisely what the switch does.

All of the switches we've considered so far had mechanical arrangements that brought metal conductors together or apart to close and open the switch. Not all switches are like this, however. Today, more and more switches use a material that can be changed from a fairly good conductor to a fairly good insulator: silicon. As you will learn in later lessons, transistors as well as many transistor-like devices are usually made of silicon. These devices can either conduct or not conduct, depending on the level of the applied current or voltage. The specifics of how this is done will have to wait until you have learned more about basic electricity, but you should know now that many of the mechanical switches formerly used in electronic applications are today being replaced by these "electronic" switches.

WHAT HAVE YOU LEARNED?

1. A certain switch has a mechanism that keeps the switch in the same position until moderate force is applied. Then, the switch jumps to the other position and is held there. This property of a switch is called a _detent_ .

2. Which switch is partly dependent on gravity for its operation, and must therefore be mounted in the proper position? Mercury

3. An ordinary on/off wall switch is a type of _Toggle_ switch.

4. Pushbutton switches, like the ones used on calculators, are _momentary_ switches.

5. In a certain toggle switch, when the metal contacts are touching one another, the switch is *(open)* *(closed)*.

6. What is the name of of the moving contact in a rotary switch? wiper

7. In a schematic diagram of a television set, the power switch is usually drawn in the ~~open~~ ~~closed~~ position, though the circuit voltages are shown for the switch in the ~~open~~ _closed_ position.

8. A certain building uses a thermostat to control the furnace used to heat the building. When the building is too cold, the thermostat must turn the

furnace on, and when the building becomes a little too warm, it turns the furnace off. This way it maintains the temperature of the building. When the building is too cold, then, the contacts in the thermostat are _closed_ and when it is a little too warm, the contacts are _open_ .

9. The oxides of most metals are *(conductors) (insulators)*.

10. What material can vary its conduction in electronic switches? *silicon*

ANSWERS

1. detent
2. mercury switch
3. toggle
4. momentary
5. closed
6. the wiper contact, or simply the wiper
7. off or open; on or closed
8. closed; open
9. insulators
10. silicon

DIRECT AND ALTERNATING CURRENTS

13 DIRECT CURRENT . . . There are two general classifications of electric current: direct and alternating. Direct current is the kind produced by batteries, such as the dry cells used in a flashlight or the storage batteries used in automobiles. Direct current can also be produced by a motor-driven direct-current generator, or electronically with rectifiers. "Direct current" is abbreviated d-c, dc, or DC.

Direct current travels in one direction only through an electric circuit. It could be compared with a river, in which the water (current) travels always in the same direction. The water flow can be turned into power by the use of a waterwheel or the more sophisticated turbines used in hydroelectric plants. Direct current traveling through an electric circuit can do many sorts of work.

14 THE DIFFERENCE BETWEEN DIRECT AND ALTERNATING CURRENTS

. . . Direct current travels continuously through a circuit in the same direction. Alternating current (AC) reverses direction continuously and at a rapid rate. Basically, that is the difference between direct and alternating current. The current moves first in one direction and then in the other—continuously back and forth, or alternating. A single back-and-forth movement is called a *cycle*. We say that the power line frequency is 60 cycles per second, because 60 sets of back-and-forth movements take place every second.

If the current direction continuously changes, how can a motor running on AC keep running in the same direction? Figure 24 provides the beginning of an answer to this intriguing question, but you will have to wait until you learn more about electricity before you have the full answer. For now, though, consider that a motor running in one direction on alternating current is perhaps not so strange. The pistons in an automobile engine move up and down (that is, alternate), and yet they apply continuous one-way motion through the crankshaft to the wheels of the automobile. It's something like that with AC.
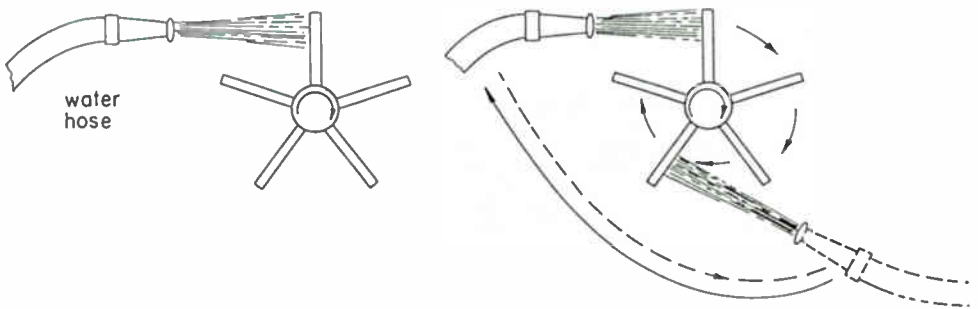
(a) Wheel spinning as water hits it represents direct current (current traveling only in one direction).

(b) Wheel also spinning if hose is moved back and forth, so that water is sprayed first one way and then the other, represents the action of alternating current. (The current reverses direction many times a second.)

Fig. 24 One way to think of the basic difference between direct and alternating current. Direct current travels always in the same direction in a circuit, whereas alternating current moves back and forth very rapidly.

15 ALTERNATING CURRENT . . . The electricity in your home, which lights the lights, plays the radio or TV, heats the iron, toasts the bread, and does a hundred other jobs, is almost sure to be alternating current—abbreviated a-c, ac, or AC.

Alternating current has two distinct advantages over direct current. It is easier to generate with simpler machinery, and it can be efficiently stepped up or stepped down in voltage, using a transformer. The fact that it can be stepped up to extremely high voltage makes it possible to transport AC over long distances with only minimum loss.

Figure 25 shows a transformer on a familiar pole such as may be near your home. This transformer steps down the AC voltage from several thousand volts to 240 or 230 volts AC, and to 120 or 115 volts AC for use in your home.

Figure 26 shows a substation transformer, which has two principal purposes. One is to step up the voltage about midway along a long run of high-tension (high-voltage) wires, to compensate for voltage loss along the way. The more common use, however, is to step *down* the voltage from a very high point (say 60,000 volts) to perhaps 4600 volts for neighborhood distribution.

Fig. 25 **This transformer reduces the power transmission voltage down to 115 and 230 volts for use in nearby homes.**
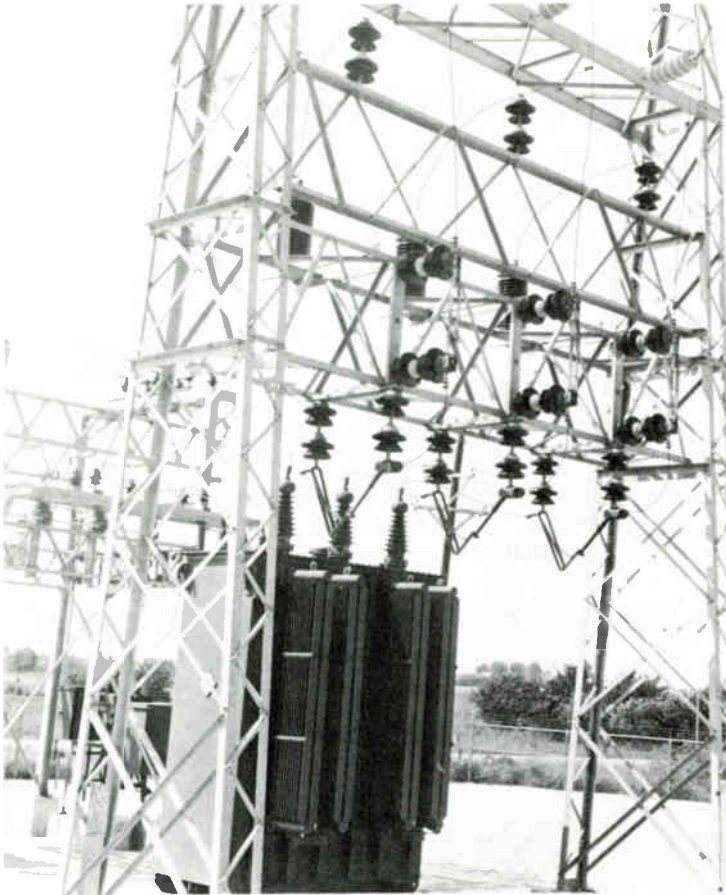
Fig. 26   A substation transformer. Note the many insulators used to support the connecting wires.

When the voltage is extremely high, it is difficult to work with. For one thing, the insulators must be long and heavy, like those shown in Fig. 15, to prevent them from sparking over and burning, especially during humid weather when the air has a high moisture content.

Because alternating current is continually moving (even though alternating in direction), it can easily be put to work while it moves. Light bulbs do not care which way the current goes through them. If you connected a light bulb to a battery as in Fig. 27(a) and then reversed the wires as in (b), you'd find the lamp lighting equally well with either direction of current. If you could reverse the wires many times a second, you would find that the lamp would appear to glow continuously, without flicker. Connecting a lamp to AC is equivalent to rapidly reversing the leads from a battery, so that the current flows through the lamp first in one direction and then in the other.
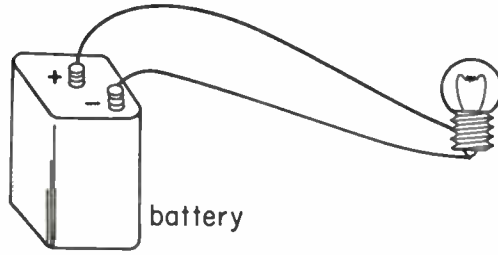
(a)
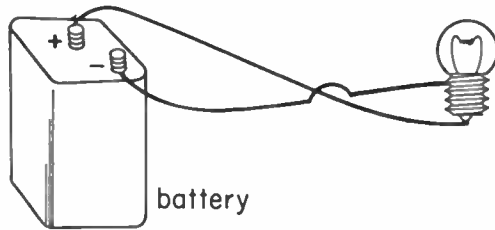
(b)

Fig. 27 **Lamp lights equally well regardless of which way the current flows through it.**

Direct-current motors won't operate on alternating current, and AC motors won't operate on DC. However, some motors have been developed for use in electric drills, vacuum cleaners, and the like that will operate on either type of current. These motors, called *universal motors* or *AC/DC motors*, are not made in sizes larger than about one-half horsepower, however, because of their cost.

You can see alternating current "in action" for yourself if you look through the blades of an electric fan toward a fluorescent light, and turn the fan off (see Fig. 28). You will see the blades appear to stop and reverse direction as they slow down. This is called the *stroboscopic effect*, and is the result of the fluorescent light actually turning off and on 120 times a second on 60-cycle current. Normally, your eyes can't detect this fast on-and-off change, but you can see the effect when it is compared with the changing speed of coasting fan blades.

fluorescent
light

electric
fan
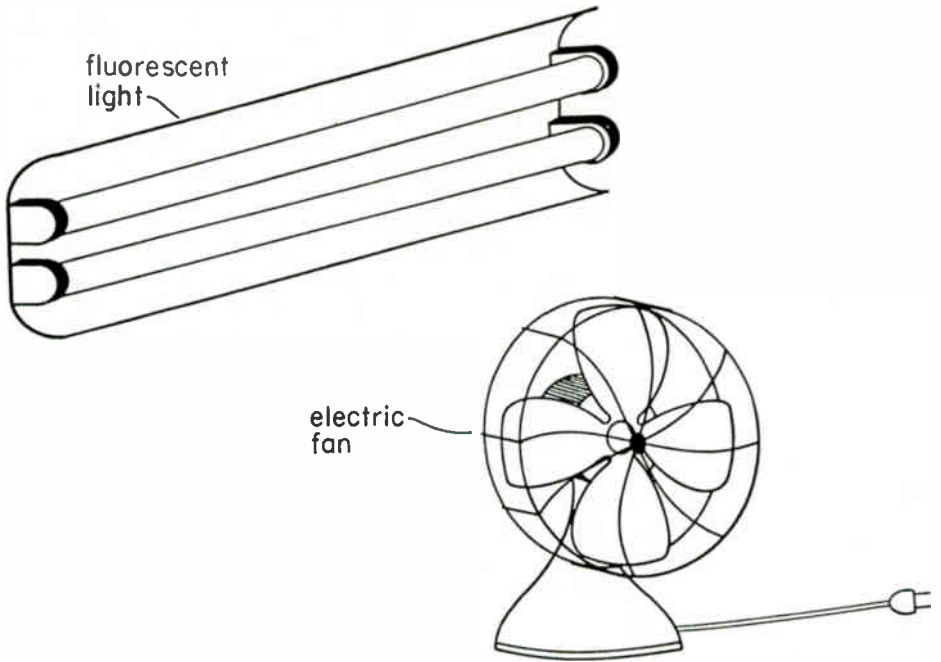
Fig. 28   Stroboscopic effect.

WHAT HAVE YOU LEARNED?

1. A device that will step up (increase) or step down (decrease) alternating current from one voltage to another very efficiently is called a _Transformer_

2. The purpose of a substation—also called a branch station—is to
   (1) drop the voltage down to such a point that it can be used in your home after it has been transported at much higher voltage.
   (2) generate alternating current.
   (3) change alternating current into direct current, so that it can be used in homes and shops.
   (4) either boost the voltage on a long electrical line or provide several circuits of lower voltage for distribution in a residential or business area.

3. High-tension lines might also be called high-_Voltage_ lines.

4. Any direct-current motor will operate normally on alternating current. _(True)_ _(False)_

5. A motor that will operate on either AC or DC is called a _universal_ motor, and is available only in _(small)_ _(large)_ sizes.

1. transformer . . . A transformer can be made above 98 per cent efficient. It can be used either to step up (increase) or step down (decrease) an AC voltage

2. (4) . . . A substation is used to boost the voltage and help compensate for voltage loss on long lines, but its more common use is to provide a lower but still rather high voltage for distribution within a town or city. For example, the high-tension lines bring in power to a city might have voltage in excess of 50,000 volts, which would require tall poles or towers and large insulators and would be extremely dangerous to work around. A substation may drop this voltage to around 10,000 volts for distribution around a town. Such a voltage is much easier to work with, and less apt to break down if it comes in contact with trees or develops a cracked insulator.

3. voltage

4. False . . . A DC motor will not work on AC, and an AC motor will not work on DC.

5. universal or AC/DC; small . . . Usually, not over one-half horsepower.

16 FREQUENCY—WHAT IS IT? . . . You have seen the inscription *Frequency: 60 Hz* on the nameplates of electrical appliances and equipment, and in catalog descriptions of electrical merchandise. The term *Hz* is an abbreviation for *hertz,* the internationally established unit for frequency. The expression 60 *hertz* or 60 *Hz* means a frequency of 60 cycles per second in all languages. The term *hertz* honors Heinrich Hertz, the German physicist who proved the existence of radio waves. (Hertz is properly pronounced HAIRtz but is commonly pronounced "hurts" in this country.)

In North America, the standard frequency of alternating current from the power line is 60 Hz—that is, 60 cycles per second. The alternating current starts at zero and builds up to maximum in one direction, and then recedes to zero. It then builds up to maximum in the opposite direction, and again recedes to zero. The current has at this point completed one *cycle*. If the frequency is 60 Hz, the current completes 60 cycles of switching back and forth in direction every second.

Outside of North America, 50 Hz is the most commonly used power-line frequency, particularly outside of the Western Hemisphere. If an appliance has a nameplate that says 50/60 Hz, it will operate equally well on either frequency.

It was only recently that the U.S. started using the international term for frequency. Therefore, the older term *cycles per second*, abbreviated *cps* and various other ways, is still widely encountered in textbooks, in literature, and on nameplates. However, this older terminology is dying out. We will use *hertz* throughout these lessons.

WHAT HAVE YOU LEARNED?

1. The term "frequency" refers to *(how high the voltage is)* *(how rapidly an AC current is changing direction)*.

2. The standard power-line frequency in the United States is __*60*__ cycles per second.

3. A phonograph designed to be used in Europe, where 50 cycles per second is standard, would run *(faster)* *(slower)* if used in the United States.

4. The accepted present-day term for cycles per second is __*Hertz*__, abbreviated __*Hz*__.

ANSWERS

1. how rapidly an AC current is changing direction.
2. 60 . . . Nowadays, we usually call this 60 Hz.
3. faster . . . The 60-cycle United States current would change direction ten more times each second than the European power, so the motor would speed up in proportion.
4. hertz; Hz . . . Note that the abbreviation is capitalized, but the full name is not.

LESSON 2330B-5
CONTROLLING CURRENT AND VOLTAGE

EXAMINATION

Each examination question is followed by a number of selections. Circle the number in front of the correct selection for each question. When you have finished, transfer your answers to the Answer Sheet provided. Then use the special envelope provided to mail the examination to the school as soon as it is completed.

1. Which of the following is a good conductor?
   (1) Plastic   (2) Copper   (3) Rubber   (4) Glass

2. What is the purpose of a conductor?
   (1) To provide a convenient mechanical means of turning an electric circuit off and on.
   (2) To prevent or greatly reduce the flow of current.
   (3) To carry electric current to and through an electronic or electrical device.

3. Which of the following will *not* carry electric current easily?
   (1) Glass   (2) Copper   (3) Salt water   (4) Silver

4. What is a good description of an *insulator*?
   (1) A material that will allow little or no current to flow
   (2) Almost any material made of metal
   (3) A material through which current flows easily

5. What is the reason for using a switch in an electric circuit?
   (1) To keep too much current from going through the circuit
   (2) To keep the fuses from blowing
   (3) To reduce the chance of a fire
   (4) To provide a convenient means of controlling current

6. Figure 29(a) is a *schematic* (wiring) diagram of a battery, switch, and lamp. Which of the following statements about it is true?
   (1) The switch is open, and the lamp is not lit.
   (2) The switch is closed, and the lamp is not lit.
   (3) The switch is open, and the lamp is lit.
   (4) The switch is closed, and the lamp is lit.

7. In Fig. 29(b), what is true of the switch and lamp? (Choose your answer from the choices given for Question 6.) ①
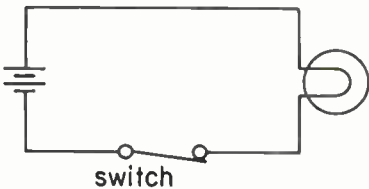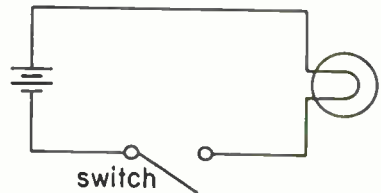
(a)   (b)

Fig. 29

8. Alternating current always travels
   (1) one way one instant, and another way the next.
   (2) in one direction.

9. Small motors that will run on either AC or DC are called
   (1) direct/alternating motors.
   (2) universal motors.
   (3) double-current motors.
   (4) all-current motors.

44   10. The standard frequency for alternating current from the power lines in the United States is

     (1) 60 Hz.   (3) 50 Hz.   (5) 440 Hz.
     (2) 45 Hz.   (4) 120 Hz.

END OF EXAM

Your spare time can mean money to you! That is why you should plan to use it efficiently. Set aside 5 to 10 hours each week for studying your CIE lessons. That is enough for good progress and you will still have time for recreation. Just cutting down a little on your TV watching may give you the necessary time.

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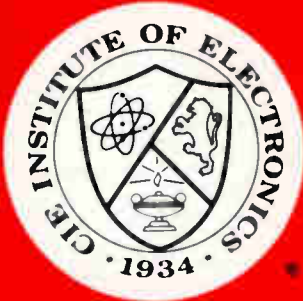
electronics

CLEVELAND INSTITUTE OF ELECTRONICS, INC. / CLEVELAND, OHIO
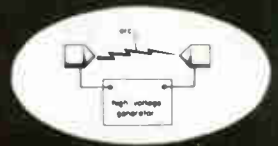
Lesson 2336A-7
Static Electricity

Lesson 2336B-7
Electric Currents and Semiconductor Devices

AUTO-PROGRAMMED® Lessons

ABOUT THE AUTHOR

Wayne Lemons has had almost forty years of practical experience in the electronics field. During World War II, he served in the U.S. Air Force as a loran and radar technician. After his discharge, in 1946, he went into radio and TV servicing. His success was such that, in 1958, he was one of ten men in the country to receive the coveted All-American Technician Award.

Mr. Lemons' experience includes many years of teaching electronics to high school students. He founded station KBFL, Missouri's first and most powerful public high school radio station. In addition, he has written seven books and more than 250 magazine articles on radio and TV servicing and other practical aspects of electronics.

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Lesson 2336A-7
Static Electricity

Lesson 2336B-7
Electric Currents and Semiconductor Devices

By WAYNE LEMONS
Technical Staff
Cleveland Institute of Electronics

Frontispiece: *A highly enlarged photograph of an NMOS microprocessor chip. IC chips such as these are easily damaged by static electricity and extra care must be taken in their handling.* Photo: Courtesy of National Semiconductor Corp.

HERE IS THE EASY WAY TO GET
THE MOST OUT OF THIS LESSON

Regular daily study is the first step on the road to more interesting work, security, better pay. For fastest progress on that path, follow the steps below. Check off each one as you complete it. Start this lesson TODAY.

YOUR STUDY SCHEDULE FOR *TODAY* . . .

☑ 1. Take two minutes to read "How to Study" on page 2. All finished? Then check the box to the left above.

☒ 2. Read "A Chat with Your Instructor" on page 4 to get a bird's-eye view of what you'll learn in this lesson. Again, check the box when you're finished.

☑ 3. Read Topics 1 and 2. There you'll learn that static electricity can be either positive or negative, and also that like kinds of electricity repel each other while unlike kinds attract each other.

☑ 4. Answer the "What Have You Learned?" questions on page 8. That way you'll make sure that you have the information—the laws of charges—straight. You'll also gain a broader understanding of charges, and of some of the practical uses made of them. As soon as you answer a question, check your answer against ours.

☑ 5. Continue in the same way—first carefully reading each topic, and then answering the "What Have You Learned?" questions. *Don't skip any of these questions.* Remember, reading alone isn't enough. It's the questions that put your mind to work, so that you both learn more and know how to put what you have learned to work on the job. Remember, if you want a better job than the other person, you must know more about electronics than he or she does. The "What Have You Learned?" questions will give you that extra lift above the rank-and-file technicians. You don't rate a check in the box for this step until you have answered every "What Have You Learned?" question in the lesson. So go on to the next step.

☒ 6. After you have studied for an hour or two (or until you get tired), stop for today—or at least take a good break. But don't put the book away until you read the next step and check the block. (You may or may not finish this lesson today.)

☑ 7. Never stop studying until you have set a definite time for your next study period. Write down here and now the time TOMORROW that you are setting aside for studying: *10 AM*

☑ 1. Take a few minutes to review—and to think about—what you learned yester-day. You'll find it a big help if—while reviewing—you write down some of the important points in a notebook. (Check the box when you're done with your review.)

☑ 2. Did you remember to set a time for your next study period before putting your text aside? If so, check the box. Success requires that you PLAN your study hours.

☑ 3. Did you remember to start each study session with a brief review of the lesson so far? If so, check the box.

NOW, THE EXAMINATION WILL BE EASY . . .

☑ 1. Now that you have studied the lesson, answer the Examination questions. Double-check your answers, referring back to the text when in doubt. Then, go on to the second lesson promptly. If you study regularly, you should complete the next lesson within a few days. Then you can send in the examinations for the two lessons together, and have this volume buttoned up.

☑ 2. Now start studying the next volume. Never wait for the return of the ex-aminations on one volume before starting the next volume.

ANY QUESTIONS? . . . Your instructor is standing by to help you. Write your questions on one of the *Request for Assistance* forms. (Page 3 tells you how to get the best results when asking for help.)

How to Study

Some tips for fast progress:

1. Don't try to study too long at one time: an hour or two is plenty. Work hard while you study the lesson material, but take a five-minute break every half hour or so.

2. Keep all your training materials together and handy—ready to go—including pencils, paper, envelopes and stamps. Get organized, so as to get the full benefit from your study time.

3. Plan *now* the best time and place to study . . . the days you will study . . . and how long. A plan that calls for one or two hours of study a day, five or six days a week, will usually give best results.

NEED HELP? HERE'S HOW TO GET IT.

To make it easy for you to get help, a supply of *Request for Assistance* forms has been supplied with your course material. The important thing to remember is that the more details you give your instructor, the better he can help you. Following is an example of a well-written query:

Dear Instructor:

I can't get the right answer to Problem 6 on page 8 of Lesson 2001. I believe the correct formula is $W = 1/2\ E^2C$, found on page 16 of Lesson 2001. *(Note that the student refers to the exact problem, and where it can be found in the lesson book.)* My work using this formula is shown below. What am I doing wrong? I notice that if I square the E, then multiply by the C, finally taking one-half of the product thus obtained, I get the correct answer. But it seems to me that if the formula was intended to be used in that manner, it would have been written $W = 1/2\ (E^2C)$.

Note that the student comments on the method of working the problem in order to get the correct answer, and also clearly states his thoughts on why the method shown in the lesson book may not be correct. (The student's work is shown on the query, but is not reproduced here.)

With all this information to work with, the instructor can see exactly what the problem is. He can then provide the correct information needed to clear up the problem. It's difficult for an instructor to give a student a specific answer for a question that is too general. Suppose, for example, that the question above was worded as follows: "I can't get the correct answer to Problem 6. Please explain how to work it." It would be very difficult for the instructor to understand exactly what kind of trouble the student was having. Remember, the more specific your question is, the more specific the instructor's answer will be.

By the way, please *don't make requests for technical assistance and nontechnical assistance on the same sheet.* Technical requests pertain to difficulties encountered in the lesson. Nontechnical requests pertain to the shipment of lesson material, payment of accounts, requests for employment service, and the like. Your technical requests are answered by your instructor, but nontechnical questions are answered by another department. If both requests are on the same sheet of paper, service is delayed. (Needlesss to say, a single sheet of paper can go to only one department at a time.)

If you are out of *Request for Assistance* forms, you can use a sheet of ordinary paper of approximately the same size. Please don't use small sheets or scraps of paper, which can easily get lost. Also, be sure to put your name, student number, and address on each sheet of paper you use.

A Chat with Your Instructor

Electricity can be either in motion, like the cars on a busy highway, or at rest, like cars parked for the night along a sleepy suburban street. In this lesson, you will learn about the uses you can make of electricity at rest. Parked cars are of use to us only in the sense that they are available to be put into motion when needed. Similarly, electricity can't do much for us as long as it is at rest. But it is of great value in electronics as a standby, ready to go into motion when needed. A device specifically designed to store electricity in a static condition until needed is called a *capacitor*. Electronic equipment uses many capacitors for this purpose. A capacitor is something like a parking lot filled with cars ready to go into action when wanted.

Almost any device—a glass rod, for example—will store a little electricity at rest, just as a few cars can be parked along the highway. Electricity at rest is often accumulated on objects by friction. It is then called *static electricity*. The electricity in a capacitor is exactly the same kind of electricity, even though we don't usually refer to it as static electricity.

After you understand the characteristics of static electricity, you'll learn how it's put into motion to form current electricity. Unless you know how to put it into motion and steer it to where you want it to go, electricity at rest is as useless to you as a car you don't know how to drive.

Lesson 2336A-6
Static Electricity

ELECTRIC CHARGES

The fundamental ingredients in the world of electronics are the positive and negative electric charges. One of the oldest and simplest ways of producing electric charge is by friction. Charges produced in this manner are called static electricity.

1 STATIC ELECTRICITY . . . We have all had experiences with static electricity. If you slide across a plastic car seat cover and then get shocked when you touch a metal part of the car, you're the victim of a static charge caused by friction. As another example, you may find that a comb, after you rub it through your hair, will attract tiny bits of paper or lint.

Any object that is holding electricity, such as the comb just mentioned, is said to be *charged*. Since the electricity on the comb is not moving, it is called *static electricity (static* means "stationary"). By comparison, electricity that is moving (such as the electricity flowing from a battery through a wire to light a lamp) is called *current electricity.*

The terms *static electricity* and *static charge* mean the same thing: generally, they refer to charges produced by friction, or by the action of other charged bodies. Static charges due to friction accumulate on nonconductors, or on conductors that are insulated from other conducting materials. Without something to stop conduction, we couldn't build up a charge by friction: the electricity would simply flow away as it was generated. Although this flowing electricity would be current electricity, it would be negligibly small. The rate of producing electricity by friction is so slow that it is only by having the electricity trapped—so that it builds up as the friction continues—that we can accumulate enough of it to be meaningful.

The *distribution* of the charge on a charged body is also of interest. The charge is always completely on the outer surface (see Fig. 1). Charges spread themselves
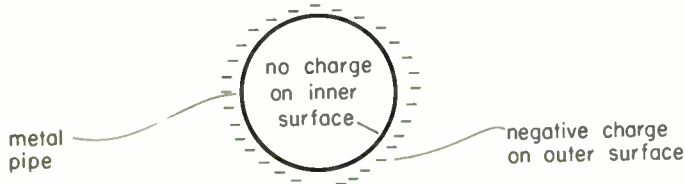
Fig. 1   The charge on a piece of metal is always on the outer surface. A pipe charged on the outer surface, as shown here, will have no charge on the inner surface.

6
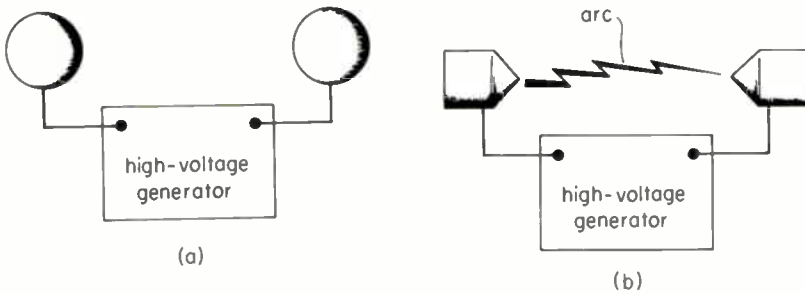
Fig. 2   Charges will move off into the surrounding air, or "arc" across, much more readily from one place to another if the charged objects have sharp corners as in (b).

evenly over smooth or rounded surfaces, but become highly concentrated at corner points or sharp edges (Fig. 2). The fact that arcing occurs much easier from sharp points means that the charge is more concentrated at those points. In Fig. 2, high-voltage generators are used to charge the bodies, but the effect is the same as if they had been charged by friction. If the bodies are charged by friction, we say they have a static charge. If the bodies are charged by connecting them to the high-voltage generators, we simply refer to the bodies as being charged. However, no matter which method is used to charge the bodies, the charge is exactly the same: Electricity is electricity.

When you are working with high voltages, never forget that charges are strongest around sharp points, as illustrated in Fig. 2. For example, when soldering on the high-voltage supply of a transmitter, you must be careful to do a smooth job. Soldering left projecting out into a point can cause arcing across to the nearby chassis. Also, trouble can result even though there is no actual arcing. Points of high-charge concentration will ionize the surrounding air. Ionized air is a conductor, so there will be a slow electrical discharge into the air from the high-charge concentration. This is called *corona discharge*. It is invisible in the light, but sometimes it can be seen in the dark as a bluish glow. Corona discharge wastes power and may be a source of radio interference also referred to as "static."

As another example, TV receivers use voltages on the picture tube that range from 8000 to 27,000 volts. Where the high-voltage wiring is near the chassis, as at the base of the damper diode, arcing over often occurs (and can frequently be heard). After making sure that there are no sharp points, you can spray the wiring with a plastic coating especially made for the purpose. The coating places a layer of insulation between the wire and the air. Since the air is no longer in direct contact with the wiring, it won't ionize so easily. Manufacturers frequently cover high-voltage points with plastic sleeves to prevent corona discharge and arcing over.

2 LIKE CHARGES REPEL; UNLIKE CHARGES ATTRACT . . . Experience shows that there are two distinct types of electric charge: *positive* (+) and *negative* (−). When two bodies charged with the same type of electricity are brought close together, they will repel each other. If one body is positively charged and the other negatively charged, the two bodies will attract each other. In short, *like charges repel and unlike charges attract,* as diagrammed in Fig. 3.

push away   pull together

push away   pull together
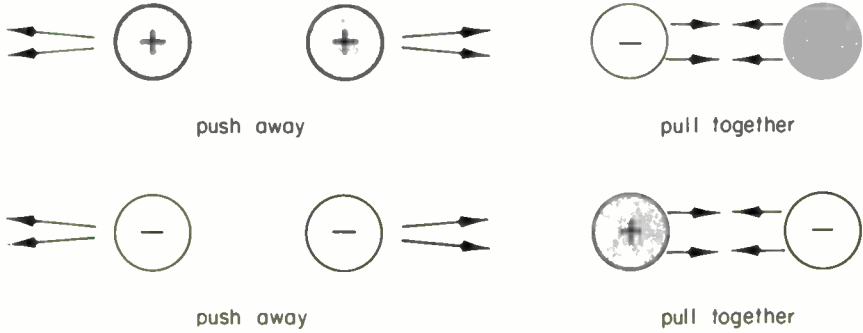
Fig. 3   Action of charged bodies on one another. Like charges push away (repel); unlike charges pull toward one another (attract).

WHAT HAVE YOU LEARNED?

1. When a glass rod is rubbed with silk, the rod becomes positively charged. When two glass rods that have been rubbed with silk are brought close together, as shown in Fig. 4(a), they *(attract)* *(repel)* each other. That is because both rods are *(positively)* *(negatively)* charged, and therefore have *(like)* *(unlike)* charges. Like charges ____repel____ each other.

glass
glass

ebonite
ebonite
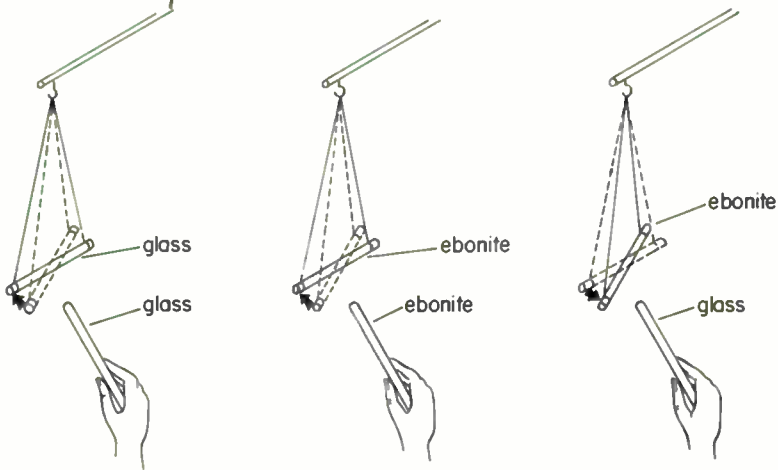
ebonite
glass

(a) Like charges   (b) Like charges   (c) Unlike charges

Fig. 4   Interaction of charged bodies.

8

2. When an ebonite rod is rubbed with fur, it becomes negatively charged. When two ebonite rods that have been rubbed with fur are brought close together, as shown in Fig. 4(b), they _repel_ each other. That is because _Like_ . charges repel each other.

3. When a charged ebonite rod and a charged glass rod are brought close together, as shown in Fig. 4(c), they _Attract_ each other. That is because the rods have *(like)* *(unlike)* charges, and such charges _Attract_ each other.

4. Take a rubber comb and rub it on a sheet of paper. You will find that the comb now attracts the paper. This shows that the comb and paper have assumed electric charges. We know that these charges are _unLike_, because they attract each other.

5. The hair of some people often stands on end after being combed on a very dry day. Why? _Static electricity - Like charges each hair_

6. A capacitor is a device specifically designed to store relatively large electric charges. When a capacitor is charged, one plate has a negative charge and the other plate has a positive charge. The plates *(attract)* *(repel)* each other.

7. One type of air cleaner passes the dust-laden air between two plates, one of which is charged negatively and the other positively. Particles of dust in the air that are positively charged will be pulled over onto the _Negative_ plate, and oppositely charged particles of dust will be pulled to the other plate.

ANSWERS

1. repel; positively; like; repel   2. repel; like
3. attract; unlike; attract   4. unlike
5. The combing puts a like charge on every strand of hair. The strands of hair thus repel each other and separate from each other as far as possible.
6. attract   7. negative . . . This is just another example of unlike charges attracting one another. This kind of an air cleaner is often used inside large industrial smokestacks to prevent smoke particles from entering the atmosphere. The process is called *electrostatic cleaning.*

3 WHAT ARE ELECTRIC CHARGES MADE OF? . . . Suppose that the glass
or ebonite rods used to demonstrate the presence of charges in Fig. 4 had not
been rubbed with silk or fur. In other words, suppose that they have no charge,
and therefore will neither repel nor attract one another, as shown in Fig. 5. Why
is that true? How does the act of rubbing the rods with silk or fur, put an electric
charge on them? To answer this, let's leave the rods for the moment and take a
quick look at the structure of matter.
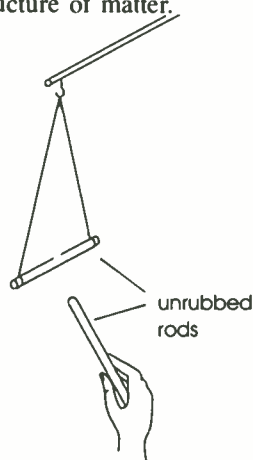
unrubbed
rods

Fig. 5   Unrubbed glass or ebonite rods neither repel nor attract each other.

As you probably know, everything in the world is made up of minute particles
that are so small they cannot be seen, even with the most powerful optical
microscope. These particles are called *molecules.* Each molecule, in turn, is made
up of several still smaller particles called *atoms.* From the electronics point of
view, however, it's not the molecules or atoms that are interesting, but rather cer-
tain parts of the atom. In particular, our interest is aroused by three atomic par-
ticles called *electrons, protons,* and *ions*—because each of these three particles
contains an electric charge!

An electron is the smallest common particle of matter in terms of mass (weight).
A proton is a particle with a mass about 1800 times that of an electron. An ion,
finally, is made up of electrons and protons in unequal numbers. It therefore has
greater mass than either an electron or a proton.

The kind of charge carried by an electron is called a *negative charge,* and is in-
dicated by the minus sign (−). A proton will be attracted to an electron, which
tells us that the two particles have unlike charges. The charge on the proton is
therefore called a *positive charge,* to distinguish it from charges of the type found
on electrons. (An ion may have either a positive or a negative charge.)
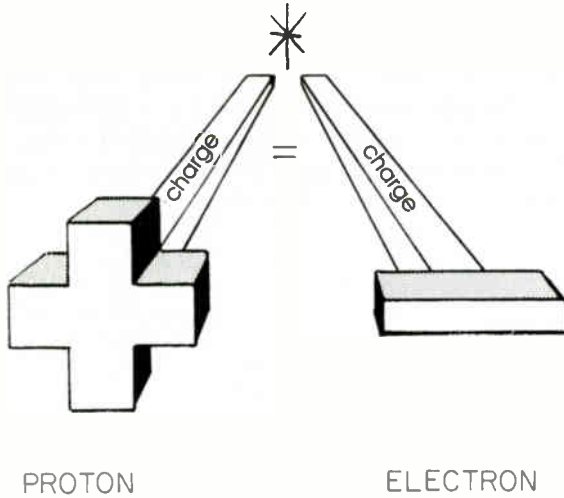
PROTON   ELECTRON

Fig. 6   Despite the difference in mass, the proton and the electron carry charges of similar intensity.

The charge carried by a proton is exactly equal in intensity to the charge carried by an electron (see Fig. 6): that is, two electrons will repel each other with a force equal to the force of repulsion between two protons. Also, the force of attraction between an electron and a proton is exactly equal to the force of repulsion between two electrons or between two protons. Normally, an atom contains an equal number of electrons and protons. If that is the case, the unlike charges of these two bodies, being of equal intensity, act to cancel each other. Thus, a normal atom is said to be electrically *neutral*—that is, it contains no net charge. This is illustrated in Fig. 7
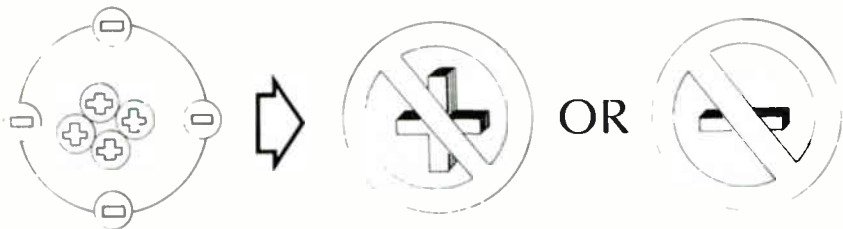
Fig. 7   An atom with equal number of electrons and protons has no positive or negative charge, and is electrically neutral.

Sometimes, though, electrons break away from their "parent" atom and move to a neighboring atom. As a result, the ratio of protons to electrons is no longer even. An atom that has an excess of electrons is called a *negative ion*, while an atom or group of atoms that has a deficiency of electrons is called a *positive ion*. See Fig. 8.

(a) **Negative ion (more electrons than protons)**   (b) **Positive ion (fewer electrons than protons)**

Fig. 8   Ions

It should be noted at this point that when any object contains a surplus of electrons, it is said to be *negatively charged*, and that when any object has a deficiency of electrons, it is said to be *positively charged*. An electric charge, then, is an invisible force that is created by either an excess or a deficiency of electrons. When there is a deficiency of electrons, the charge is *positive;* when there is an excess of electrons, the charge is *negative.* Charges behave according to the laws of attraction and repulsion: like charges repel; unlike charges attract.

Like charges repel
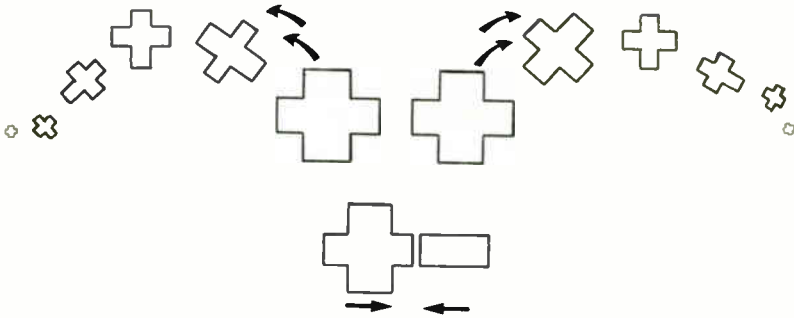
Unlike charges attract

Fig. 9   The laws of attraction and repulsion.

To help you remember the action taking place between like and unlike charges, consider Fig. 9. Can you see now why friction will sometimes build up a charge? When a glass rod is rubbed with silk, some of the free electrons on the glass are pulled over onto the silk. The rod becomes positively charged as a result, because it has lost electrons. Similarly, the cloth becomes negatively charged, because it has gained electrons.

4 THE POWER OF AN ELECTRON . . . The laws of attraction and repulsion apply in all cases of electrification and in all electric circuits. The force of attraction between protons and electrons is enormous. The force of repulsion between one electron and another is equally great. It's been said that if you had electrons only in two groups the size of small marbles and placed two feet apart, the repelling force between the two groups would be something like 90 trillion tons. See Fig. 10. (Of course, no one explains how you would capture a group of free electrons of that size and hold them together!)

←—two feet—→
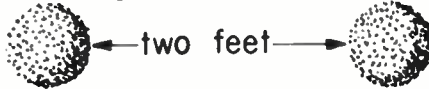
Fig. 10   Two concentrated groups of electrons the size of marbles and 2 feet apart would have a repelling force of about 90 trillion tons!

WHAT HAVE YOU LEARNED?

1. The smallest common particle of matter is the _Electron_, which carries a _negative_ charge.

2. A particle that always carries a positive charge equal in intensity to the negative charge of an electron is known as a _proton_.

3. An ion is an atom or group of atoms that has either an excess or a deficiency of electrons. If the atom has an excess of electrons, it's known as a _negative_ ion. If it has a deficiency of electrons, it's known as a _positive_ ion.

4. The law of attraction tells us that _unlike_ charges attract. Thus, an electron and a _proton_ will attract each other.

5. The law of repulsion tells us that _like_ charges repel. Thus, two electrons will _repel_ each other.

6. A substance with a deficiency of electrons will show a _positive_ charge.

7. Any substance containing an equal number of electrons and protons is said to be electrically _neutral_.

8. Chemical action within a battery places a negative charge on the negative terminal and a positive charge on the other terminal. A copper wire has many electrons that are free to move along the wire. If a length of copper wire is connected between the terminals of a battery, the positively charged terminal will _attract_ the electrons within the wire, while at the same time the negative charge at the other terminal will _repel_ these electrons. As a result, the mobile electrons within the wire move along the wire from the _Negative_ terminal of the battery to the other terminal.

path of electrons

electron gun

A

B
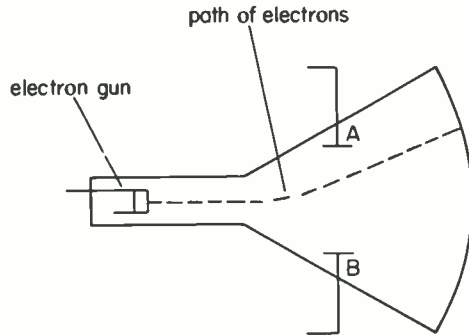
Fig. 11

9. In a cathode-ray tube (your TV picture tube, for example), a stream of electrons is shot from an electron gun as shown by the dashed lines in Fig. 11. Plates *A* and *B* are oppositely charged, so that one attracts and the other repels the electron beam, thereby bending it toward plate *A* as shown. In Fig. 11, then, plate *A* is _positively_ charged, and plate *B* is _negatively_ charged.

ANSWERS

1. electron; negative   2. proton   3. negative; positive
4. unlike; proton   5. like; repel   6. positive
7. neutral   8. attract; repel; negative
9. positively; negatively

5 STATIC ELECTRICITY AS A NUISANCE . . . Oddly enough, we are more concerned with static electricity because of the serious trouble it sometimes causes than because of any practical use that can be made of it. The biggest display of static electricity, for example, occurs during the common thunderstorm. During a thunderstorm, the small water droplets that make up clouds become electrically charged (because of friction caused by their violent agitation). As these droplets collect into large clouds, their total collective charge becomes great enough for an arc—the lightning—to occur between oppositely charged clouds, or between clouds and the earth. And, as we know, lightning that reaches the earth can be a destroyer and a killer.

Static electricity can also be quite a problem in industry. Explosions have been caused in vapor-laden atmosphere by sparks that resulted from static charges generated by leather or rubber belts rubbing against their drive pulleys. That chain you see dangling from the rear of a gasoline truck is used to discharge any static charge built up in the tank by the friction of the gasoline sloshing around in the tank.

One way to prevent trouble from static electricity is to take steps to prevent static electricity from being generated. Another way is to conduct it to ground as it builds up. The paper-stacking mechanism in Fig. 12 uses both methods. (Printers are constantly harrassed by static electricity, which causes the paper to stick together

paper

Paper moves across foil tinsel, which removes static build-up.

tinsel

part of printing press that stacks paper
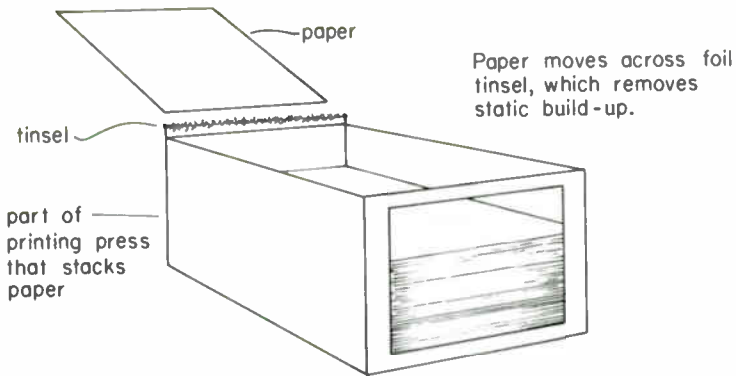
Fig. 12 **Combatting static electricity in the printing trade.**

and to the press.) The conducting tinsel in Fig. 12 is grounded, so it drains away static charges already on the paper. The tinsel also holds the incoming sheet up above the stack below, so that sliding friction—which would build up more static electricity—is avoided.

6 PRACTICAL APPLICATIONS OF STATIC ELECTRICITY . . . Static electricity is not all bad. Many modern-day office copying machines, for example, use static electricity to draw ink or charged particles onto paper to reproduce a letter or other document. Also, as previously mentioned, electrostatic cleaners remove dust and other particles from the air by passing the dust-laden air through a strong electric field that ionizes the air and places a negative charge on the dust particles. The negatively charged dust is then collected on a plate or screen with a positive charge.

In addition, some factories use static electricity in applying paint. A highly positive charge is placed on the part to be painted, and a negative charge (which is grounded for safety) is placed on the paint sprayer. Since the spray mist leaving the sprayer has a negative charge, almost all of it is attracted to the part to be painted. Not only is the coat of paint even, but practically none of the paint is wasted. Electrostatic painting is especially useful for painting a fence, car, or other object that has a lot of open spaces (see Fig. 13). Also, it can be used to paint metal parts that are attached to plastic parts that must not be painted. (The plastic parts may need to move back and forth in normal operation, and paint would cause them to stick.) If the plastic parts can't easily be removed during the painting process, an electrostatic spray can be used to coat the metal but not the plastic.

A SPRAY PAINTING ROBOT
HAS A NEGATIVE CHARGE

CAR BODY HAS A POSITIVE
CHARGE
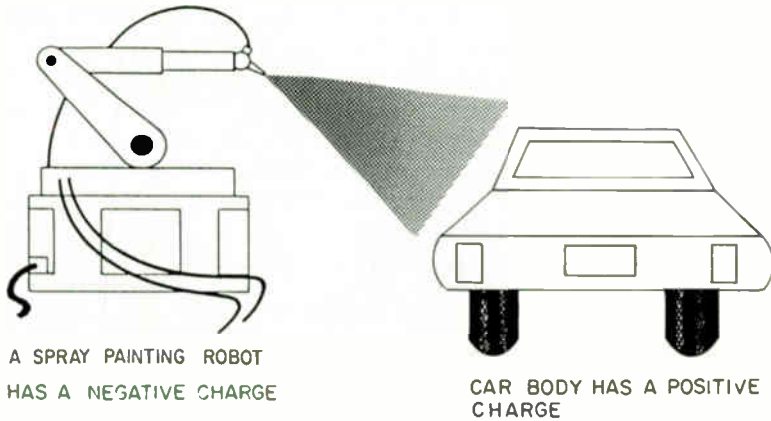
Fig. 13   Putting static electricity to good use.

Often, a number of items are spray-painted at one time by placing them around the outer edge of a plastic cage that has a paint-spray nozzle spinning around in the center. All the metal parts that are to be painted are connected to a positive charge, while the center nozzle is connected to a negative charge. The parts can be completely painted without ever clouding the plastic cage with paint, since all the paint is drawn to the metal parts (Fig. 14).

spinning
paint
nozzle

plastic cage

metal parts
to be painted

line connecting all
metal parts to positive (+)
charge
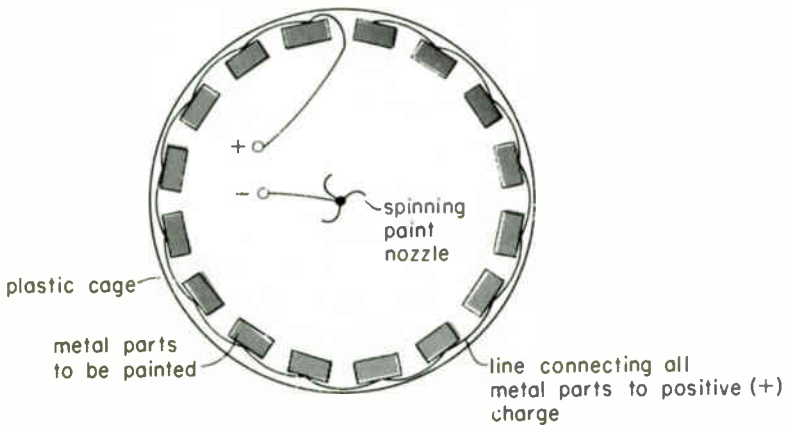
Fig. 14   One method of spray-painting a number of parts using charged paint particles that are attracted to the parts to be painted.

16   Static electricity, which causes sheets of paper to stick together, can be used to hold two parts together for certain kinds of processing, such as duplication. You can get an idea of the pulling effect of an electric charge by placing the back of your hand near the front of a large-screen TV set. (The effect is much more noticeable if the picture tube doesn't have the protective glass or plastic shield in front of it, as when the picture tube and chassis have been removed from the cabinet.) A large-screen TV has about 17,000 to 27,000 volts (positive charge) connected to the second anode near the faceplate—enough of a charge to cause the hair on the back of your hand to stand up.

<div align="center">

LESSON 2336A-6
STATIC ELECTRICITY

EXAMINATION

</div>

Each examination question is followed by a number of selections. Circle the number in front of the correct selection for each question. When you have finished, transfer your answers to the Answer Sheet provided.

1. The smallest common particle of matter is the
   (1) electron.   (2) proton.   (3) ion.   (④) atom.

2. Figure 15 shows a cross-sectional view of a charged aluminum tube. You would expect the charge to be
   (1) more concentrated at point C.
   (2) more concentrated at point B.
   (③) more concentrated at point A.
   (4) about equal at all three points.

point A   point C   point B

Fig. 15   cutaway view
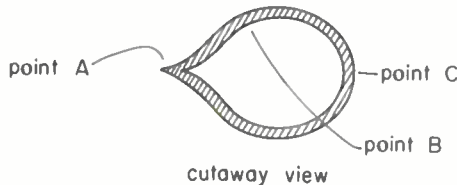
3. In Fig. 15, the static charge at point B (which is on the inside surface) would be
   (①) about the same as point C.   (3) more than at points A or C.
   (2) zero.   (4) about half the amount at point A.

thread

support   support
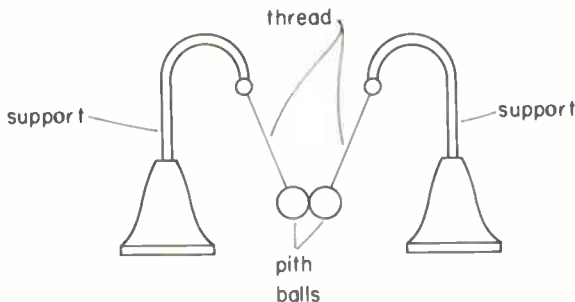
Fig. 16   pith balls

4. In Fig. 16, the pith balls suspended from the two supports by thread
   (1) both have negative charges.
   (2) are one positive and the other negative.
   (3) are both neutral.
   (4) both have positive charges.

5. An electron
   (1) may have either a positive or a negative charge.
   (2) has a negative charge.
   (3) has a positive charge.
   (4) is the same thing as an ion.
   (5) is the same thing as a proton.
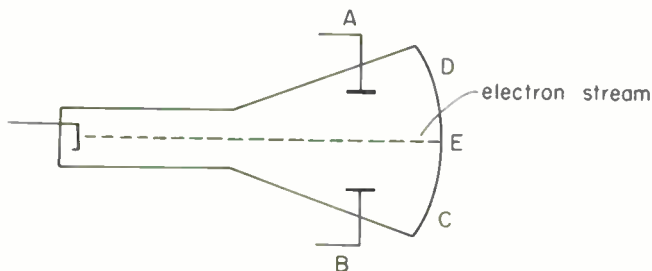
Fig. 17

6. In Fig. 17, if a negative charge is placed on plate A and a positive charge is placed on plate B, the electron stream
   (1) will deflect toward point D.
   (2) will deflect toward point C.
   (3) will continue to travel straight to point E.

7. Two identical combs are charged by combing your hair. If one is suspended in the center by a fine thread, and the other is brought close to it, they will
   (1) be attracted to each other.
   (2) repel each other.
   (3) neither attract nor repel each other.

8. CIE uses a letter-copying machine in which the blank paper on which the copy is to be made is given positively charged areas that conform with the black areas on the letter being copied. Powdered dry ink, which is also charged, is attracted to the charged areas and permanently bonded there by heat. What type of charge is given to the powdered ink?
   (1) Negative
   (2) Positive
   (3) Either positive or negative is satisfactory

9. Any object that is holding electricity is said to be
   (1) equal.   (2) neutral.   (3) charged.

10. An electron, as compared with a proton,
    (1) has the same weight.
    (2) has the same amount of charge (both are negative).
    (3) has the same amount of charge (both are positive).
    (4) has an equal but opposite charge.

END OF EXAM

Lesson 2336B-6
Electric Currents
and Semiconductor
Devices

ELECTRIC CURRENTS

7 CHARGE MOVEMENT THROUGH A CONDUCTOR . . . The movement or flow of electricity (charge) from one point to another is called an *electric current*. Moving a charge from one point to another by means of a conducting wire is similar to moving water from one point to another by means of a pipe. In Fig. 18(a), water is shown moving from tank *A* to tank *B* by means of the connecting pipe. In Fig. 18(c), similarly, the electricity moves from one charged body to the other by means of the connecting wire. Neither the water nor the electricity will move, however, unless some pushing or pulling action causes the movement. Gravity provides the force in Fig. 18(a); the attraction between opposite charges and the repulsion between like charges provide the force in Fig. 18(c).

The negative charge on the left-hand body in Fig. 18(c) is due to the fact that there are more electrons than protons in that body. Electrons, being extremely light in weight, tend to be mobile. Some of them, called *free electrons,* readily move around in certain materials, particularly metals. When a metal wire is connected between two charged bodies, then, as shown in Fig. 18(c), the free electrons—being negatively charged—are repelled into the connecting wire by the negative charge on the left-hand body. At the same time, these free electrons are attracted by the positive charge on the right-hand body. As a result, free electrons move through the connecting wire from the left body to the right body, and this constitutes a current.

(a)Excess water in tank A flows to tank B by gravity

(b)Flow stops when water levels are equal or "neutralized"

Θ = excess electrons

⊕ = excess protons
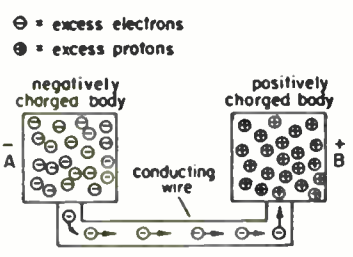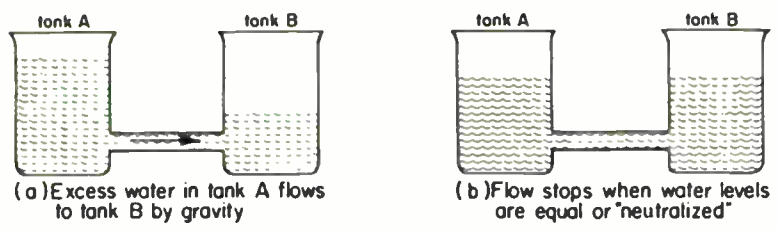
(c)Excess electrons are repelled from negative body and attracted to positive body through conductive wire
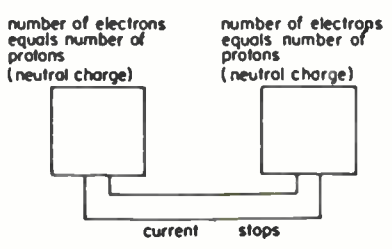
(d)Charge movement stops when bodies become neutralized

Fig. 18   The movement of charge (or flow of current).

The flow of water from tank *A* to tank *B* stops, as shown in Fig. 18(b), when the levels become equal, or "neutralized." By the same token, the movement of charge stops, as shown in Fig. 18(d), when the body on the left loses its excess electrons and the body on the right gains enough electrons that it no longer has an excess of protons. When both bodies are neutralized (that is, uncharged), there is no longer any force, of either attraction or repulsion, to cause a movement of electrons along the wire.

WHAT HAVE YOU LEARNED?

1. In an electrical conductor, some electrons are held in place while others are _____*free*_____ to move about. These moving electrons are therefore called _____*Free*_____ electrons.

2. Would a flow of positive ions constitute an electric current? Why or why not?

yes —current flowing
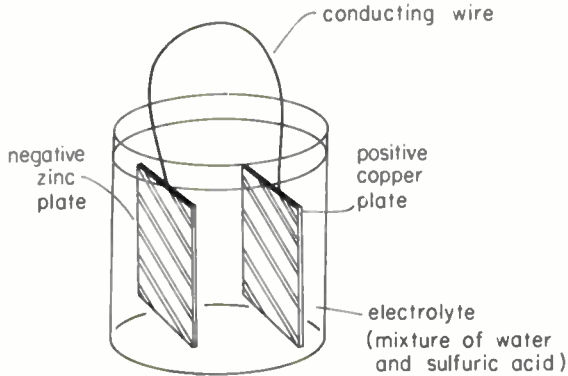
Fig. 19   Simple battery

3. You can make a simple battery by submerging a zinc plate and a copper plate into an acid solution, as shown in Fig. 19. Current will flow through the conducting wire between the two plates. In order to have a current, there must be two oppositely charged bodies with a conducting path between them. Since current flows through the conducting wire in Fig. 19, the battery plates must be *(uncharged)* *(charged with the same polarity)* *(charged with opposite polarity)*.

4. The action of the acid solution in Fig. 19 keeps the zinc plate continuously negatively charged and the copper plate continuously positively charged. Free electrons will therefore be repelled through the connecting wire from the ___neg.___ plate, and attracted to the ___positive___ plate. Therefore, the direction of electron flow through the connecting wire is from the ___Neg.___ plate to the other plate.

ANSWERS

1. free; free   2. Yes . . . A current results from the movement of an electric charge. Since ions carry charges, their movement forms a current. Although moving electrons are by far the most common form of current, current flow through many liquids consists mostly of moving positively and negatively charged ions.
3. charged with opposite polarity
4. negative; positive; negative

8 PRODUCTION OF A CONTINUOUS CURRENT . . . In the circuit of Fig. 18(c), current would last only a fraction of a second or so after the wire was connected between the two charged objects. As soon as the excess electrons were drained from the negatively charged body, both bodies would lose their charge and current would cease to flow.
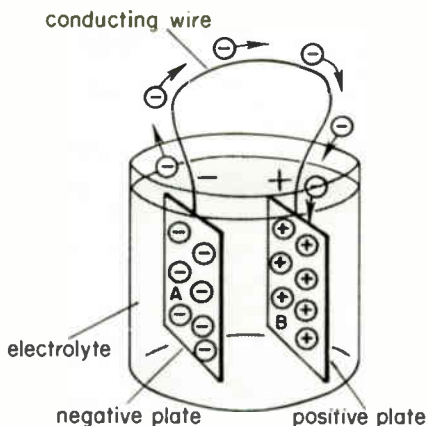
Fig. 20   An electron pump keeps charges on the bodies so that there is a continuous flow of current. (A battery is an example of an electron pump.)

In order to produce a continuous current, then, it is necessary to have some way to maintain opposite charges on the two plates *after* a wire is connected between them. The charges can be maintained by some kind of electron pump—a battery, for example. The simple battery of Fig. 20 consists of two plates, one positively and one negatively charged, that are immersed in a chemically active liquid. Battery plates *A* and *B* correspond to charged bodies *A* and *B* in Fig. 18(c). The function of the electrolyte is to keep plate *A* continuously negatively charged, by constantly pumping onto it additional electrons to replace those flowing off through the conducting wire that forms the battery circuit. Similarly, the electrolyte keeps plate *B* positively charged by removing electrons from it as fast as they arrive through the conducting wire. Because of the pumping action of the electrolyte, the plates don't lose their charge even though there is a steady electron flow through the conducting wire. The battery is *discharged* when it has been supplying current so long that it is no longer possible for the battery to maintain charges on the plates.

WHAT HAVE YOU LEARNED?

1. The action of the electrolyte in a battery is to keep pumping electrons onto the ___negative___ plate and pumping them off the ___positive___ plate. The battery is a pump. It must exert force in order to do this pumping, because the electrons are *(attracted)* *(repelled)* by the plate onto which they are being pumped, and therefore want to move in the opposite direction.

1. negative; positive; repelled

9 WHAT AN ELECTRIC CURRENT IS . . . The term "electric current" refers to the process of transferring electric energy from one point to another. Usually, this process is carried out by the movement of positively or negatively charged particles, such as electrons and ions. By far the most common process is the movement of free electrons. That is the way in which electric energy is transferred through all ordinary metallic conductors, for example.

The current through many liquids is caused by both positive and negative ions moving simultaneously in opposite directions. Current in certain parts of a transistor is by means of positive charges called *holes*. (You will see in a later lesson that alternating current flows through a capacitor, although in some cases there is no movement of charged particles within the space between the plates of the capacitor.)

So, as you can see, an electric current can result from a number of different types of action. Many years ago, electric current was defined as electron flow, but that definition is too restricted for the modern world of electronics.

10 CURRENT DIRECTION . . . *Current direction* does not refer to the direction in which electric charges move. Instead, current direction is nothing more than an agreed-upon direction for tracing around a circuit, and a reference direction for the purpose of stating electrical laws. Let's see what that means.
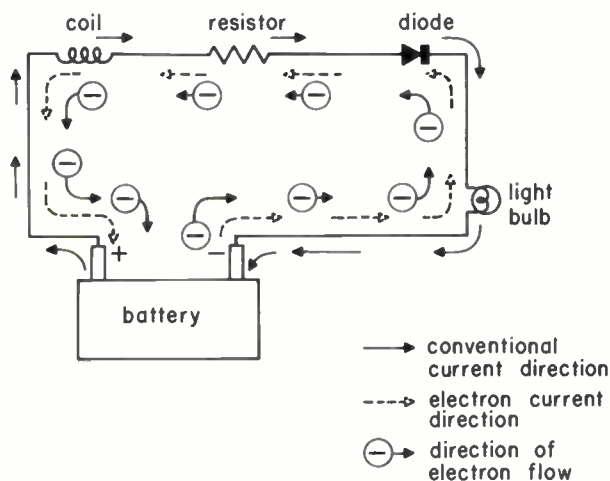
Fig. 21   **Electron flow direction and current direction. The conventional current direction, used by engineers, is opposite to the direction of electron flow.**

Consider the circuit of Fig. 21. One way to trace around such a circuit is to start at the positive terminal of the battery, and follow around until you come back to the negative terminal, as shown by the solid arrows. Engineers who trace in that direction (that is, from positive to negative) are said to use *conventional current direction.*

The alternate way to trace around a circuit is to start at the negative battery terminal and trace around to the positive terminal, as shown by the dashed arrows in Fig. 21. This tracing direction is called the *electron current direction.* It is so named from the fact that it is also the direction in which the free electrons that carry the charges move in the circuit.

Unfortunately, not everybody in electronics can agree on which direction to use as the current direction. Practically all engineers, engineering colleges, and engineering textbooks use the conventional current direction. But military schools, technical institutes, and technicians generally use the electron current direction, since beginners are less confused if they trace around a circuit in the same way as the electrons go.

(a) Direction of electron current   (b) Conventional direction of current
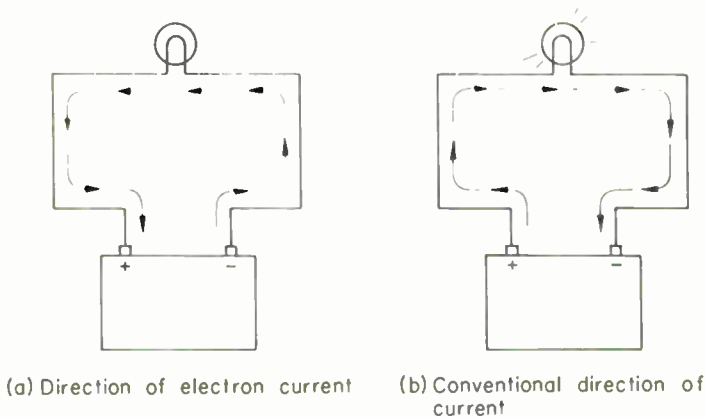
Fig. 22   The direction of current really makes no difference, since the flow of charges does its work—such as lighting the lamp—regardless of which way we say the current flows. It's important, however, to settle on one way or another for convenience in tracing through circuits. In this course, we use the "electron flow" direction—negative to positive—because we feel it is less confusing for the student.

Professors in engineering colleges consider it mathematically more convenient to use conventional direction, since it is hard to equate "negative" with an excess of anything and "positive" with a lack of anything. We feel, as we show in Fig. 22, that it isn't too important which definition of current direction we use. However, *we always use the electron current direction in this course,* since it is less confusing for students. At the same time, you must also know about the conventional direction since you will frequently have to talk with engineers and consult technical literature in which the conventional direction is used.

1. The conventional theory of current direction says that current travels from *(positive to negative)* *(negative to positive)*.

2. Electron flow is from *(positive to negative)* *(negative to positive)*.

3. This course uses the *(conventional)* *(electron)* direction of current, since we feel it is less confusing for beginning students.

4. Some schools use the conventional direction of flow, for *(mathematical)* *(technical)* reasons.

ANSWERS

1. positive to negative   2. negative to positive
3. electron . . . This way, you can start in a circuit at the source of the electrons (which becomes very important in the study of picture tubes, oscilloscope tubes, and so on) and trace through the circuit following the same direction and path that the electrons take.
4. mathematical . . . If you hear of something that is +2, you immediately feel that is is *more* than −2. When you use the conventional method of current, you can consider that a +2 *is* more than a −2. But in reality, a −2, *from the electron standpoint,* is greater by 4 points than a +2, since a negative charge represents an *excess* of electrons and a positive charge represents a *shortage* of electrons.

SEMICONDUCTOR DEVICES

There is no principle in electronics more basic—and more important—than the one that states that like charges repel and unlike charges attract. All of the devices discussed in this lesson operate on that principle.

11 MORE ABOUT ELECTRONS . . . All through your study of electronics, you are going to be talking about and working with something that no one has ever seen—the electron. True, you can see and feel the *effects* of the electron, just as you can see and feel the effects of the air, but even with extreme magnification man has not been able to see an electron—or air either, for that matter!

At the time of Michael Faraday's study of electrolysis in the early 1800s, scientists suspected that there might be particles that were even smaller than the atom. But it was not until 1897 that Sir Joseph J. Thomson announced that he had discovered the electron. The discovery hinged on many previous experiments with electric discharges in a vacuum. These electric discharges set off inside a glass envelope caused a glow in the small amount of gas left inside the envelope. The experiments had proved that the glow was caused when the particles moved from the negative (−) side (called the *cathode*) to the positive (+) side (called the *anode*). These moving particles were consequently called *cathode rays*.
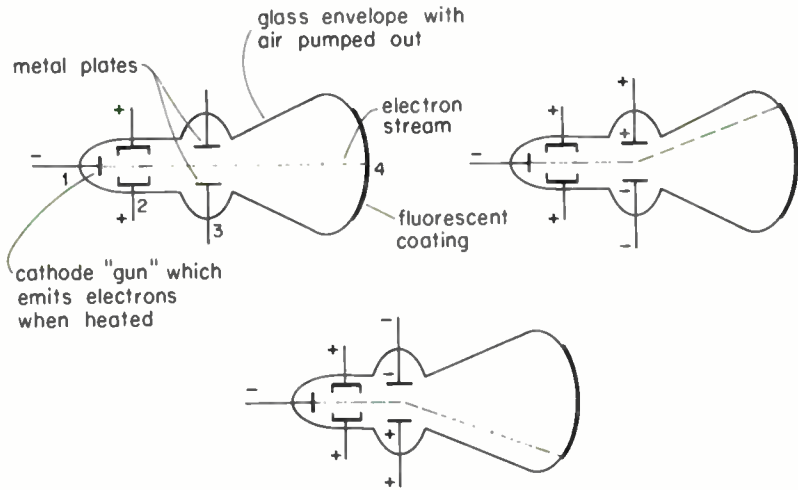
Fig. 23 **Simplified version of the equipment used to display a flow of electrons. By placing a high voltage between the cathode (1) and the sleeve (2), electrons are pulled toward the positive voltage on the sleeve, but pass through a hole in the sleeve and are carried by their momentum to the flourescent screen (4), causing a glow. Placing voltages on the deflection plates (3) causes the beam to move toward the positive plate, indicating that the stream inside is negative.**

Figure 23 shows a device similar to the one used by Thomson to prove the existence of the electron. Note the similarity of the device to a small present-day TV picture tube. (A common abbreviation used by engineers and technicians for a TV picture tube is *CRT*, which means *cathode-ray tube*.) Thomson's device showed that the electric discharge inside the glass envelope could be moved or deflected by placing a voltage charge across the metal plates inside the tube, and on either side of the discharge path.

Because a positive charge attracted the cathode ray, or electron stream, it was evident that the electrons were negative charges. By mathematical analysis and by the balancing of charges, Thomson proved that the charges were indeed electrons, and not atoms or ions. The electron is so small that it has been calculated it would take three billion billion billion (3×10^{27}) of them to weigh one ounce!

Some electrons in certain materials are not bound to their atoms, and thus are free to move about. They are called *free electrons,* and it is these free electrons that permit electric charges to flow. All materials have a few free electrons, but certain materials—mostly metals—have enough of them to permit easy passage of electric charges. If electric charges can flow easily through a material, we say that the material is a *conductor.* If electric charges cannot easily flow through a material, we call the material a *nonconductor,* or *insulator.*

26   A third type of material concerns us most in modern electronics, however: the *semiconductor*. As the name implies, the material is about a "halfway" conductor— that is, it can't be considered an excellent conductor, but neither can it be considered a good insulator. All transistors are made from such semiconductor material, and as a result are often called *semiconductors* or *solid-state devices*. The advantage of semiconductor material is that the number of charge carriers inside it can be controlled during manufacture.

WHAT HAVE YOU LEARNED?

1. The electron is *(larger)* *(smaller)* than an atom.

2. An electron is a *(positive)* *(negative)* charge.

3. A TV picture tube is sometimes referred to as a *CRT.* What do the initials *CRT* stand for?   *Cathode - ray Tube*

4. The electrons that move electric charges through a material are called _____ *Free* electrons.

5. A material that will pass electric charges easily is called a *Conductor*.

6. The two names used for a material that will not pass electric charges easily are *insulator* and *non-conductors*

7. A material that is neither a good conductor nor a good insulator is called a *Semiconductor*

ANSWERS

1. smaller . . . Atoms are made up of electrons, protons, and neutrons
2. negative . . . This was proved by Thomson's experiment, and confirmed by all subsequent experiments. A positive charge attracts and electron beam, and—since unlike charges always attract each other—it is evident that the electrons themselves are negative.
3. cathode-ray tube . . . *Cathode* is a term used by scientists, engineers, and technicians to indicate the source of electrons.
4. free . . . Theoretically, the outer rings of electrons that surround an atom in conducting materials (metals and so on) are free to move through the material from one atom to another, and so carry electric charges.
5. conductor   6. nonconductor and insulator
7. semiconductor . . . You often hear transistors called semiconductors, since transistors are made of semiconductor material.
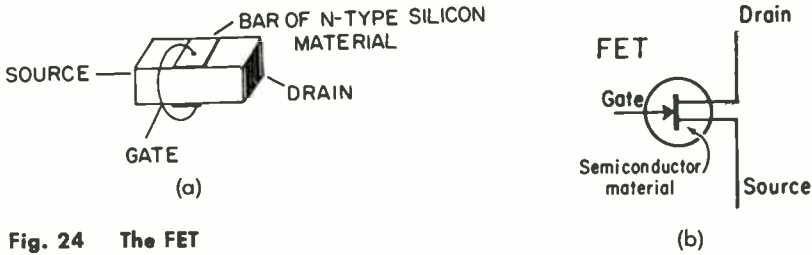
Fig. 24   The FET
(a) Physical representation
(b) Schematic symbol

12   CHARACTERISTICS OF A FIELD-EFFECT TRANSISTOR . . . The *field-effect transistor*, more often referred to as an *FET*, is rapidly becoming one of the most popular semiconductor devices in the world of electronics. The basic FET, as you'll discover in this lesson, and as Fig. 24(a) shows, is a simple three-terminal device consisting of nothing more than a thin bar of silicon semiconductor material with a contact at each end. (The typical FET symbol is shown in Fig. 24(b).) Because the FET has only one channel of semiconductor material that will pass current, it is thought of as a *unipolar* device. The FET is manufactured in one of two ways, so that the channel of semiconductor material has either free negative charges (electrons) or free positive charges (called *holes*). What is called *N*-type material has free electrons, while *P*-type material has free holes. (In our example, we will use *N*-type material for the channel.)

The unique property of an FET is that it is a voltage-controlled device. This sets it apart from the basic transistor, which is a current-controlled device. (You will learn more about these transistors in the following sections.) Since the FET is a simple voltage-controlled semiconductor device, it has certain characteristics that are to be found in no other semiconductor device. For example, the FET is considered to be a true voltage-amplifying device, since it is a voltage-controlled device. Being a voltage amplifier, the FET can greatly amplify an input signal, and can amplify high and low frequencies equally well. The FET provides the user with excellent operation-temperature stability, and with little distortion of the amplified signal.

13   CONTROLLING THE ELECTRON FLOW THROUGH AN FET . . . The FET would be of no use to us if we had no way of controlling the voltage across it. The way we control the amount of voltage across the FET is to control the electron flow (current) through the device. This is done by applying the proper amount of voltage to each of the three leads of the FET. Each of these leads, performs a certain important task, and is referred to by a separate name, as Fig. 24 shows.

28   The *source* is a special contact on the semiconductor channel that receives an input voltage that is less positive than the voltage on the drain. The voltage applied to the source produces a current that is proportional (that is, of similar magnitude) to the input voltage.

The *drain* is a special contact on the semiconductor channel, just like the source contact. The drain's function is to collect the current flowing through the semiconductor channel. To be able to collect the electron flow (current) through the semiconductor material, the drain has to be connected to a more positive voltage source than the source is connected to.
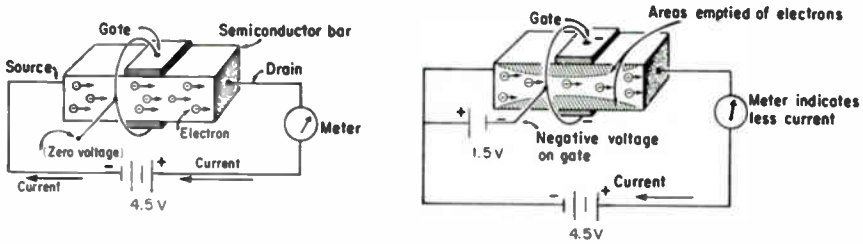
(a) With zero voltage on the gate

(b) With a small voltage applied to the gate
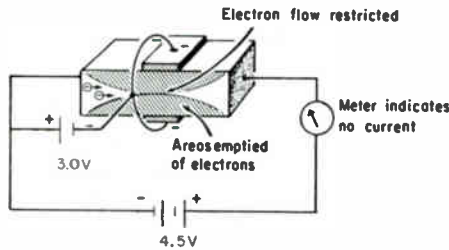
(c) With a larger voltage applied to the gate

Fig. 25   Current through an FET.

The *gate,* finally, is the terminal on the FET that controls the amount of current that flows through the semiconductor channel. The gate is made of a different type of silicon semiconductor material than the current-flowing channel is made of. Actually, it consists of two channels inset into the current flowing channel, as seen in Fig. 25(a). If there is no voltage on the gate, the current flows freely through the channel from the source to the drain. When a voltage that is more negative than the voltage on the source is applied to the gate, the gate will emit a field into the current channel. This constricts the flow of current, as shown in Fig. 25(b). The more negative voltage applied to the gate structure, the larger the current-constricting field will be, and the less current will flow through the channel. In fact, as Fig. 25(c) shows, the field can become so large that it will cut off all current in the channel—a condition known as *pinch-off.* By varying the voltage on the gate we can vary the amount of current through the channel, and thus the amount of voltage across the FET.

If you take another look at Fig. 25, you will see that one voltage supply is connected between the gate and the source, and another is connected between the drain and source. Note that on the gate-to-source battery, the gate is connected to the negative terminal and the source to the positive terminal. This assures that the gate is always negative with respect to the source. Now, if you look at the drain-to-source battery, you will see that the source is connected to the negative terminal and the drain to the positive terminal. This connection assures that the drain is always more positive than the source.
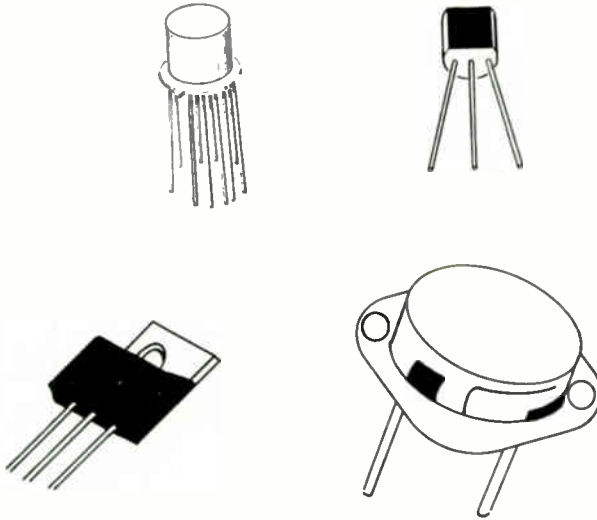
Fig. 26   Various styles of FETs.

By simply putting a variable voltage source—such as the voltage output from a microphone, say—between the gate and the source, the FET can provide voltage amplification of the variable input source. This amplifying capability is unique to the FET, and has made it more and more popular in the world of electronics. As a result, FETs are available today in many shapes and sizes, as Fig. 26 illustrates.

WHAT HAVE YOU LEARNED?

1. An FET is considered to be a unipolar device because _only one conductor material_

2. The unique property of an FET is that it is a _Voltage controlled component_

3. List the three leads of the FET. ~~collector~~ _source - gate - drain_

4. Which lead on the FET controls the amount of current that can flow through the device? _Gate_

1. it has only one channel of semiconductor material.
2. voltage-controlled device.
3. source, drain, gate
4. The gate.

14 CHARACTERISTICS OF TRANSISTORS . . . In the previous two sections, you learned about the FET, a voltage-controlled transistor. In this section and the one following, you will learn about a transistor that is controlled by current instead of voltage. At the same time, the basic transistor is similar to the FET in three important respects: both are three-terminal devices, both are solid-state devices, and both are used as amplifying components. (A solid-state device is a device that is made from some type of semiconductor material that will control the flow of current.) Transistors are found in many of the electronic devices manufactured today, from television sets to huge factory automation systems.
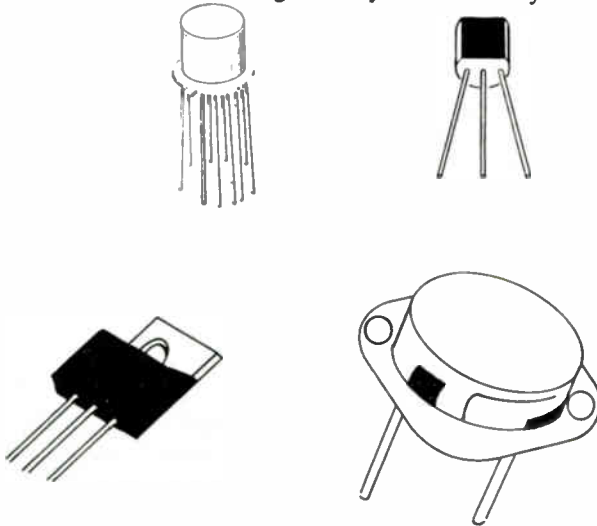
Fig. 27   Various styles of transistors.

Transistors are available in many different sizes, shapes, and power ratings, as Fig. 27 shows. They offer the user the advantages of small, lightweight devices that don't require a large supply voltage or a lot of operating power.

15 CONTROLLING THE ELECTRON FLOW THROUGH A TRANSISTOR . . . The electron flow through a transistor is controlled by the base element. Figure 28 shows the two general types of transistors that are commonly available. The transistor in Fig. 28(a) is a PNP, which consists of two pieces of P-type silicon material with a piece of N-type silicon material between them. A PNP transistor
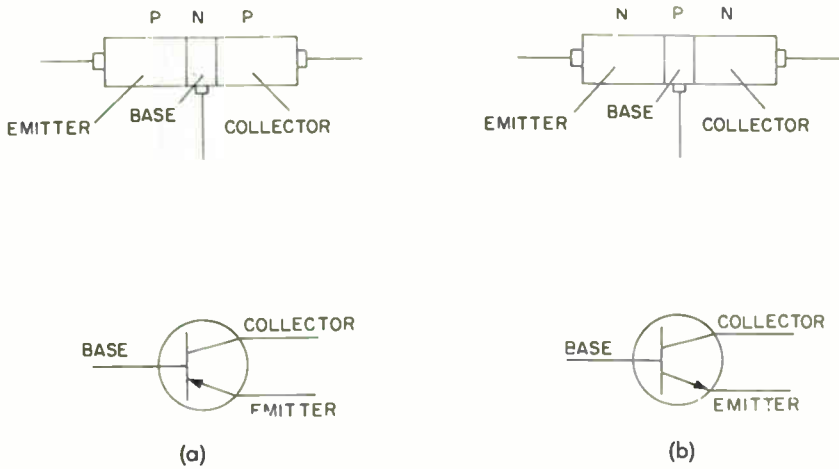
Fig. 28   Physical and schematic representations of the PNP and NPN transistor.
(a) PNP
(b) NPN

symbol shows the arrow pointing toward the base. Figure 28(b) shows the NPN, which consists of two pieces of *N*-type silicon material with a piece of *P*-type silicon material between them. An NPN transistor symbol has the arrow pointing away from the base. (Note that the emitter arrow in the transistor symbol always points towards the *N*-type material.) Each of these transistors has a different type of material for its base element: the NPN has a *P*-type base, while the PNP has an *N*-type base. The way in which current is controlled through the transistor depends on the amount and type of current applied to the base element.

The transistor, as you remember, is a three-terminal current-controlled device. The three terminal leads are called the *emitter, base,* and *collector.* The emitter's job is simply to emit current into the transistor. The base controls the amount of current that flows from the emitter to the collector. The collector, finally, collects all the current in the transistor, and transfers it to some type of load, such as a speaker.

To better understand how a transistor works, let's walk through an example using an NPN transistor. If we think of the base as a set of gates controlled by the input current (as shown in Fig. 29), we can see that by applying more positive current to the base the gates will open wider and let more current through. By varying the current to the base, you vary the opening and closing of the current gates, and thus in turn vary the amount of current flowing from the emitter to the collector. Note that with the NPN transistor, we would have to use a base voltage that is positive with respect to the emitter. However, a PNP transistor requires a base voltage that is negative with respect to the voltage applied to the emitter.

32
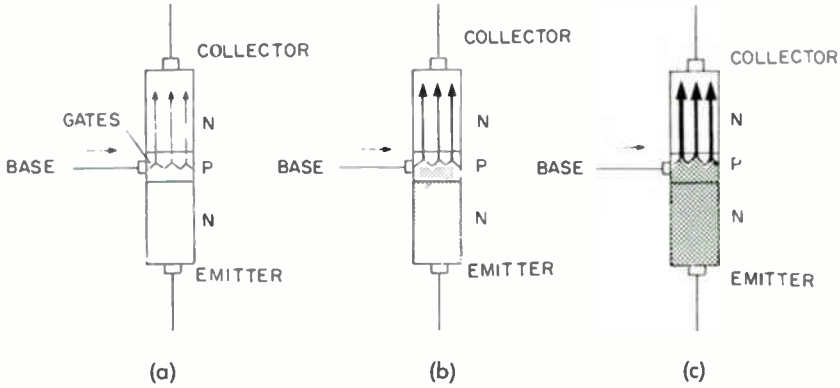
Fig. 29   By controlling the amount of current to the base, we can control the amount of current from the emitter to the collector.
(a) Small amount of current applied to base
(b) More current applied to base
(c) Maximum amount of current applied to base

Don't be too concerned if you didn't completely understand this material on transistors. This is only an introductory lesson, and we'll be covering this material again, in much greater detail, in future lessons.

WHAT HAVE YOU LEARNED?

1. List the two principal advantages of transistors. *size – Low operating voltage*

2. List the two general types of transistors. *PNP NPN*

3. Name the three leads of a transistor *Collector – Base – Emitter*

4. The current through a transistor is controlled by *The base current.*

ANSWERS

1. They're small, lightweight devices that don't require a large supply voltage or operating voltage.
2. NPN, PNP
3. base, collector, emitter
4. the input current that is applied to the base element.

16 INTEGRATED CIRCUITS . . . Throughout this decade and well into the next, advancements in integrated circuit semiconductor technology will continue to flourish and grow. Every electronic product available today will be affected by the growth and development of the integrated circuit. With all the advantages integrated circuits offer, it is essential that the electronic technician be familiar with them in all their available forms.

These integrated circuits (or, more commonly, simply ICs) that we will be discussing are actually nothing more than tiny "chips" of semiconductor material that are capable of functioning as complex electronic circuits. The IC's job is to replace a number of parts with one small package. Each IC contains dozens of such components as transistors, FETs, resistors, and capacitors. Since all of these components are mounted on one tiny piece of silicon material, they can't be separated from each other, nor can any individual component be repaired or replaced if it goes bad. If an IC malfunctions in any way, the whole IC has to be replaced. This is the one drawback of ICs; however, they offer many advantages that far outweigh this one disadvantage. These include reduced overall circuit size, reduced interconnections between circuit elements, improved circuit performance and reliability, and—last but by no means least—lower overall cost. ICs let the user design more complex circuits at a much lower cost than would be possible using discrete components.
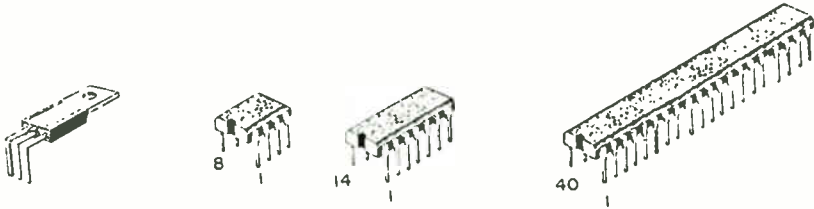
Fig. 30   Typical physical representations of available ICs.

Various types of ICs are available, as shown in Fig. 30. Although the voltage regulator on the left looks like a transistor or FET, it is actually an IC that contains a silicon chip with many transistors etched into it. The IC next to it is an eight-pin flat-pack op amp (operation amplifier)—internally, a very complex audio amplifier, although externally it appears to be a very simple device. The next IC in Fig. 30 is a 14-pin digital IC that contains several logic gates of the same type on the same chip on the same package. By placing several gates inside the same package, both size and cost are reduced. The last IC is a 40-pin microprocessor. In this device, thousands of transistors are etched onto a chip of silicon. By doing so, a microprocessor device that might have taken up an area of several 6-inch by 9-inch circuit boards is reduced to the area of the 40-pin package.

34   As the development and production of integrated circuits continues, more and more discrete component circuits will be incorporated into such compact integrated-circuit packages. Computer circuitry has been and will continue to be the area most affected by the continual development of this technology. Computer ICs will continue to become more and more complex, while at the same time holding the line in chip size—although the package size will increase, due to the increased number of external connections that will be made available.

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LESSON 2336B-6
ELECTRIC CURRENTS AND SEMICONDUCTOR DEVICES

EXAMINATION
</div>

Each examination question is followed by a number of selections. Circle the number in front of the correct selection for each question. When you have finished, transfer your answers to the Answer Sheet provided. Then use the special envelope provided to mail the examination to the school as soon as it is completed.

1. The movement of electric charges through an ordinary piece of wire is carried out by the
   (1) free electrons.   (3) protons.
   (2) ions.   (4) positive charges.

2. Any material through which electrons or electric charges will easily flow is called a(n)
   (1) nonconductor.   (3) conductor.
   (2) insulator.

3. A crystalline material that is classed as neither a good insulator nor a good conductor may be called a
   (1) conductor.   (3) semiconductor.
   (2) nonconductor.   (4) CRT.

4. The assignment of a current direction is just a convenience for circuit tracing and analysis. The direction assigned is not necessarily the same as the direction of movement of the charged particles making up the current. As used in this course, the current direction through the resistor in Fig. 31 is
   (1) from *A* to *B*.   (2) from *B* to *A*.

Fig. 31   battery

5. If you were discussing electronics with an engineering college graduate, you would probably find that he used the conventional current direction in tracing circuits. Thus, he would think of the current direction through the resistor in Fig. 31 as
   (1) from *A* to *B*.   (2) from *B* to *A*.

6. Which one of the following is NOT a lead on a normal transistor?
   (1) Emitter   (3) Gate
   (2) Base   (4) Collector

7. Which lead on an FET controls the amount of current flowing through the device?
   (1) Source   (3) Base
   (2) Drain   (4) Gate

8. The difference between the normal transistor and the FET is that
   (1) the transistor is a voltage-controlled device, while the FET is a current-controlled device.
   (2) the transistor has four leads, as compared with the FET's three leads.
   (3) the transistor is a current-controlled device, while the FET is a voltage-controlled device.

9. Which one of the following is NOT a similarity between normal transistors and FETs?
   (1) Both have three terminals
   (2) Both have base elements
   (3) Both are used as amplifying components
   (4) Both are solid-state devices

10. Which one of the following is a false statement about the integrated circuit?
    (1) The IC provides improved circuit performance.
    (2) The IC costs more than conventional circuits..
    (3) If the IC malfunctions, the whole IC has to be replaced.
    (4) An IC can be made smaller in size than regular circuits.

END OF EXAM

CLEVELAND INSTITUTE OF ELECTRONICS, INC. / CLEVELAND, OHIO

electronics

Lesson 2333A-5
Power Distribution

Lesson 2333B-5
Portable Extension Cords

AUTO-PROGRAMMED® Lessons

About the Author

After more than 20 years' experience in electronics and other branches of engineering, Charles A. Mayer has developed an in-depth understanding of both the theory and the practical applications of a number of fields of study. Drawing on a broad background that includes design, construction, testing, operation, preventive maintenance, and troubleshooting, he has written on a wide variety of subjects: electronics, robotics, computer science, welding, and project engineering, among others.

After serving as an electronics technician with the U.S. Navy (submarine service), Mr. Mayer earned a B.S. in Industrial and Management Systems Engineering at the Pennsylvania State University. His practical experience includes project engineering in industrial applications as well as technical writing for a number of industrial trade magazines. Instruction continues to be an integral part of Mr. Mayer's professional positions, both in the military and in industry.

Mr. Mayer serves in the U.S. Navy Reserve as a Chief Electronics Technician for the Commander of the Submarine Force, Atlantic Fleet.

These are **AUTO-PROGRAMMED*** lessons. The technique will greatly assist you in learning and retaining the technical concepts presented in the lesson material.
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Lesson 2333A-5
Power Distribution

Lesson 2333B-5
Portable Extension Cords

By Charles A. Mayer
Technical Staff

Frontispiece: *in the lesson, you'll learn how to assemble a heavy-duty extension cord, using a few basic hand tools.*

A Chat with Your Instructor

One way or another, you probably deal with electrical hardware everyday. But you may not be aware of exactly how these electrical units do their various jobs. Why, for example, do some portable electric appliances and tools have a third prong on the AC plug? And is it safe to use an adapter to connect such an appliance to a receptacle or extension cord that has only two slots?

Many other common questions come to mind: Why do electric power companies use large, many-tiered insulators on some poles, and smaller insulators on others? What is the reason for the three wires that come into our homes from the power lines? What size of wire is needed for an extension cord meant to supply power to an appliance rated at 1000 watts? When you wire an electrical connection to a receptacle or plug, does it make any difference which way you wrap the wire around the screw terminal? And on and on.

You'll learn the answers to these and many other questions as you work your way through the lessons ahead. Good luck, as you continue to work toward your goal!

Lesson 2333A-4
Power Distribution

POWER FROM GENERATION TO CONSUMPTION

1 POWER TRANSMISSION LINES . . . Most of the electric power used in the United States comes to the consumer from electric power companies. Typically, power travels from a power-generation plant to its destination through long conductors. Poles or towers normally support the familiar long-distance high-tension lines. (The term high-tension refers to the large amount of physical stress in the heavy conductors.) Some conductors run underground, especially in newer "planned" residential and industrial developments.

The economical transportation of electric power over long distances calls for low current and high voltage. Otherwise, as we'll see too much energy would be wasted in the lines as heat, making the long-distance transportation of electric power too expensive to be practical.

It's easy to efficiently change the current and voltage of AC electric power by means of transformers. To increase the voltage for transmission of power over long distances, power companies normally use step-up transformers. Step-down transformers then decrease the voltage to suitably low values for use in homes, shops, and factories. The cylindrical containers that you may have noticed attached to some electric poles along the street contain step-down transformers.

2 HOW TO MEASURE ELECTRIC ENERGY CONSUMPTION . . . The electric power companies measure the amount of energy that you consume, in terms of kilowatt-hours. Let's see what the term kilowatt-hours means, so that we'll have a good handle on electric power as far as its measurement is concerned.

Every electrical appliance and accessory carries a rating value that indicates how much power the item requires for operation. A label attached to the appliance shows this rating, along with other information. We're all familiar with the wattage ratings of light bulbs—40-W(watt), 60-W, 100-W, and so on. Many of us buy light bulbs of a certain wattage rating because of the amount of illumination they produce. And although it's true that a 100-W bulb will produce more illumination than a 40-W bulb of the same type, the amount of illumination is actually reflected by the lumens rating, which is also listed on the package. Also, the light output of one type of bulb may differ from the light output of a different type of bulb even though it has the same wattage rating. A 40-W fluorescent bulb, for example, provides more than 2500 lumens, while a 100-W standard inside-frosted incandescent bulb provides less than 2000 lumens. Further, while yielding more light output, the 40-W fluorescent bulb operates at less than half the cost of the incandescent bulb, since the cost of electricity is based on power consumption rather than an luminosity (brightness).

Right now we're interested in the amount of power consumption, and the wattage rating gives us that information. Power, in watts (W), is equal to the product of the voltage, in volts (V), multiplied by the current, in amperes (A). And we can rearrange this equation according to the quantity we're seeking. To calculate the current that a load will draw, for example, we can divide the power (in watts) by the voltage (in volts). So, if our line has a nominal voltage of 120 volts, then a 60-watt bulb will draw 0.5 amperes—or 60W/120V = 0.5 A.

We've just used one of the most important of all electronics formulas:

$$\text{Power} = \text{Voltage} \times \text{Current}$$
$$(\text{Watts}) \quad (\text{Volts}) \quad (\text{Amperes})$$

or, in electronics "shorthand":

$$P = E \times I$$

This power formula can take two other forms, which are:

$$E = \frac{P}{I}, \text{ and } I = \frac{P}{E}.$$

You'll find this formula not only useful in your electronics studies and work, but in your daily life as well. Let's look at another example.

A typical household toaster requires about 1200 W (Fig. 1). How much current will flow when one such toaster operates? If the line voltage is 120 V, dividing 1200 W by 120 V gives us a current in the circuit of 10 A (Fig. 2). What will happen though, if we try to operate two 1200-W toasters from the same circuit, and that circuit contains a 15-A fuse? Two 1200-W toasters operating at the same time will consume 2400 W. The current for such a load would therefore be 20A (2400 W/120 V = 20 A.) As Fig. 3 shows, this would overload the 15-A circuit, causing the fuse to heat up and open the circuit, disconnecting both toasters from the power source.
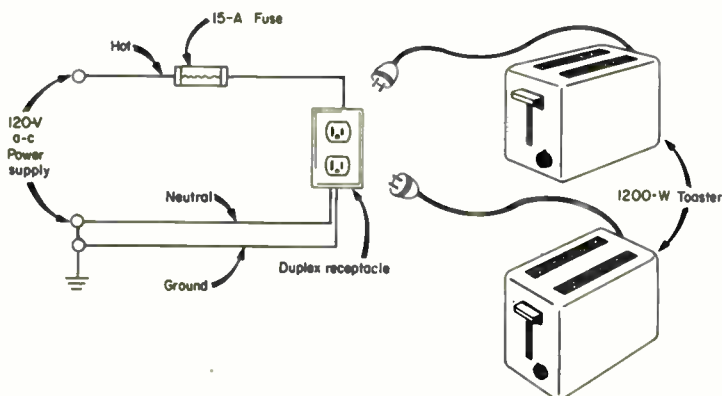
Fig. 1   Typical household electrical circuit

4

15-A Fuse 10 Amps 0 Amps open
120 V d-c Toaster (1200W)
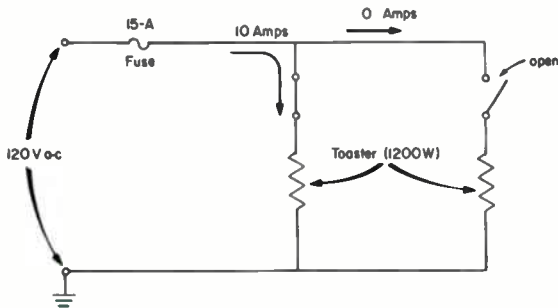
Fig. 2   Schematic of circuit with only one toaster connected

15-A Fuse (heating) 10 Amps
20 Amps 10 Amps
120 Volts 1200W Loads (Toasters)
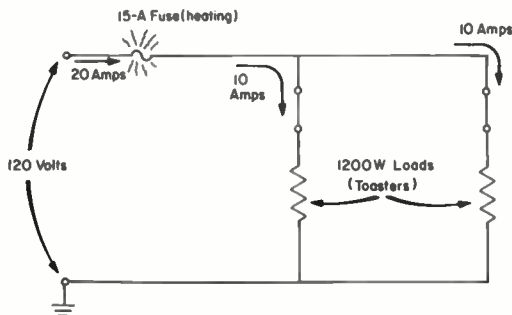
(a) Circuit immediately after both toasters are energized

15-A Fuse (open) 0 Amps
0 Amps
120 Volts
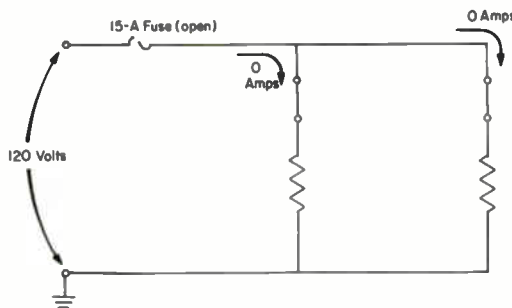
(b) Circuit a fraction of a second after attempting to operate both toasters

Fig. 3   Schematic showing effect of operating two toasters simultaneously

All electrical appliances have labels that indicate their power consumption ratings. With this information—and other information that you'll learn in this lesson—you'll be able to figure out such things as how many electrical items you can plug into a given circuit in your home. You'll also find out why it's unsafe to replace a fuse that keeps blowing with one with a higher amperage rating.

Notice the symbol for the toasters in figures 2 and 3—this is the schematic symbol for resistance. Resistance is a measure of the opposition to the flow of current and it is expressed in units called Ohms. A formula which relates re-

sistance to current and voltage is Ohm's law. This law states that the voltage (E) across a component is equal to the current (I) through the component times (×) the resistance (R) of the component. As a formula Ohm's law is:

$$E = I \times R$$
(volts) (Amperes) (Ohms)

This formula can be used to derive formulas for resistance and current. The other forms of Ohm's law are:

$$R = \frac{E}{I}, \text{ and } I = \frac{E}{R}$$

The symbol for Ohm is the Greek letter Omega (Ω). You will learn more about Ohm's law in a future lesson.

WHAT HAVE YOU LEARNED?

1. True or False? A 100-W bulb will always have a greater light output than a 40-W light bulb. *False* *Lumens*

2 . A formula that you can use to calculate current is
(a.) I = E/R
(b.) I = R/E
(c.) I² = P × R.
(d.) I = E × R.

ANSWERS

1. False ... Different types of bulbs have different lumens-per-watt ratings.
2 . (a)...I =E/R is the version of Ohm's law used to find current.

3 POWER, VOLTAGE, AND CURRENT . . . The total amount of energy required to operate a particular appliance is the product of the power level (in watts) required by the appliance multiplied by the time that the appliance is operating. Assume, for example, that the rating of your television set is 120-W. If your set is on for 2 hours a day during a particular month, the set will be on for approximately 60 hours during that month. The total amount of energy required to operate the television set during that month, then, is 120-W times 60 Hr (hours), or 7,200 watt-hours (Wh). Note that, for convenience, we normally convert Wh to kilowatt-hours (kWh). The prefix kilo- means 1000; therefore, 1 kWh equals 1000 Wh. The amount of energy needed to operate your TV for one month then, is 7.2 kWh. So, if the billing rate for our electric energy consumption is 10 cents per kWh, the cost to operate your TV set for the month is equal to 7.2 kWh × 10 cents/(kWh), or 72 cents ($0.72).

Watthour meters, like the one in Figure 4 are electro-mechanical devices that measure energy consumption. The stator of the watthour meter contains coils that provide a magnetic flux proportional to the voltage and current. The magnetic flux determines the torque, and therefore the rotational velocity of the rotor. (The rotor is visible in Fig. 4 near the center of the meter face.) The shaft of the rotor
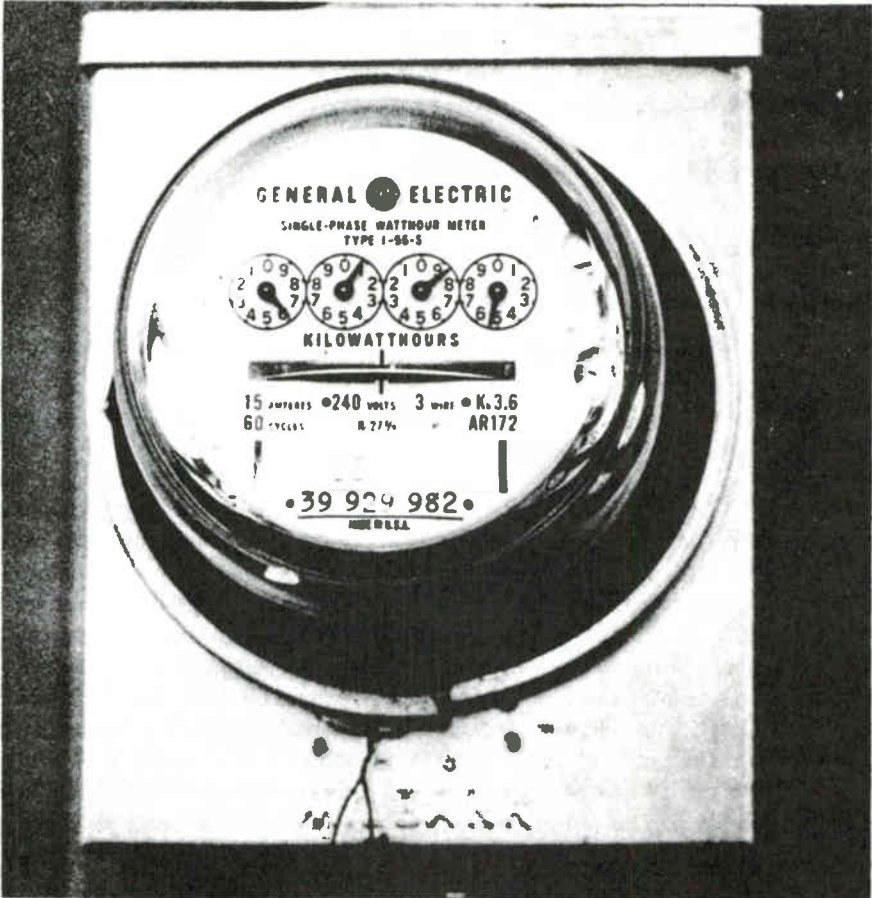
Fig. 4   Watthour meter

contains a gear, which in turn drives the pointers that are visible on the meter face. This rotor operates like the mechanical speedometer on an automobile, indicating the amount of energy usage at any given point in time. Try observing your watthour meter during different load conditions, such as when a large load—an air conditioner, refrigerator, or washing-machine motor for example— turns on or off. You'll see that, larger the load, the faster the gear wheel rotates.

The pointers and their associated numbered dials that you can see above the gear wheel in Fig. 4 operate similarly to the mechanical odometer in an automobile: in other words, they indicate the cumulative energy consumption. Since the rotational velocity of the rotor is proportional to the energy usage (voltage times current), the reading on the register indicates the cumulative number of watt-hours. Note that care must be taken when reading watt-hour meters since some indicators rotate in a clockwise direction while others rotate in the counterclockwise direction. (The reading on the meter of Figure 4 is 6085 kWh.)

1. The prefix kilo means
   (a) 1.
   (b) 10.
   (c) 1000.
   (d) 1,000,000.

2. The kilowatt-hour reading on your electric bill tells you
   (a) the cost of electricity.
   (b) the name of the meter reader.
   (c) your account number.
   (d) the amount of electrical energy consumed during the billing period.

3. The dials of the electric meter at your residence tell you the
   (a) kilowatts.
   (b) kilowatt-hours.
   (c) voltage.
   (d) current.

4. The rotating disk on the electric meter indicates
   (a) that the meter is working properly.
   (b) that the electric meter is energized.
   (c) the power on the incoming line.
   (d) the rate of power consumption.

ANSWERS

1. (c) . . . The prefix kilo means 1000. For example, kilovolt means 1000 volts; kilometer means 1000 meters; and kilohm means 1000 ohms; and so on.

2. (d) . . . Typically, electric companies list the readings at the beginning and end of the current billing period on your electric bill. The amount of energy consumed, therefore, is the difference between the two readings.

3. (b) . . . The marks on the dials correspond to kilowatt-hours.

4. (d) . . . The faster the dial rotates, the higher the rate of energy consumption. Each time the dial rotates, a predetermined number of watt-hours has been consumed. If you count the number of times the disk rotates in a given unit of time, you'll know how many watts of power (more or less) you used during the time you counted the revolutions.

4 LOW CURRENT AND HIGH VOLTAGE MEANS LOWER COST . . . We noted earlier that power companies step up the voltage of electric power for long-distance energy transportation. Let's see why this is done: As we saw earlier, the power required to do a particular job can be calculated as the product of the voltage times

the current. Let's use our toaster as an example. If power is transmitted without using step-up and step-down transformers, proper operation of our 1200-W toaster will require a 10-A current to flow along the entire length of the transmission line. The toaster current won't lose much power (wasted as heat) in the wiring in our home, since the 10-A current will have to travel only a short distance. But think of the power lines that span many miles across the countryside. Let's say we have a power line that exhibits a resistance to current of 0.100 Ω (ohms) per mile. (Some lines have even lower resistances.) For a run from, say, Niagara Falls to Cleveland (about 200 miles, the total resistance would be 20 Ω (200 miles × 0.100 Ω per mile). See Fig. 5. (The power lost in the transmission line is called the line loss, or I^2R—"pronounced-eye-squared are"—loss.)
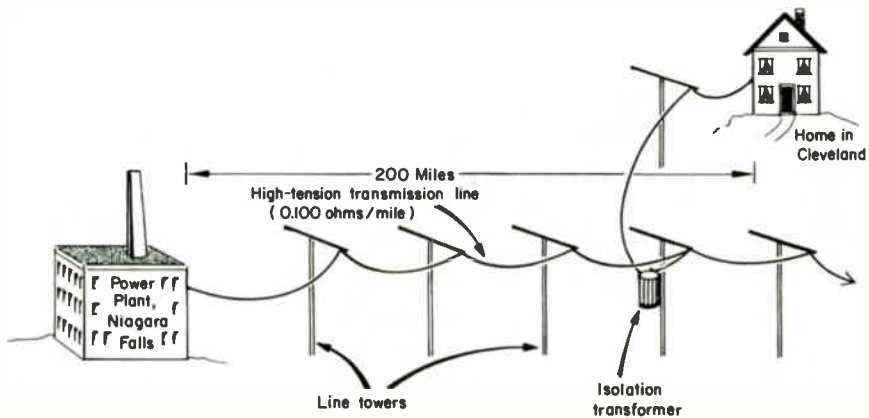
Fig. 5   Low-voltage power transmission

Now that we know both the current (10-A) and the resistance (20 Ω), we can calculate the power loss. We'll start with our power formula
$$P = E \times I$$
Substituting (from Ohm's law) $I \times R$ in place of E gives us
$$P = (I \times R) \times I$$
or
$$P = I^2 \times R$$
Substituting our known values for I and R we find that
$$P = 10^2 \times 20$$
$$= 100 \times 20$$
$$P = 2000 \text{ watts!}$$
In other words, we've wasted almost twice as much power (2000W) in the form of heat loss in our transmission line as we obtain as useful power (1200W) to toast our breakfast muffins. Multiply this by the hundreds and thousands of toasters, air conditioners, TV sets, microwave ovens, and units of shop and factory elec-

trical equipment that a local electric company normally supplies to even a small city! Obviously, power waste in the transmission lines of this order would mean substantially higher costs to consumers who would have to pay for the generation of almost three times the amount of power that they actually consumed in their homes!

Another difficulty in transmitting power at low voltage results from the voltage drop caused by every load connected to the line. If there were no loads connected to the line, no current would flow. In other words, a voltage of 120V at the source would produce a voltage of 120V at the destination. But as soon as we pop in our muffins and turn on the toaster, the current requirement of 10A along the entire length of the 200-mile-long transmission line (Niagara Falls to Cleveland) results in a voltage drop of 200V along the line. In order for the voltage in the Cleveland kitchen to have a value of 120V the source in Niagara Falls would have to increase from 120V to 320V—just to supply that single small load (our toaster)! If we figure a mere 1,000 homes with toasters popping, our current requirement increases to 10,000A, the power loss in the long-distance transmission line shoots up to 2,000,000KW, and the necessary voltage at the source 200,120V!

By increasing the voltage on a transmission line to a very high level—50,000 to 750,000V, or even more—by means of step-up transformers, we can reduce the current to a very low level. Figure 6 is a schematic of a system that transmits power at high voltage, and then steps down the voltage to a value low enough for use by the consumer. For ease in calculations, we'll use a 120-kV (kilovolt) transmission line. The transmission-line current needed to operate our toaster would then be 0.01A (1200W/120,000V = 0.01A).

Note: The power supplied to a transformer is approx. the same as the power leaving it
Example: A 10 to 1 step up transformer with 120V and 10 amps at the primary will result in 1200V and 1 amp at the secondary
(V × 1 in = V × 1 out)
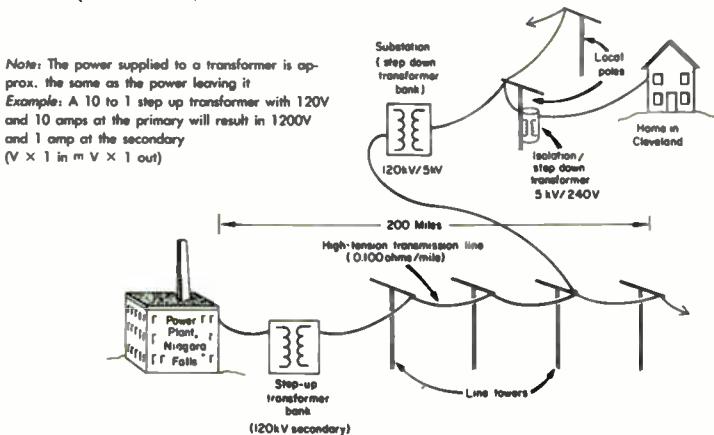
Fig. 6   High-voltage transmission of electric power

By increasing the voltage from 120V to 120,000V (a factor of 1000), we reduce the current by the same factor—from 10A to 0.01A. From this, it might appear

that we haven't gained anything: in either case, the power needed to operate the toaster remains at 1200W. However, use of the high-voltage system dramatically lowers the amount of power lost in the transmission line. For the 120-kV transmission line, line loss due to the toaster current would be 0.002W (0.01A × 0.01A × 20 Ω). Because power consumption is proprtional to the square of the current, reducing the current by a factor of 1000 reduces the power loss by a factor of 1,000,000. With the high-voltage system, putting our toaster on the line would require an increased voltage of only 0.2V at the source, as compared to an increase of 200V needed with the low voltage system. In other words to power one thousand toasters by the high-voltage transmission line would require a nominal increase from 120,000V to 120,200 volts at the source. (This would of course make up for the voltage drop of 200V along the line due to the current needed to supply the toasters.)

Note also that the low-voltage system requires a higher voltage at the source than the high-voltage systems does. That's because the full current of the loads must flow along the entire length of the transmission line, and the power used in any component—the line, in this case—is proportional to the square of the current. In other words, if you double the current, the power increases by a factor of four.

High-voltage/low-current transmission lines also provide significant savings in construction and maintenance costs of the power transmission lines themselves, due to the reduction in size of the necessary conductors. The amount of current that a conductor must carry determines its size, and consequently the size of the supporting poles and towers. Picture a network of cross-country power lines: To transmit the same amount of power without the use of step-up and step-down transformers would require either conductors thousands of times larger or increasing the number of conductors a thousand-fold. In either case, the cost and sheer physical size of the conductors, plus the staggering amount of power that would be wasted as transmission-line loss, would be so prohibitive that most areas of the country would find electric power priced out of their reach.

Of course and inevitably, there are certain drawbacks to using very high voltage for transmitting power over long distances. Extremely high voltages require expensive insulators and standoffs on supporting poles and towers, along with special insulation and piping capable of containing the high-pressure gas necessary to prevent ionization and arcing. Tree branches must also be kept away from transmission lines. Arcing and conduction from a line to ground can cause significant loss of power, all well as increase the potential for forest and field fires.

Substations, located in the vicinity of electric-power consumers, are large banks of transformers that step down the voltage to several thousand volts for local distribution. Lowering the voltage in this manner between the substation and the smaller transformers you see on neighborhood poles eliminates the need for special high-voltage conductors and insulators.

1. A typical high voltage on a transmission line would be
    (a) 120 V DC.
    (b) 120 V AC.
    (c) 100,000 V DC.
    (d) 100,000 V AC.

2. To increase and decrease the voltage on transmission lines, power companies use
    (a) transformers.
    (b) batteries.
    (c) rectifiers.
    (d) optical fibers.

3. Which one of the following consumes the most electric power when operating?
    (a) A 50/100/150 W three-way light bulb
    (b) A solid-state 19-inch television set
    (c) A two-slice toaster
    (d) A gas range with oven

4. Modern high-voltage transmission line conductors have a resistance of
    (a) O Ω.
    (b) less than one Ω per mile.
    (c) 1 Ω per mile.
    (d) 1 Ω per foot.

5. When additional loads are turned on by consumers, the voltage at the generating plant
    (a) increases significantly.
    (b) decreases significantly.
    (c) stays about the same.
    (d) oscillates, and then settles to a new level appropriate to the demand upon it.

ANSWERS

1. (d)
2. (a) . . . Batteries supply DC power at only one voltage; rectifiers transform AC power in DC power; optical fibers are good for the transmission of such very low-level signals as telephone communications.
3. (c) . . . A two-slice toaster consumes about 1200 W. The light bulb uses 50, 100, or 150 W, depending on the switch setting on the lamp; the solid-state TV set uses about 100 to 200 W; and the gas range uses no electric power, except for the oven and hood lights (about 100 W total) and a trickle for the clock.

4 . (b) . . . Every practical conductor offers at least a small amount of resistance to current.

5 . (c) . . . At any instant of time, your power company is generating millions of watts of power. When you turn on your TV set or toaster, therefore, there is only a very small change in the overall demand for electric power, and consequently virtually no change at the generating station.

POWER IN THE HOME AND WORKPLACE

5 THREE-WIRE SYSTEMS . . . A three-wire system is the normal means of distributing low-voltage power (120 and 240 V) to your home or workplace. Figure 7 shows a typical home installlion. Note that one lead is connected to earth ground, With this type of hookup, you can tap off either 120 V for most home needs or the 240 V required for such large loads as washing machines, air conditioners, and stoves. Figure 8 shows how this three-wire system is able to supply both 120 V and 240 V simultaneously.
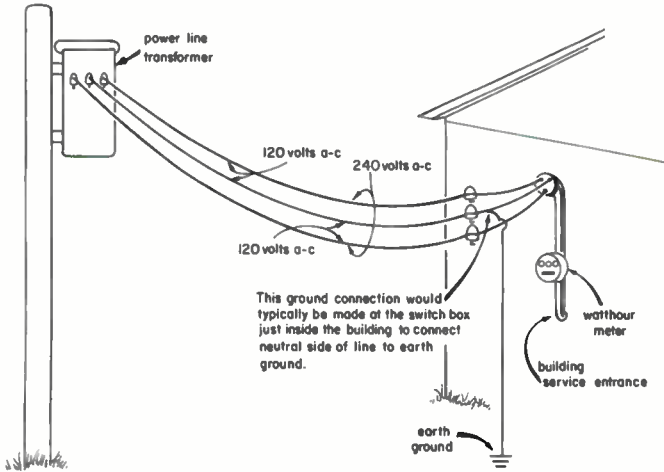
Fig. 7   Three-wire home installation supplying 120 and 240V
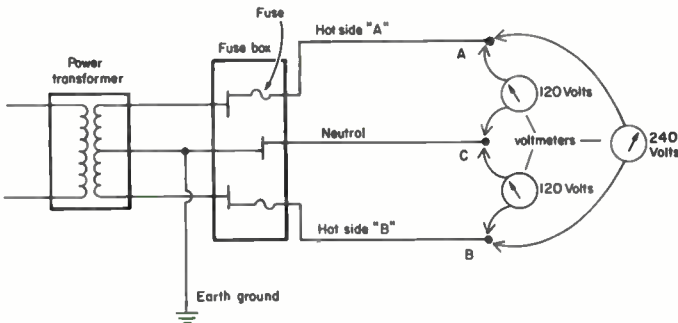
Fig. 8   Schematic of a typical three-wire home installation

With one lead connected to earth ground, the voltage from either of the other two leads to ground measures 120 V. This means that the highest voltage that you can place across your body while standing on the ground is 120 V. But don't be fooled: 120 V can be fatal. It's extremely important that any appliance that's used in a damp location and has a metal frame, such as a washing machine, have its frame connected to earth ground.

Ground connections are also important with metal-cased portable tools, which are frequently used while the operator stands on the ground, on wet concrete, or on some other damp surface. Many such tools come with a UL label (Underwriters Laboratories). To be able to carry the UL label, double-insulated tools must have two separate layers of insulation between the user and the electrically energized parts of the tool. If one layer of insulation were to break down for any reason—say, because vibration and rubbing caused the normal insulation of some internal wire to wear away and expose the bare conductor—the user would still be protected by the second layer of insulation between the wire and any external part of the tool. Since double-insulated power tools don't require a ground lead and therefore have a two-wire cord, it's safe to use a two-wire extension cord with these tools.

According to the National Electric Code (NEC), safe grounds can be made using certain grounding electrodes. These include buried lengths of copper conductors, 8-foot-long ground rods, underground gas or water piping or metal tanks, and the concrete-encased steel reinforcing rods found in building footers. Check the current NEC and local codes for the requirements in your area, since these are subject to revision. For example, the long-recognized grounding standard—a 10-foot-long underground water pipe—is still an acceptable ground, but since 1970 it must be used in combination with one or more additional grounding electrodes.

Note The NEC is a U.S. standard, the regulations may differ in other countries.

WHAT HAVE YOU LEARNED?

1. The voltage (s) available in a typical residential installation is (are)
   (a) 120 V.
   (b) 240 V.
   © 120 V and 240 V.
   (d) 120 V, 240 V, and 440 V.

2 . The electric company uses _____ wires to supply electric power to a home.
   (a) One
   (b) Two
   © Three
   (d) Four

3. The voltage(s) in your home is (are)
  (a) not dangerous—a slight tingle is the most you'll feel if you happen to touch one of the conductors.
  (b) able, because of power-line trouble, to rise to a dangerously high level.
  (c) dangerous only if you are in the bathtub or another damp location.
  (d) lethal
  (e) dangerous only when 240 V is used (120 V is safe to the touch).

4. True or False? Earth ground and concrete can't conduct electricity.

5. You can safely convert a drill with a three-prong plug to a double-insulated version by
  (a) removng the ground prong from the plug, which lets you plug it into a two-slot receptacle.
  (b) taking the tool to an authorized repair facility.
  (c) coating the outside of the tool with an insulating material.
  (d) None of the above, nor by any other method.

ANSWERS

1. (c)
2. (c)
3. (d).. Any electrical circuit with a voltage in excess of approximately 30 V is potentially fatal if you come in contact with it.
4. False ... both the earth and concrete can contain a great amount of moisture, and can therefore conduct electricity with only little resistance to current.
5. (d) ... None of the above, nor by any other method. The design of double-insulated tools is considerably different from that of other tools. Therefore converting a tool to a double-insulated version is definitely not feasible.

6 RECEPTACLES AND PLUGS . . . Most of the electrical receptacles, or outlets, in the home are duplex—meaning that each unit contains two places into which you can plug an appliance. Most of the receptacles installed in recent years are of the grounded variety—that is, each place where you can insert a plug has two slots and a D-shaped hole. The NEC presently requires that all new receptacles be of the grounded type. For older installations (prior to 1968), the Code requires grounded types in wet or damp locations, such as in basements and near kitchen and bathroom sinks.

Figure 9 shows a grounded-type duplex receptacle. Note that one slot in each pair of slots is shorter than its mate. Facing the outlet, with the ground hole below the slots, the shorter slot is to the right of the longer slot, as Fig. 9 shows. If properly wired, the shorter slot is always connected to the "hot" side of the line, and the longer slot connected to the neutral side. (The ground hole is connected

to earth ground.) According to the NEC, the neutral side of the line must be con-
nected to the (earth) grounding electrode near the location where 120/240-V power
enters the building. This connection is normally made at the main breaker (or
fuse) box.
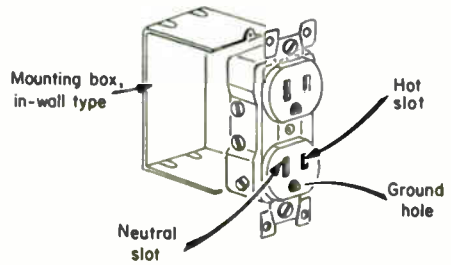
Fig. 9   Duplex receptacle, grounded type

When used properly, grounded-type plugs and receptacles prevent electric shock.
If the "hot" wire somehow touches the metal frame. Dangerous conditions can
exist if you use an appliance that has a grounded lead in an ungrounded recep-
tacle.

Some two-slot receptacles—that is, ones that do not have a ground connection
hole, as shown in Fig. 10—also have one short and one long slot. As with the
three-hole kind, these should have the shorter slot wired to the "hot" side of the
line and the longer slot wired to the neutral side. Other types have two slots, either
flat or T-shaped, of the same length. With these, there's no way to identify the
hot side without using a meter or other testing device. Even when a grounding
type is installed, you should always test the outlet to determine the hot side, since
more than one inexperienced or careless electrician has inadvertently miswired
a receptacle.
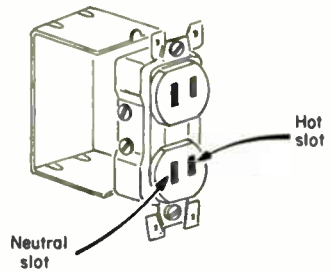
Fig. 10   Duplex receptacle, non-grounded type

Plugs, like receptacles, come in a variety of styles. Some of these are shown in Fig. 11. Two-prong plugs can be inserted into most two- or three-slot receptacles. The prongs of the non-polarized plug in (a) are of the same width, so it fits into most receptacles with either prong plugged into the hot side of the receptacle. For certain appliances, such as double-insulated tools, this is acceptable. But for others, safety considerations dictate that the plug be polarized as in Fig. 11 (b). The grounded-type plug in Fig. 11 (c), finally, has three prongs that mate with the three holes of a grounded-type receptacle.
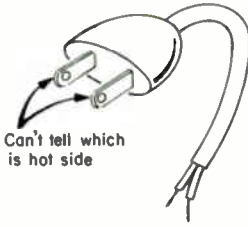
(a) Non-polarized two prong   (b) Polarized two-prong
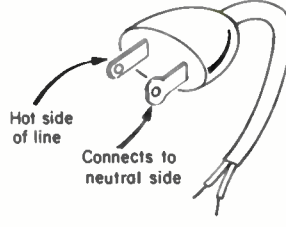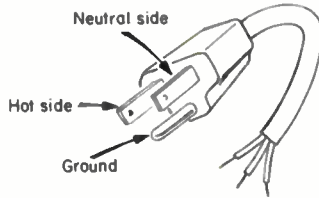
(c) Three-prong, grounded

Fig. 11   Typical electric plugs

In appliances that have one side of the power line connected to metal parts that could be touched by the user, polarized plugs must be used if the appliance carries the UL label. In two-prong polarized plugs, one prong is wider than the other. See Fig. 11 (b). This allows the plug to be inserted in only one way into a polarized receptacle. The wider prong fits only into the wider slot of the receptacle, and is therefore connected the neutral side of the line. The narrow prong, likewise, fits into the narrow slot, where it connects to the hot side of the line. *This safety feature should never be defeated by clipping the edges of the wider prong.* In three-prong grounded-type plugs, it's not necessary that one prong be wider than the other. Because of the D-shaped ground prong, such a plug can be inserted in only one way into a grounded receptacle.

Underwriters Laboratory (UL) is a testing laboratory that was set up by the insurance industry to recommend precautions to be taken in the construction of electrical equipment with the goal of minimizing fire and shock hazards. If a manufacturer wants his products to carry the UL label, he must submit the product to one of the UL testing sites. After testing the product. UL makes a list of all deficiencies and returns the product to the manufacuturer, who must correct all violations of UL requirements. The product is then retested. When all deficiencies have been corrected, UL personnel inspect the actual manufacturing facilities. Only after the product and the manufacturing plant pass the exacting scrutiny of UL will UL add that vendor to its list of approved vendors. Hence, the label "UL listed" is something worth looking for when selecting an electrical appliance or component.

WHAT HAVE YOU LEARNED?

1. A grounded-type receptacle has _____ openings for prongs.
   - (a) two
   - (b) three
   - (c) four
   - (d) five   —Do noTagree

2. True or False? To bring an older home up to Code, you should replace all two-opening receptacles with the grounding type. True —deTermin neuTraL+insTall

3. The D-Shaped opening on a grounded type receptacle is connected to the _____ lead in the outlet box.
   - (a) hot
   - (b) cold
   - (c) neutral
   - (d) earth ground

4. The term duplex means that the receptacle
   - (a) can operate ungrounded or grounded appliances.
   - (b) can operate either polarized or non-polarized appliances.
   - (c) can supply either 120 or 240 V.
   - (d) has two places to plug in appliances.

5. True or False? All appliances are required by law to carry the UL label.

1. (b)
2. False ... Only those receptacles that are in damp or potentially damp locations need to changed to the grounded type in older installations.
3. (d) ... Earth-ground is the connection with the green screw. The brass-colored screw connects to the hot side of the line, and the silver-colored screw connects to the neutral lead. (Note that none of the connections are referred to as "cold").
4. (d)
5. False

7 PROTECTION OF ELECTRIC CIRCUITS . . . Every properly designed electric device operates with a safe amount of current. If a fault occurs and causes a short circuit, the larger than normal current that results can produce an unsafe condition.

Current that is too high causes excess heat to develop. This excess heat in turn can cause damage to the electrical device, and create the potential for an electrical fire. High heat can also damage the insulation that covers the device's wiring and internal components. If the insulation deteriorates, a person touching the device could receive an electrical shock.

As you can see, some method of preventing overcurrent conditions must be employed wherever electrical devices operate, whether in the home, shop, or factory. Typically, fuses and circuit breakers are used to protect against excess current. Fuses and circuit breakers provide the same type of protection, but they do their jobs in different ways. Typically, a fuse contains a strip of metal that is designed to melt when a predetermined amount of current flows through it. When the strip melts, it opens the circuit and cuts off any further flow of current. Obviously, since the internal strip melts, the fuse is worthless and must be replaced in order to restore current. Some cartridge fuses, such as those often used as mainline fuses at the entrances to single-family dwellings, come with a renewable strip inside the cartridge holder. The renewable strip is accessible by removing one end cap of the cartridge.

Circuit breakers, on the other hand don't have to be replaced after they've done their job and opened the overheated circuit. Most common circuit breakers can be reset and immediately reclosed, as easily as flipping on a hallway switch. Some circuit breakers provide dual service, functioning as the switch that turns the electrical equipment on and off as well as protecting the equipment from overcurrent conditions.

Figure 12 shows several types of fuses and fuseholders used on residential installations and in automobiles. According to the NEC, only type S fuses and holders can be installed on new installations. Type S fuses and holders are available in three classifications: 0 to 15 A, 16 to 20 A, and 21 to 30 A. Screw threads of

Type S fuses and holders are made so that fuses within one classification will only fit in holders of the same classification. For example, a 20-A type S fuse can be used in a 16-to-20-A fuseholder, and will not fit in a 0-to-15-A fuseholder, for example. This feature prevents the installation of a 30-A fuse, say, in a circuit designed to handle no more than 15 A.
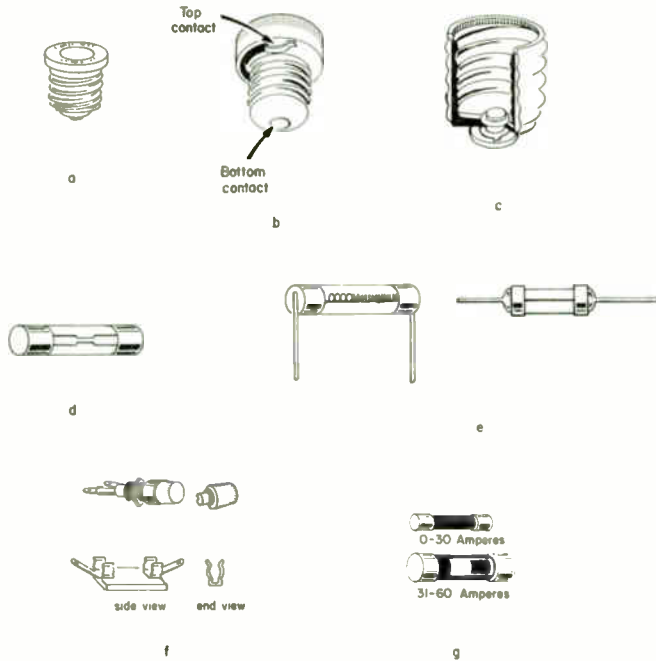
Fig. 12   Typical household and automotive fuses and fuseholders
(a) Edison-base plug fuse, Type W or T
(b) Type S time-delay plug fuse
(c) Type S adapter. (Fits Edison-base fuseholder.)
(d) Automotive Fuse
(e) pigtail fuses
(f) Fuseholders for automotive fuses
(g) Cartridge fuses

The dangerous practice of using a fuse with a higher amperage rating than the circuit can handle was, unfortunately, commonplace—particularly in situations where Edison-base fuseholders are used. Standard quick-blow Edison-base fuses—also referred to as Type W fuses—are available for use as replacements in older installations, but they should be used only if there is no evidence of overfusing or tampering. If even a chance of overfusing exists, special adapters that accept only Type S fuses should be inserted in the Edison-base fuseholders. That way, there is no risk of accidental overfusing.

Type S adapters carry the same three amperage classifications as Type S fuses and holders: 15 A, 20 A, and 30 A. Once the adapter is inserted in the fuseholder, its design prevents it from being removed. Plug-type fuses can be installed only where the voltage from any line to ground measures no more than 125 V. (Residential 120/240-V systems fit this category.) Even though the line-to-line voltage is 240 V, maximum line-to-ground voltage measures 120 V.

Besides their safety feature in preventing overfusing, most Type S fuses have another advantage over standard Edison-base fuses—a time-delay feature. If you look through the window cap of a Type S fuse, you'll see that the filament has a spring-like appearance. This gives the fuse the ability to carry a slight overcurrent for a short period of time. When electric motors start up—particulary those in refrigerators and air conditioners—they require additional current to get themselves up to speed as compared to the current required during normal operation. (You've probably noticed your lights dimming when one of these motors starts up.)

When many of our homes were constructed 50 or so years ago, electric refrigerators were just coming on the scene. As for air conditioners, which we are coming to look at as one of life's basic necessities, these were practically unheard of before the 1960s. In these quieter times, the only items in a typical American home that used any significant amount of electricity were lights, irons, ranges, and radios. Since none of these items contains a motor, none required a starting current greater than its normal operating current. When people started installing refrigerators and air conditioners, and using high-horsepower vacuum cleaners and the like, fuses began to blow frequently because of the demands of increased starting currents. One totally universal answer was—and, unfortunately, still is— to overfuse the circuit, usually with a 30-A fuse. Since many household circuits are designed for a maximum of 15 A with size 14 AWG wire, you can see that this practice permits twice the maximum allowable current to flow—an extremely dangerous condition.

To deal with this problem, slow-blow versions of Edison-base fuses, called Type T fuses have been developed. Like Type S fuses, these allow for higher starting currents while protecting the circuit at the proper maximum continuous amperage. Cartridge-type fuses, like the ones used as main line fuses in residential installations, are also available in slow-blow types.

Figure 13 shows how a circuit breaker protects a circuit. In this type of circuit breaker, a portion of the circuit current flows through a heating coil. The heating coil is wrapped around a bimetallic strip. When the current in the circuit exceeds the current rating of the breaker, heat from the coil causes the bimetallic strip to bend, forcing the contacts apart and thus opening the circuit. Once the contacts open, the current is reduced to zero; as a result, the bimetallic strip cools down and tries to force the contact to close. However, once the breaker has tripped to the open position, a spring catch holds the contacts open. Before you can reclose

the breaker, you must push the reset button to unlatch the spring catch. The breaker can then be reclosed. (See Fig. 13.)
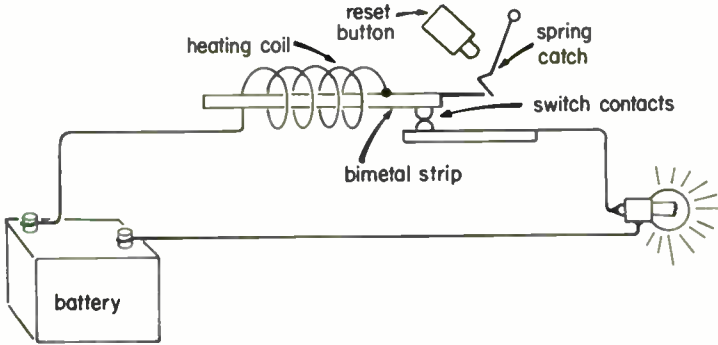
(a) Circuit breaker with contacts closed
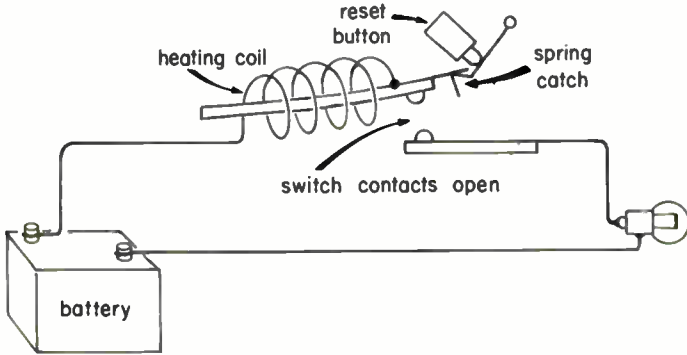
(b) Tripped circuit breaker

Fig. 13   Circuit breaker protecting lamp circuit

Other types of breakers use different reset devices. One type of breaker that's quite popular for home use has a switch handle that moves to a middle position when the breaker trips. Before you can reclose this type of breaker, you must first move the switch handle to the open position. This open/tripped/closed feature of the switch handle allows you to see at a glance which, if any, breakers have tripped (as well as which are closed and which are open).

If a fuse blows or a breaker trips repeatedly, you should not simply continue to replace the fuse (or reclose the breaker). A good rule of thumb is to try to reenergize the circuit once by replacing the fuse or closing the breaker. If the new fuse also blows (or the breaker immediately reopens), you can be fairly sure that some sort of fault exists along the line. You should try to determine what's causing the over-

current condition, and remove the fault before replacing the fuse or reclosing the breaker. If you can't find a fault, try one more reclosing. If the new fuse blows, have an electrician check out your system. If the breaker reopens, you may have a defective breaker: try replacing the breaker with another one. Be sure to use a replacement that fits the design of you breaker panel, and that has the proper trip rating for the circuit you intend to protect.

Circuit breakers offer one big advantage over fuses: they can be reused again and again after tripping. Fuses, on the other hand, are one-shot devices: once a fuse blows, its useful life has come to an end. Breakers can also double as switches, allowing loads to be turned on and off at the breaker box. This feature comes in especially handy for energizing outdoor or garage receptacles only as you want to use them. To provide such a feature with a fuse box, separate line switches would have to be installed.)

Breakers and breaker panels have a higher intial cost than comparable fuses and boxes, but this initial saving can disappear over time as additional fuses must be purchased. In any case, whether you select breakers or fuses, remember that both of these devices essentially do the same job—protect the wiring from dangerous overcurrent conditions.

Figure 14 shows another handy item—a breaker inside an Edison-base plug. Available with 15-A, 20-A, and 30-A ratings, these circuit protectors let you replace blown fuses with a resettable device. They include a time-delay feature that can handle the high starting (surge) current of motors. When a high current causes the device to trip, the button on the cap extends out beyond its normal position. To reset, simply push in the button. As with any overcurrent-protection device, never use a circuit protector with a higher amperage rating than the wiring can handle. For most residential installations, 14 AWG wire should be protected with a 15-A protective device; 12 AWG wire with a 20-A device; and 10 AWG wire with a 30-A protector.

Fig. 14   Breaker with Edison-base plug

Figure 15 shows several ways of wiring an automotive lamp circuit. Note that the fuse closest to the power source provides the best protection. Referring to Fig. 15 (a) and (b), note that if wires B and C accidentally contact each other, forming a short circuit, the fuse will open and disconnect the battery from the rest of the circuit. Note also, however, that this design offers no protection if wires A and

C short together, as shown in Fig. 15 (c). In this case, the short-circuit current doesn't flow through the fuse, since it's located farther from the battery than the point where the short occurred. In this case, the fuse would protect neither the wiring nor the battery. Since this short-circuit condition presents no resistance to current, the battery would try to provide an extremely high current which, in turn, would cause the wire to become overheated and very possibly damage the battery or even start a fire. Figure 15 (d), finally, shows that placement of the fuse (or breaker) as close as possible to the source offers maximum protection to the greatest portion of the circuit.

(a) Circuit in proper operation

(b) A short between B and C would blow the fuse.

(c) A short between A and C would not blow the fuse. Wires A and C would get extremely hot, and could even start a fire.

(d) Best place for fuse is near power source, since it would be almost impossible for wires A and C to short together. This means that almost the whole circuit is protected by the fuse.
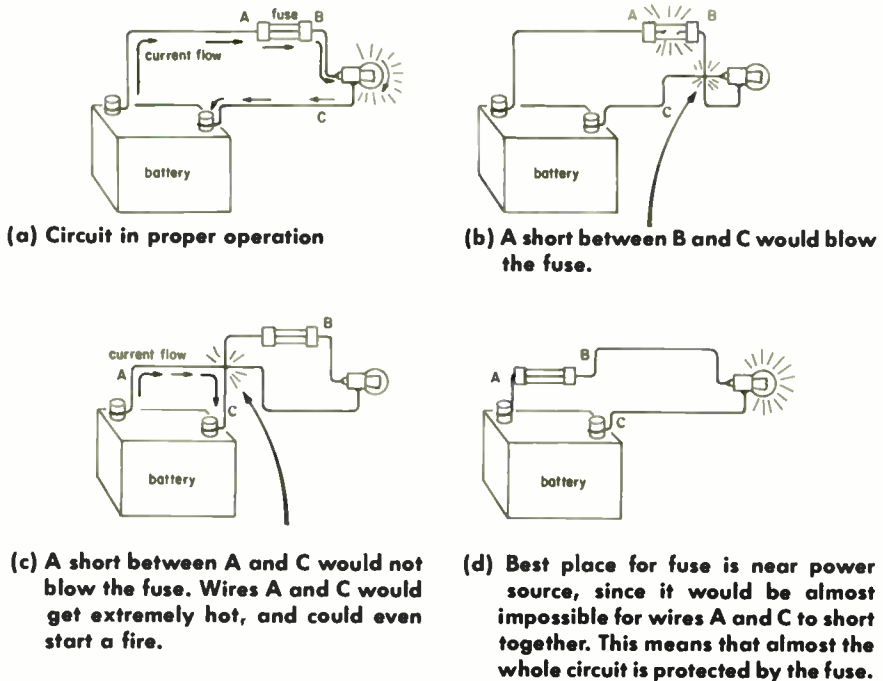
Fig. 15   Automotive lamp circuit

The electrical wiring system in our homes require fuses or breakers only on the hot sides of the line: the grounded neutral line doesn't require a fuse. Figure 16 shows why we locate fuses and breakers on the hot sides of the line in such systems. In Fig. 16 (a), with the hot side of the line correctly fused, a short caused by the hot lead coming in contact with the ground lead will cause a high current. But, since this high current flows through the fuse, the fuse will blow to protect the circuit. On the other hand, with the fuse placed on the neutral side of the

line as shown in Fig. 16 (b), the high current caused by the fault will bypass the fuse, allowing the circuit to overheat and create the potential for a fire or other damage. Placing the fuse on the neutral side of the line provides little, if any, protection from most fault conditions. In installations that use plug-type fuses, the shell side of the fuseholder must be connected to the load side of the line.

(a) Hot lead fused (correct)

(b) Neutral lead fused (incorrect)
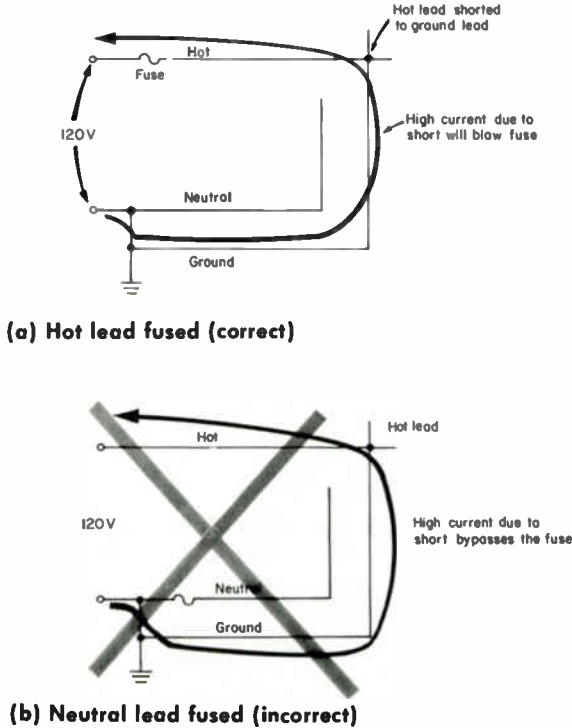
Fig. 16   Placement of fuse in circuit

WHAT HAVE YOU LEARNED?

1. A short circuit is one that has
   - (a) higher than normal resistance.
   - (b) lower than normal resistance.
   - (c) a wire that's too short.
   - (d) a wire that's not long enough.

2. The metal strip of an Edison fuse that has melted due to an overcurrent condition
   - (a) can be repaired by bridging the opening with fusable solder.
   - (b) has done its job, and the entire fuse needs to be replaced.
   - (c) has an extremely high melting point.
   - (d) is the time-delay section of a slow-blow fuse.

3. True or false? Because of the design of most electrical circuits, you should never install a fuse where a breaker is called for, or vice versa.

4. When a _____ has opened due to an overcurrent condition, a renewable strip can be installed in the holder of some versions to restore the device to working order.
   (a) cartridge fuse
   (b) Type S plug fuse
   (c) circuit breaker
   (d) combination breaker in Edison-base plug

5. Plug fuses can be used in circuits that have maximum voltage (line to ground) of _125_ volts and current ratings of _30_ amperes, respectively.
   (a) 125, 15
   (b) 125, 30
   (c) 240, 60
   (d) 240, 30

6. To reset most household breakers, you must
   (a) open the cover of the breaker and replace the strip.
   (b) reset the breaker with the push button or switch handle.
   (c) call the electric company before restoring power.
   (d) unplug all loads on the affected circuit.

7. True or false? Breakers are designed to be protective devices, and should be used only for protection—never as switches.

8. Overheating of electrical equipment is normally caused by excessive
   (a) resistance.
   (b) voltage.
   (c) current.
   (d) insulation.

9. Fuses or breakers should be used to protect _____ circuits.
   (a) high-voltage
   (b) low-voltage
   (c) low-current
   (d) all

10. If a fuse or breaker continues to open frequently in the summer time,
    (a) use a higher-amperage fuse (after getting the approval of a licensed electrician)
    (b) try a slow-blow (time-delay) version of the device with the same amperage rating as the original device.

(c) remove some of the loads from the overloaded circuit, and place them on another circuit.

(d) Both (b) and (c) are correct choices.

11. Type S adapters allow the installation of

(a) fuses of any amperage rating in the adapter.

(b) Edison-base fuses in a Type S holder.

(c) one amperage classification Type S fuses in an Edison-base holder.

(d) a Type S fuse of a different classification than the one called for by the original Type S installation.

12. Time-delay fuses are available in a _____ version

(a) Type S

(b) Type T

(c) cartridge

(d) Any of the above

13. Circuit breakers offer _____ as an advantage over fuses

(a) resetability

(b) versatility

(c) lower cost

(d) (a) and (b)

(e) all of the above

ANSWERS

1. (b)

2. (b) . . . Once the metal strip (which has a low melting point) melts, you must replace it. With a renewable fuse, replace the metal strip with a new one, keeping the original cartridge. For a non-renewable fuse, you must replace the entire unit including the cartridge or holder.

3. False . . . In most cases, fuses and breakers perform identical functions, and one can be used in place of the other. Note, however, that you may have to do some rewiring in making the breaker-fuse interchange, to accommodate the replacement box holder.

4. (a) . . . The meltable strip in a Type S fuse isn't replaceable, while neither a circuit breaker nor a combination breaker in an Edison-base plug contains a consumable strip, and can therefore be reset without replacement of any kind.

5. (b)

6. (b)

7. False . . . Its ability to work in a dual role—as a switch and a protective device—is one of the principal advantages of using circuit breakers.

8. (c) . . . The heat produced is proportional to I^2R. R is determined by the physical construction of the conductor, and remains constant.

9. (d) . . . Fuses or circuit breakers can and should be used in all types of circuits.

10. (d) . . . In the summertime, air conditioners and refrigerators are frequently being turned on and off. When a motor is first turned on, it draws a large smount of current initially and continues to do so until it reaches its operating speed; consequently, it may

briefly overload the circuit. Slow-blow fuses permit such brief overloads. If you con-
tinue to blow fuses, however, you may have to place some loads on other circuits.

11.(c)

12 (d) . . . Time-delay fuses are available in all three forms.

13 (d) . . . Circuit breakers offer both resetability and versatility. They do cost more than
fuses, however.

Lesson 2333A-5

POWER DISTRIBUTION

EXAMINATION

1. Step-up and step-down transformers are used to change voltage and
   (1) current.
   (2) resistance.
   (3) power.
   (4) all of the above.

2. Electrical power is measured in
   (1) volts.
   (2) amperes.
   (3) ohms.
   (4) watts.

3. A light bulb that has a voltage rating of 120 V and draws 0.5 A will consume
   _____ watts of power.
   (1) 40
   (2) 60
   (3) 120
   (4) 240

   $$120 \quad P = E \times I$$
   $$\frac{15}{60.0}$$

4. Long-distance transmission of electricity requires
   (1) high current, low voltage, and low resistance.
   (2) low current, high voltage, and low resistance.
   (3) high current, high voltage, and high resistance.
   (4) low current, low voltage, and low resistance.
   (5) low current, high voltage, and high resistance.

5. The electric wires coming to your home are connected so that
   (1) one supplies 240 V, the second supplies 120 V, and the third is ground.
   (2) you can receive either single-phase or three-phase power.
   (3) the telephone and cable companies can use the same wires.
   (4) two of the wires supply 120 V each when connected to the third wire,
   and 240 V when connected to each other.

6. It's important that you always connect the installed ground lead of an appliance to earth ground
   (1) to guard against the possibility of electrical shock.
   (2) to save on the cost of electricity.
   (3) so that the circuit protective device will open if a short occurs.
   (4) Both (1) and (3) are correct.

7. A two-prong plug tells you that the appliance to which it's attached
   (1) is ungrounded.
   (2) is polarized.
   (3) operates with 120 V.
   (4) must be operated from a receptacle that has only two openings.

8. On a two-prong plug in which one prong is wider than the other, the wide prong
   (1) is connected to the ground lead.
   (2) is connected to the hot lead.
   (3) is connected to the neutral lead.
   (4) can be trimmed to fit all receptacles.

9. To determine the proper amperage rating of the protective device you'll need for a household electrical circuit,
   (1) check the wire size of the circuit to be protected.
   (2) call the electrical supply company that markets the brand of box you have.
   (3) add up the current ratings of all the items you want to supply from that circuit.
   (4) try a 30-A device first, then a 20-A device, and finally a 15-A device. Use the device with the lowest amperage rating that stays on line.

10. Fuses and breakers should be located in the _____ side of the line.
   (1) ground
   (2) neutral
   (3) hot
   (4) All of the above

END OF EXAM

To keep up your good progress, mail in this assignment and immediately go on to the next lesson.

Lesson 2333B-5
Portable Extension Cords

COMMERCIAL EXTENSION CORDS

8 HOW TO SELECT THE PROPER EXTENSION CORD...You've probably discovered that for most jobs around the house that call for portable electric tools you need a portable extension cord. Although extension cords are commonly used in the home to supply power to TV sets, lamps, alarm clocks, and the like, portable cords should actually be used only for temporary installations. If you don't have an outlet where you need power on a permanent basis you should consider installing—or having your landlord install—an additional permanent outlet.

Many buildings—older ones in particular—are sorely lacking in the number of outlets needed to accommodate even a moderate number of the electrical items that we take for granted in this age of stereos, home computers, cable converter boxes, VCRs, as well as an assortment of electrically powered food processors, popcorn poppers, electric knives, and rotisseries. It's easy to see that the home builders and electricians of yesteryear had no inkling of the electrical needs of today. In any case, you should upgrade with permanent installations wherever possible. Most electric companies will provide higher-amperage service to your residence if you request it. New circuits can then be run to the high-usage areas in your home.

Two questions must be answered before selecting an extension cord. First, how long must the cord be in order to reach from an accessible outlet to the location where the portable appliance or tool will be used? And second, how much power will be required for the loads to be operated? The first question is easily answered. Because most retail outlets offer extension cords in a variety of lengths, you don't need exact measurements; 3-, 6-, 9-, 12-, 15-, 25-, 50-, and 100-foot lengths are readily available. Be sure to select a cord that's somewhat longer than the use dictates. A cord that's too short is useless and frustrating—plus the little extra length comes in handy for extension-cord runs that might create a hazardous situation. For example, additional length lets you take the cord through a window or up and over a doorway, rather than across the doorway floor where someone might trip over it.

Extension cords are available in a variety of wire diameters. Typical use usually dictates how the various cords are packaged and displayed. For example, light-duty (low-amperage) cords are usually displayed with lamps; medium-duty cords with power tools and outdoor appliances; and heavy-duty cords with air-conditioner

supplies. For the most part, this is helpful to people who are unfamiliar with electrical theory, since it leads them to the cords best suited to the intended use. However, it's obviously important that the technician have a much better handle on proper wire sizing.

You've probably noticed that light-duty cords have a smaller wire diameter than heavy-duty ones. Later on in this lesson we'll see how such other considerations as voltage and physical environment determine the type and size of insulation. For this part of our discussion, though, we'll concentrate on wire size as determined by the current (or power) requirements.

Large-diameter wire can handle higher current than small-diameter wire, just as large-diameter pipe can accommodate a higher rate of water flow than small-diameter pipe (or a four-lane highway can handle more traffic flow than a two-lane highway). Using the same reasoning, a larger-diameter wire can always be used in place of a smaller-diameter wire, just as large pipes can deliver small amounts of water and multi-lane highways can carry light traffic. And using over-sized wire has some advantages: for one thing, a current of 10 A in a larger wire produces less heat (line loss) than does 10 A in a smaller wire. (Higher cost and greater physical bulk are disadvantages to using larger-diameter wire.)

On the other hand, never use a wire that has a smaller diameter than recommended. The overheating that inevitably results when the recommended maximum amperage is exceeded is a definite fire hazard. Overheating also breaks down the protective insulation, which can easily set the stage for a "shocking experience."

We'll now see how to determine the correct wire size. Table 1 lists the ampacity for conductors of various sizes used in flexible extension cords. (Ampacity is the maximum current, measured in amperes, that a wire can carry continously without exceeding its maximum temperature rating.) We'll learn more about the different types of cords later on in the lesson, but for now we'll assume that we're using the type of cord that fits the description of column A in Table 1. To determine the proper wire size, let's say we need to supply a tool that will draw 6 A, as marked on the nameplate of the tool. As you can see, in this instance the task of wire selection is a snap. We can see that any of the cord sizes listed in Table 1, size AWG 18 or larger, is acceptable for this job.

Table 2 lists the diameters (in inches and millimeters corresponding to the various American Wire Gauge (AWG) number. Note that a larger gauge number means a smaller wire diameter. For example, wire that measures AWG 10 is larger in diameter than wire that measures AWG 18. For the most part, selecting the proper wire size is a fairly straightforward process: simply note the current requirement of the load, use a chart like table 2 to find which size wire can carry that load, and select a cord of at least that diameter.

Table 1
Current-Carrying Capacity of Flexible Conductors

Wire Size AWG number	Capacity (in amperes) [1]	
	A [2]	B [3]
18	10	7
16	13	10
14	18	15
12	25	20
10	30	25

1. Based on a maximum ambient temperature of 30° C (86° F) for Types SP, SPT, SJ, SJT, S, ST, SVT.
2. Column A values apply where no more than two conductors in the cord are current-carrying conductors. The cords may have more than two conductors, as in three wire cord, where the third wire is used as a ground (non-current-carrying) wire.
3. Column B values apply where no more than three conductors in the cord are current-carrying conductors. The cord may have more than three conductors, as in four conductor Type SJ cord, but the fourth wire can only be used as a non-current-carrying ground lead.

Source: National Electric Code Handbook (1984 Edition), published by the National Fire Protection Association.

Table 2
Wire Diameters by AWG number

American Wire Gauge AWG Number	Wire diameter		Side View	End View
	(in.)	(mm)		
28	0.013	0.32		
26	0.016	0.40		
24	0.020	0.40		
22	0.025	0.64		
20	0.032	0.81		
18	0.040	1.02		
16	0.051	1.29		
14	0.064	1.63		
12	0.081	2.05		
10	0.102	2.59		
8	0.128	3.26		
6	0.162	4.12		

Let's take a look at some cases that call for a little more knowledge. (As a technician, such expertise in these situations will come to be second nature.) Suppose, for example, you have a circular saw that has lost its nameplate; however, you know—from a label on the tool, or from the owner's handbook—that the usable power of the tool is 2.0 hp (horsepower). Here, we have to convert the horsepower rating to another form of stating power. You may know that one horespower is theoretically equivalent to 746 W. However, since all motors run at less than 100 percent efficiency, and since the characteristics of AC produce reactive currents that don't produce useful power, we will use the handy conversion factor that states that 1000 W of electrical input power produces 1 hp of useful mechanical output power. (Don't be too concerned with the term reactive current at this point in your studies: you'll learn more about AC circuits and reactive components in a later lesson.) Since an input of 1000 W produces 1 hp of output power, then the input power needed to produce 2 hp of output power is:

$$P \text{ input } = 2.0 \text{ hp } \times \frac{1000 \text{ W}}{1 \text{ hp}}$$

$$= 2.0 \times 1000 \text{ W}$$
$$= 2000 \text{ W}$$

Remember to use the conversion factor of 1000W = 1 hp for any practical problem. Do not use the theoretical conversion.

Next, we find the current required to run the saw. In a previous lesson, we learned that power (in watts) is equal to the product of the voltage (in volts) times the current (in amperes). Stated mathematically:

Power (P) = Voltage (E) × Current (I)

Rearranging the terms, we see that

$$P = E \times I$$

leads to

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

Replacing the terms of the equation with the information known, we find that

$$I = \frac{2000 \text{ W}}{120 \text{ V}}$$
$$I = 16.7A$$

Referring to Table 1, we can see that a cord made of wire size AWG 14 or larger can safely supply power of our circular saw.

If you're going to operate more than one item simultaneously, simply group the items together, add up the current demands of all loads, and refer to a chart like Table 1. Note that if you're going to operate a 16.7-A saw, a 1.7-A drill, and a 1-A

sander, but only one of them at any given time, then the highest amperage load—in this case, the saw—determines the necessary wire size (AWG 14). Since either the drill or the sander operating alone requires less current than the saw, it follows that a cord that can safely supply the saw can be used for the drill and sander. Had we selected the cord based on the current requirement of the drill or sander, we might have selected a wire diameter of AWG 18. Cord of this size will safely handle the drill or sander, or even both together. But, since wire of size AWG 18 is rated only for a maximum of 10 A, it shouldn't be used to supply the power to operate the 16.7-A saw. Note that if other people are working on this project with you, and that therefore all three items could possibly be operating at the same time, then the sum of the individual current requirements—16.7 A + 1.7 A + 1 A, or 19.4 A—indicates that you should use size AWG 12, or larger, wire.

In most cases, cords of sufficient length and wire diameter are readily available at hardware and electrical-supply stores. Purchasing ready-made cords is usually the most economical way to go. In general, cords should not be spliced together. Try to use a continuous length of uncut wire that reaches from the power source to your work area. However, if you find that you need a cord that's larger in diameter or longer, most hardware and electric-supply stores sell cords of various diameters that can be cut to any length. You'll also need to purchase an attachment plug (the male end) and a receptacle (the female end) that match the type and size of cord that you purchase. Electric-supply stores usually carry a number of different types of cord, plugs, and receptacles. Unless you know how to match these items, however, you'll have to rely on the experience of others—and the experienced and knowledgeable personnel who work in hardware and electric-supply stores are usually a better bet than the kind of temporary help you'll encounter at department or discount stores. It's true that by going the latter route you may save a few cents on the puchase price—but using the wrong combination of wire plugs and receptacles could result in a dangerous situation. (Later on in this lesson you'll learn how to make up your own extension cord.)

WHAT HAVE YOU LEARNED?

1. True or False? You should always buy an extension cord at least twice as long as you actually need.

2. True or False? If you need a 19-foot extension cord you'll have to make your own, since a cord of that exact length is not available in a store.

3. True or False? When making up an extension cord, you should always use a wire of the largest diameter you can find.

4. True or False? Only one power tool should be supplied from a single extension cord.

5. You measure the distance from the nearest electrical outlet to your work area to be 14 feet. A good choice of cord length would be __25__ feet.
   - (a) 12
   - (b) 15
   - (c) 25
   - (d) 100

6. If you want to increase the amperage that comes into your home,
   - (a) use higher-amperage fuses or breakers.
   - (b) add more breakers to your breaker box.
   - (c) install additional in-wall wiring runs.
   - (d) call the electric company.

7. Which one of the following wire diameters is the largest?
   - (a) AWG 18
   - (b) 0.050-in.
   - (c) 1.40-mm
   - (d) AWG 20

ANSWERS

1. False . . . However, you should choose a cord length that's long enough that you don't have to stretch the cord tight when it's in use. A cord that's about half again to twice as long as the distance from the receptacle to the work area is a good choice.
2. False . . . You'd choose a 25-foot cord for this job.
3. False . . . Cord of larger diameter is safe to use—however, unless you need the heavier cord for higher-power application at another time, you can keep your costs down by buying the cord that's sized for the job you want to do now.
4. False . . . You can supply as many appliances as you want from a single cord, as long as you don't exceed the ampacity of the cord.
5. (c) . . . 15 feet doesn't allow adequate slack in the cord, 12 feet is too short, and 100 feet is too long.
6. (d)
7. (c) . . . Refer Table 2 obviously AWG 16 is larger than either AWG 18 or AWG 20 wire, a diameter of 0.05 in. is slightly smaller than AWG 16 wire, and finally 1.40 mm is larger than AWG 16.

9 TYPES OF ELECTRICAL CORD AND INSULATION ... Different types of cord require different insulation. The wire in most flexible cords is made of copper, although aluminum conductors are also available.

Warning: when using aluminum conductors, special switches and receptacles must be used. These are marked "CO/ALR," which means they are suitable for either copper or aluminum hookups. Attempting to connect aluminum wire directly to copper wire, or to a terminal that isn't specifically designed to be connected to aluminum, can easily create a fire hazard. Corrosion

can build up between the copper and aluminum materials, and produce a high-resistance connection. Even with a current well below the rated design of the circuit, the heat produced under these conditions can be high enough to destroy the connection, cause a flash, and start a fire.

Let's take a look now at some of the various types of insulation and their uses. In order to reduce the risk of electrical shock to the user (as well as to keep the conductors from contacting each other), portable flexible cords have one or more layers of insulation surrounding each conductor. Multi-conductor cords may also have an outer layer of insulation that surrounds all the wire in the cord. This provides additional protection, as well as physically holding the wires together. Here, we'll examine only the types of insulation commonly found on extension cords, (for more information on cords suitable for high-temperature, hazardous, extra-hard usage, and other special situations consult the National Electric Code, Under-writers Laboratory standards, and the various manufacturers' literature.)

First, let's look at light-duty cord. You're probably most familiar with household parallel cord, sometimes called lamp cord or zip cord. See Fig. 17. If you make a slit at one end of a length of parallel cord and then pull the leads away from each other, the cord will split, or zip apart. Parallel cord carries electrical designation of types SP, SPE, or SPT. The letters of the designation indicate the material and usage of the insulation. (The letter P stands for parallel.) Type SP carries a thermoset material as insulation, Type SPE has an elastomer (thermoplastic) cover, and Type SPT sports an all-plastic outerwear. These three types are interchangeable, and all are suitable for use in light-duty conditions. They are available in sizes AWG 18 up to AWG 10 and are useful for most portable items. Types SP, SPE, and SPT, are suitable for use in damp locations. Insulation thickness runs from 30-60 mils for size AWG 18 up to 110 mils for size AWG 10. (1 mil = 0.001 in.). Parallel cord comes in two-or three-conductor versions; the third conductor can be used only as a non-current-carrying ground lead.

stranded conductors

groove, rib, stripe, or ridge on insulation of one wire

plastic cover
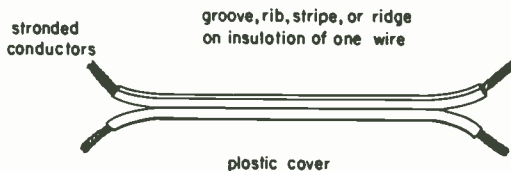
Fig. 17   Two-wire parallel (Zip) cord

For most jobs, you'll probably want to select a cord that can handle more rugged conditions than the SP types can. Here's where junior hard-service cord (Type SJ) comes into play. Most of us are familiar with the circular-cross-sectioned Type SJ cord shown in Fig. 18. Like Type SP cord, Type SJ comes with conductors that range in diameter from AWG 18 up to AWG 10. Type SJ cord has insulation

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Fig. 18   Heavy-duty extension cord cable

around each of the conductors, as well as an outer jacket that surrounds all the insulated conductors within the cord. That helps make Type SJ cord more rugged than Type SP cord. You could cut through the outer cover of Type SJ cord, and the insulation surrounding each of the conductors would still offer sufficient protection from shock or shorting. The insulation on Type SP cord, in most cases, also acts as the outer cover; therefore, a cut through the outer cover of this type will expose the copper conductor.

Like Type SP, Type SJ offers the choice of thermoset (Type SJ), thermoplastic elastomer (Type SJE), and thermoplastic (Type SJT) materials as insulators. Usually, the outer cover is made of the same material as the insulation material. Types SJO and SJTO cord are made with oil-resistant material as the outer cover. Types SJOO and SJTOO cord have both layers (insulation and outer cover) made of oil-resistant material. Nominally, thickness of the insulation on Type SJ cord runs from 30 to 45 mils around each conductor. In addition to the insulation, Type SJ offers additional protection in the thickness of the outer cover.

Type SJ cord comes in two, three and four conductor versions. If Type SJ cord is used (meaning that only two conductors in the cord carry current), then the ampacities listed in column A of Table 1 apply. If three of the conductors in the three or four conductor versions carry current, then the reduced ampacities shown in column B of Table 1 must be respected as the maximum-allowable current values. (This situation is more likely to be found in an industrial or commercial setting than around the home.)

For such extra-hard-usage jobs as theater stages and garages, hard-service cord types S, SE, SO, SOO, STO and STOO fill the bill. These designations are similar to those used for the different versions of Types SJ and SP cord. E, for example stands for elastomeric material, and O stands for oil resistance. Hard-service cord come in wire sizes between AWG 18 and AWG 2.

Other cord-type designations, such as HS, HSJ, and HSJO, denote hard-service, junior hard-service, and oil-resistant junior hard-service cord. Type H (x) cord is the choice where continuous high-current situations are expected, since it can handle 20 to 50 percent more current than can similarly sized Type S (x) cord. Types SV, SVE, SVO, SVT, SVTO, and SVTOO are vacuum cleaner cords, which have the same current limits as a Type S (x) cords of equal diameter.

One of the few situations in which the use of asbestos is still tolerated is in the insulation of heat-resistant cord. Cotton Type, CFPD, and asbestos types AFC

and AFPD have slightly less ampacity than Type S(x). Thermoset-jacketed heat-resistant cords, Types AFS and AFSJ, have the same ampacity as Type H(x) heater cord.

WHAT HAVE YOU LEARNED?

1. Most flexible cord is made with _copper_ wire.
   (a) aluminum
   (b) copper
   (c) steel
   (d) nickel-chromium

2. For less rugged situations, such as light-duty general household chores, Type _____ cord fits the job.
   (a) SPT, AWG 16, 18
   (b) SJ, AWG 14
   (c) STO, AWG 10
   (d) HS, AWG 12

3. Insulation on most flexible cord is made of
   (a) rubber. ⎱
   (b) plastic. ⎰
   (c) aluminum.
   (d) copper.

4. Such electrical designations as SPT, SJ, and HSJO identify
   (a) the current-carrying capacity of the cord.
   (b) the type of insulation and protective covering of the cord.
   (c) the manufacturer's name, as listed in the NEC Code.
   (d) UL approval of the cord.

ANSWERS

1. (b)
2. (a)
3. (b) . . . Rubber is still found on some cord that was made in the past. Aluminum and copper are conductors, not insulating materials.
4. (b)

MAKING YOUR OWN
EXTENSION CORDS

10 HOW TO MAKE A LIGHT—DUTY EXTENSION CORD... We'll now see the proper way to make two kinds of extension cords: first, a light-duty cord, and then—in the next topic—a heavy-duty one. Study each of the figures and captions in the following pages carefully: they tell the story, and point out the precautions you should take.

Before building an extension cord, decide what you'll be using the cord for. Choose a wire size that can easily handle the current requirements of the most powerful appliance that you intend the cord to supply. As we pointed out earlier, you can always use a larger wire size than you need, but never one that is too small for the job.

As with all flexible extension cords, each conductor has many fine strands of copper wire woven together to make up the stranded conductor. This stranding allows the cord to withstand many cycles of bending without breaking. You may be familiar with Type NM nonmetallic-sheathed cable—the type most commonly used to supply electrical power in the home. Each of the conductors in a length of Type NM wire is made of a single strand of wire—hence, the term solid-wire conductor. A solid-wire conductor is stiff, however, making it hard too handle, and it won't take many flexings before it breaks. (You can see why it's best to make extension cords with stranded-wire conductors.)

flexible cord AWG 18 sometimes called zip cord or parallel lamp cord.

two-prong male plug

female receptacle
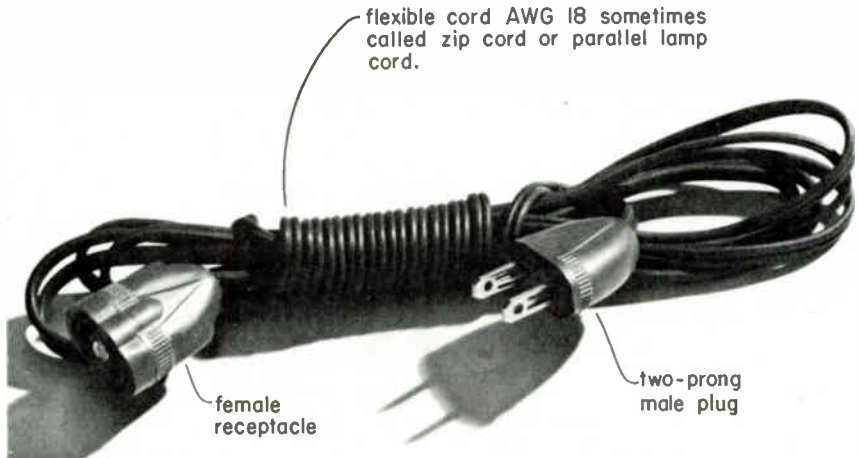
Fig. 19   Light-duty extension cord

The extension cord in Fig. 19 is constructed from Type SPT flexible plastic-insulated cord. The wire inside the insulation measures AWG 18. Where we'll tell

you how to assemble one of the many types of available plugs and receptacles suitable for making up or repairing a Type SPT extension cord. Remember, with this size of wire (AWG 18) and light-duty insulation (Type SPT), the cord we'll end up with is suitable only for low-power appliances.

Figures 20 and 21 show how to start making the cord. Begin by making a small cut in the groove between the two conductors. (A pocket knife or pair of diagonals does this job nicely.) Then, grasp one conductor with the thumb and forefinger of each hand, and separate the conductors. (a separation of an inch or so is plenty.) With a wire stripper, strip about ½ in. off the insulation from the end of the wire, exposing the conductor. You can use a wire stripper or knife for this job; just be sure that you don't nick the strands of the conductor. If you should happen to nick the strands, start over with a clean cut at the end of the cord. Nicked strands can break loose and cause two kinds of damage: one, by reducing the diameter of the conductor, the amount of current that cord can safely handle is reduced; and two, loose strands can fall from the connection, bridging the hot and neutral conductors and causing a short.
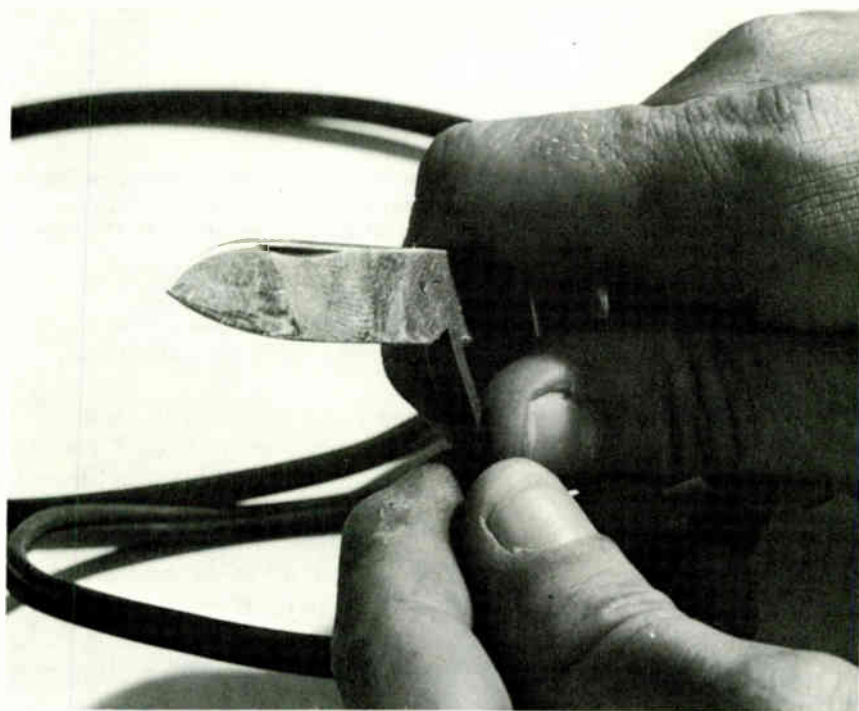
Fig. 20   Use a knife to cut a small slice down between the two wires (conductors). Be careful not to slice the insulation too closely to either of the wires.
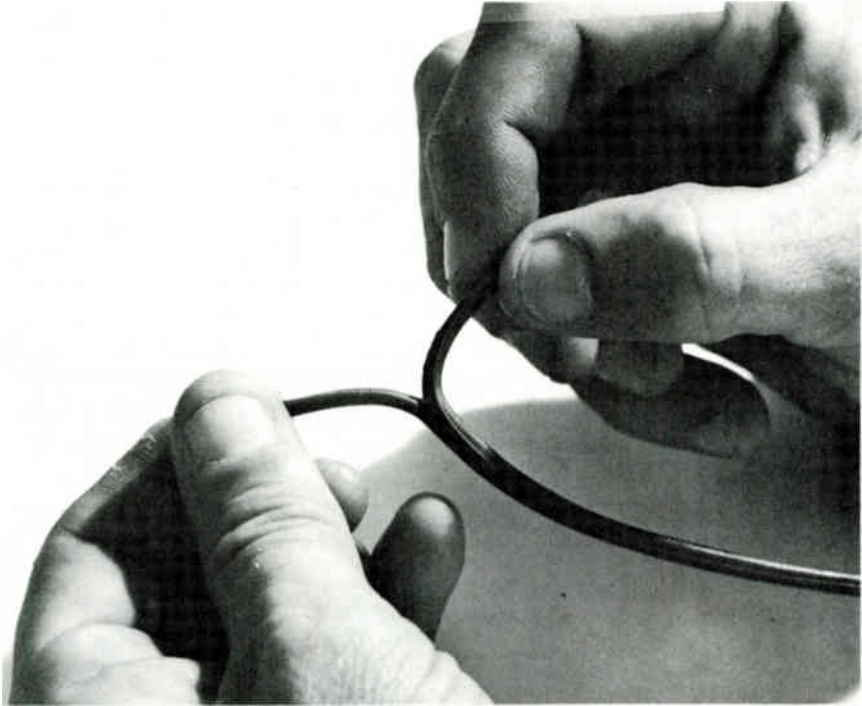
Fig. 21   After you've made a slight cut in the cord, take the cord ends in your fingers and just pull. This type of cord separates easily: it will "zip" apart. Separate the two conductors for a length of approximately 1½ inches.

Next, tightly twist the exposed strands at the end of the conductors, using your thumb and forefinger so that there are no strands "flapping in the breeze."

Note. NEVER tin the ends of stranded conductors with solder if you're going to make a pressure-type connection. The screw head, when tightened, makes a pressure connection to hold the wire in place. If the end of the wire has been tinned, current flowing through the connection causes the solder to heat up and soften. The connection then loosens, creating a high-resistance point. Since the current remains the same, (as required by the load), the power that the connection must dissipate increases as the resistance increases according to Ohm's law ($P = I^2 \times R$). Normally, the connection has very little resistance, and therefore the heat that the connection must dissipate is minimal. Increasing the resistance of the connection by only a few ohms can lead to disastrous results.

When connecting the wires to the screw terminals, be sure to wrap the wire around the terminals in the proper direction, as shown in Fig. 22. This will allow the

screw head to pull the wire closer to the center as it's tightened. Note that if you wrap the wire around the screw in the wrong direction, when you try to tighten the screw it will push the wire strands outward and make a poor connection. Figures 23 and 24 show how to complete the cord construction.
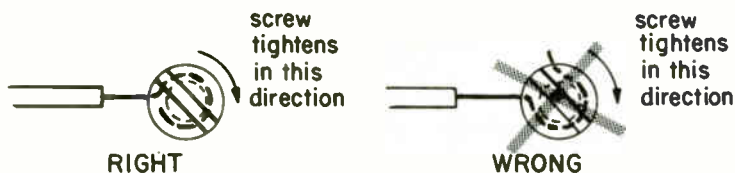
Fig. 22 **Place the bare wire around a terminal screw in the direction in which the screw tightens. (Wrapping the wire in the opposite direction tends to force the wire out from under the screw as you tighten it.**

(a)   (b)
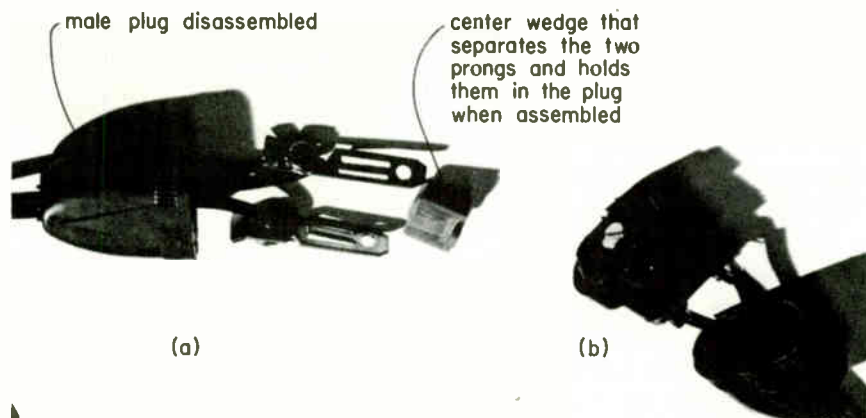
Fig. 23 **(a) Disassemble the male plug. This type has a center wedge that can be pushed out of the plug with a screwdriver inserted through a hole in the rear of the plug. Remove the two prongs. Insert the cord through the plug. Place the stripped wire in the slot of the prong, wrap it around the screw, and tighten.**
(b) Disassemble the female receptacle. This type has a screw in the center that holds the receptacle together. Insert the wires, and connect them to the screws. Reassemble the plug and receptacle.

Push the center
plug in firmly.
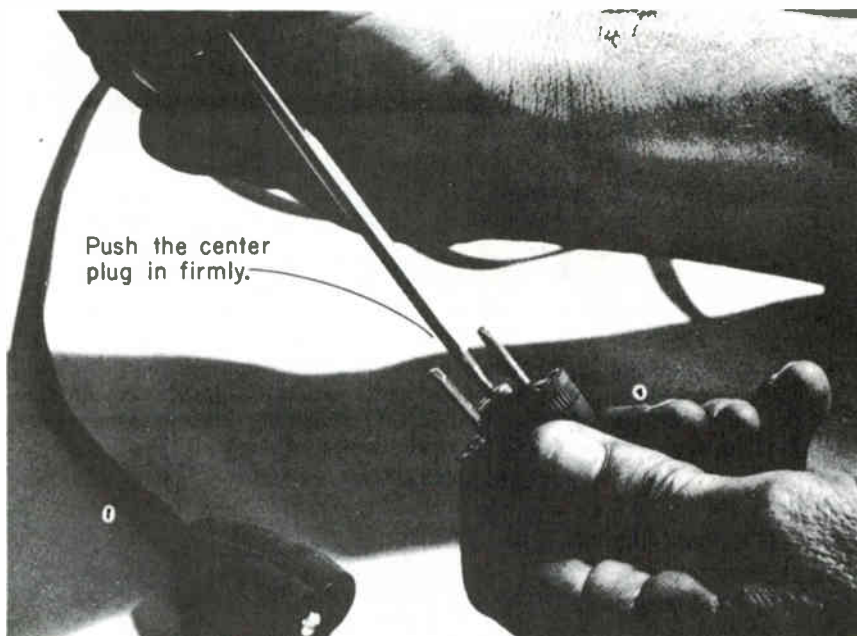
Fig. 24   Assembly of the male plug and female receptacle.

After connecting the wires to the screw terminals, attach the cap. Some caps, such as the one shown in Fig. 23 use a center plug that attaches to the cap with a screw. In other designs, the cap merely snaps onto the plug, with detents holding it in position. Some plugs can be assembled by merely inserting the end of an unstripped piece of wire into the plug, and then snapping the cap in place.

After connecting the plug end, hook up the receptacle in the same manner.

After making up an electrical cord, always check it with a multimeter or continuity tester. There must be infinite resistance between conductors, and there must be no resistance as measured from the plug end to the receptacle end of each conductor. An informal tour of your local hardware, electrical, or electronics supply house will help familiarize you with basic electrical gadgetry

11 HOW TO MAKE A HEAVY-DUTY EXTENSION CORD ... Now let's tackle the task of making up a heavy-duty cord. Remember to follow all the safety precautions and hints that you learned for making the light-duty cord. Any modifications that you need to make for the heavy-duty cord are noted in the captions to Figs. 25 through 36. Start by assemblying the materials and tools you'll need for the job, and follow the photographs and captions of Fig. 25 through 36 closely.

Fig. 25   First step in any project: organize your work and tools. For our portable
          heavy-duty extension cord, we'll use Type SJT, AWG #14/3 (three-
          conductor) cord. Markings on the outer covering of the cord identify these
          parameters. This cord was taken from an extension cord whose receptacle
          had been damaged. Clockwise from the cord—the tools we'll use in this
          project: wire stripper, flat-bladed screwdriver, pocket knife, diagonal wire
          cutter, and replacement male plug and female receptacle.
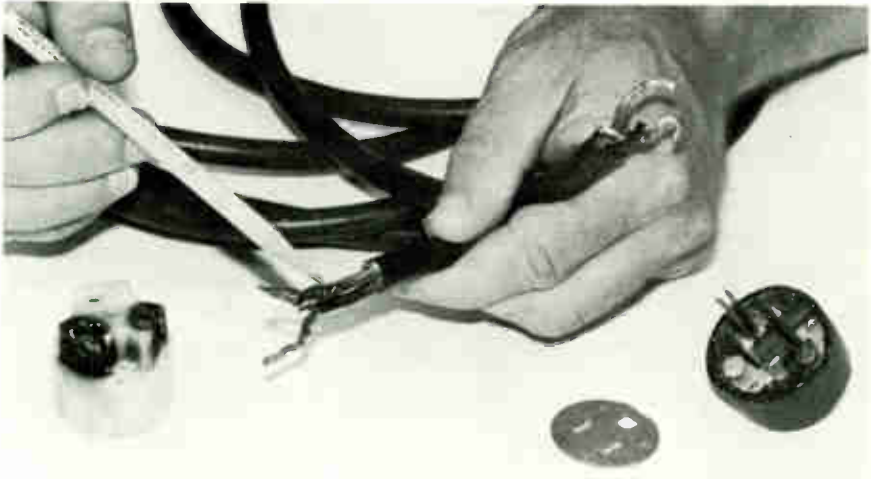
Fig. 26   Here we show why the cord needed repair. Notice that the stripped ends
          of the wire have been tinned with solder. The female receptacle, lower
          left, that had been attached to these wires, shows the result of a connec-

tion made with stranded wire that has been tinned. Current that flowed through the connection generated enough heat to soften the solder, thus making a loose connection. The loose connection then became a high-resistance point. The connection could not dissipate the generated heat, and, as the photograph shows, became charred. Pressure-type connections, such as the screw types shown here, require only that you tighten the screw with a small-to-medium sized screwdriver to make a good connection. The lower right-hand corner of the picture shows an old-style plug, one that is no longer approved for use. The cardboard (or plastic) cover which slides down over the prongs, can easily become loose and fall off. This leaves a hazardous partially exposed connection.
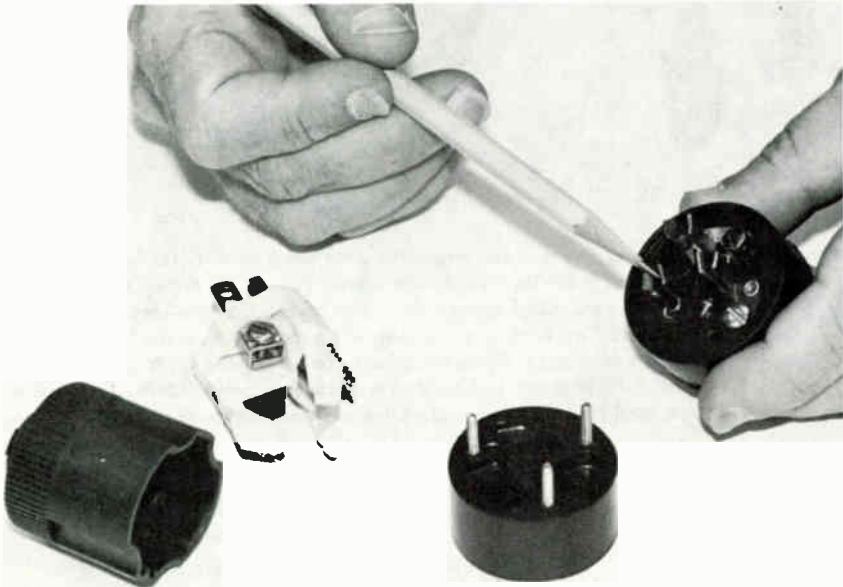
Fig. 27   Inspect the internal portions of the replacement plug and receptacle. Make sure the connection clips, as indicated in the figure, are correctly aligned to mate with the male plug. If a clip has been bent, or the gap between the sides of a clip are spread apart too far, the receptacle will not mate correctly with the plug. You can align the clips using your fingers, or, using small pair of pliers.
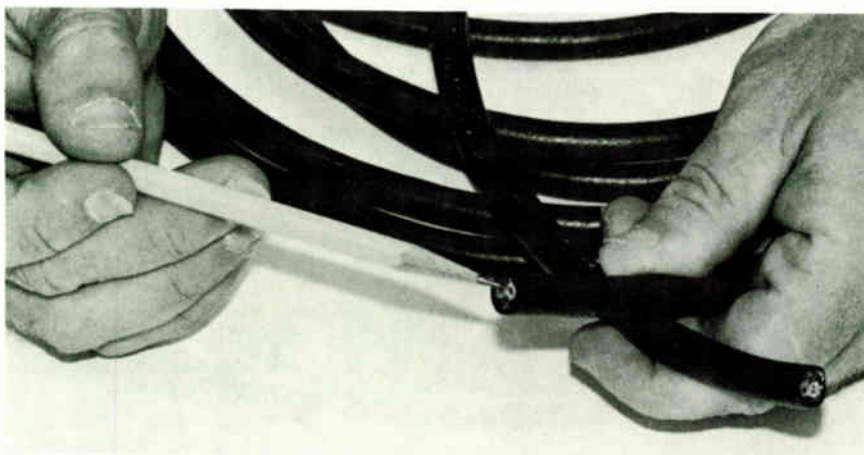
Fig. 28   Start the repair by making a clean cut on both ends of the cord. Diagonal pliers do a good job. Make sure that you cut off enough old cord to remove any damaged or charred wire.

Fig. 29   Strip off 1-½ to 2 inches of the outer cover, exposing the three insulated conductors. The length of exposed insulated conductor depends on the type of receptacle you have. For the receptacle shown in the photograph, 1-¾ inches was the proper length. Take care not to nick the insulation on the conductors. If you nick the insulation, just clip off that section and strip off some additional outer cover.
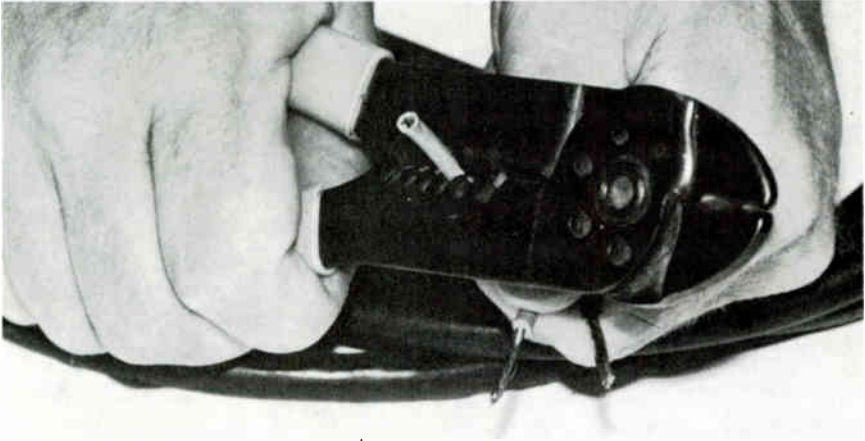
Fig. 30   Next, strip off about ¾ inch of the insulation from the conductors. Inex-
pensive multi-size wire strippers, such as the one shown, do the job well.
You can also use a pocket knife to strip the wire, but the chances of nick-
ing or cutting through some of the strands of the conductors are greater
when using a knife. Check your stripped lengths by fitting the cord in place
in the receptacle before going to the next step. Make any adjustment you
need to the stripped lengths now.

Fig. 31   Tightly twist the exposed ends of the stranded conductors in a clockwise
direction using your thumb and forefinger in a clockwise direction. Make
sure all of the strands are twisted together. Loose strands can become short
circuits when you put the finished product to use.
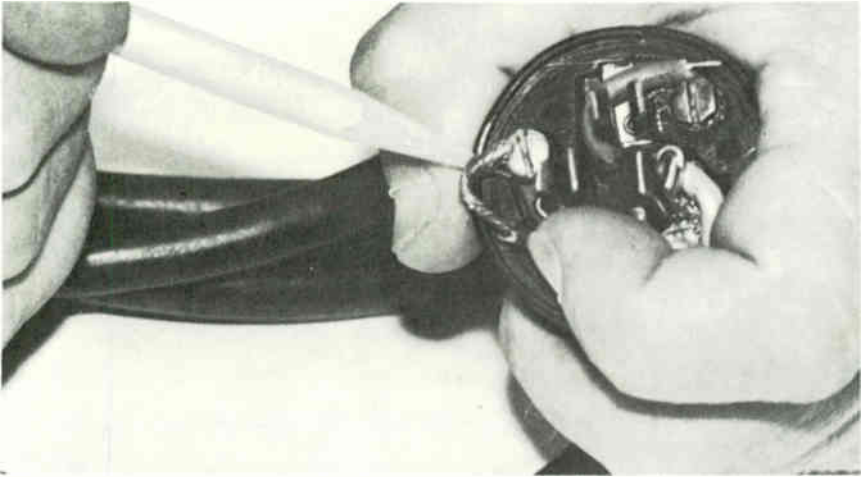
Fig. 32   Fit the receptacle into the wire. Looking at the receptacle end wire as shown in the figure, the color of the insulation, in a clockwise direction, should be a green-white-black. If the color scheme is reversed, this end of the wire should be attached to the male plug. Strip the insulation from the other end of the cord for the receptacle. Note the direction that you should wrap the wire around the screw terminal. Wrapping the wire around the screw in a clockwise direction, as shown in the figure, will help to pull the wire tight around the screw when you tighten the screw.
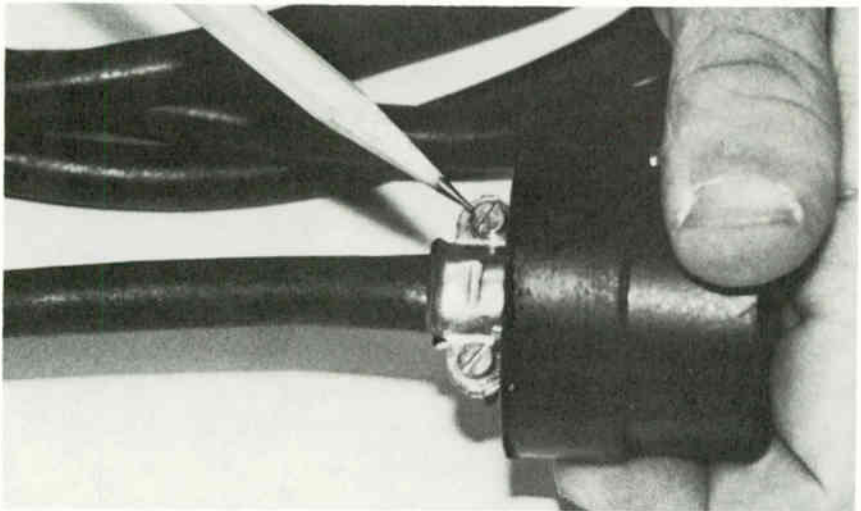
Fig. 33   After attaching the protective cap to the end of the receptacle, make sure you tighten the screws that secure the receptacle to the cord. This fastener should grip the outer cover of the cord. If you try to fasten this clip around the red-, green-, and/or black-insulated conductors, you may cause a short. Also, the clip will not properly secure the receptacle to the cord unless it grips the outer cover.

48
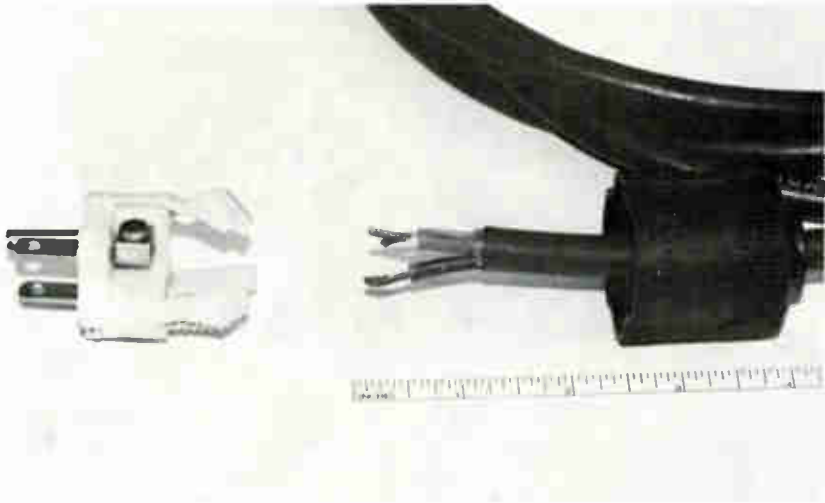
Fig. 34   Now for the male plug. We have stripped off the outer cover back, 1-½ inches for this style plug. For this plug, ½ inch of each of the conductors was exposed. Remember to fit the cap onto the wire before making the connection.
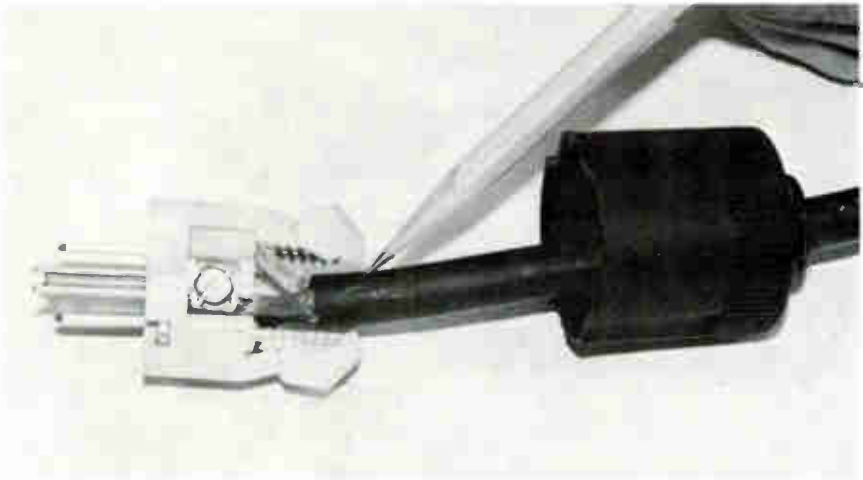
Fig. 35   With this style plug, the wire end should be tightly twisted, but left straight. The connector in the figure has a slot, into which the wire fits. When you tighten down on the screw, it clamps the connector tight around the wire. Notice the clips that we point out in the figure. These are the grippers that close around the cord when the cap is attached to the plug. The grippers must hold the outer cover of the cord. They will not properly secure the plug to the cord if you have stripped the outer cover back too far.

Fig. 36   The finished product. After you fasten the cap to the plug, sit back and relax. Remember to test the cord with a multimeter, as we did for the light-duty cord in the previous topic.

WHAT HAVE YOU LEARNED?

1. With a light-duty cord, you should strip off the insulation to expose about _____ inch of the conductor.
   (a) ¼
   (b) ½
   (c) ¾
   (d) 1

2. True or False? Tinning the exposed ends of the conductors with solder will help make a better connection at the attachment plug and receptacle of your extension cord.

3. Looking at the screw head of an attachment plug or receptacle connection, the wire should be twisted around the screw _____ turn(s) in a _____ direction.
   (a) one; clockwise
   (b) one; counterclockwise
   (c) several; clockwise
   (d) several; counterclockwise

1. (b) ... This is sufficient length of conductor to provide a good wrap around the screw. If you expose too little conductor, you may not be able to obtain a good connection when you tighten the screw. If you expose too much conductor, you run the risk of causing a short between the hot and neutral leads.
2. False ... NEVER tin the end of stranded wire that you are going to use in a pressure connection as the screw connection. When the cord is in use, the current flowing through the connection can heat up the solder and cause it to become soft. The connection then loosens and becomes a point of high-resistance, which can cause a fire.
3. (a)

Lesson 2333B-5

PORTABLE EXTENSION CORDS

EXAMINATION

1. Extension cords are properly used as

     (1) permanant installations where additional outlets are needed to operate modular entertainment equipment.

     (2) power supplies to garages and basements where no permanent outlets exist.

     (3) temporary installations.

2. The ___2___ determines the amount of current that a cord can handle.

     (1) length of the cord

     (2) wire diameter

     (3) type of insulation

     (4) thickness of the insulation

3. In order to supply a load of 20 A, a conductor with a wire size of _____ will safely handle the job.

     (1) AWG 18

     (2) AWG 16

     (3) AWG 15

     (4) AWG 12

4. A portable electric power tool is rated at 1.00hp. What rating, in watts, should you use to calculate the current required by this tool?

     (1) 0.001796

     (2) 746

     (3) 0.001

     (4) 1,000

5. How many amperes will the tool given in the previous question draw? (Use a line voltage of 120 V.)

$$I = \frac{P}{E} \qquad \frac{1000}{120} = 8.33$$

    (1) 8.33 A
    (2) 0.833 A
    (3) 89.6 A
    (4) 0.011 A

6. Insulation
    (1) protects the user from electrical shock.
    (2) prevents the conductors from contacting each other.
    (3) prevents the conductors from contacting electrical ground.
    (4) All of the above

7. For rough service around the home, such as the use of power tools, lawn-care equipment, and the like, you would likely choose _____ flexible cord.
    (1) Type SPT, AWG 18
    (2) Type SJ, AWG 16 or 14
    (3) Type ST, AWG 10
    (4) Type HSJO, AWG 12

8. For a portable extension cord, you should choose
    (1) solid-wire conductors.
    (2) stranded-wire conductors
    (3) ribbon cable.
    (4) coaxial cable.

9. True or False? Since a stranded conductor contains many fine wires, it's OK to use the conductor if you nick only of few of the strands.
    (1) True
    (2) False

10. After making up an extension cord, a test with a multimeter or continuity tester will show the cord to have _____ resistance from conductor to conductor, and _____ resistance from the plug end to the receptacle end of each conductor.
    (1) zero; zero
    (2) zero; infinite
    (3) infinite; zero
    (4) infinite; infinite

END OF EXAM

To keep up your good progress, mail in this assignment and immediately start the next lesson.

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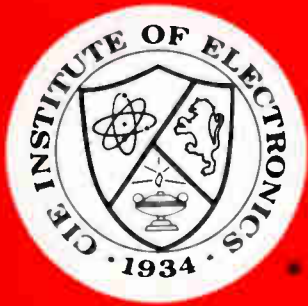
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$$\frac{E}{I \times R}$$

Lesson 2339A-6
The Three Basics of Electric
Circuits: Voltage, Current, and Resistance

Lesson 2339B-6
Ohm's Law, Conductors, and Insulators

AUTO-PROGRAMMED® Lessons

ABOUT THE AUTHOR

Wayne Lemons has had more than forty years of practical experience in the electronics field. During World War II, he served in the U.S. Air Force as a loran and radar technician. After his discharge in 1946, he went into radio and TV servicing. His success was such that, in 1958, he was one of ten men in the country to receive the coveted All-American Technician Award.

Mr. Lemons' experience includes many years of teaching electronics to high school students. He founded station KBFL, Missouri's first and most powerful high school radio station. In addition, he has written seven books and more than 250 magazine articles on radio and TV servicing and other practical aspects of electronics.

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Lesson 2339A-6
The Three Basics of Electric
Circuits: Voltage, Current, and Resistance

Lesson 2339B-6
Ohm's Law, Conductors, and Insulators

By WAYNE LEMONS
Technical Staff
Cleveland Institute of Electronics, Inc.

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

A Chat with Your Instructor

You have already learned that an electric current is formed by the movement of electric charges. These moving charges are usually—but not always—free electrons. The force moving the charges is usually the repulsion that exists between like charges and the attraction that exists between unlike charges. The strength of this force is, of course, one of the factors that determines the speed and number of the moving charges. The names for this force, and how it is measured (in volts), are the subject of this lesson.

The *voltage,* or force, is one of the three important features of any electric circuit. One of the other two features is the rate at which electric charges move through the circuit. This rate is the *current* strength, and is measured in *amperes.* Electric current, then, is the motion of electricity (that is, electric charges) from one point to another.

In an electric circuit, the current performs much the same function that a fleet of trucks does in hauling coal from mine to market. The rate at which the coal moves depends upon both the number of trucks and how fast they travel. Similarly, the rate at which electricity is moved from point *A* to point *B* (the current strength) depends upon both the number of charges (usually free electrons) that are moving and how fast the charges travel. A current strength of two amperes, for example, might be made up of many free electrons moving slowly, or of only a few free electrons moving at a faster pace. Contrary to what many people believe, these free electrons never move very fast along a solid conductor—never more than a fraction of an inch a minute.

The important thing to remember about current is that an ampere is a measure not of the *amount* of electricity, but rather of the rate at which the electricity is moving. We measure the *amount* of electricity—say, the charge within a capacitor—by a unit called the *coulomb,* which will also be discussed in this lesson. Measuring the amount of electricity within a capacitor in coulombs corresponds roughly to measuring the amount of coal on hand in our fleet of trucks, in tons.

Force and current strength, then, are two of the three important features of every circuit. The third feature is *resistance,* measured in *ohms.* Resistance is the electrical friction that makes it hard for current to flow. Consequently, we can adjust the current in a circuit to the value we want by adding a *resistor* of the right value. In this lesson, you will also learn how to tell the value of a resistor by the color bands printed on it.

Lesson 2339A-5: The Three Basics of Electric Circuits: Voltage, Current, and Resistance

1 INTRODUCTION TO WIRING DIAGRAMS . . . People who work in electronics commonly refer to wiring diagrams as *schematic* (skee-MAT-ick) diagrams. So that wiring diagrams can be drawn clearly and rapidly, certain easily drawn symbols are used to represent the parts with which electrical and electronic circuits are built. A few of these symbols are shown in Fig. 1, and you should become familiar with them now. Note that the positive terminal in the symbol for a battery is always drawn as a long line, and the negative terminal as a short line. The + sign shown in Fig. 1(a) and (b) to indicate the positive battery terminal is not really needed, and is often omitted.

(a)   (b)   (c)   (d)
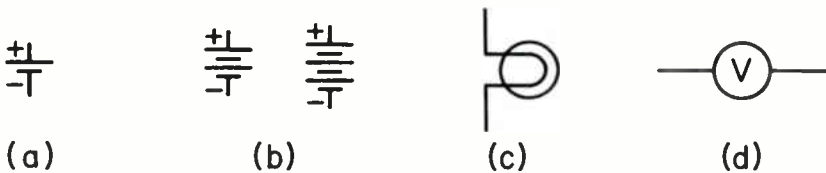
Fig. 1 **(a) A single-cell battery, such as a flashlight cell. (b) A battery with more than one cell. (Note that the symbol only indicates this plurality of cells, and does not specify the number of cells.) (c) A lamp (often called a light bulb, or just a bulb). (d) A voltmeter.**

Figure 2 shows you how to tell whether or not wires that cross on a diagram make an electrical connection at the crossing point. There are two rules to remember: (1) If wires meet but do not cross, as in Fig. 2(d), an electrical connection is always indicated. (There may or may not be a dot at the meeting point.) (2) When wires cross each other, as in Fig. 2(a), (b), and (c), there is no electrical connection unless there is a dot at the crossing point, as in (a). If there is no connection, a hook, as in (c) makes that fact clear. However, in the interest of speed, the hook is omitted more often than not, and the crossing point without a connection is drawn as in (b).

(a) A dot where wires cross always indicates a connection.

(b) If wires cross without a dot, there is no connection.

(c) A hook also means no connection.

(d) If wires meet, but do not cross, a connection is always indicated whether or not there is a dot.
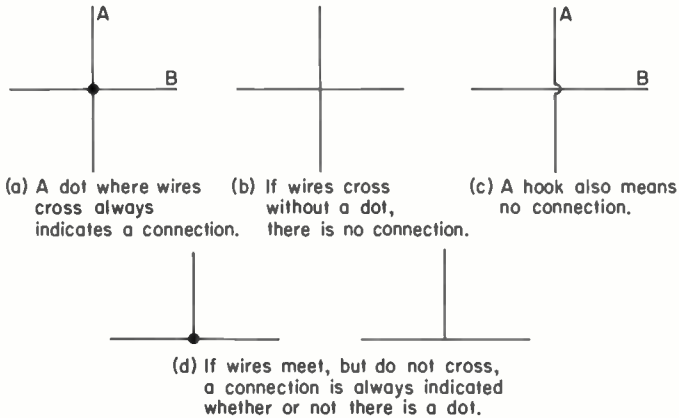
Fig. 2 How connections and crossings without connection are shown on schematic diagrams

WHAT HAVE YOU LEARNED?

1. The negative terminal of the battery in Fig. 3 is the *(upper)* *(lower)* terminal.

2. The symbol for the battery in Fig. 3 indicates that the battery has three cells. *(True)* *(False)*

3. What does the symbol at *A* in Fig. 3 represent? Bulb

4. What does the symbol at *B* in Fig. 3 represent? Voltmeter

5. Would removing the dots at *C* and *D* in Fig. 3 change the circuit represented by the diagram in any way? No
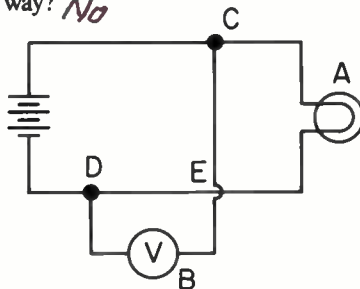
Fig. 3

1. lower . . . The short line in a battery symbol indicates the negative terminal.
2. False . . . The symbol indicates more than one cell, but no specific number.
3. A lamp . . . A lamp is an electric light.
4. A voltmeter . . . As the name suggests, this is an instrument for measuring voltage.
5. No . . . With or without the dots, a connection is indicated at these points because the wires do not cross each other. Where the wires actually cross, as at point *E*, there is no connection unless a dot so indicates.

VOLTAGE

2 WHAT VOLTAGE IS . . . Voltage is the name given to electrical pressure. When we say a circuit is operating on 6 volts, for example, we mean that the amount of electrical pressure *across* the circuit is 6 volts. Electrical pressure alone is not power, for the same reason that the pressure in a water system is not power: the pressure does not make the water flow until a faucet is opened. The electrical outlet in your home has voltage at its terminals, but you use no power until you plug in something—a lamp, a toaster, whatever—that draws current.

Although voltage alone is not power, we can think of it as *potential power* (which means standby power). For this reason, voltage is also called *potential*. Voltage is called *difference of potential* as well, because to take advantage of voltage you must have two terminals, one different from the other—the + and − terminals of a battery, for example. You've seen a bird land on a bare high-voltage wire without being hurt: that's because the bird was not across a difference in potential. If the same bird should somehow be able to straddle two lines carrying high voltage, it would be electrocuted on the spot. See Fig. 4.
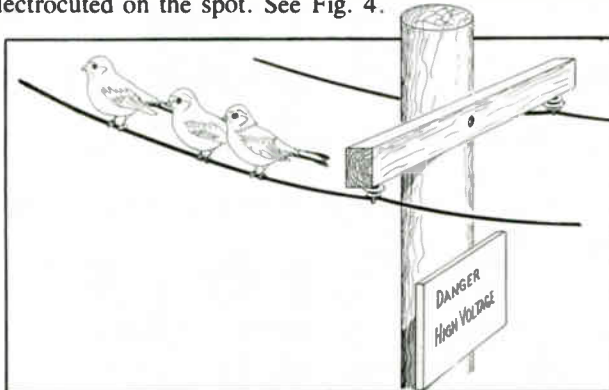
Fig. 4   The birds can use the high-voltage line for a perch because they're only touching one side. In order for current to flow, there must be connection to a difference of potential—that is, to two different points. Thus, if one of the birds could somehow straddle the two wires shown, it would be Bye-Bye Birdie!

3 NAMES AND SYMBOLS FOR VOLTAGE . . . We've already mentioned potential and difference of potential as other names for voltage. Voltage is also often called *electromotive force,* abbreviated *emf.*

The letter *E* is one commonly used symbol for voltage. As you will see later, it is the symbol used for voltage in formulas. The letter *V* is also used for voltage, particularly in dealing with transistors. *V* is used in expressions of quantities of volts—5 V, 120 V, and so on. A V inside a circle in a wiring diagram indicates a voltmeter, as you saw in Fig. l(d).

4 HOW VOLTAGE IS MEASURED . . . Logically enough, to measure voltage you use a voltmeter. Since voltage is a difference in potential, a voltmeter is always connected *across* the circuit. In Fig. 5, for example, the voltmeter is reading the difference of potential across a flashlight cell. The meter reads 1½ volts, which is the normal voltage of an ordinary flashlight battery.

(a) Pictorial diagram   (b) Wiring diagram or schematic
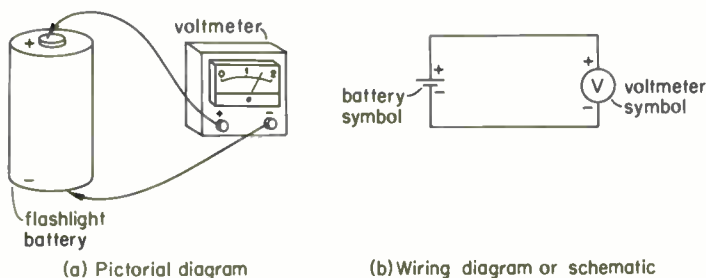
Fig. 5   A voltmeter measures across the battery—that is, from + to − (or from − to +, if you prefer).

We hasten to point out that the battery is not necessarily good simply because the voltage of the cell measures 1½ volts. Even an almost worthless battery can still read full, or almost full, voltage. We'll explain the technical reasons for this later on, but for now it's enough to know that a voltmeter requires only a tiny bit of current to deflect (move) the pointer needle. Therefore, even an almost run-down battery can still supply enough current to operate the meter (but not enough to do any useful work). A little later in this course, after you've studied Ohm's law and learned about resistors, we'll show you how to use a voltmeter to check most dry cell batteries.

1. List three other names for voltage. *EMF, Potential dif.*

2. If you were going to compare voltage with a water system, you would compare the voltage with the *(water itself)* *(faucet)* *(pressure that forces the water out of the pipes)* *(pipes)*.

3. In Fig. 6, which voltmeter—*A*, *(B)* or *C*—will read battery voltage?

4. A wise precaution if you are working around high voltage would be to *(work with both hands near the high-voltage points)* *(keep one hand in your pocket)* *(always touch between high voltage points with just one hand)*.

5. What kind of meter would you use to measure a difference in potential? *Volt*

6. It is impossible to have voltage present except when it is performing work. *(True)* *(False)*
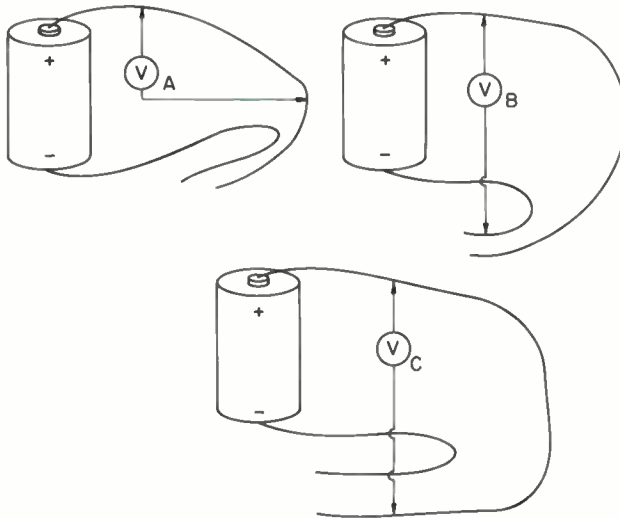
Fig. 6

ANSWERS

1. Potential, difference of potential, electromotive force (emf).
2. pressure that forces the water out of the pipes . . . Voltage is the moving force for electric current, just as pressure is the moving force for water.
3. *B* . . . This is the only voltmeter that is connected *across* the battery. If you trace out the connections, you'll find that the meter leads are connected to the same wire in both *A* and *C.*

4. Keep one hand in your pocket . . . That way you can't get connected across the high voltage through your two hands. The third choice is INCORRECT: *you should never touch voltages above 50 volts for any reason.* Use a voltmeter to measure such voltage. Don't try to "feel" it, or you may never feel anything again.

5. Voltmeter . . . "Potential" is just another name for voltage.

6. False . . . Every battery has voltage, whether anything is connected to the battery or not. A wall outlet in your home has voltage, although until you plug something into it you won't be using any electricity. Voltage is simply a potential force. It can neither cause electric current to flow nor do any work until you make a complete circuit in which current can flow.

5 METHODS OF DEVELOPING VOLTAGE . . . Voltage sources may be grouped as follows: batteries, generators, thermocouples, photovoltaic cells, piezoelectric crystals, and static charges. Let's take a look at each method in turn.

Batteries . . . When two plates of unlike metals are immersed in a conducting solution containing many ions (called an *electrolyte*), one plate becomes negatively charged with respect to the other. The charges set up a voltage between the plates. If the two immersed plates are connected externally, the voltage causes a current to pass through the connecting circuit.

Generators . . . Figure 7 shows how a voltage is developed by a generator. When a conductor is moved through a magnetic field, a voltage is developed between the ends of the conductor. A generator consists of a revolving armature wound with wire that continuously moves within a magnetic field, and thus develops a voltage. The voltage continues as long as the armature continues to revolve.
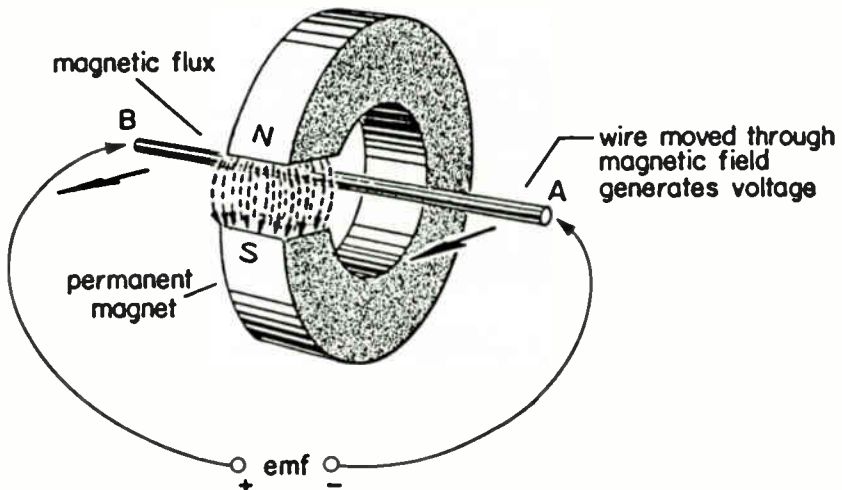
Fig. 7   Inducing voltage in a generator

8   *Thermocouples* . . . A thermocouple consists of two pieces of different metals joined together. When the junction between the metals is heated, a voltage is produced as shown in Fig. 8. The amount of voltage depends upon the metals used and the temperature developed at the junction.
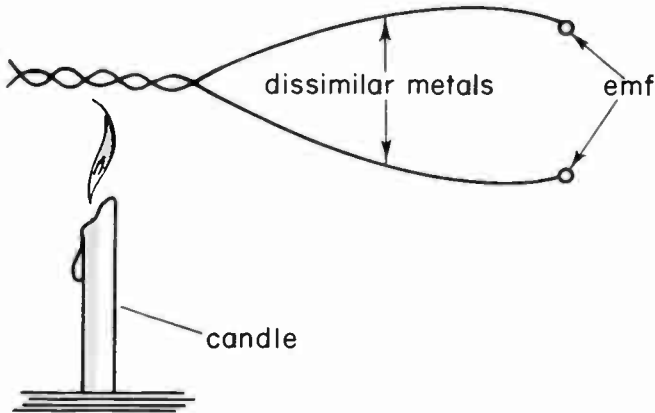
Fig. 8   A thermocouple. When the junction is heated, a voltage is developed.

Photovoltaic cells . . . If light is allowed to fall upon devices made of certain materials, notably selenium and silicon, these devices generate a voltage whose amplitude increases as the intensity of the light increases. Figure 9 shows a typical circuit in which such a device is used to operate a sensitive relay.
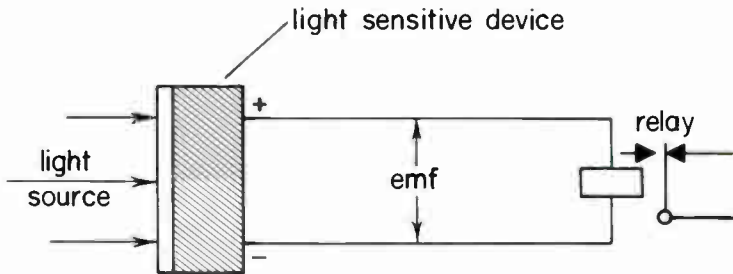
Fig. 9   Circuit including a device that generates a voltage when exposed to light.

Piezoelectric crystals . . . When certain crystalline materials are compressed, they produce a voltage. Conversely, if they are charged electrically, they deform in width, length, or thickness, or bend. Each effect is known as a *piezoelectric effect*. The voltage generated increases or decreases with corresponding changes in pressure. Piezoelectric materials that are commercially available include Rochelle salt, lithium sulfate, quartz, and such ceramic compositions as barium titanate. Quartz crystals are often used in oscillators.

Static charges . . . We have seen how friction can produce a voltage, usually referred to as a static voltage. Machines designed to develop static charges can produce extremely high voltages. Friction is not always required to produce such static charges.

WHAT HAVE YOU LEARNED?

1. In a thermocouple, the voltage developed is determined by the _____ of the junction and the types of _____ used in constructing the thermocouple.

2. When certain crystalline materials are compressed, they produce a voltage. This is known as the _____ effect.

3. In a transmitter master oscillator, a piece of quartz is often used as a _____. When quartz crystals are compressed, they generate _____. This effect is known as the _____ effect.

4. Suppose a light source is set on one side of a conveyor belt, and that a photovoltaic cell on the other side faces the light. When a package goes by on the conveyor belt, all light is cut off. After the package passes, light falls on the photovoltaic cell and produces a _____. The voltage produced by the cell is amplified and used to actuate a counter. If the front of the cell should become covered with dirt, light would be cut off at all times. Thus, the cell could produce no _____ when a package passed, and no signal would be applied to the _____.

ANSWERS

1. temperature; metal   2. piezoelectric
3. crystal; voltage; piezoelectric
4. voltage; voltage; counter or amplifier

CURRENT AND RESISTANCE

6 THE FLOW OF ELECTRICITY . . . The real workhorse of electricity is current. Without current, there would be no such thing as electric power. The heat generated by an electic hotplate or stove, the light radiated by a lamp, the sound in a radio or TV speaker, the rotation of an electric motor—all are the result of the flow of current. (Nevertheless, voltage is just as important as current, since without voltage there would be no current.)

7 MEASURING CURRENT . . . The pressure or potential of an electric circuit is measured in volts, as already noted, with voltage being measured *across* the circuit from one side to another. The *current* in a circuit is measured in *amperes* (AM-peers), which is usually shortened to *amps.* To measure current, we use an ammeter (AM-eater). Because we are measuring the *flow* of current (rather than the pressure), the ammeter must be connected *into* the circuit instead of across it—that is, a wire conductor is broken and the ammeter is connected in *series,* in order to read current.

Figure 10(a) shows a voltmeter connected across the battery, and (b) shows the battery wires connected to light a small lamp. Note that the voltmeter readings in (a) and (b) are the same: the voltmeter tells us nothing about the current used to light the lamp. As you know, an ammeter reads current. If the wire between the battery and the lamp is broken and an ammeter is inserted in the break, the meter will read the current through the lamp as shown in (c). Note that all the current to be measured must flow through the ammeter. The symbol for current is *I*, which stands for intensity. The abbreviation for ampere or amperes is A.
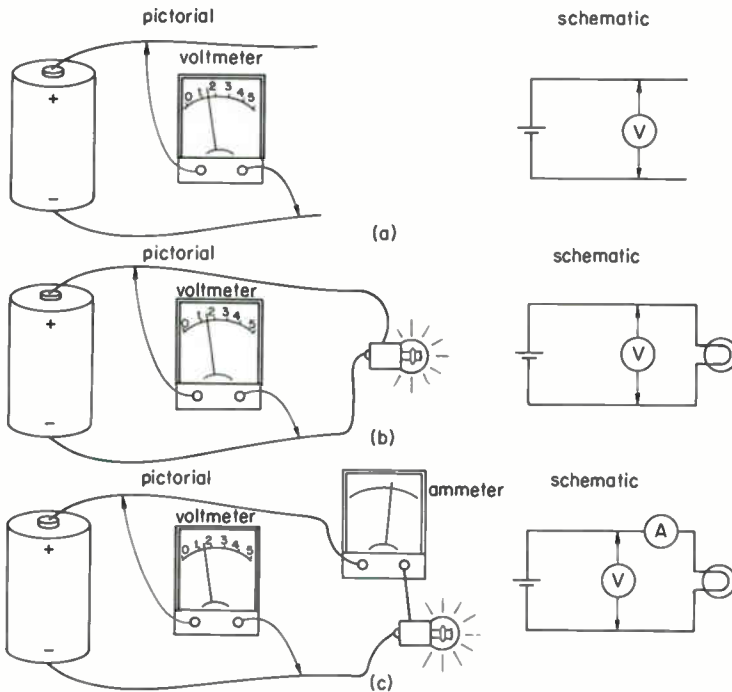
Fig. 10 Connection in a circuit of voltmeters and ammeters.
(a) Voltmeter measures voltage of battery
(b) The voltmeter reading remains unchanged when lamp is connected to battery
(c) An ammeter, connected in series with the lamp, measures current

1. If you wanted to compare the flow of electricity to some part of a water system, you could compare it to the *(pipes) (pressure) (water) (taps)*.

2. Based on how the meters are connected in the circuit in Fig. 11, meter 1 should have the letter *(A) (V)* inside the circle and meter 2 should have the letter *(A) (V)*.

3. If you compare electric current to a child coasting downhill on a sled, the current would be the *(hill) (snow) (child and sled)*.

4. The symbol for current is the letter _____, and the abbreviation for ampere or amperes is the letter _____.

Fig. 11   lamp
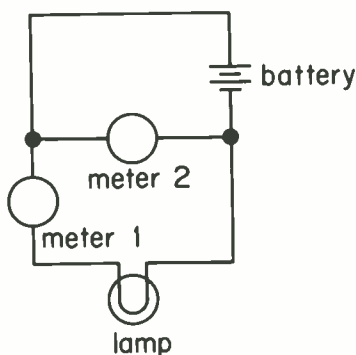
ANSWERS

1. water . . . It is the water, and not the water pressure or the pipes, that flows in a water system.
2. *A; V* . . . Meter 1 is in series with the lamp, so it is connected to read the current in amperes (A). Meter 2 is connected from one side of the battery to the other—in other words, across the battery—so it is connected to read volts (V).
3. child and sled . . . The hill could be compared to the voltage, the snow to the resistance of the circuit (which we will study next), and the child and sled (the moving parts) to the current.
4. *I; A*

8 QUANTITY OF ELECTRICITY . . . The quantity of electricity at a point—say, on body *A* in Fig. 12(c)—is the amount of charge at that point. Since the charge on body *A* consists of excess electrons, one way to measure the amount of charge—or the *quantity* of electricity—is to count the number of excess electrons. Quantity of electricity is measured by means of a unit called the *coulomb*. If there are 6,240,000,000 billion excess electrons, the charge or quantity of electricity is one coulomb (COO-loam). If there were twice that many electrons, the charge would be two coulombs, and so on.
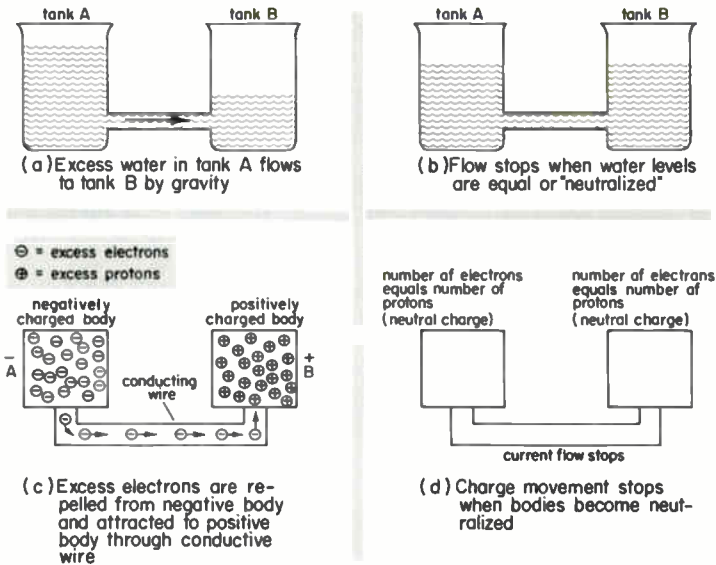
Fig. 12   The movement of charge (current).

The charge on body *B* in Fig. 12(c) is due to a *shortage* of electrons. You measure the quantity of electricity in the same way: one coulomb for each 6,240,000,000 billion* electrons short. Quantity of electricity is indicated by the symbol Q.

WHAT HAVE YOU LEARNED?

1. A capacitor is a device for storing electricity. The amount of electricity stored is measured in _____. The electricity stored in a charged capacitor consists of a(n) *(excess) (deficiency)* of electrons on the negative plate and a(n) *(excess) (deficiency)* of electrons on the positive plate. Because of this, there is a _____ between the two plates that is measured in _____. The greater the quantity of electricity stored, the _____ the potential between the two plates.

---

*You may find the figure 6,280,000,000 billion given in some books. Recent measurements show 6,240,000,000 billion to be more accurate, however.

2. The glass covering the scale of your voltmeter is dirty. You pick up a rag, and vigorously rub the glass to make it clean. The meter pointer swings erratically over the scale. Why?

ANSWERS

1. coulombs; excess; deficiency; voltage; volts; greater
2. The rubbing action placed a charge (a quantity of elecricity) on the glass. The charge exerted a force on the delicate needle, causing it to move erratically.

9 CURRENT STRENGTH . . . Let's now look at current from a different point of view. The rate at which the electricity is being moved is called the *current strength*, and is measured in amperes. If in Fig. 12(c), for example, the negative charge on *A* moves rapidly over to *B*, the current strength through the wire between the two bodies is high. If it takes considerable time for the charge on *A* to move over to *B*, the current strength through the wire is low.

The current strength is one ampere when the charge is moving from *A* to *B* at the rate of one coulomb per second—that is, when electrons are leaving *A* and arriving at *B* at the rate of 6,240,000,000 billion electrons each second.

WHAT HAVE YOU LEARNED?

1. Figure 13 shows a wire connecting a resistor *R* between the charged plates of a capacitor. Because of the potential of the opposing charges, a 2-A (ampere) current flows through the connecting wire. As a result, the quantity of electricity stored in the capacitor *(increases) (decreases)*. The amount of electricity stored changes at the rate of _____ coulombs each second. If the original charge on the capacitor was 20 C (coulombs), the charge after the current has been flowing for 3 sec (seconds) will be _____ coulombs (assuming the current stays at a steady 2 A).

2. Referring again to Fig. 13, if the current strength when the wire is first connected is 2 A, will it actually be this much 1 sec later? Why?

3. A current of 6 A flows through an electric toaster for 30 sec. The quantity of electricity used by the toaster during that time is _____ coulombs.

capacitor
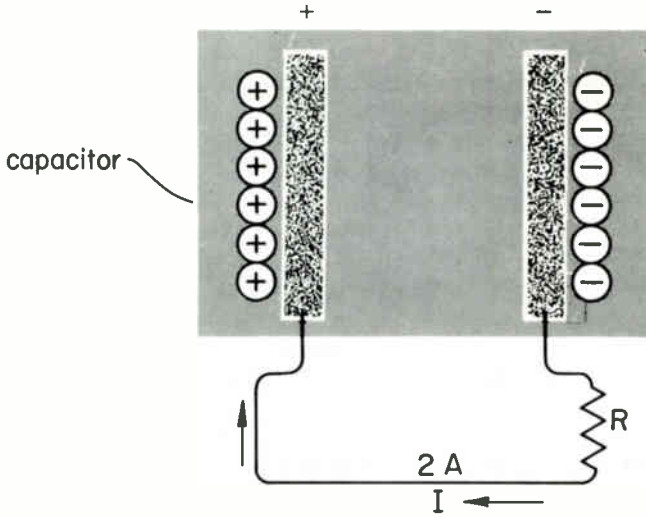
Fig. 13

ANSWERS

1. decreases; 2 . . . When electricity moves at the rate of one coulomb per second, the current is one ampere. Therefore, a 2-A current moves a charge at the rate of 2 C per sec, 14 . . . From (b), the charge is being reduced at the rate of 2 C per second, or 6 C in 3 sec. 20 C − 6 C = 14 C.

2. No . . . As the amount of charge goes down, the potential between the plates goes down, so there is no longer so much force pushing electrons through the wire.

3. 180 . . . One ampere flowing for one second is one coulomb. Therefore, 6 A flowing for 30 sec is 6 × 30 = 180 C.

10 RESISTANCE . . . Even the best conductor offers some opposition to the passage of free electrons and other charged particles through it. This opposition to current is called *resistance*. Resistance can be regarded as electrical friction. Resistance opposes the flow of current, just as mechanical friction opposes the pulling of a heavy box across the floor, for example. In a good conductor, such as copper, the resistance is low, so that current flows with little opposition. (This is somewhat similar to a box being pulled over slick ice.) In a poorer conductor, like iron, the current has more trouble getting through, so the resistance is said to be higher. (This might correspond to pulling the heavy box over a rough surface, such as an uneven stone floor.)

It's well known that friction causes heat—and electrical friction is no exception. When current flows through a resistance, heat is produced. For a given amount of current, the higher the resistance the greater the amount of heat produced. Increasing the voltage so that more current flows will therefore also increase the amount of heat produced.

Resistance is a desirable property in such circuit components as toasters and electric stove elements, which are intended to produce heat. In such circuit elements as the conductors that connect a lamp to a battery, however, resistance is an undesirable property. If the heat is developed at a greater rate than the conductors can pass it on to the surrounding air, the temperature of the conductors may rise so much that the conductors become a fire hazard.

Resistance is indicated by the letter symbol R. The unit used to express resistance is the *ohm*. A special symbol, the Greek capital letter omega, is used as an abbreviation for ohm or ohms. It looks like this: Ω. Now a formal definition of the ohm: An electric circuit has a resistance of one ohm when an applied electromotive force of one volt causes a current to flow through the circuit at the rate of one ampere.

Resistance is often intentionally added to an electric circuit to limit current. The extra resistance needed to limit current to a specific value is usually lumped into a single electric component, called a *resistor*, that is designed to dissipate (get rid of) heat rapidly without damage to itself or nearby objects.

WHAT HAVE YOU LEARNED?

1. An abbreviation you will often see and hear is *emf.* This stands for _____ _____. Two other names for the same thing are _____ and _____.

2. An emf is a _____ that tends to make current flow in a circuit. However, this flow of current is limited by opposition encountered in the circuit, called _____.

3. Whenever current flows through resistance, _____ is produced.

4. The unit used to express resistance is the _____, and resistance is indicated by the letter symbol _____. The abbreviation for ohm or ohms is _____.

5. An electric circuit has a resistance of one ohm when one volt causes a _____ to flow at the rate of _____.

6. The heat emitted by an electric light bulb is caused by current passing through the filament. Therefore, the filament must possess _____. In a similar manner, the heat emitted from any piece of electronic equipment when operating must also be due to the passage of _____ through the _____ of the various circuits.

7. In servicing a mobile transceiver, you find a badly scorched resistor. This indicates that excessive _____ has passed through the resistor, and produced more _____ than the resistor was able to dissipate.

ANSWERS

1. electromotive force; potential, voltage
2. force; resistance   3. heat
4. ohm; R; Ω 5. current; one ampere
6. resistance; current; resistance(s)   7. current; heat

11 RELATIONSHIP BETWEEN VOLTAGE, CURRENT, AND RESISTANCE . . .

Now that we've determined the nature of voltage, current, and resistance, let's see how the three are interrelated. First, suppose we connect a 100-V (volt) battery, a resistor, a switch, and an ammeter as shown in Fig. 14(a). Before the switch is closed, the ammeter reads zero, since there can be no current through the circuit until a voltage—from the battery, in this case—is applied.
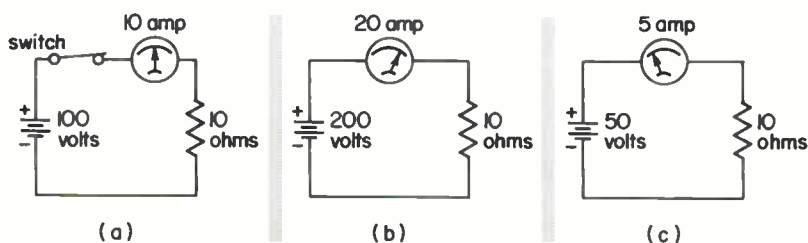
Fig. 14   The effect of increasing or decreasing applied voltage with circuit resistance unchanged.

When the switch is closed, the pointer on the ammeter will move across the scale from left to right, indicating a flow of current through the circuit. For the sake of illustration, let's say the ammeter pointer moves exactly halfway up-scale, and that the indicated current at this point is 10 A, as shown in Fig. 14(a).

Now, if we replace this battery with one supplying twice the voltage, as in Fig. 14(b), the ammeter will move all the way across the scale, indicating that the current is now 20 A. You can see that when we doubled the applied voltage, we doubled the circuit current. This relationship holds true, however, only if the circuit resistance remains unchanged.

Finally, if we replace the original battery with one supplying half the voltage, as in Fig. 14(c), the ammeter pointer will move one-quarter the length of the scale, indicating 5 A.

In summary, as long as the circuit resistance remains unchanged, any change in
voltage will produce a similar change in current. In other words, if the voltage
is doubled, the current is doubled; if the voltage is halved, the current is halved;
and so on.

Now, let's see what happens when we keep the same applied voltage but change
the resistance of the circuit. In Fig. 15(a), with a resistance of 10 Ω, we get a
half-scale reading of 10 A on the ammeter. In (b), we replace this resistor with
one having twice the resistance of the first. The ammeter pointer drops to one-
quarter of full scale, or 5 A. Doubling the circuit resistance has therefore reduced
the circuit current by one-half. If we now cut the original circuit resistance by
one-half, as in Fig. 15(c), circuit current will double, and so on. Summing up,
as long as the applied voltage is unchanged, any change in resistance will produce
an opposite change in current. If the resistance is doubled, circuit current will
be halved; if the resistance is halved, the circuit current will double; and so on.
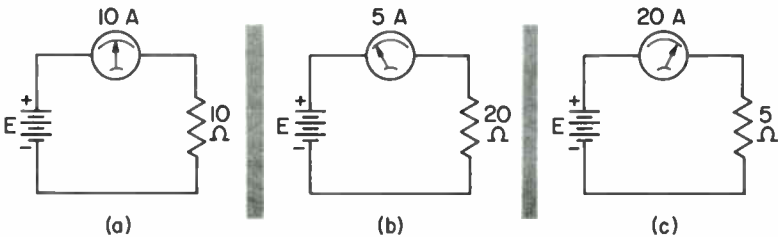
Fig. 15   **Doubling the resistance halves the current, provided the voltage does not change.**

WHAT HAVE YOU LEARNED?

1. In the circuit in Fig. 16, the ammeter reads 8 A. A new battery having three
times the voltage of the original one is connected into the circuit. The new value
of current, as indicated by the ammeter, will be _____ amperes. This shows
that when you triple the voltage, you _____ the current, provided the cir-
cuit _____ remains the same.

2. In another circuit, we obtain a current reading of 6 A. If a resistor having three
times the value of the first one is substituted into the circuit, the current will be
_____ amperes. This shows that as we triple the resistance, the current is reduced
to _____ its original value, provided the applied voltage is _____.

Fig. 16

ANSWERS
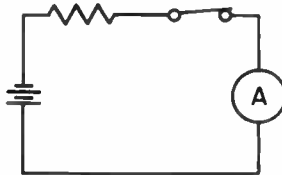
1. 24; triple; resistance   2. 2; one-third; constant

LESSON 2339A-5
THE THREE BASICS OF ELECTRIC CIRCUITS:
VOLTAGE, CURRENT AND RESISTANCE

EXAMINATION

Each examination question is followed by a number of selections. Circle the number in front of the correct selection for each question. When you have finished, transfer your answers to the Answer Sheet provided.

1. In a circuit diagram, if wires meet but do not cross there is
   (1) no way of knowing for sure what is intended.
   (2) a connection.
   (3) no connection unless there is a dot at the intersection.
   (4) no connection.

2. What other expression can be used to describe an "electric current"?
   (1) Electron flow, or flow of other electric charges
   (2) Flow of potential difference
   (3) Proton flow

3. What other expression can be used to describe a "difference of potential"?
   (1) Conductance   (3) Current   (5) Coulomb
   (2) Resistance   (4) emf

4. A coulomb is a unit used to
   (1) measure the breakdown voltage of an insulator.
   (2) measure the amount of attraction or repulsion between charges.
   (3) measure the amount of electricity.
   (4) indicate the strength of an electric current.

5. Four means by which an electrical potential may be generated are
   (1) generator, thermocouple, battery, and piezoelectric crystal.
   (2) piezoelectric crystal, thermocouple, battery, and transistor.
   (3) generator, thermocouple, resistor, and battery.
   (4) hydraulic pump, battery, generator, and photoelectric cell.

6. What is the unit of resistance?
   - (1) Coulomb
   - (2) Volt
   - (3) Mho
   - (4) Ohm
   - (5) Ampere

7. If you were going to compare a water system to an electrical system, you would compare the water *pressure* to
   - (1) charge.
   - (2) current.
   - (3) voltage.
   - (4) coulombs.

8. You can produce heat electrically by
   - (1) passing current through a coil with no resistance.
   - (2) passing current through a resistance.
   - (3) passing current through a circuit without resistance.
   - (4) rubbing a glass rod with a silk cloth.

9. An electric toaster works on the principle that heat is generated when
   - (1) a charge is put on metal plates.
   - (2) voltage is used.
   - (3) current passes through a resistance.
   - (4) sparks jump across a gap.

10. A certain resistor is drawing 9 A of current. If the resistance is reduced to one-third of its original value (and the voltage isn't changed), the circuit current will then be
    - (1) 3 A.
    - (2) 4 A.
    - (3) 12 A.
    - (4) 27 A.

END OF EXAM

SUCCESSFUL STUDY TIP . . . It is not likely that you can spare more than an hour or two a day for home study. However, that is plenty for good progress, provided you make good use of your time. Learning to use your time efficiently is an essential part of top-job training. This means that when you come to a text statement that you don't understand, read it again, think about it a bit, and make a reasonable effort to understand it—*but don't waste a lot of time sweating over it.* Go on, and if you think it's important, use your *Request for Assistance Form* to ask for additional explanation. Similarly, if you come to an examination question you can't answer, make a reasonable effort to find or figure out the answer—then go on to the next question.

Lesson 2339B-5
Ohm's Law, Conductors,
and Insulators

OHM'S LAW

Current, voltage, and resistance are related in such a way that, if any two are known, the third can be easily calculated. The formulas for doing this, known as *Ohm's laws,* are as follows:

To find the voltage . . . Voltage *(E)* is equal to current *(I)* multiplied by resistance *(R)*, or in formula form:

$$E = I \times R$$

To find the current . . . Current is equal to voltage divided by resistance, or in formula form:

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

To find the resistance . . . Resistance is equal to voltage divided by current, or in formula form:

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

Let's take a look at these extremely important laws, one by one.

12 OHM'S LAW FOR VOLTAGE . . . The ammeter in Fig. 17 indicates that the battery is forcing 5 A of current through the opposition of the 8-Ω resistor. For the current to be 5 A, the voltage *(E)* must be a certain definite value. If the voltage is lower than required, it will not have enough force to push 5 A through the resistor, with the result that the current will be less than 5 A. On the other hand, if the voltage is too high, the current will be more than 5 A.
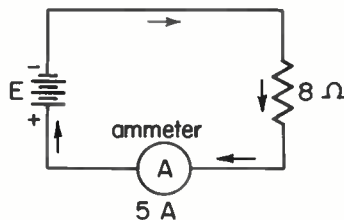
Fig. 17   The battery forces current through the resistance against the opposition of the resistor.

To find the value E must have, multiply the current by the resistance:

$$E = I \times R$$
$$= 5 \text{ A} \times 8 \text{ } \Omega$$
$$E = 40 \text{ V}$$

Hence, the voltage of the battery E in Fig. 17 is 40 V.

Now let's consider a more practical problem. In the problem illustrated in Fig. 18, instead of using a resistor for the circuit load as we did in the preceding example, we'll use the filament of a lamp. All you have to do to prove to yourself that the filament has resistance is to note its color when voltage is applied. As current passes through it, the filament becomes red and then white, indicating the presence of heat. And heat, you will recall, is due to the presence of resistance.
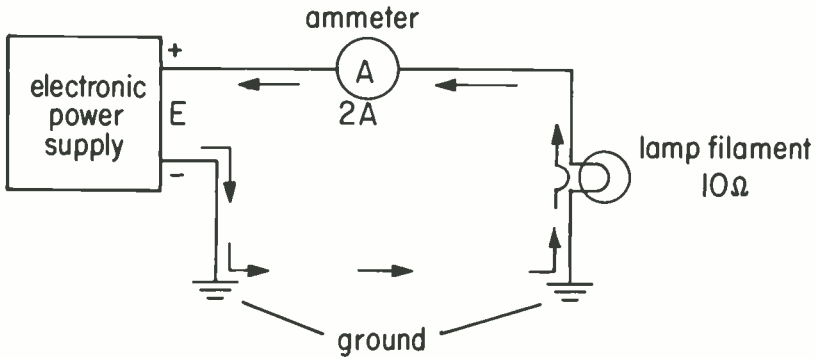
Fig. 18   A DC circuit using an electronic power supply.

Also, instead of using a battery as the voltage source as we did in Fig. 17, in Fig. 18 we'll use the DC output voltage of an electronic power supply. The negative terminal of the power supply is connected to ground, as is the lower end of the lamp filament. (Ground is usually the metal chassis on which the components making up an electronic circuit are mounted.) As far as the current is concerned, the chassis acts in the same way that any other metallic conductor of negligible resistance would act. Thus, as shown, current still flows from negative to positive. We also have an ammeter connected between the upper end of the filament and the positive terminal of the power supply to measure current.

From the manufacturer's literature, we learn that the filament of the lamp has a resistance of 10 Ω when heated, and that a current of 2 A should flow through it if it is to heat to the correct temperature. What voltage power supply should we use in order to have the correct current through the filament? As before, we merely multiply the resistance by the current:

$$E = I \times R$$
$$= 2 \text{ A} \times 10 \text{ } \Omega$$
$$E = 20 \text{ V}$$

Hence, the electronic power supply chosen should have an output of 20 V.

The three forms of Ohm's law can be used for any DC circuit, and for all the AC circuits found in this lesson. In a later lesson, you'll learn about a modification of the law that's required for use with some AC circuits.

WHAT HAVE YOU LEARNED?

1. If the current in a given circuit is 5 A and the resistance is 200 Ω, the voltage (by Ohm's law) is _____ V, since $E =$ _____.

2. Ohm's law in the form given in this lesson holds true for *(some)* *(all)* DC circuits.

3. In transmitter circuits using FET transistors, a suitable DC operating voltage (called the *bias voltage*) between the source and ground is often obtained from a resistor—R in Fig. 19—connected between the source and ground. If R is 5,000 Ω and a 0.001-A DC current flows through it as shown, then the DC bias voltage between source and ground, as read by the voltmeter, is _____ volts. The current direction is indicated by the arrow in the drawing. Remembering that current flows from _____ to _____, the voltage developed by the FET that causes the current to flow is positive at the *(top)* *(bottom)* of the resistor and negative at the *(top)* *(bottom)*.

4. A DC relay coil requires a current of 2 A to close the contacts. You measure the resistance of the coil with an ohmmeter, and find it to be 12 Ω. What voltage must you use to operate this relay?
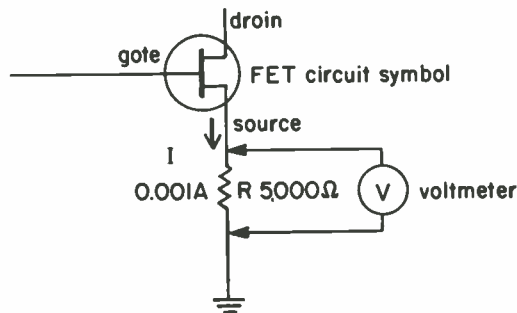
Fig. 19

1. 1000; $I \times R$, or IR 2. all
3. 5 V . . . E = 0.001 A $\times$ 5000 Ω = 5 V; negative; positive, bottom; top.
4. 24 V

13 OHM'S LAW FOR CURRENT . . . The amount of current in a circuit depends on two factors: the voltage and the resistance. Increasing the applied voltage makes more free electrons move around the circuit, and therefore increases current. Increasing the resistance produces a greater opposition to current, and therefore decreases current.
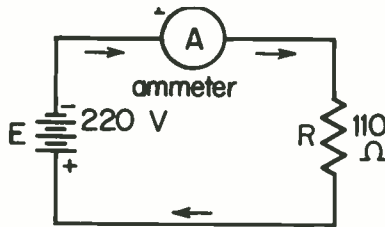
Fig. 20

Ohm's law tells us that the amount of current, in amperes, is equal to the applied voltage, in volts, divided by the circuit resistance, in ohms. In Fig. 20, for example, the current read by the ammeter is

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

$$= \frac{220 \text{ V}}{110 \text{ }\Omega}$$
$$= 220 \div 110$$
$$I = 2 \text{ A}$$

Hence, the ammeter reads 2 A.

We know that $E = IR$, so to prove that our work is accurate we can make the substitution $E = 2 \times 110 = 220$ V. Regardless of what values are given for E and R in a DC circuits, the value of I may always be determined by using the form of Ohm's law described above.

WHAT HAVE YOU LEARNED?

1. Use Ohm's law to find how much current in amperes an electric toaster with a resistor of 25 Ω will draw when connected to a 100-V line.

24 2. Will a 10-A fuse be sufficient to protect an electrical appliance with a resistance of 10 Ω when used on a 120-V line?

3. In Fig. 21, the same applied voltage—that is, 100 V—appears across each of the four resistors. Using Ohm's law, the current, in amperes, through branch *A* is _____; the current through branch *B* is _____; the current through branch *C* is _____; and the current through branch *D* is _____. Now, at point *X*, these four currents combine and flow back to the voltage source. Therefore, the total current as read by the ammeter is _____.

4. Suppose that in the circuit in Fig. 21 the ammeter reading drops from 13.5 A to 11.5 A. Where would you look for trouble, and what would you expect to find?
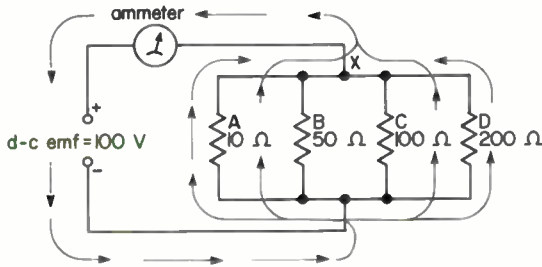
Fig. 21

ANSWERS

1. 4 A . . . $I = \dfrac{E}{R} = \dfrac{100 \text{ V}}{25 \text{ Ω}} = 4$ A
2. No . . . By Ohm's law, the appliance will draw 120 ÷ 10 = 12 A. Since this is more current than the fuse can carry, the fuse will blow. A 15-A fuse should be used instead.
3. 10 A; 2 A; 1 A; 0.5 A; 13.5 A . . . 10 + 2 + 1 + 0.5 = 13.5 A
4. Look in branch *B* carrying 2 A, since this is the amount by which the ammeter reading drops. You will find an open circuit, which means that no current can flow through that branch.

14 OHM'S LAW FOR RESISTANCE . . . In the third and final version of Ohm's law, the three factors *E*, *I*, and *R* are related by the formula

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

This tells us that resistance is the quotient (the answer in division) obtained when we divide the given value of *E*, in volts, by the given value of *I*, in amperes. For example, suitable operation of the transistor in Fig. 22 requires that the voltage across *R* be 10 V. The current through *R* is 0.02 A. What value of resistance should you use for *R*?
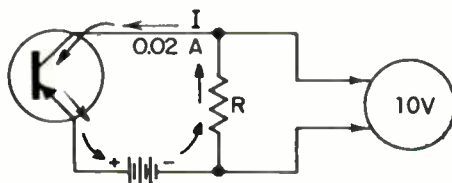
Fig. 22   Basic collector circuit of a transistor.

The solution is found using the resistance version of Ohm's law:

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

$$= \frac{10 \text{ V}}{0.02 \text{ A}}$$

$$R = 500 \text{ }\Omega$$

The three forms of Ohm's law are used so often in electronics that you will soon find that you've memorized them without even trying. In the meantime, however, Fig. 23 will serve as a memory aid. Just place your finger over the desired quantity, and the correct arrangement of the other two quantities in the equation is indicated. For example, if you are looking for E, place your finger over E, and you are left with $I \times R$. If you want I, cover this symbol with your finger and you get $\frac{E}{R}$. Finally, if you want R, cover it with your finger and you have $\frac{E}{I}$.

Fig. 23   An aid to remembering Ohm's law.

WHAT HAVE YOU LEARNED?

1. If the voltage applied to a circuit is 300 V and the current through the circuit is 3 A, the resistance of the circuit, by Ohm's law, is _____ ohms.

2. You often use Ohm's law to find the correct value for a resistor to use in a transistor circuit. For example, a transistor won't work right unless a DC current of the correct value (called the *bias current*) flows through the transistor between base and emitter, as shown in Fig. 24. Suppose that, for proper operation of the transistor in Fig. 24, the bias current should be 0.003 A. What resistance value should be used for R in order to hold the current to the right value? (You can assume that the resistance inside the transistor is negligible.)

3. While servicing an inoperative transmitter, you find a resistor whose value you suspect to be incorrect. An ammeter connected in series with the resistor indicates a current of 3 A through the resistor. Using a voltmeter, you determine that the voltage across the resistor is 150 V. What is the value of the resistor, in ohms?
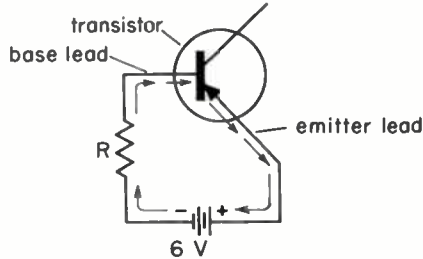
Fig. 24

ANSWERS

1. 100   2. 2000 Ω . . . $R = \dfrac{E}{I} = \dfrac{6\ V}{0.003\ A} = 2000\ Ω$

3. 50 Ω . . . $R = \dfrac{E}{I} = \dfrac{150\ V}{3\ A} = 50\ Ω$

CONDUCTORS AND INSULATORS

15 READING THE COLOR CODE ON RESISTORS . . . The resistance value of a resistor is indicated by a series of color bands around the resistor. To read the resistance value, hold the resistor so that the end with the color bands—or the end with most of the color bands—is to your left. The first three color bands, reading from the left, show the resistance value, in accordance with Table 1. Start by writing down the numbers represented by the first two color bands. The third band tells you how many zeros to put after the first two numbers, as shown in Fig. 25(a). Note that if the third band is black, *no* zeros are to be added.

Table 1
Color Code for Resistors

Color	Value	Color	Value
Black	0	Green	5
Brown	1	Blue	6
Red	2	Violet	7
Orange	3	Gray	8
Yellow	4	White	9

For example, the resistance indicated in Fig. 25(a) is 26,000 Ω. The first band is red for 2, (see Table 1), the second band is blue for 6 (Table 1), and the orange third band means that three zeros must be added after the 26. Figure 25(b) provides another example.

first digit of resistance value (RED)

second digit of resistance value (BLUE)

number of zeros to be added (ORANGE)

fourth band indicates tolerance
gold: 5%
silver: 10%
no fourth band : 20%

(a) How color bands of a resistor are read

green

brown

yellow

5 1 = 510,000Ω

add 4 zeros
(no fourth band;
hence tolerance is 20%)

(b) Example of reading resistor color bands
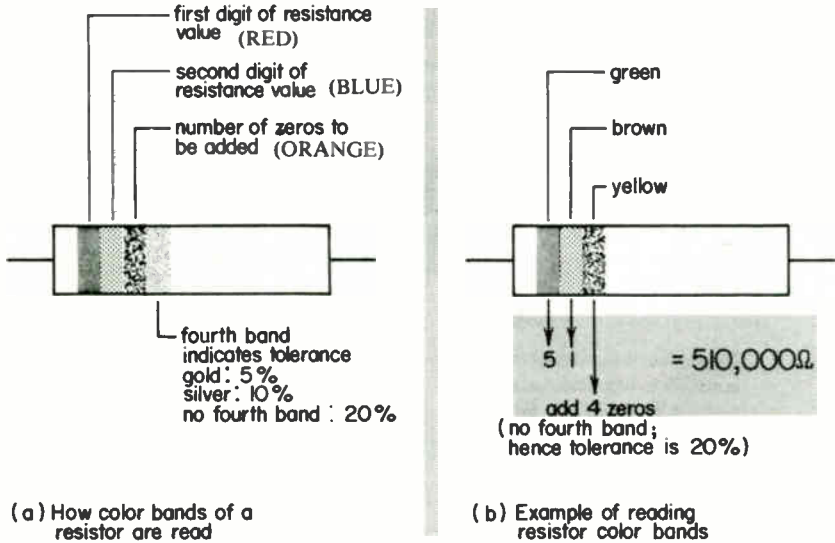
Fig. 25   Resistor color bands.

To repeat, if the third band is black it means that *no zeros* are to be added. Figure 26 provides an example where the third band is black.

yellow
violet
black
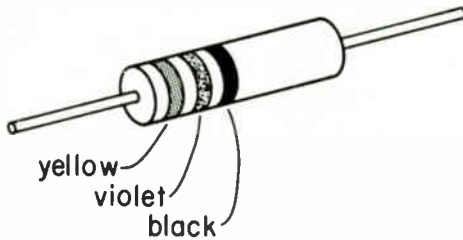
Fig. 26   What is the value of this resistor? Remember that the third band tells you how many zeros to add, and black is the color for zero, so you add no zeros. Therefore, read yellow 4; violet 7; and black 0, so the resistor size is 47 with no zeros—47 Ω, and not 470 Ω.

28 Occasionally, you will find a gold or silver third band. (Don't confuse it with the fourth band, which is generally gold or silver, and which we will discuss later.) A gold or silver third band indicates resistance values less than 10 ohms. If the third band is gold, the resistance is between 1 and 10 ohms; if silver, the resistance is between 0.1 and 1 ohm. Suppose that you wished to find the value of a resistor whose first three bands are red, blue and silver. The first two bands give the number 26, and—since a silver third band tells us that the resistance is between 0.1 and 1 ohm—the resistance is 0.26 ohm. If the third band were gold, the resistance would be 2.6 ohms. See Fig. 27 for another example.

yellow
violet   third band gold
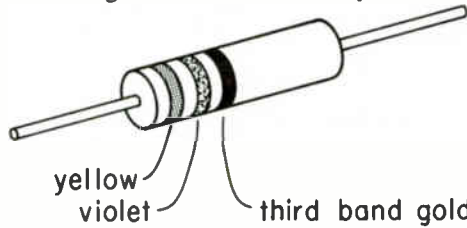
Fig. 27 Since the third band is gold, we know the resistance will be between 1 Ω and 10 Ω—in this case, 4.7 Ω. If the third band were silver, the resistance would be 0.47 Ω. Silver and gold third bands refer to resistance value. Silver and gold fourth bands refer to tolerance.

16 TOLERANCE OF RESISTORS . . . The *actual* resistance of resistors may vary somewhat from the color-coded value because of the difficulty of manufacturing resistors to exact values. The *fourth* color band indicates tolerance. If the *fourth* band is silver, the tolerance is 10 per cent. If it is gold, the tolerance is 5 per cent. A silver *fourth* band, then, means that the actual resistance will be within 10 per cent of the color-coded value. If the first three bands are brown, black, brown and the fourth band silver, the indicated resistance is 100 ohms and the actual resistance will be somewhere between 90 and 110 ohms. If the fourth band were gold, the resistance would be between 95 and 105 ohms (5% of 100 = 5; 100 + 5 = 105, and 100 − 5 = 95). Figures 28 and 29 provide two examples of color-coded resistor tolerance.

second   third
first   forth

orange
black
orange
silver
(10%)

10% of 30,000 = 3000
30,000 − 3000 = 27,000
30,000 + 3000 = 33,000
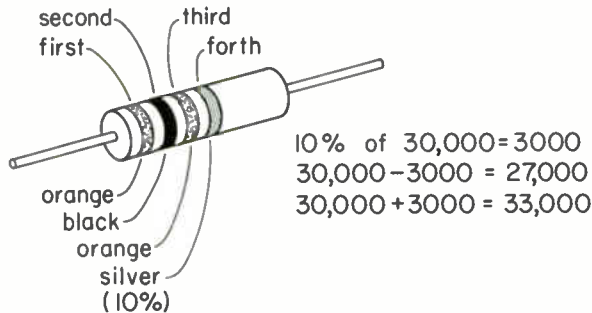
Fig. 28 A 30,000 Ω resistor with a tolerance of 10 percent could measure anywhere between 27,000 Ω and 33,000 Ω.

green	5% of 560 =28
blue	560 − 28 =532
brown	560 + 28 =588
gold
(5%)
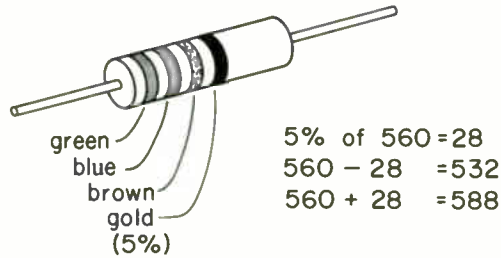
Fig. 29   A 560 Ω resistor with a 5 percent tolerance could measure anywhere between 532 Ω and 588 Ω.

Many of the resistors found in old equipment have only three color bands, lacking the fourth that shows tolerance. Such resistors have tolerance of 20 per cent. (See Fig. 30 for an example.) They can be replaced with 10 per cent tolerance resistors—the least expensive manufactured today.
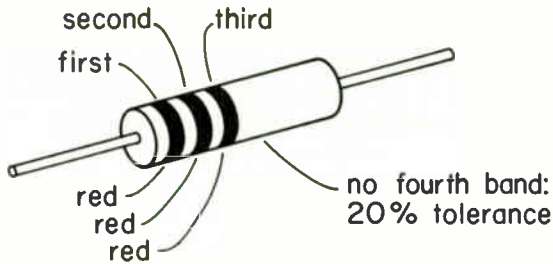
Fig. 30   A 2200 Ω resistor with 20 percent tolerance could measure between 1760 Ω and 2640 Ω (20 percent below or above 2200Ω).

Some resistors have a fifth color band to indicate *reliability.* If included, this band will be yellow, orange, red, or brown in the order of reliability—yellow being the most reliable (least apt to fail) and brown the poorest. Naturally, the higher their reliability, the more you pay for them.

Resistors with a tolerance closer than 5 per cent are called *precision* resistors. The commonest precision resistors have a 1 per cent tolerance. Their resistance and tolerance are usually stamped on them. If color-coded, the last band—the tolerance band—will be brown, to indicate 1 per cent. Color coded one-percent resistors have four color bands to indicate resistance—the first three for the figures, and the fourth band for the number of zeros to be added. Thus, the tolerance band, brown, becomes the fifth band. There is obvious room for confusion between the color-coding for precision resistors and that for ordinary resistors. However, this information on precision resistors is added for reference only, since you won't come across color-coded precision resistors very often. The color code featured in the following exercise (and throughout this course) refers to ordinary resistors.

1. Give the color-coded values and tolerance for each of the following resistor markings:

(a) Brown, green, red

(b) Orange, orange, yellow

(c) Green, blue, yellow, silver

(d) Blue, gray, green, gold

(e) Green, brown, black, gold

(f) Red, black, black

(g) Brown, brown, brown, gold

(h) Yellow, violet, gold

(i) Yellow, violet, gold, silver

(j) Yellow, violet, silver, gold

(k) Yellow, violet, black, silver

(l) White, brown, brown, gold

2. The color code value of the resistor in Fig. 31(a) is _____ ohms. If the resistor measures 49,000 Ω it *(is) (isn't)* within tolerance. The lowest value the resistor could measure and still be within tolerance is _____ ohms.

3. The resistor in Fig. 31(b) should measure _____ ohms, with a tolerance of _____ per cent. The third band of the resistor indicates that you should add _____ to the first two numbers.

4. The resistor in Fig. 31(c) would be color-coded _____, _____, _____.

5. With a tolerance of 20 per cent, a resistor color-coded 5600 Ω could measure anywhere between _____ and _____ ohms.

6. The resistor in Fig. 31(d) measures 28,750 Ω, and the color bands are orange, black, orange. Is the resistor within tolerance? What is the highest resistance the resistor could measure and still be within tolerance?

7. The resistor in Fig. 31(e) is color-coded _____ ohms, and its tolerance is _____ per cent.

a)
yellow
violet
orange
gold

b)
black
black
red

c)
5600 Ω resistor
20%

d)
orange
black
orange
28,750 Ω

e)
gold
silver
black
yellow
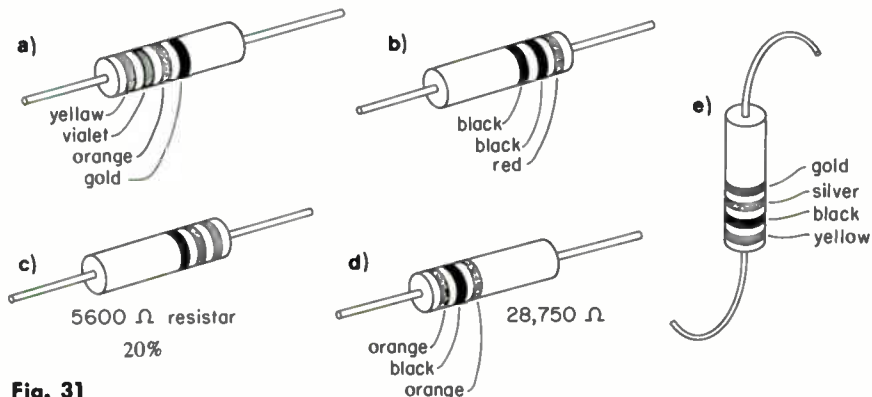
Fig. 31

1. (a) 1500 Ω with 20 per cent tolerance . . . Remember, no fourth band means 20 per cent tolerance.
    (b) 330,000 Ω, with 20 per cent tolerance
    (c) 560,000 Ω, with 10 per cent tolerance
    (d) 6,800,000 Ω, with 5 per cent tolerance
    (e) 51 Ω, with 5 per cent tolerance . . . Black in the third band means "add no zeros."
    (f) 20 Ω, with 20 per cent tolerance . . . The first two bands gives the digits 20. Since the third band is black, we add *no* zeros to the value given by the first two bands.
    (g) 110 Ω, with 5 per cent tolerance
    (h) 4.7 Ω, with 20 per cent tolerance . . . Remember that silver and gold don't refer to tolerance unless found in the fourth band. Here, the gold is in the third band, which means that the resistor value is between 1 and 10 Ω, and must therfore be 4.7 Ω.
    (i) 4.7 Ω, with 10 per cent tolerance
    (j) 0.47 Ω, with 5 per cent tolerance
    (k) 47 Ω, with 10 per cent tolerance
    (l) 910 Ω, with 5 per cent tolerance

2. 47,000; is . . . 47,000 × 0.05 = 2350, 47,000 + 2350 = 49,350. 49,000 is less than 49,350; 44,650 Ω . . . The tolerance of the resistor is 5 per cent. Five per cent of 47,000 is 2350, and 47,000 − 2350 = 44,650.

3. 20 Ω; 20 per cent . . . If a resistor doesn't have a fourth color band, the tolerance is 20 per cent; no zeros . . . Remember to start reading with the color band nearest an end of the resistor.

4. Green; blue; red

5. 4480; 6720 . . . 20 per cent of 5600 is 1120.

6. Yes; 36,000 Ω . . . The tolerance of this resistor is 20 per cent. Twenty per cent of 30,000 is 6000, so the resistor could measure up to 36,000 Ω.

7. 0.40; 5

17 INSULATORS . . . In some materials, the electrons are held in a fixed pattern, and—theoretically—there are no free electrons. A material with no free electrons would be classed as a perfect insulator. Since all materials have at least a few free electrons, however, there is actually no such thing as a perfect insulator. Thus, practical insulators are materials that have a very small number of free electrons per unit volume compared with metallic conductors.

Under the influence of ordinary voltage application, insulators have extremely high resistance to current. If, however, the applied voltage exceeds a critical value (called the *breakdown voltage*), many electrons are torn from their fixed positions and become free electrons. As a result, a high-value current passes through the insulator, which is then said to be punctured.

32　When an alternating voltage is applied to an insulator, each reversal of applied voltage causes particle rearrangement within the insulator and the release of heat. If the applied voltage is of low frequency, such as the 60-hertz (or 60-cycles per second) commercial power frequency, this release of heat is ordinarily of little consequence. Some materials that are good insulators at commercial power frequencies are cotton, hard rubber, paraffin, clay, shellac, fiber, Bakelite, silk, and glass. At radio frequencies, these insulators are unsuitable because of energy absorption from the circuit. The energy appears as heat in the insulator. Good insulators for use at radio frequencies (RF) are quartz, polymerized styrene, steatite bodies, Pyrex, Mycalex, Isolantite, mica, and polyethylene.

Insulators are subject to many deteriorating influences, and must be selected carefully for a given application. For example, an antenna strain insulator exposed to the elements must not only be a good insulator but must also be able to withstand the pressure of the antenna it supports, be relatively unaffected by the elements, and be available at low cost. Glazed porcelain is ideally suited to this application; in fact, no other insulator has all of the desirable characteristics.

WHAT HAVE YOU LEARNED?

1. A practical insulator has a very _____ number of _____ electrons per unit volume, compared with conductors.

2. A _____ voltage causes an insulator to be punctured, and a high _____ to pass through the insulator.

3. The application of an _____ voltage causes heat to be released by an insulator. This release is due to the rearrangement of particles that takes place within the insulator.

ANSWERS

1. small; free　　2. high; current
3. alternating

18 FACTORS AFFECTING THE RESISTANCE OF A CONDUCTOR . . . Four factors have a critical affect on the resistance of a conductor: temperature, length of the conductor, size of the conductor, and type of material. Let's consider each in turn.

Temperature . . . Temperature critically affects the resistance of an electrical conductor. For example, as the temperature of copper increases, the resistance of the copper also increases; likewise, if the temperature decreases, the resistance decreases, as shown in Fig. 32. Copper, then, is said to have a *positive temperature coefficient*. Any metal whose resistance increases as the temperature increases is said to have such a positive temperature coefficient.
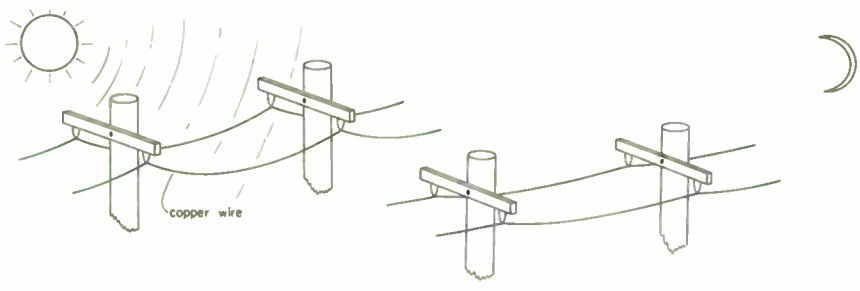
Fig. 32 The hot sun shining on the copper wire causes the resistance of the wire to increase. At night, when the wires cool off, the resistance is less.

Most metals have positive temperature coefficients; carbon is an example of a substance that has a *negative* one. An increase in the temperature of carbon *decreases* its resistance. Also, there are some alloys whose resistance varies a negligible amount with changing temperature. They are said to have a "zero temperature coefficient," and are used as conductors when a constant resistance is important—as in oscillator circuits where a high-frequency stability is needed.

Length of conductor . . . Length also affects the resistance of an electrical conductor. If we cut two pieces of wire from the same reel, one of them twice the length of the other, the electrons will have twice as much trouble making the trip through the longer wire (see Fig. 33). Therefore, the resistance of the longer wire to the flow of current is twice as great as that of the shorter wire. This indicates that the resistance of an electrical conductor is proportional to its length. In other words, if the length is tripled, resistance is tripled; if the length is halved, the resistance is also halved; and so on.
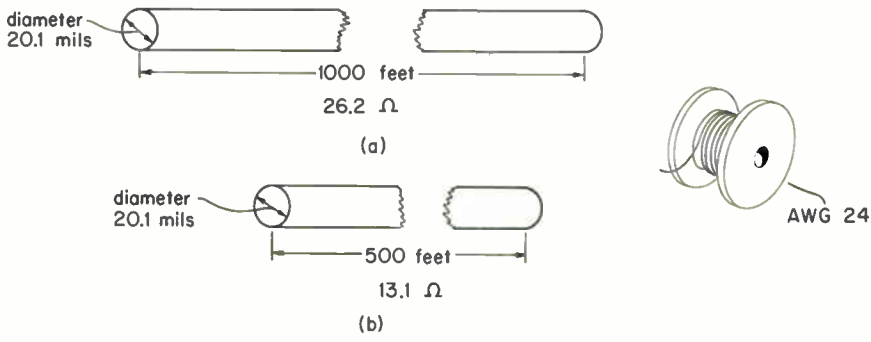
Fig. 33 The wire in (a) and (b) is of the same material (copper) and has the same diameter. However, (a) is twice as long, and therefore has twice the resistance.

34   *Size of conductor (cross-sectional area)* . . . Another factor that governs the resistance of a conductor is the cross-sectional area of the conductor—the area of the end of the conductor when cut squarely across. The larger the wire, the easier it is for the electrons to move along it, and thus the lower the resistance. Doubling the cross-sectional area cuts the resistance in half; similarly, halving the cross-secional area doubles the resistance. However, doubling the *diameter* cuts the resistance to *one-fourth* of its previous value, because doubling the diameter increases the cross-sectional area by four times (see Fig. 34).

diameter
64 mils

1000 feet

resistance = 2.58 Ω

diameter
32 mils

1000 feet
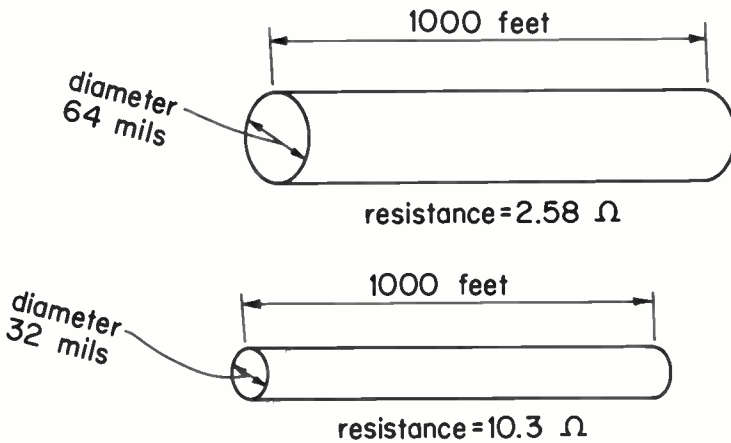
resistance = 10.3 Ω

Fig. 34   **Cutting the diameter in half increases the resistance four times. (Note that this is diameter, not area.) Cutting the areas in half increases resistance two times. The area is reduced to one-fourth by decreasing the diameter one-half.**

Before going further, make sure you understand the difference between diameter and cross-sectional area. Figure 35(a) shows this difference. The diameter of a wire is simply the distance across the end of the wire when cut squarely across. Cross-sectional area refers to the amount of surface you will see if you look at the end of a square-cut wire. If one wire is twice the diameter of a second wire, the first wire has much more than twice the cross-sectional area of the second. To see why this is true, take a look at Fig. 35(b). This figure shows you that two wires each $1/2$ in. (inch) in diameter will fit inside a tube 1 in. in diameter, but not nearly fill the tube. Hence, the cross-sectional area of two wires each $1/2$ in. in diameter is evidently much less than the cross-sectional area of a wire 1 in. in diameter. In fact, we could squeeze two more wires $1/2$ in. in diameter into the space left over in the 1-in. tube of Fig. 35(b) if the wires could flex to conform to the shape of the left-over space. That is why we say that the 1-in. wire has four times the cross-sectional area of the $1/2$-in. wire.

hatched area
that you see
at the end is
the cross —
sectional area

diameter

(a)

(b)
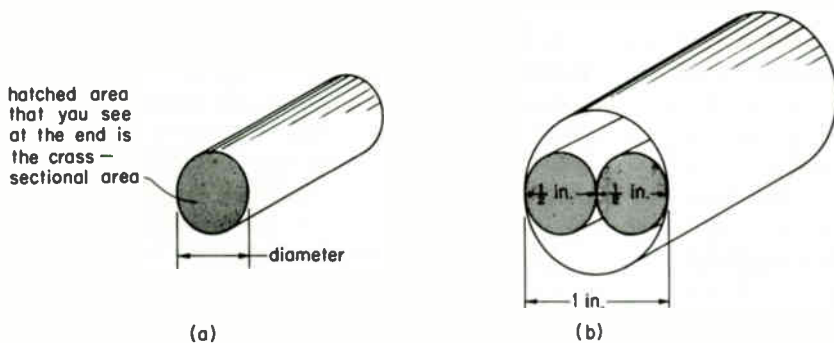
Fig. 35   Doubling the diameter of a wire more than doubles the cross-sectional area; in fact, it quadruples the cross-sectional area.

Cross-sectional area varies as the square of the diameter. For example, if one conductor is five times the diameter of another, its cross-sectional area is $5 \times 5 = 25$ times as great. That means that the resistance of the larger wire is only one twenty-fifth that of the smaller wire.

Type of material . . . Finally, the type of conductor material also affects the resistance of a conductor. Some materials have more free electrons per unit volume than others. The greater the number of free electrons per unit volume, the better conductor that material becomes. A silver wire has a lower resistance than a copper wire with the same dimensions, and the copper wire has a lower resistance than an aluminum wire with the same dimensions. In summary, the resistance of an electrical conductor is dependent on the type of conductor material.

Silver is the best conductor, but its high cost limits its use to special applications where a low resistance is more important than cost. The conductivity of copper is nearly as good as that of silver. Because it is low in cost, solders well, and can be bent to shape easily, it is by far the most widely used of all conductors. Gold is the next best conductor, but is economically unfeasible.

Aluminum is the fourth best conductor, and has the added advantage of light weight. Unfortunately, it's difficult to solder, which limits its usefulness as a general conductor. It's used in electronics mostly for shielding against stray fields, and for constructing panels and chassis. Its light weight is a great advantage in these uses.

All metals are conductors. However, since the next best conductors after aluminum have resistances at least three times as great as that of copper, only the metals previously mentioned can be considered as first-class conductors. An important nonmetallic conductor is carbon, which is used where a soft material is needed, as in motor brushes. Its resistance is higher than that of most metals.

36 Relay contact materials require additional properties besides suitable conductivity, of course. The material used must resist pitting and burning away from the arcing that occurs when the contacts open. The contacts, when idle, must not gather up a high-resistance surface film from interaction with atmospheric gases. Both tungsten and silver meet these requirements, and make good relay contacts. Although expensive, both are widely used for the purpose.

Before we leave the subject of conductors and their resistance, it should be pointed out that, when soldering in any part of an electric circuit, resin should be used as the soldering flux. Resin has the very important property of being completely noncorrosive. All other fluxes are at least partially corrosive. The use of any flux other than resin may, therefore, in time, lead to high-resistance connections due to corrosion.

WHAT HAVE YOU LEARNED?

1. List the four factors that affect the resistance of a conductor.

2. Most metals have a _____ temperature coefficient, which means that resistance _____ as temperture increases.

3. Carbon has a _____ temperature coefficient, since its resistance _____ as temperature increases.

4. Suppose you have a length of wire whose resistance is 1 Ω. If you use another length of the same wire that is twice as long, the resistance is _____. If you use another length of the same wire that is only half as long as the original wire, the resistance is _____.

5. Assume you have a conductor that is 12 ft. (feet) long, has a resistance of 10 Ω, and has a cross-sectional area of 1 sq. in. (square inch). If this area is reduced to ½ sq. in., the resistance of the conductor is changed to _____ ohms.

6. Copper has more free electrons than aluminum. Therefore, the resistance of copper is *(greater) (less)* than that of aluminum.

7. Soldered connections in an electrical circuit should always be made by using _____ as soldering flux.

ANSWERS

1. Temperature, length, cross-sectional area, material
2. positive; increases   3. negative; decreases
4. 2 Ω; 0.5 Ω 5. 20   6. less   7. resin

EXAMINATION

Each examination question is followed by a number of selections. Circle the number in front of the correct selection for each question. When you have finished, transfer your answers to the Answer Sheet provided. Then use the special envelope provided to mail the examination to the school as soon as it is completed.

1. Copper is by far the most widely used conductor, because it
   (1) has a low resistance that is not affected by temperature changes.
   (2) solders well, and is stronger than all other metals.
   (3) is the best conductor of all metals.
   (4) is one of the best conductors, solders well, and is reasonably low in cost.

2. Four materials that are good insulators at radio frequencies are
   (1) quartz, porcelain, cotton, and clay.
   (2) quartz, polymerized styrene, steatite bodies, and Pyrex.
   (3) Isolantite, polyethylene, slate, and glass.
   (4) Pyrex, Mycalex, hard rubber, and fiber.

3. Four materials that are not good insulators at radio frequencies, but prove satisfactory for use at commercial-power frequencies, are
   (1) quartz, porcelain, Bakelite, and fiber.
   (2) slate, fiber, Mycalex, and Pyrex.
   (3) cotton, hard rubber, paraffin, and clay.
   (4) cotton, hard rubber, mica, and polyethylene.

4. Which one of the following groups states the three forms of Ohm's law?

   (1) $E = IR, R = \dfrac{I}{E}, I = \dfrac{R}{E}$

   (2) $E = IR, R = EI, I = \dfrac{E}{R}$

   (3) $E = IR, R = \dfrac{E}{I}, I = \dfrac{E}{R}$

   (4) $E = \dfrac{I}{R}, R = EI, I = \dfrac{E}{R}$

5. What effect does the cross-sectional area of a conductor have upon the resistance of the conductor?
   (1) If you double the cross section, the resistance is doubled.
   (2) If you halve the cross section, the resistance is halved.
   (3) If you double the cross-sectional area, the resistance is halved.
   (4) The cross-sectional area has no effect on resistance.

6. If the diameter of a conductor of given length is doubled, how will the resistance of the conductor be affected?
   (1) Doubled   (3) Reduced to one-fourth
   (2) Halved   (4) Remain the same

7. What four factors govern the resistance of a conductor?
   (1) Length, temperature, conductance, emf
   (2) Current, voltage, conductance, temperature
   (3) Length, tensile strength, temperature, current
   (4) Length, cross-sectional area, temperature, type of material

8. The resistance and tolerance of the resistor in Fig. 36 are
   (1) 68,000 Ω, 10 percent.
   (2) 68,000 Ω, 20 percent.
   (3) 86,000 Ω, 5 percent.
   (4) 86,000 Ω, 10 percent.
   (5) 680,000 Ω, 5 percent.

blue — gray — orange — silver
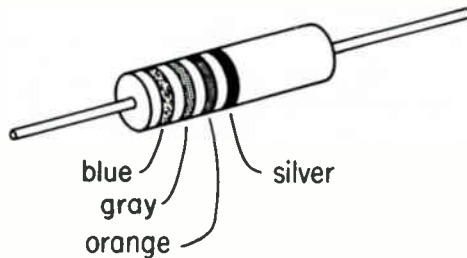
Fig. 36

9. You are asked to repair an electric toaster that does not produce sufficient heat. According to the nameplate, the unit should draw 6 A when used on the standard 120-V electrical outlet. You measure the resistance of the toaster with an ohmmeter, and find it to be 30 Ω. The toaster resistance should be (assume hot and cold resistances are equal)
   (1) 0.05 Ω (3) 3 Ω (5) 40 Ω
   (2) 5 Ω (4) 20 Ω

10. The current *actually* being drawn by the defective toaster in the question above is
   (1) 0.6 A.   (3) 3 A.   (5) 12 A.
   (2) 1.2 A.   (4) 4 A.

END OF EXAM

CLEVELAND INSTITUTE OF ELECTRONICS, INC. / CLEVELAND, OHIO
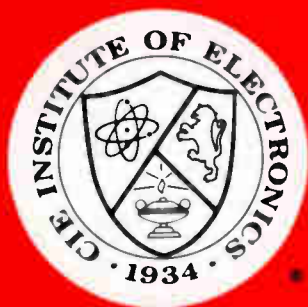
electronics
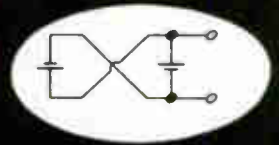
Lesson 2342A-6
Connecting and Tracing
Battery Circuits

Lesson 2342B-6
Identifying Components

Lesson 2342C-6
Tracing Wiring on
Printed Circuit Boards

AUTO-PROGRAMMED® Lessons

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Lesson 2342A-6
Connecting and Tracing Battery Circuits

Lesson 2342B-6
Identifying Components

Lesson 2342C-6
Tracing Wiring on Printed Circuit Boards

Technical Staff
Cleveland Institute of Electronics, Inc.

A Chat with Your Instructor

This volume is mainly concerned with improving your ability to read and interpret the wiring diagrams called *schematics*. The volume starts with a look at the various methods of connecting batteries to get the voltage or current output desired. It ends with you actually circuit-tracing an electronic power supply that's used in place of batteries, and which changes the AC (alternating-current) line power into smooth DC (direct current).

We urge you to study this volume carefully, and to do *all* of the questions in the *What Have You Learned?* sections. Nothing is so important to the electronics professional as the ability to follow and interpret schematic diagrams. Every piece of electronic equipment was first a schematic conceived by an electronics engineer, and then painstakingly put down on paper before it was transformed into an actual piece of electronic gear. Schematics are the very language of electronic circuits—the medium between the ideal and the practical to the design engineer, and the instruction book for the technician called upon to make a faulty circuit work again. Learn all you can about them—starting here and now!

Lesson 2342A-5
Connecting and
Tracing Battery Circuits

BATTERIES

1 USING BATTERIES . . . Batteries—a common source of power in electronics today—are available in many varieties, shapes, and voltage ratings. Two or more batteries can be connected together to make a higher-voltage power source or to make one that can supply either more current, or the same current for a longer period of time.

The most familiar batteries are flashlight cells; Fig. 1 shows the four most common sizes. The smallest of the cells shown is the AA size, often called a *penlite cell*. The next is the C size, and the largest is the old standby, the D cell. (The D cell is the familiar battery used in standard flashlights.) Also shown is the 9 volt transistor radio battery.

Fig. 1   Popular sizes of flashlight cell and transistor radio batteries.

The positive terminal of ordinary flashlight cells is the center post at the top; the negative terminal is the zinc container. Contact to the negative terminal is always made at the bottom end of the cell, since the sides of the zinc container are coated with insulating material.

2 BATTERY VERSUS CELL . . . Technically, a single-unit battery is properly referred to as a *cell*, and from this standpoint, a single flashlight "battery" is really a flashlight cell. However, it's common practice to call any battery that's complete in itself a battery, even if it has only one cell. That's why you'll often find the words "flashlight battery" printed on what is actually a flashlight *cell*.

A 12-V (volt) automobile battery has six 2-V cells, and is therefore known as a six-cell battery. Each of the units, in this case, is called a cell, since the cells are units of a package, and not complete units in themselves.

Any single (unit) part of a battery that is housed in the same package with other such units, then, is called a cell. Any single unit cell that is used as a complete unit in itself, such as a flashlight cell, may also be correctly called a battery. If these single-unit batteries are connected to make a larger battery, however, the individual units should again be referred to as cells. For example, four flashlight batteries connected to make a 6-V battery for a radio would be a *four-cell* battery— NOT a *four-battery* battery.

3 BATTERY SYMBOLS . . . Just as for other electrical and electronic parts, there are special symbols for batteries. The symbols appeared in the preceding lesson of this course, but let's go over them again in more detail.

(a)   (b)
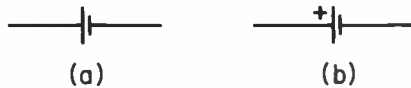
Fig. 2   Schematic, or wiring, diagram symbols for a simple battery. The long bar is the positive (+) side of the battery. Sometimes, the person who prepares the schematic will include a + sign, as in (b).

The symbols in Fig. 2 are for a low-voltage battery—usually, but not always, a one-cell battery such as a flashlight cell. Since the most commonly used cells are 1.5-V, the symbols of Fig. 2 might represent a 1.5-V battery. You can never be sure what size battery is meant when you see the simple symbol of Fig. 2. A simple battery, as you know, uses the symbol in Fig. 3(a). On the other hand, if a battery is made up of two or more cells in series, it's standard practice to use two long and two short bars for the symbol, as shown in Fig. 3(b) and (c). (You can usually assume that this symbol represents a battery of at least 2.5 V). Finally, two single battery symbols connected by dashed lines represent a battery made up of two or more individual cells, as shown in Fig. 3(d).

1.5 VOLTS	6 VOLTS	9 VOLTS	9 VOLTS
—┤┠—	—┤┃┠—	—┤┃┠—	—┤┠---┤┠—
EVEREADY 950	Use 4 AA type batteries	EVEREADY 216	Use 6 C size cells
a	b	c	d
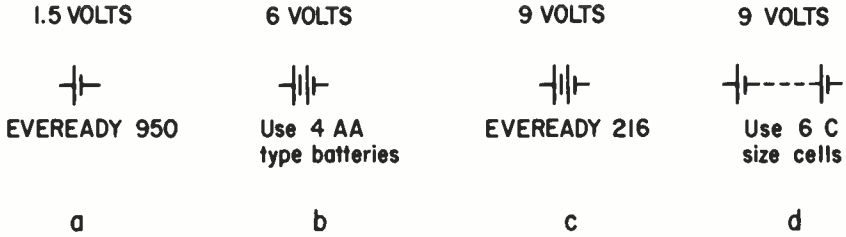
Fig. 3   Battery symbols, with type or type number and voltage included near the symbol as replacement information.

The battery voltage, and sometimes even the manufacturer's serial number, may appear alongside the battery symbol, or somewhere else on the schematic or wiring diagrams. About the only general statement we can make is that a symbol with one long and one short bar represents a relatively low-voltage battery, and that the long bar represents the positive battery terminal.

CONNECTING BATTERIES

Batteries, like all electrical components, can be connected in three different ways: parallel, series, and series-parallel. Each of these connections has advantages: (1) parallel, longer battery life; (2) series, more output voltage; and (3) series-parallel, the combination of longer life and more output voltage.

Fig. 4   Batteries connected in parallel.

4 PARALLEL CONNECTION . . . Connecting batteries (or anything else, for that matter) in parallel means connecting all like sides together. Figure 4 shows two flashlight cells connected in parallel. Note that the positive (+) sides are connected together, and so are the negative (−) sides. Note also that if one battery were removed, the battery that remained would still supply voltage to the output lead wires. When a second battery is connected in parallel with the first, the voltage doesn't change, since the output wires are still across the same voltage—in this case, the 1.5 V of the flashlight cell.

What is the advantage of a parallel connection? The answer is that such a connection provides *two* batteries to supply current to an electrical load. (A *load* is anything connected to a battery to do useful work—a light bulb, a radio, or whatever.) If two batteries are connected in parallel and used to light a lamp, for instance, the lamp will not be any brighter than it would be with only one battery, but the two batteries will last twice as long.

One important rule to remember when connecting cells or batteries in parallel is that all the units *must* have the same voltage rating. If you were to connect a 1.5-V battery, say, in parallel with a 2-V battery, the higher voltage of the 2-V battery would overcome the 1.5 V of the other battery. As a result, the 2-V battery would quickly discharge through the 1.5-V battery, and both would be ruined.

Be very careful when connecting cells in parallel that you always connect negative terminals to negative terminals and positive terminals to positive terminals. If either of the cells in Fig. 4 were reversed from the position shown—that is, if the positive of one was connected to the negative of the other—the resulting short circuit would ruin both cells.

One application of batteries in parallel, that you're probably familiar with is the use of jumper cables to temporarily connect a fully charged battery in parallel with a weak one in order to get a car started on a cold morning. The added current capacity of the two batteries in parallel provides the starter the extra current it needs to turn over the engine despite the effects of extreme cold.

5 HOW MANY BATTERIES IN PARALLEL? . . . As many batteries as are needed can be connected in parallel, so long as all the batteries have the same voltage. Batteries in parallel share the job of supplying current to a load. Hence, the life of the overall battery increases by a proportional amount as additional batteries or cells are connected in parallel. Figure 5 shows batteries in various physical layouts, and with electrical connections that may appear to be different at first glance; however, all the connections are in parallel. Note that in each case the positive terminals are tied together, as are the negative ones.
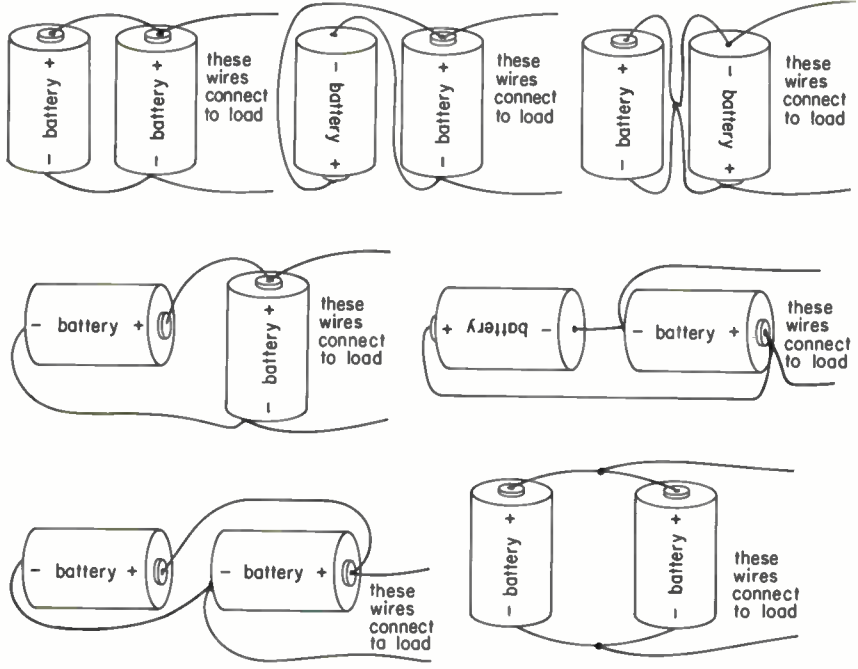
Fig. 5   All of the batteries above are connected in parallel, even though they are not all in the same physical position, or oriented in the same direction.

Because there are a number of ways to arrange batteries physically it can sometimes be difficult to trace through a circuit. The solution is to start at *one* end of *one* battery, trace to see where it goes, and then go from that point to the next battery (and so on).

6 TRACING PARALLEL BATTERY CIRCUITS . . . The number of positions in which batteries can be placed is almost innumerable. Even two batteries can be arranged in a number of ways, as shown in Fig. 5. Obviously, then, when tracing through a battery circuit, you can't let yourself be confused by the physical position of the batteries. Rather, you should concentrate on checking how the wiring connects from one battery to the other. If you trace out the wiring in all seven arrangements shown in Fig. 5, you'll find that the positive (+) sides are tied together and the negative (−) sides are tied together in all cases.
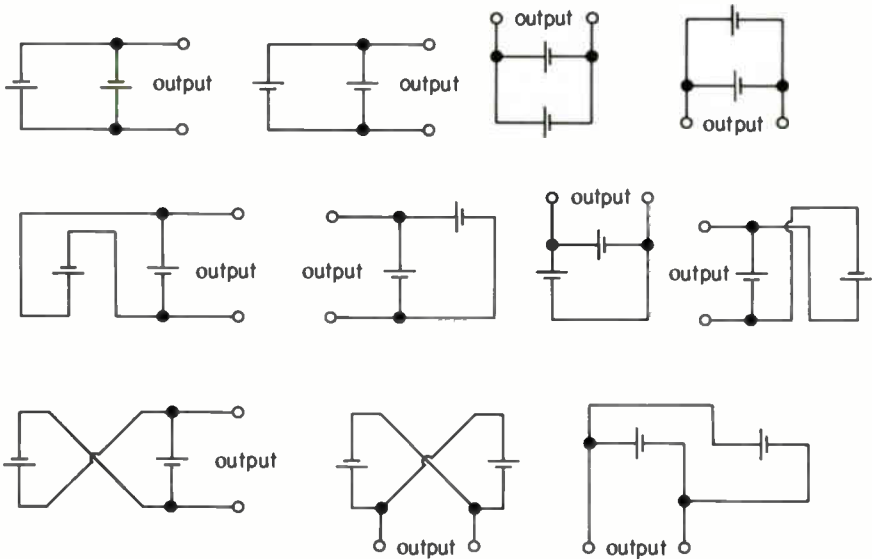
Fig. 6   Various schematic diagrams that could be used to indicate two batteries in parallel.

7 SCHEMATIC VARIATIONS . . . Wiring diagrams or schematics of a pair of batteries can have many variations, also. Figure 6 shows some of the possible schematics that could be used to indicate two batteries in parallel. Again, you must follow the wiring by starting at one battery and proceeding to the next. Again, you can see that every diagram shows the positive sides of the battery connected together and the negative sides also, with the output taken off across any battery. This means, of course, that the batteries are in parallel, and that the output voltage is the same for the entire circuit as for any one battery by itself. The wires marked "output" connect to the load. Remember that a load is anything connected across the battery terminals to which the battery is supplying current.

1. The voltage required to light the lamp in Fig. 7 is __2__ V.

2 V

2 V

2 V

Fig. 7   lamp
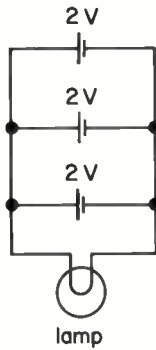
2. If a 3-V battery and a 4-V battery are connected in parallel,
   (1) they will produce a 7-V supply.
   (2) the 4-V battery will discharge through the 3-V battery.
   (3) they will produce 3.5 V without harm to either battery.
   (4) the smaller battery won't work so hard.

3. If four batteries in parallel will run a particular radio for 200 hr (hours), how long will one battery run the same radio? *50 hr*

4. Draw the wires necessary to connect all three cells in parallel to the lamp in Fig. 8.
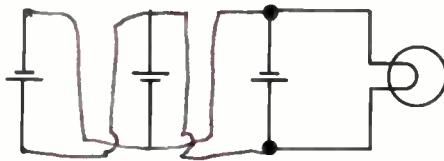
Fig. 8

5. Which of the drawings (one or more) in Fig. 9 is (are) NOT connected in parallel correctly?

(a)

(b)

(c)

(d)
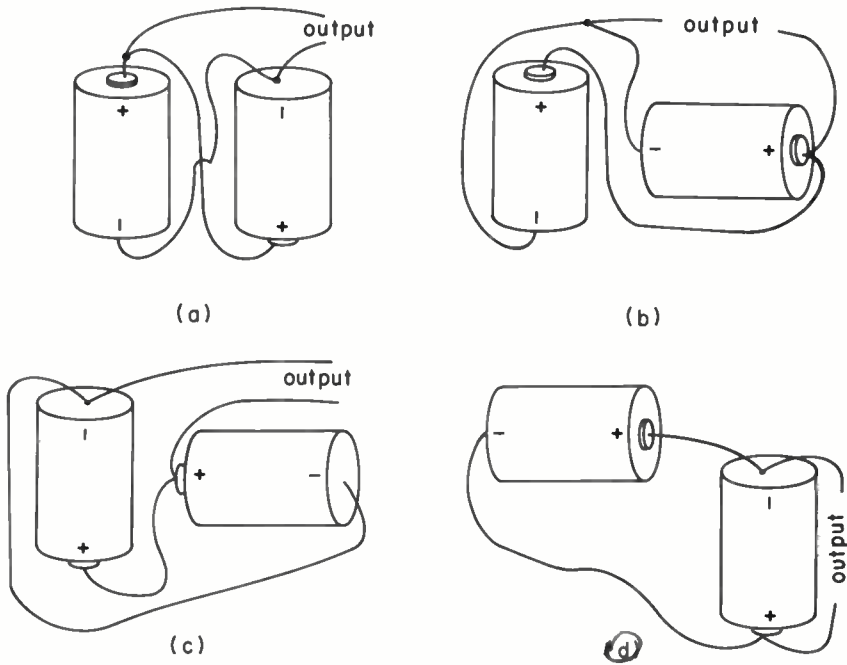
Fig. 9

6. Which one of the schematics in Fig. 10 does NOT have the batteries connected in parallel correctly?

(a)

(b)

(c)

(d)

(e)
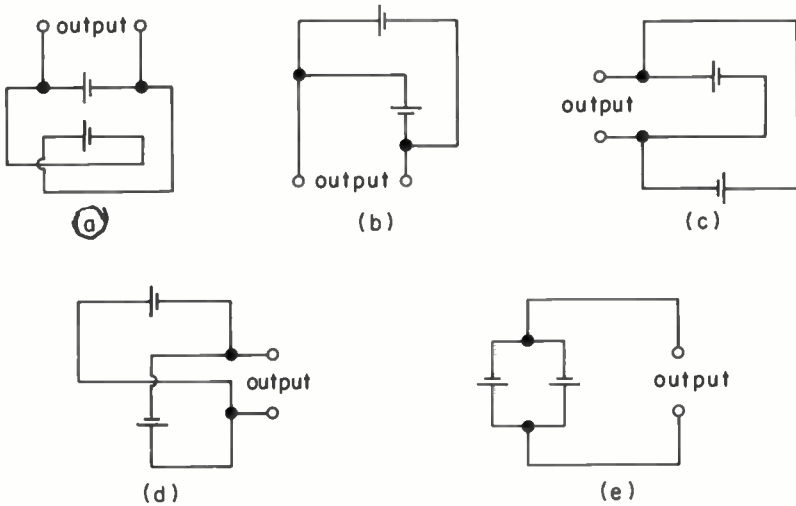
Fig. 10

1. 2   2. (2) . . . Batteries of *unlike* voltage should *never* be connected in parallel.
3. 50 hr . . . This assumes, of course, that all batteries are identical.
4. See Fig. 11.   5. (d)   6. (a)
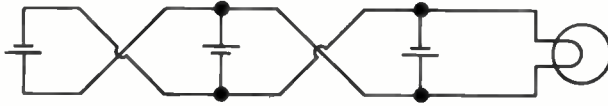
Fig. 11

8 SERIES BATTERY CONNECTIONS . . . By far the most common connection for batteries is the series connection. This is the connection used in a flashlight, for example, in which the positive side of one battery makes a connection with the negative side of the next battery. Figure 12 shows two pairs of batteries connected in series. Note that the output is taken from the positive side of one battery and the negative side of the other battery in both cases.
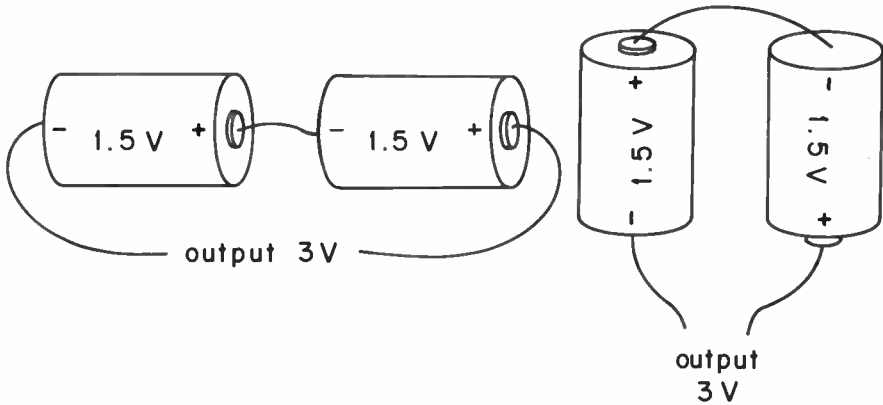
Fig. 12   Two ways to connect flashlight cells in series to increase the output voltage.

The series connection increases the output voltage of a group of cells or batteries. For example, two 1.5-V flashlight cells connected in series have an output voltage of 3 V; three 1.5-V in series have an output voltage of 4.5 V; four have an output of 6 V; and so on.

In series connection, batteries of different voltages can be used; for example, a 2-V battery can be connected in series with a 6-V battery to supply 8 V. However, the batteries shouldn't differ greatly in respect to the amount of current they can produce. The reason is that in a series connection, the battery is only as good as its weakest link. In other words, the battery's current producing capability is limited to the amount of current that can be produced by its least productive cell.

To connect in series cells having unequal current producing capabilities is simply a waste of battery size (and money). Because the same current flows through each of the batteries, series-connecting batteries does *not* increase battery life.

9 SYMBOLS FOR SERIES-CONNECTED BATTERIES OR CELLS . . . Figure 13 shows three common symbols for series-connected batteries. If the cells are separated and a line is drawn between them, as in (a), this indicates that the battery consists of two individual, separate batteries. An example of this would be a battery made out of two flashlight cells connected in series. The symbol in (b) usually—thought not always—indicates that the battery has a higher voltage than a single cell and is made up of two or more cells that are all contained in a single package. A good example of this would be the common 9-V transistor radio battery that consists of six 1.5-V cells all contained in a single package. However, this symbol is also sometimes used to indicate multiple individual cells as in a large portable radio or cassette recorder in which four, six, or even eight individual flashlight cells are connected together to form a battery pack. The symbol in Fig. 13(c) indicates that the battery is a higher-voltage one made up—as represented by the dashed lines—of several separate, individual cells, usually (again, not always) three or more in number.

(a)   (b)   (c)
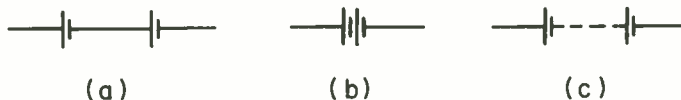
Fig. 13   Battery symbols.
(a) Two batteries or cells connected in series
(b) Multiple-cell battery
(c) Three or more individual batteries or cells connected in series.

WHAT HAVE YOU LEARNED?

1. When batteries are connected in series, the voltage *(increases)* *(decreases)* *(remains the same)*.

2. To properly connect batteries in series, you must connect the positive side to the ___Negative___ side of the next battery in the series.

3. True or (False) In a series connection, the output voltage is always taken off the plus and the minus connection of one of the batteries.

4. Only one of the pairs of batteries in Fig. 14 is correctly connected in series. Which one is it?
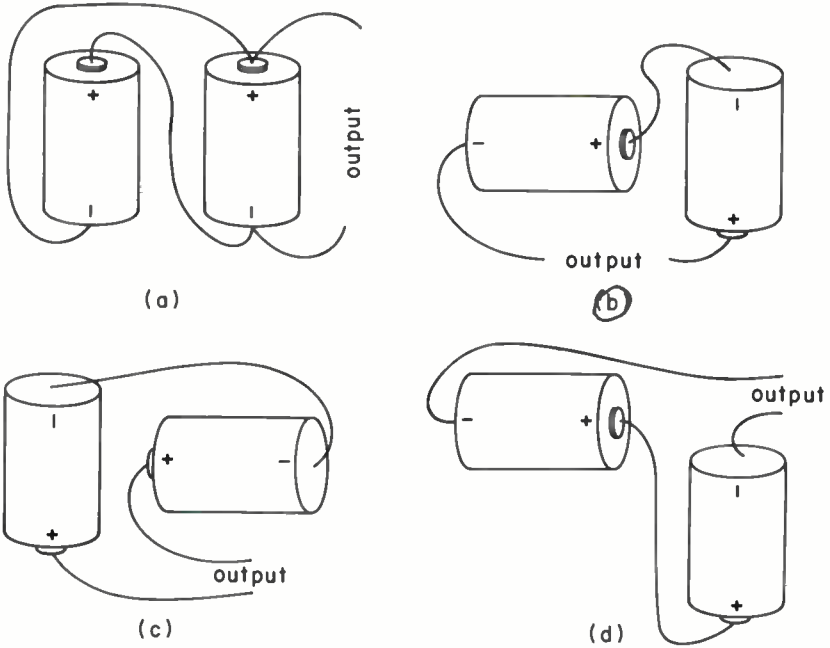
Fig. 14

5. Which of the schematics in Fig. 15 is (are) correct for a series connection of two batteries?
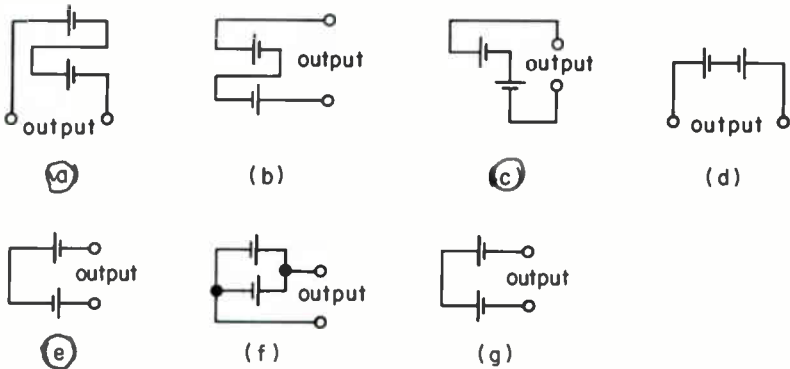
Fig. 15

6. If the connections are correctly made for two 2-V batteries in series, what is the output voltage?   4V

7. More than two batteries may be connected in series, as shown in Fig. 16. They don't have to be of the same voltage, although they should be of similar size and type. What's the output voltage of the batteries connected as shown in Fig. 16? Is this a series or a parallel connection? *Series* **19.5 V**

Output
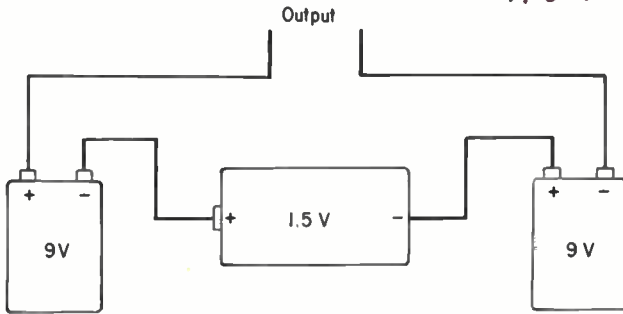
Fig. 16

8. The pictorial diagram of Fig. 17 shows three batteries connected to light a lamp. Which one of the schematic diagrams represents the circuit in the pictorial diagram?
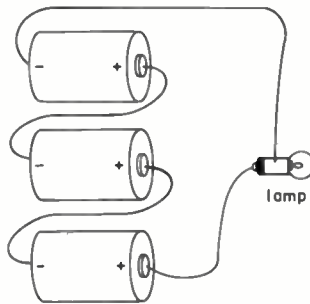
pictorial diagram
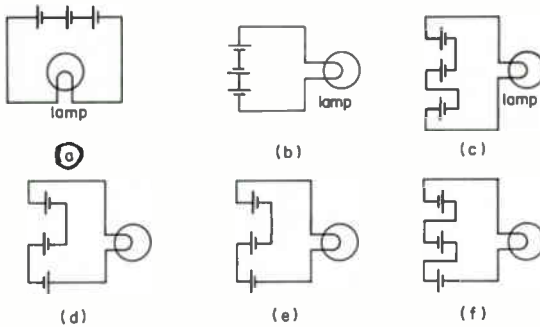
schematic diagrams

Fig. 17

9. If the batteries in Fig. 13(a) will supply a constant current for 20 hr, how long will one of the batteries supply the same current? *20 hr.*

1. increases . . . This is the principal purpose of connecting batteries in series—to step up the voltage.

2. negative . . . This holds true regardless of the number of batteries in series. The output is then taken off the negative of the first battery in the series and from the positive of the last one—or, conversely, from the positive terminal of the first battery and the negative terminal of the last one.

3. False . . . See explanation for question 2, above.

4. (b) . . . All the others violate some rule of connecting a series circuit. For example, (a) isn't a practical connection at all, since the positives and negatives of both batteries are connected to each other. This connection will run the batteries down very quickly, since each battery is forcing current through the other. See Topic 11 and Fig. 21 for a more detailed explanation.

5. (a), (c), and (e) . . . In (g), the batteries are connected positive to positive, and in (b) and (d) negative to negative. The batteries in (f) are connected in parallel instead of in series.

6. 4 V . . . Batteries in series add to the output voltage according to the value of each battery. Three 2-V cells in series would be 6 V, and so on.

7. 19.5 V . . . 9 + 1.5 + 9 = 19.5; Series

8. (a) . . . All the other schematics reveal something wrong—either two positive terminals or two negative terminals tied together.

9. 20 hr . . . Connecting batteries or cells in series does not affect the life of the batteries.

10 BATTERIES IN SERIES-PARALLEL . . . Sometimes, we need to connect batteries so as to provide more current and longer life, as well as more voltage. Figure 18 shows three ways in which four flashlight batteries can be connected in series-parallel to double both the battery life and the battery output voltage.
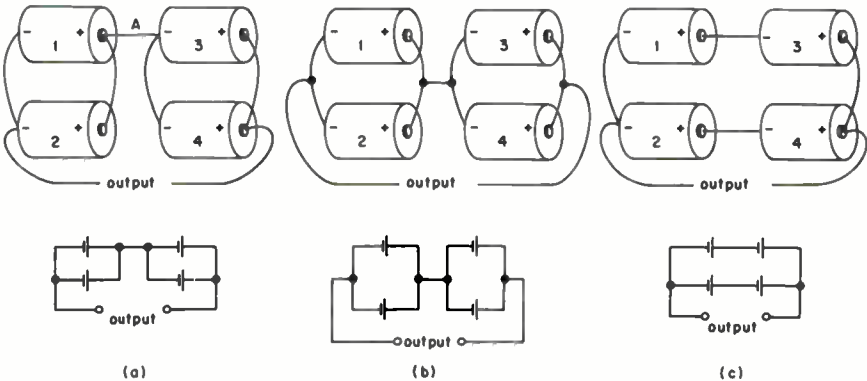
Fig. 18   Batteries connected in series-parallel.

What we actually have in Fig. 18(a) are two pairs of parallel-connected batteries, with those pairs connected in series by wire A. The output is taken from the positive terminal of one pair of batteries and from the negative terminals of the other pair. The parallel connections increase the current capability of the system while the series connection increases the output voltage. Note that the output voltage is the same as if only batteries 1 and 3 were connected in series: batteries 2 and 4 simply add additional current availability by being in parallel with batteries 1 and 3.

Figure 18(b) is exactly the same circuit electrically as the circuit in (a), even though at first glance it might appear to be different. Note that batteries 1 and 2 are in parallel, as are batteries 3 and 4. The two pairs of batteries are then connected in series, with the output taken from the positive (+) side of one pair of parallel batteries and from the negative (−) side of the other pair of parallel batteries.

Figure 18(c) is also a series-parallel connection, with both the same current and the same output voltage as (a) and (b). Here, however, batteries 1 and 3 are connected in series, as are batteries 2 and 4. The two pairs of series-connected batteries are then connected in parallel.

So, for series-parallel connections, you may either connect battery groups in parallel and then connect the groups in series, or connect the batteries in series groups and connect the series groups in parallel at each end. Whichever method you choose, the voltage output will be determined by the number of series-connected batteries. In Fig. 18, for example, each of the flashlight cells has 1.5 V. Since two are connected in series, the output voltage is 3 V. The parallel batteries add to the available current or battery life, but—as with all parallel connections—they have no part in increasing or decreasing the output voltage.

WHAT HAVE YOU LEARNED?

1. Which one of the schematic diagrams in Fig. 19 has exactly the same electrical connections as the pictorial diagram?   *B* C

2. Which one of the schematic diagrams in Fig. 19 though not an exact representation of the pictorial, will have the same output current and voltage?   *A*
   d *+c*

3. If each of the cells in the pictorial diagram of Fig. 19 is a 1.5-V unit, what will be the output voltage of the group?   4,5 V

4. If the same amount of current were drawn in each case, the group of batteries as connected in the pictorial diagram of Fig. 19 would last *(twice)* *(three times)* as long as three of the same kind of batteries in series.

16

pictorial diagram

schematic diagrams
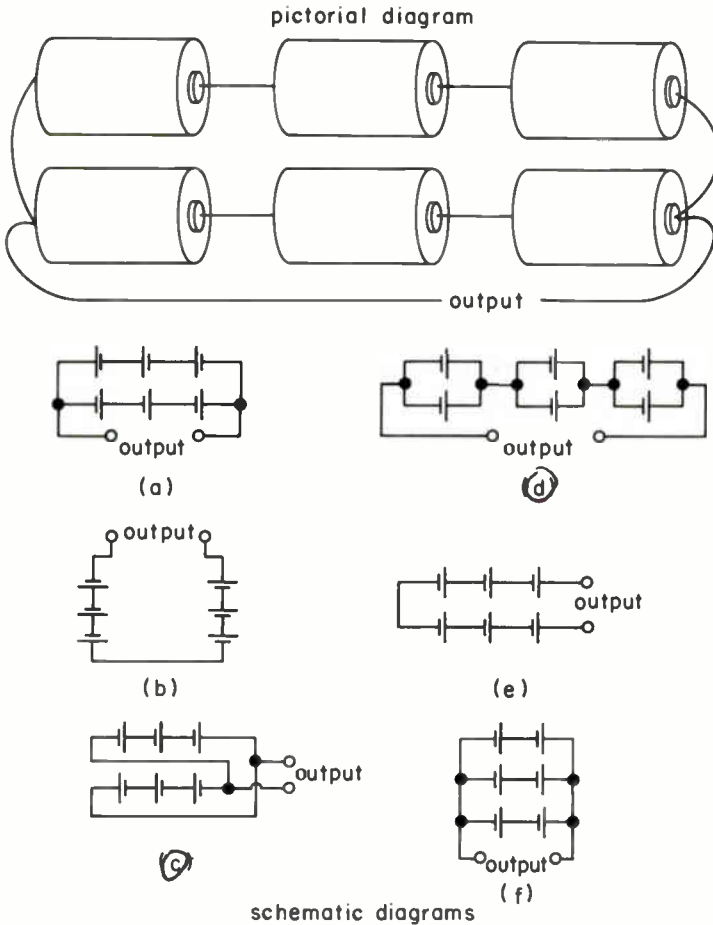
Fig. 19 Note. All batteries have the same voltage

5. The voltage output of the batteries in the pictorial of Fig. 19 is the same as
   (1) two batteries in series.
   (2) two batteries in parallel.
   (3) three batteries in series.
   (4) three batteries in parallel.

heavy current flow

zero output

schematic of incorrect connection
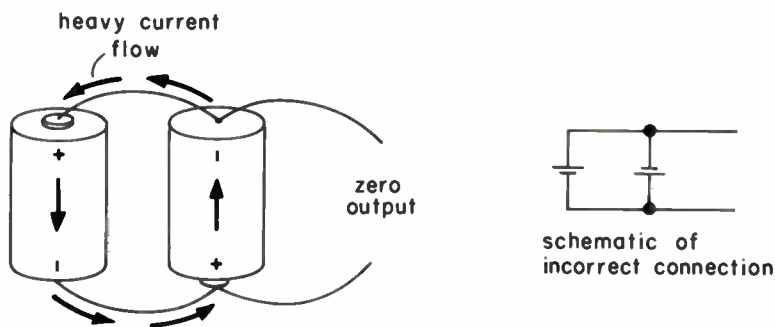
Do NOT connect batteries this way !

Fig. 20 **An incorrect connection of parallel batteries will cause heavy current to flow between and through the batteries, but not to the output leads. The heavy current will cause the batteries to heat, so—if the batteries are warm to touch—check the connections. Heat will eventually damage batteries.**

ANSWERS

1. (c) . . . The batteries are so connected that two sets of three batteries are connected in series, and the two sets then connected in parallel.

2. (d) . . . The batteries are connected in three sets of two parallel groups, and the parallel groups then connected in series. Both (c) and (d) have the same voltage output and current capability, and are said to be connected in series-parallel.

3. 4.5 V   4. twice . . . Actually, the circuit is simply two sets of three batteries connected in series, with one set connected in parallel with the other set. This doubles the available current—that is, it can supply the same current twice as long.

5. (3)

11 MISCONNECTING BATTERIES . . . You should always take care connecting batteries. An incorrect connection in a parallel group of batteries will act as a short across the battery pack, and quickly run all the batteries down. An incorrect connection in a series circuit usually won't damage the batteries, but it will reduce the voltage output.

Figure 20 shows what will happen if two batteries are connected in parallel the wrong way. Each battery will drive current through the other, and the batteries will soon discharge completely. During the discharge, they will heat up. A hot battery always indicates heavy current—either because the battery connection is incorrect, or because excessive current is being drawn from the output. Always check parallel connections carefully to make sure that all the (+) leads are tied together and go to one output lead, and that all the (−) leads are tied together and go to the other output lead.

18   Figure 21 shows two flashlight cells connected incorrectly in series. The output
      in this case is zero, because the two batteries are "bucking" each other. No cur-
      rent flows, however, so the batteries won't be damaged. Reversing one cell in a
      series connection, then, has the effect of cancelling the voltage output of two cells,
      since the reversed cell neutralizes the effect of the another cell. In Fig. 22, for
      example, the four cells, which would normally have a 6-V output connected in
      series, have only a 3-V output, since the one reversed cell effectively cancels its
      own output voltage as well as that of one other cell.

(a) Incorrect connection

(b) Schematic of incorrect connection

Fig. 21
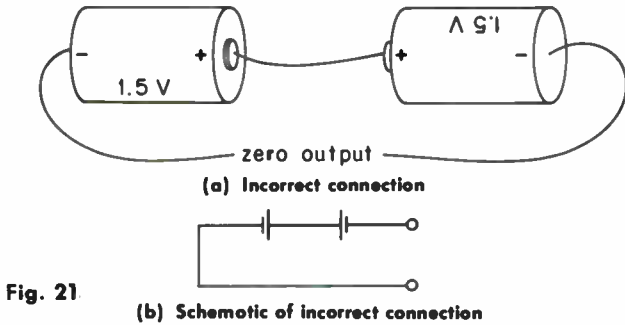
Two identical cells connected in this manner—in opposition, or bucking—
have zero voltage output. However, since no current flows, the batteries
aren't damaged.

In series connections, always make sure that the negative of one battery is con-
nected to the positive of the next, and that one output lead comes off the negative
of the battery at one end of the group while the second output lead comes off
the positive of the battery at the other end of the group.

Schematic
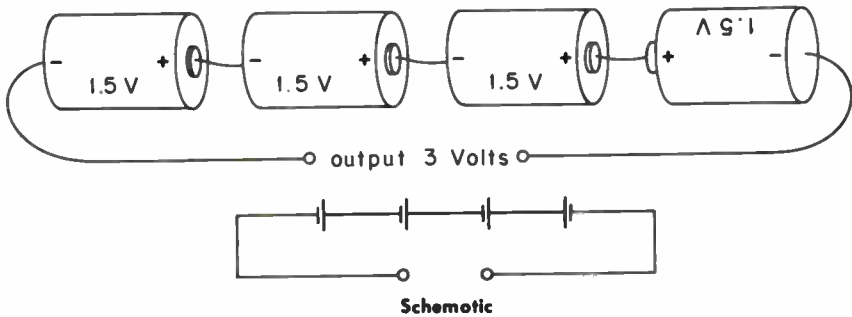
Fig. 22   A reversed cell cancels the voltage of itself and one other cell.

EXAMINATION

Each examination question is followed by a number of selections. Circle the number in front of the correct selection for each question. When you have finished, transfer your answers to the Answer Sheet provided.

1. A 12-V automobile battery has six 2-V cells. Since the six cells make a 12-V output, we know the cells are connected in
   (1) series.   (2) parallel.   (3) series-parallel.   (4) opposition.

2. You've no doubt installed flashlight cells. The cells (or batteries) in a flashlight are connected in
   (1) series.   (2) parallel.   (3) opposition.

3. The long bar of the battery symbol used in schematics indicates that the side of the battery it represents has ___+___ polarity.
   (1) an unknown   (2) neutral   (3) a (+)   (4) a (−)

4. For the cells connected as shown in Fig. 23,
   (1) the output voltage is the same as for one cell.
   (2) the output voltage is twice that of one cell.
   (3) they are incorrectly connected and will be quickly damaged.

Fig. 23

5. You have a 1.4-V cell, a 3-V cell, and a 9-V cell. There's only one way you can connect all three cells, since all have different voltage values. Connected in this way, the cells give a voltage of
   (1) 1.4 V.   (2) 13.4 V.   (3) 3 V.   (4) 9 V.

6. The batteries in Fig. 24 are connected in
   (1) opposition.   (2) series.   (3) parallel.   (4) series-parallel.

7. Assuming that each cell in Fig. 24 has a rated voltage of 1.5 V, what's the output voltage of the battery?
   (1) 1.5 V   (2) 3 V   (3) 4.5 V   (4) 6 V
   (5) Zero, or nearly so, if the cells have been left connected in this manner for any length of time, because they're not correctly connected.
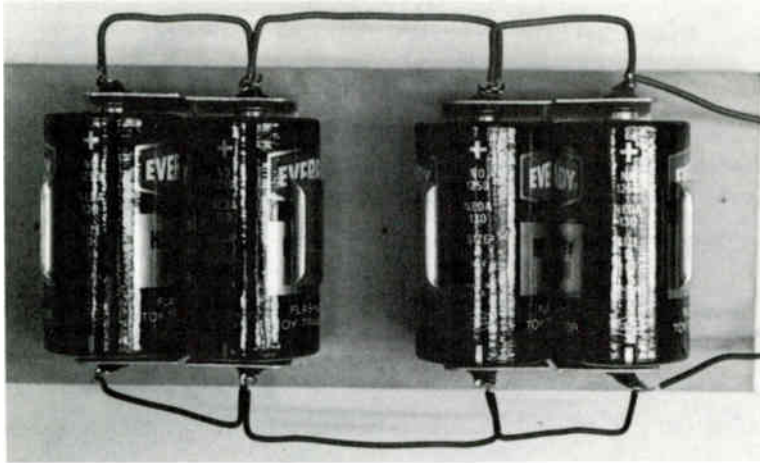
Fig. 24

8. The batteries in Fig. 25 are connected in
   (1) series-parallel.   (2) parallel.   ③ series.
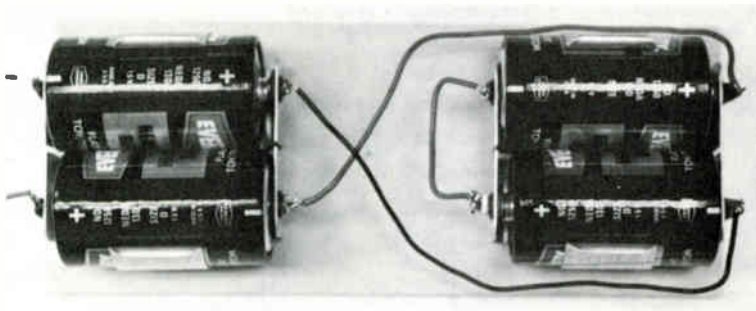
Fig. 25

9. What's the output voltage of the battery in Fig. 25, assuming each cell is 1.5 V?
   (1) 1.5 V   (3) 4.5 V   (5) 9 V
   (2) 3 V   ④ 6 V
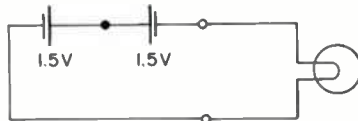
Fig. 26

10. For the cells connected as shown in Fig. 26,
    (1) the output voltage is twice that of one cell.
    (2) the output voltage is the same as for one cell.
    ③ the cells are bucking, and the net result is zero voltage at the output.

END OF EXAM

Lesson 2342B-5
Identifying Components

12 HOW BATTERIES ARE CONNECTED: A REVIEW . . . To summarize the preceding topics on battery connections: battery cells may be connected either in series, in parallel, or in a combination of these (series-parallel) in order to form a larger battery. Figure 27 shows how to connect cells in series, and Fig. 28 shows how to connect them in parallel. Note that in the series connection, the negative terminal of one cell connects to the positive terminal of the next cell. That is, the negative terminal of cell 1 connects to the positive terminal of cell 2; the negative terminal of cell 2 connects to the positive terminal of cell 3; and so forth. In the parallel connection, all the positive terminals are connected—to each other and to the positive side of the load. Similarly, all the negative terminals are connected together, and to the negative side of the load.

(a) Pictorial diagram

(b) Schematic diagram
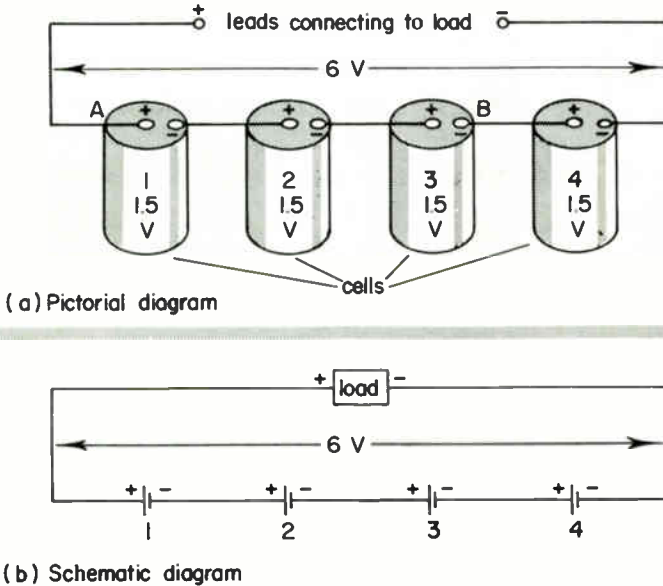
Fig. 27   Cells connected in series.

When cells are connected in series, the battery voltage is equal to the sum of the voltages of the individual cells. Thus, in Fig. 27, where four 1.5-V cells are shown connected in series, the battery voltage is 4 × 1.5 = 6 V. Batteries are connected in series when a voltage higher than that available from a single cell is needed. Since few cells offer a voltage higher than 2 V (ordinary dry cells are only 1.5-V), and since higher voltages are usually needed, cells are connected in series much more often than in parallel.

22 When cells are connected in parallel, the total battery voltage is the same as the voltage of a single cell. Thus, in Fig. 28, where four 1.5-V cells are shown connected in parallel, the battery voltage is 1.5 V. Although cells of different voltage value may be connected in series, only identical cells should be connected in parallel; otherwise, the higher-voltage cells in the parallel group will discharge through the lower-voltage ones. Care must also be taken that a bad cell isn't connected in parallel with good cells, since the good cells could be ruined by discharging through the bad one.

(a) Pictorial diagram

(b) Schematic diagram
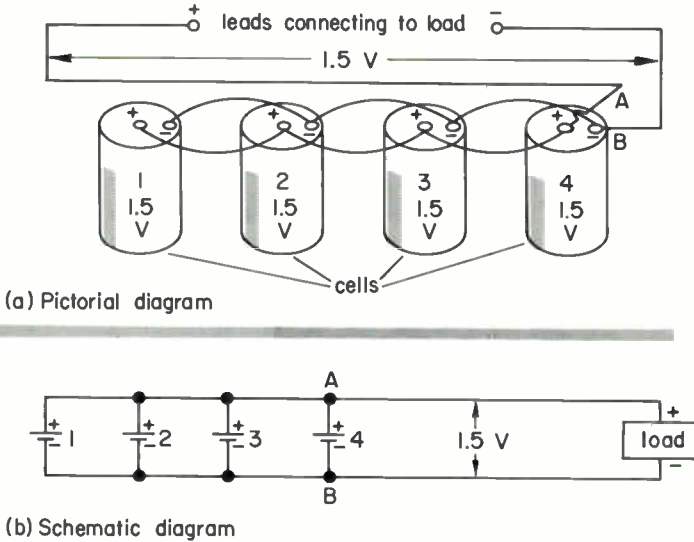
Fig. 28   Cells connected in parallel

Cells are connected in parallel in order to increase the life of the battery while under load. To put it another way, cells are connected in parallel when they are to be used in a circuit drawing a heavy current. Two cells in parallel will operate approximately twice as long under a given load as a single cell before they have to be replaced or recharged. Similarly, three cells in parallel will last approximately three times as long, and five cells in parallel will last about five times as long. (Note that the life of cells under load is *not* increased by using a series connection.)

If both higher voltage and longer life are needed, cells can be connected in a series-parallel arrangement. Enough cells are connected in series to give the desired voltage, and then this group of cells is in turn connected in parallel with as many identical groups of series-connected cells as are needed to provide the required battery life. Figure 29 shows how to connect a number of 1.5-V cells to give a battery voltage of 4.5 V, while at the same time providing a battery life equal to twice the life of a single cell. Cells 1, 2, and 3 are first connected in series, as shown in Fig. 29(a). The voltage of the three in series is 3 × 1.5 = 4.5 V.

Then, cells 4, 5, and 6 are also connected in series, and they too provide 4.5 V.
We therefore have two 4.5-V batteries in (a).
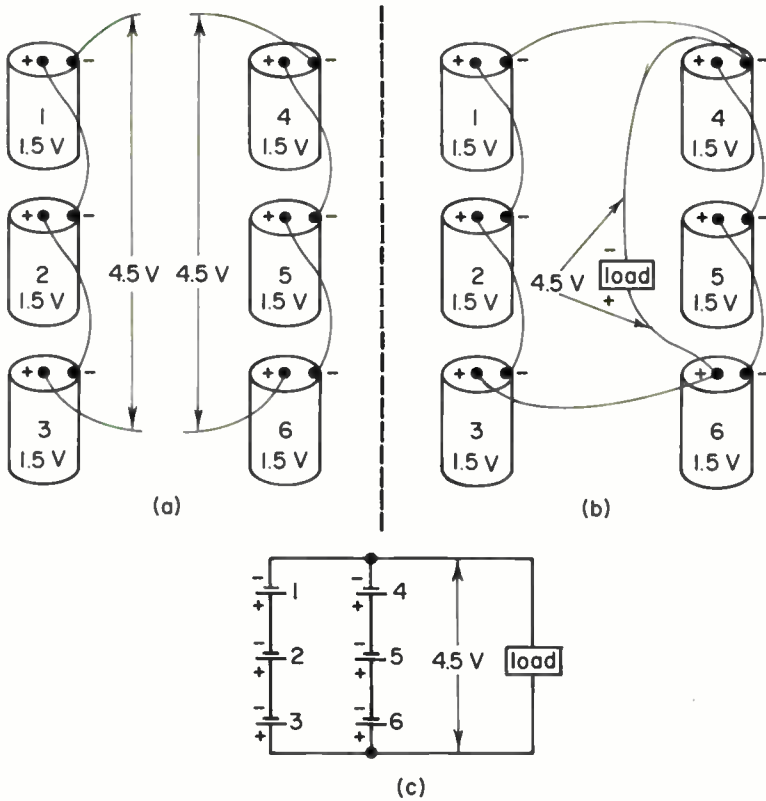
Fig. 29   Cells connected in series-parallel.

Now, if two batteries are connected in parallel, the voltage will be the same as
for one battery, but they will have twice the life with a given load that a single
battery would have. Figure 29(b) shows the two batteries of (a) connected in parallel.
Note that the two negative terminals of the batteries of (a) are connected together,
as are the two positive terminals. The schematic diagram of the series-parallel
connection of (b) is shown in (c).

Suppose now that a single cell of the battery of Fig. 29(a) can supply a current
of 4 A (amperes) for 10 hr before it is discharged. It follows, then, that one of
the groups of three cells in series in (a) will also be able to supply 4 A for 10
hr. Connecting cells in series won't make them last any longer, but it will provide
a higher voltage. However, the battery of Fig. 29(b) will last longer, because it's
made up of *two* batteries in parallel. It will supply a current of 4 A for 20 hr.
(Of course, it could furnish a current of only 2 A, say, for twice as long, or 40 hr.)

24　Besides providing a longer load life, there's another reason why batteries are often connected in parallel or in series-parallel. When a heavy current is drawn from a cell, the cell voltage drops appreciably. By connecting cells in parallel or in series-parallel, this voltage loss is reduced. Two cells in parallel, or two groups of series-connected cells in parallel, will have only half the voltage loss of a single cell or of a single series-connected group of cells.

WHAT HAVE YOU LEARNED?

1. If you have a 1.5-V cell, a 1.3-V cell, and a 2-V cell, there's only one way the three can be connected—in _____Series_____. The battery voltage would be _4.8_ V.

2. You need a 90-V battery to power an amplifier. You have a 30-V battery, a 45-V battery, and a 60-V battery. How can you get the required 90 V? Connect 30V and 60V in Series —leave 45 V out

3. A No. 6 dry cell, which develops 1.5 V, can supply a current of 2 A for 15 hr before needing replacement. How long will three No. 6 dry cells connected in series supply a current of 2 A? 15 hr.

4. You want to connect the necessary number of No. 6 dry cells to supply a constant current of 2 A at 1.5 V for 45 hr. You would use _3_ cells, connected in _parallel_.

5. The electrical system in most modern cars requires 12 V to operate properly. The voltage per cell of storage batteries of the type used in cars is approximately 2 V. Are the cells of a car storage battery connected in series or in parallel? How many cells has a car storage battery? Series need 6 cells

(a)

(b)
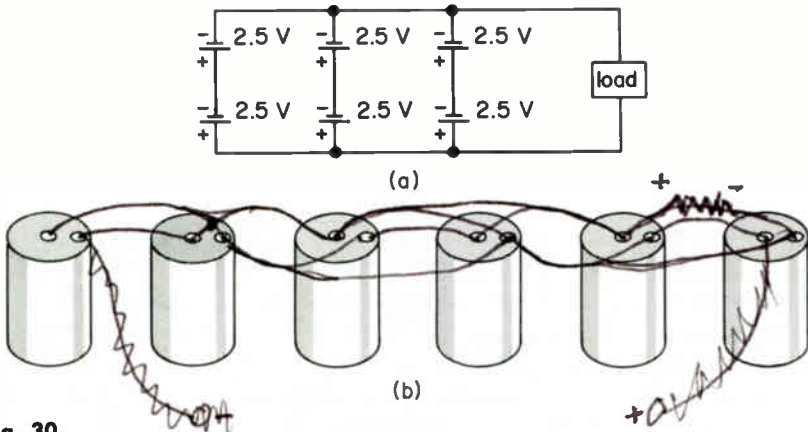
Fig. 30

6. The cells in the battery circuit of Fig. 30(a) are connected in _Series/parallel_ The battery voltage is __5 V__. Each cell in this battery has a life of 25 hr when delivering a 1-A current continuously. This battery will deliver a 1-A current continuously for approximately __75__ hr.

7. Draw lines to connect the cells in Fig. 30(b) in accordance with the schematic diagram of Fig. 30(a).

ANSWERS

1. series . . . Only cells of equal voltage can be connected in parallel; 4.8 . . . 1.5 V + 1.3 V + 2 V = 4.8 V
2. By connecting the 30-V and 60-V batteries in series.
3. 15 hr . . . The life of cells is *not* extended when the cells are connected in series.
4. three; parallel . . . One cell will last 15 hr: 3 × 15 hr = 45 hr.
5. Series . . . Enough 2-V cells must be connected in series to obtain a 12-V output from the battery; Six . . . The battery voltage of six 2-V cells in series is 6 × 2 V = 12 V.
6. series-parallel; 5 V; 75 . . . Three groups of cells are connected in parallel for a life of 3 × 25 hr = 75 hr.
7. See Fig. 31.
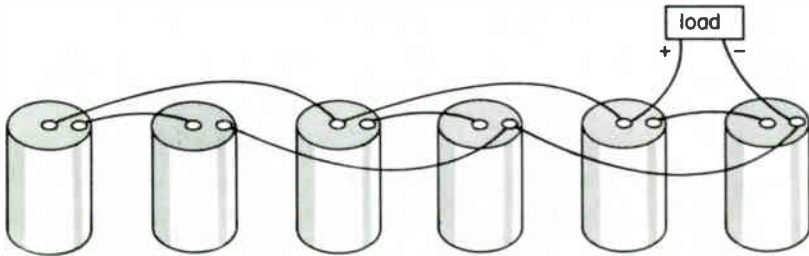
Fig. 31

13 WIRING DIAGRAMS . . . A wiring, or schematic, diagram is the written language
used to explain the electrical layout of a circuit. It's absolutely essential for anyone
interested in electronics to be able to read and understand the symbols and layouts
used in electrical and electronic circuits. Using a schematic, you can trace the
electron flow around the circuit, and thereby understand how the circuit works.

Schematics are extremely useful when you have to repair a circuit or group of
circuits. By knowing how many volts should be here, or how much resistance should
be there, you can find the point in the system where everything is not as it should be.

It's often desirable when troubleshooting printed circuits that you have both
schematic and pictorial diagrams of the circuit. For one thing, the pictorial diagram
may include callouts that identify the circuit parts as they relate to the schematic.
In addition, many printed circuit boards have identifying numbers printed on them
to help in troubleshooting (see Fig. 32).
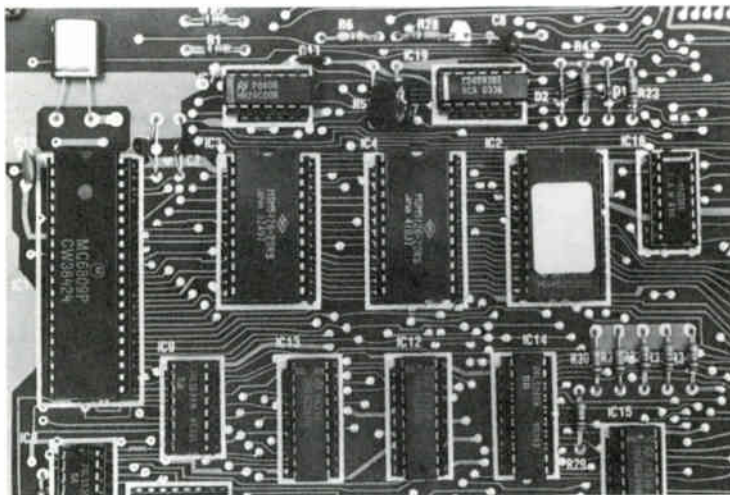
Fig. 32 **A printed circuit board of a microprocessor system. Each component
mounted on the board is given a label that consists of a letter(s) and a
number. These same marks are used on the schematic to ease component
identification.**

In the following pages, we won't cover *all* the many and varied ways in which
circuit diagrams are drawn; however, but you'll find the basic information here.
Using a little basic logic, you'll be able to cope with most of the variations you'll
encounter.

14 RELATING A SCHEMATIC TO THE ACTUAL CIRCUIT . . . To be proficient
in electronics, you must be able to pick out the actual circuit components and
relate them to the schematic—and, conversely, relate the schematic to the actual
components. Figure 33 shows a breadboarding socket with nine components (elec-
tronic parts) mounted on it. The parts are a 555 timer chip, five resistors, a light-
dependent resistor, a speaker, and a 9-V battery.
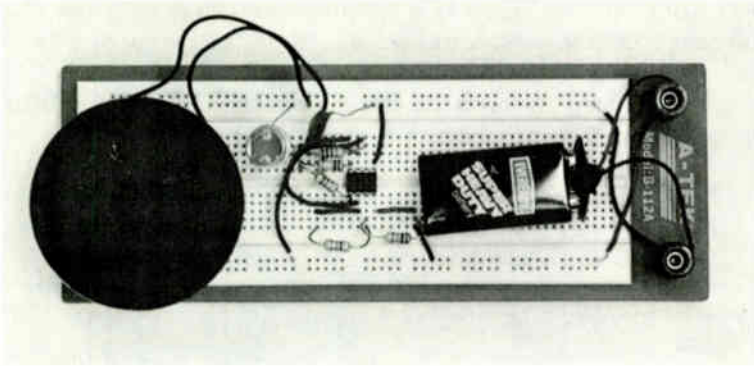
Fig. 33

15 RESISTORS . . . Resistors are used in just about every electronic circuit. They
control the amount of current in a circuit, keeping it within desired values. If the
resistance is high, the current will be low; if the resistance is low, the current
will be high. Present-day circuit design calls for resistors with hundreds of dif-
ferent values, from below 1 Ω (ohm) to above 100 MΩ (megohms). A megohm
is one million Ω.

In schematics, resistors are labeled with the letter R, usually followed by a number.
The number has no relation to the size of the resistor; it's simply a reference number
arbitrarily assigned by the person who draws the original schematic or circuit
diagram. Usually (but not always), resistors will be numbered on the schematic
in consecutive order, from left to right. The size (amount of resistance, in ohms)
of a resistor is also often included on the schematic, or it may be included in a
table that accompanies the schematic.

red
red
red

R1
2200 or
2.2K

(a) Pictorial diagram   (b) Schematic diagram
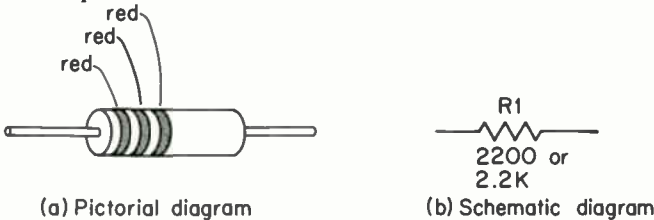
Fig. 34   **A fixed resistor. K = 1000, so—when it's used with a resistor value—it
indicates 1000 Ω. The symbol for ohms, Ω, is often used on schematics,
but sometimes the "ohms" is understood, and no symbol is used. All that
is given is a value, such as 1000, 3300, 1 K, or 3.3 K.**

28   Figure 34 shows a resistor and its schematic symbol. This is a *fixed* resistor—that is, one that has a fixed value (in ohms), and cannot be changed—or at least isn't designed to be changed—in value. Some resistors, such as the volume controls on a radio, are designed to be changed in value by rotating a shaft. These are called *variable* resistors, and will be discussed later on.

16

PARTS LABELING . . . Figure 35 is the circuit diagram or schematic of a two-transistor amplifier. The resistors are labeled R_1, R_2, R_3, and so on. R_1 is the volume control; the 1 $k\Omega$ indicates that the volume control full resistance is 1 kilohm (or 1 thousand ohms). The arrow on one of the connectors to R_1 identifies it as a variable resistor. The remainder of the resistors are fixed types.
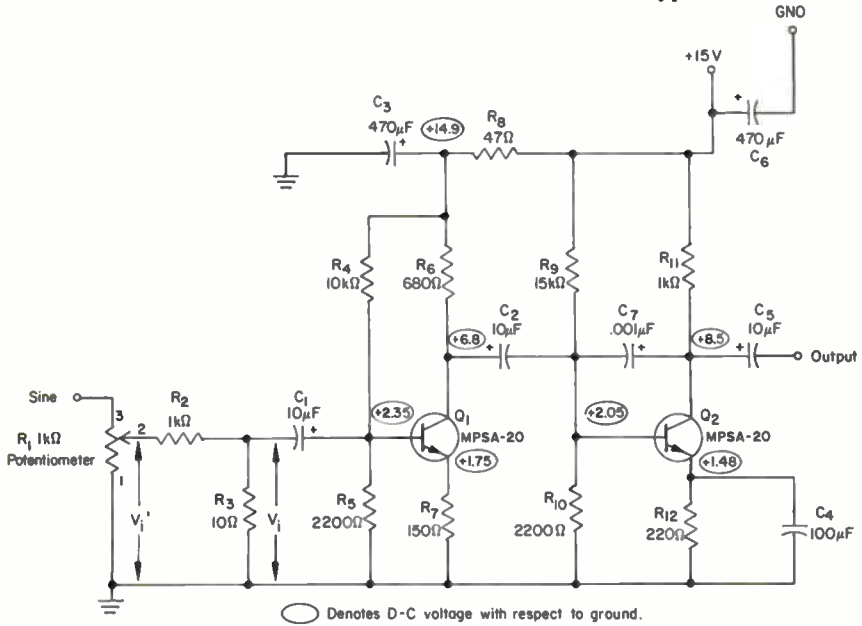
Fig. 35

Capacitors in a circuit (there are seven in this one) are labeled C_1, C_2, and so on, and transistors are labeled Q_1 and Q_2. The capacitors are also marked as to their size, such as 470 μF (microfarads), while the transistors are labeled by replacement type number, such as MPSA-20.

The ground symbol on the schematic in Fig. 35 indicates that all parts so marked are tied together; for example, the lower ends of R_1 and R_3 are tied to the same point. Also tied to this point are R_5, R_7, R_{10}, R_{12}, and the negative side of C_4.

At this time in your studies, you're not expected to understand exactly how the circuit of Fig. 35 works, or even what the various components are for. The sole purpose of this topic is to show you how to read a schematic diagram, how to identify the names and values of the parts, and how to tell how the parts are connected together.

Figure 35 points up something you may already have noticed: there are different symbols and abbreviations for the same things. In the literature (and in the body of texts such as this), you'll often find the form "R_1"; in a wiring diagram, however, it will be "R1." In recent literature, you'll find "kΩ" and "MΩ" used as abbreviations for kilohms and megohms, respectively; in wiring diagrams, you'll find "K" and either "M" or "MEG." The reasons are that the literature is printed from type, while the original wiring diagrams are drawn by hand—and that while abbreviations have changed over the years, many of the older ones are still in use. As you proceed with your study of electronics, however, you'll come to be at home with all the variations.

17 TRANSISTORS . . . The transistors in Fig. 35 are of the three-lead type. (Other transistors have four leads, with one lead tied to the case.) A transistor, as you may know, is a small device used for *amplifying*—that is, increasing voltages, like those from the sine input in Fig. 35, and building them up until they're strong enough to operate an output device, such as a loudspeaker.

The three terminals (leads) of a transistor are called the *emitter* (*E*), the *collector* (*C*), and the *base* (*B*). Each serves a special purpose (which will be explained later), so it's important that you don't get them mixed up when you wire a circuit. Figure 36 shows the pictorial and schematic diagrams for a transistor. To identify the leads on an actual transistor, hold the transistor as shown in Fig. 36(a) and look at the bottom with the three leads pointing toward you. The center lead is

(a) Pictorial diagram

(b) Schematic diagram
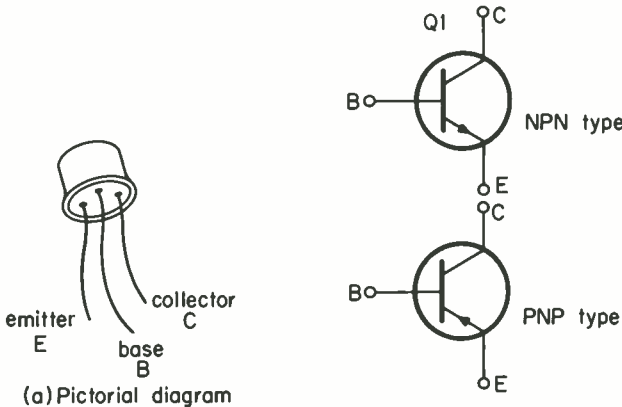
Fig. 36   Transistor diagrams.

30   then the base; the lead to your left is the emitter; and the lead to your right is the collector. The arrow on the emitter lead in the schematic drawing of a transistor may point either out (for an NPN-type transistor) or in (for PNP-type transistor). NPN and PNP transistors are similar, except that one uses battery polarity that is the reverse of that used by the other. You will learn more about NPN- and PNP-type transistors in a later lesson.

Figure 37 shows some of the many ways in which a transistor symbol is positioned on a schematic. You should have no trouble telling which terminal is which, even though not all the terminals include the *E, B,* and *C* markings. The emitter has an arrow, the base is a straight line, and the collector angles out from the base at the same angle as the emitter but without an arrow.
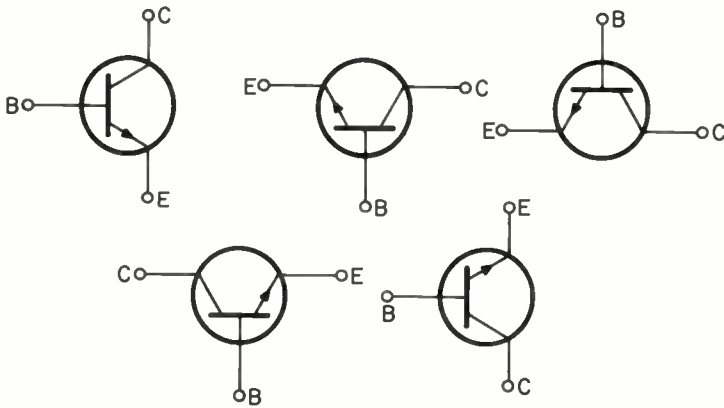
Fig. 37   Various ways in which the schematic diagram for one transistor could be drawn.

Figure 38 shows some other common arrangements of the leads on actual transistors. As you can see, Fig. 38(a) differs from Fig. 36(a) in that a projecting metal tab has been included near the emitter to help identify the leads. When the transistors are arranged as in (b), look at the bottom with the two terminals that are grouped together on your left. The leads are then emitter, collector, and base, from left to right. To determine the lead configuration for (c), look at the bottom of the transistor: the leads will be (from left to right) base, collector, and emitter. If the transistor is shaped like (d), hold the flat side up, but note that the leads are now emitter, collector, and base, from left to right. Other lead configurations are possible: Fig. 38(e) shows still another arrangement.
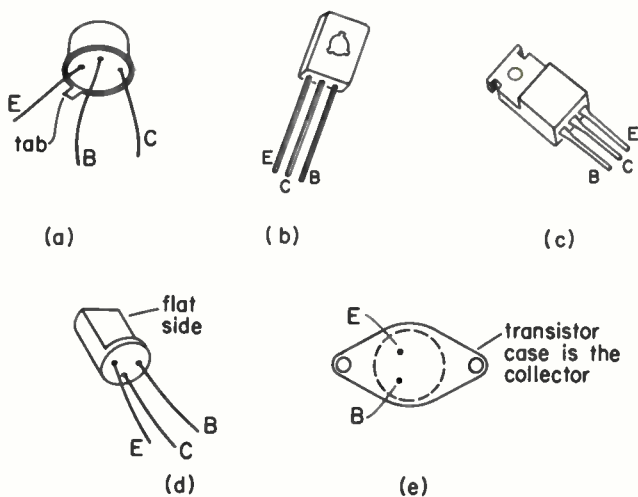
Fig. 38   Common transistor lead arrangements.

WHAT HAVE YOU LEARNED?

1. In Fig. 39, resistor R_2 has a resistance of _____ ohms.
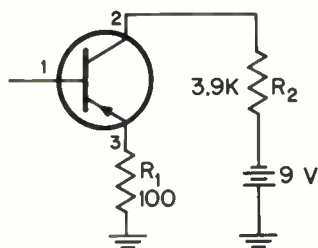
Fig. 39

2. Resistor R_1 in Fig. 39 would have a color code of _____,
_____, and _____.

3. The terminals of the transistor in Fig. 39 are numbered 1, 2, 3. Give the terminal name that corresponds to each of these numbers.

4. The *(positive) (negative)* side of the battery is directly tied to one side of R_1 in Fig. 39.

5. Is Fig. 39 the complete schematic for the circuit mounted on the bread board in Fig. 33?

6. The two transistors in Fig. 40 are directly tied together between two of their elements. (This is called *direct coupling*.) The leads that are tied together are the _____ of Q_1 and the _____ of Q_2.

7. In Fig. 40, the positive side of the battery is connected to the _____ terminal of transistor (Q_1) (Q_2).

8. True of False? Resistor R_1 in Fig. 40 is a 220-Ω resistor.
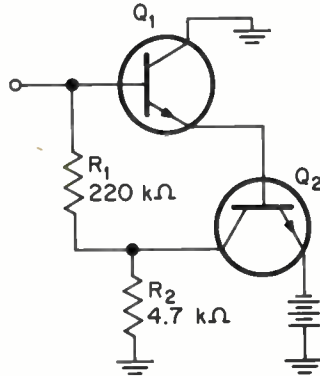
Fig. 40

ANSWERS

1. 3900 . . . "K" stands for 1000, so 3.9 × 1000 = 3900.
2. brown, black, brown . . . Brown for 1, black for 0, and brown again meaning add one zero—100 Ω.
3. 1 is the base, 2 is the collector, 3 is the emitter.
4. Positive . . . The positive side of the battery is tied to "ground," and so is one side of R_1. Remember that all points with the ground symbol are connected together. (It should be noted that the term "ground" here doesn't mean an actual earth ground: rather, it means a *common tie point*, as in an automobile, where one side of the lights, horn, ignition coil, etc., is tied to the chassis or frame of the car. The chassis (or frame) then acts as a common return for all the electrical devices, which saves running a separate wire to one side of each device. All that is needed is one "hot" wire and the ground return.)
5. No it isn't . . . This circuit shows only two resistors, for one thing, whereas the circuit in Fig. 33 uses five.
6. emitter; base
7. collector . . . Remember that points with the ground symbol connect together; Q_1.
8. False . . . It's a 220,000-Ω resistor. Either "K" or "k" means "multiply by 1000."

18 CIRCUIT TRACING . . . Probably the most important asset an expert electronics technician has is his or her ability to read a schematic diagram. The schematic in Fig. 41 is the representation of the pictorial diagram of a transistor amplifier. The schematic doesn't really "look like" the pictorial, but—to the experienced electronics professional—it means the same thing, and is easier to understand!
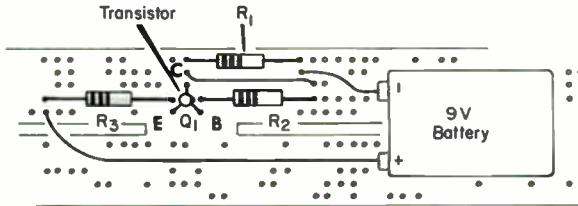
(a) Pictorial drawing (top view)
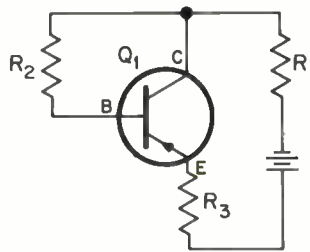
(b) Schematic diagram

Fig. 41   Pictorial and schematic diagrams of a simple amplifier.

Schematics take up less space than pictorial diagrams, and they can be arranged in a symmetrical order. True, a pictorial diagram has an advantage in that it represents the actual physical layout of the parts; however, a pictorial becomes hopelessly complex when parts lie one on top of the other, as they often do in present-day electronic circuits.

It takes practice in order to be able to look at a schematic diagram and recognize what the symbols mean, and what the "real" parts look like. It isn't always easy to trace a circuit, but we can't overstress the importance of being able to do so. And, here's an important hint: If you're just starting out in electronics, one of the best things you can do when you don't understand a circuit is to redraw it. Almost everyone draws schematics a little differently than the next person—plus, as you'll see in this lesson, the same circuit can be drawn in a number of different ways. So, if you don't understand a circuit, redraw it in a way you can understand. That doesn't mean you can change the connections in any manner, of course; it simply means you may be able to rearrange the parts in such a way that the connections make more sense to you.

LESSON 2342B-5
IDENTIFYING COMPONENTS

EXAMINATION

1. In Fig. 42, assuming each battery cell is a 1.5-V cell and the lamp is rated at 3 V, which drawing shows the cells correctly connected?

   (1) (a) 6V   ② (b) 3V   ⊗ (c) 4.5V   (4) (a), (b), and (c)

(a)

(b)

(c)
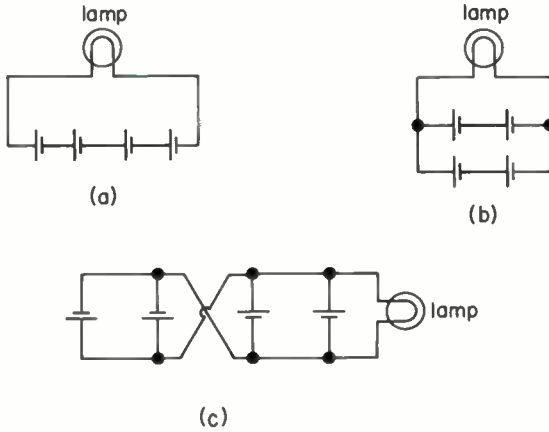
Fig. 42

2. In Fig. 42, assuming each cell is 1.5 V, which circuit is correctly connected if the lamp is rated at 1.5 V? (Choose your answer from the choices given for Question 1.)   3 (c)

3. Which circuit of Fig. 43 has an output of 4.5 V, assuming each cell has a rated voltage of 1.5 V?

   (1) (a) 9V   ② (b) 4.5V   (3) (c) 1.5V   (4) (d) 1.5V

(a)

(b)

(c)

(d)
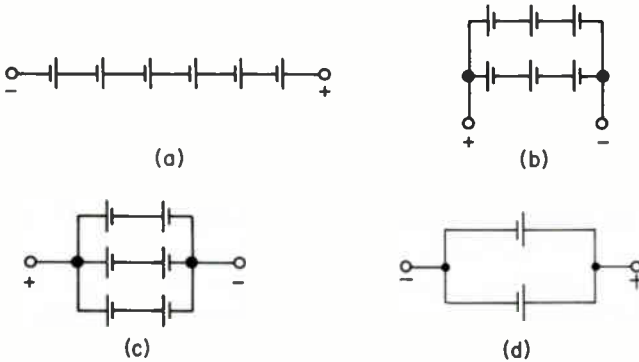
Fig. 43

4. In Fig. 44, one end of C_2 is tied to the emitter of the transistor. The other end is electrically connected to
   (1) R_1 and R_2, and the negative side of the battery.
   (2) the base and collector.
   (3) the base and the positive side of the battery.
   (4) ground and the positive side of the battery.

R₄
100 kΩ

transistor

C₁

in

C₃

out

R₃
1 kΩ

R₁
10 kΩ

C₂

R₂
470 Ω

on-off
switch

6 V
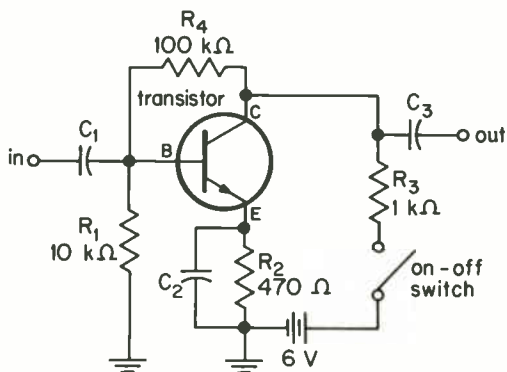
Fig. 44

5. In Fig. 44, resistor R_4 is electrically connected (with no components in between) to the
   (1) collector and base of the transistor only.
   (2) collector and base of the transistor, plus R_1, R_3, C_1 and C_3.
   (3) base and ground.
   (4) collector and base of the transistor, as well as to the positive side of the battery.

6. In Fig. 44, the negative ($-$) side of the battery is electrically connected directly (with no resistors or other parts in between) to which of the following? (Note: This question is similar to WHYL Problem 4 of Topic 17. Remember that parts may be connected together by means of the chassis, or "ground".)
   (1) R_1, R_2, and C_2 (3) R_2, but not C_2 or R_1
   (2) R_2 and C_2, but not R_1 (4) R_1 and R_2, but not C_2

7. The type of transistor shown in the schematic of Fig. 44 is
   (1) a PNP.   (2) an NPN.
   (3) either a PNP or an NPN; there's no way of telling which.

8. If a single cell of Fig. 45 will deliver a continuous current of 2 A for 12 hr, how long will the 6-cell battery operate the light? (Assume the bulb draws 2 A.)

(1) 2 hr   (3) 6 hr   (5) 72 hr

(2) 4 hr   (4) 48 hr
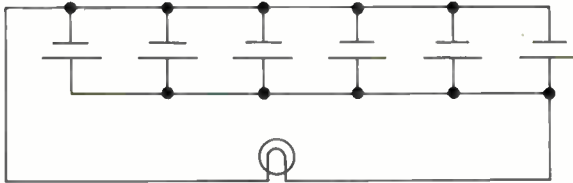
Fig. 45

9. If a single cell in Fig. 46 will deliver a continuous current of 2 A for 12 hr, how long will the 6-cell battery operate the light? (Assume the bulb draws 2 A—and remember how cells are connected for longer life.)

(1) 2 hr   (3) 6 hr   (5) 48 hr

(2) 4 hr   (4) 12 hr
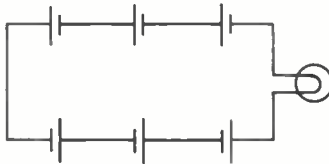
Fig. 46

10. To avoid replacing the battery in a portable stereo radio so often, you install an extra battery that is identical with the first. This additional battery should be installed

(1) in parallel with the first, so that the operating voltage will not be changed but the battery life will be doubled.

(2) in parallel with the first, so that a stronger current can be furnished to the counter.

(3) in series with the first. The higher voltage will enable the counter to operate longer before battery replacement is necessary.

(4) in series with the first, so that a strong current can be furnished almost up to the time when the battery is completely discharged.

END OF EXAM

Learning circuit tracing is a vital part of your electronics training. Additional practice in the next few lessons will make it easy for you.

Lesson 2342C-5
Tracing Wiring on
Printed Circuit Boards

19 TRACING THROUGH WIRING . . . As an example of circuit tracing, let's draw a schematic diagram for Fig. 47(a) to see how the battery is connected. For openers, we can make the wiring look a lot less formidable by simply redrawing the battery as you would see it looking down on it from above. (At the same time, we'll straighten out the wiring.) The result is shown in Fig. 47(b). The next step is to replace each cell in (b) with its proper electronic symbol. Our drawing then looks as in (c). The final step is to rearrange the parts and wiring to make the drawing as clear as possible, as in (d)—which is the finished schematic diagram for the battery of (a). (It's always a good idea to number the cells as shown, so that corresponding cells in the various diagrams can be easily identified.)
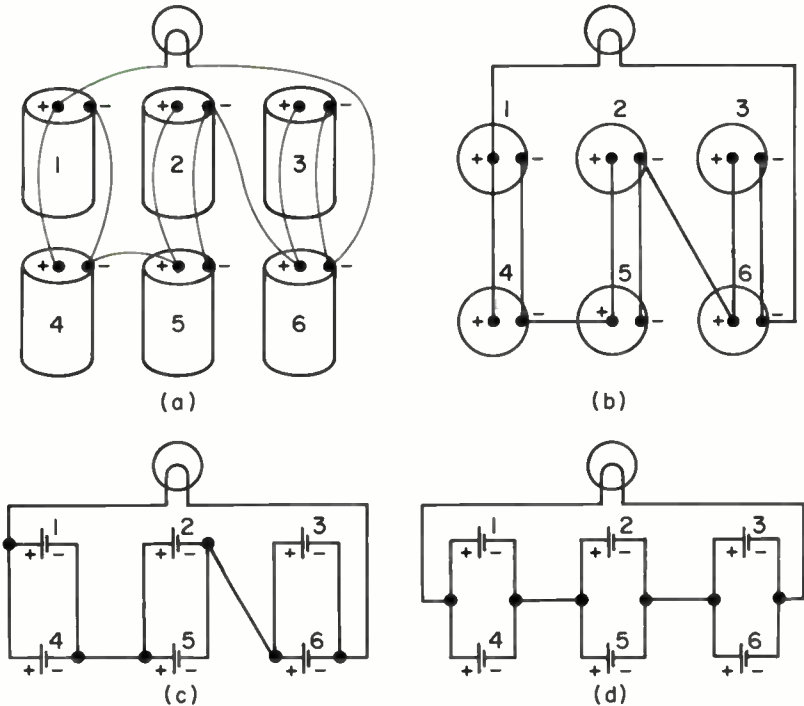
Fig. 47   Steps in drawing a schematic diagram for wiring.

38   Now let's try another circuit—that of Fig. 48(a). As before, we first draw the cir-
cuit as if we were looking down on it from above (and with the wiring straightened
out), as in (b). Note that we've made one small change in the wiring connections:
In (a), the negative terminal of cell 1 (the outside terminal of a dry cell is always
the negative terminal) is connected to the negative terminal of cell 5. Therefore,
if we'd drawn (b) strictly in accordance with (a), we would've connected the negative
terminals of cell 1 and 5 together, as shown by the dashed line in (b). Instead,
we connected the negative terminal of cell 1 to the negative terminal of cell 4.
Electrically, there's no difference, since the negative terminal of cell 1 is still elec-
trically connected to the negative terminal of cell 5 by means of the wire between
the negative terminal of cell 4 and the negative terminal of cell 5. We made this
change strictly to simplify the appearance of the schematic: the simpler we can
get the wiring to look, the easier it is to analyze it.
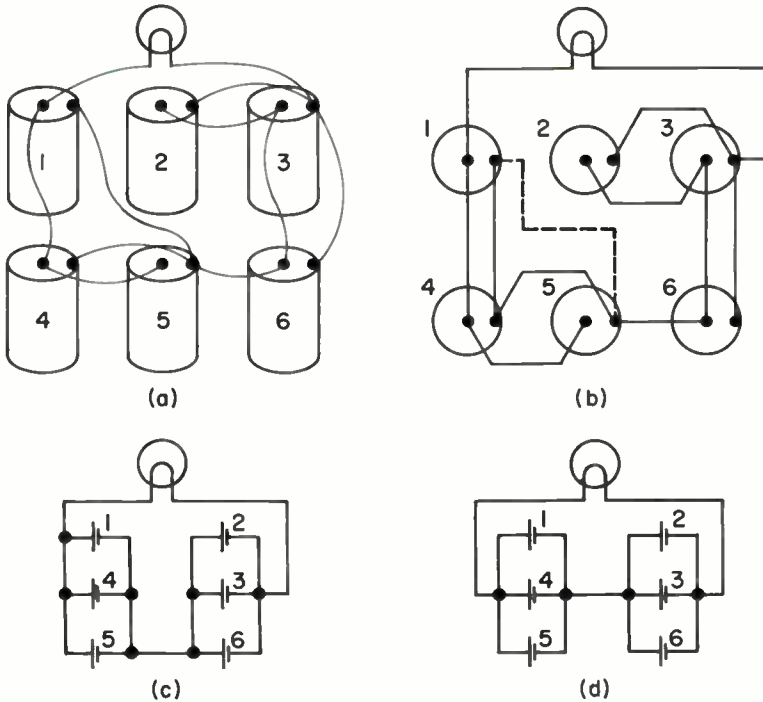
Fig. 48   Another example of drawing a schematic diagram.

Our next step is to study Fig. 48(b) to see if we can detect some pattern to the
wiring. Note that the positive terminals of cells 1, 4, and 5 are connected together,
and so are the negative terminals. These three cells are connected in the same
way as the cells in Fig. 28—that is, in parallel. Next, we examine cells 2, 3, and
6 and note that these three cells are also connected in parallel.

We can now make a new drawing—Fig. 48(c)—in which we use the electrical sym-
bol for a cell (rather than a cell top). Also, we rearrange the cells so that 1, 4, and 5, which are in parallel, are in one row, and cells 2, 3, and 6 are in another row. In (d), finally, the diagram is further rearranged to make it as clear as possible.

20 TRACING OUT A CIRCUIT . . . To trace out a circuit means either to draw the schematic diagram from the actual circuit, or to relate an already available schematic to the circuit. Take another look at the pictorial diagram of Fig. 41(a). How can we reduce the schematic diagram of this circuit? One way is to start at some point in the circuit, and follow the wires to and through each of the components until we have traced a complete circuit. A good place to start is at one of the battery terminals, and then follow the wiring through the components back to the other battery terminal. Often, there's more than one path back, and all paths must be included on the schematic.

Let's start by drawing the symbol for the battery in Fig. 49(a). Now, beginning at the negative terminal of the battery, let's see if we can get back to the positive terminal. Looking at the pictorial diagram, we can trace the wire from the negative terminal to a point that connects to an electronic component—in this case, a resistor—so we draw the symbol for the resistor on our schematic as shown in Fig. 49(b). (We can label this resistor whatever we wish, but we've chosen to call it R_1.) Now, we start from the other lead of R_1 and find that it connects to a junction where current can flow in two directions. We draw this on our schematic as in Fig. 49(c). At this point, it doesn't make any difference which path we take, so let's say we take the one going to the transistor. We draw the transistor symbol on our diagram as in Fig. 49(d), with the connection from R_1 going to the collector lead. (Refer back to how to identify transistor leads, if necessary.) The emitter lead of the transistor is connected to resistor R_3, which then returns to the positive side of the battery, which we draw in as shown in Fig. 49(e).

This is one of the complete circuits back to the battery for this transistor amplifier. Remember, though, that we had a second path for current from R_1, as indicated in Fig. 49(c), so we must now go back to that point and trace out the other path. It connects to resistor R_2, and the other end of R_2 connects to the transistor base terminal. When we have this drawn in, we have the complete circuit as shown in Fig. 49(f).

Beware that some schematics will have a solid black dot at each connection point and others will not. If you have a schematic that does not use these dots, it does not mean that there is not a connection at those points. The dots are only used for emphasis. For example, figure 49(a) has a black dot on each terminal of the battery, but 49(b) does not.
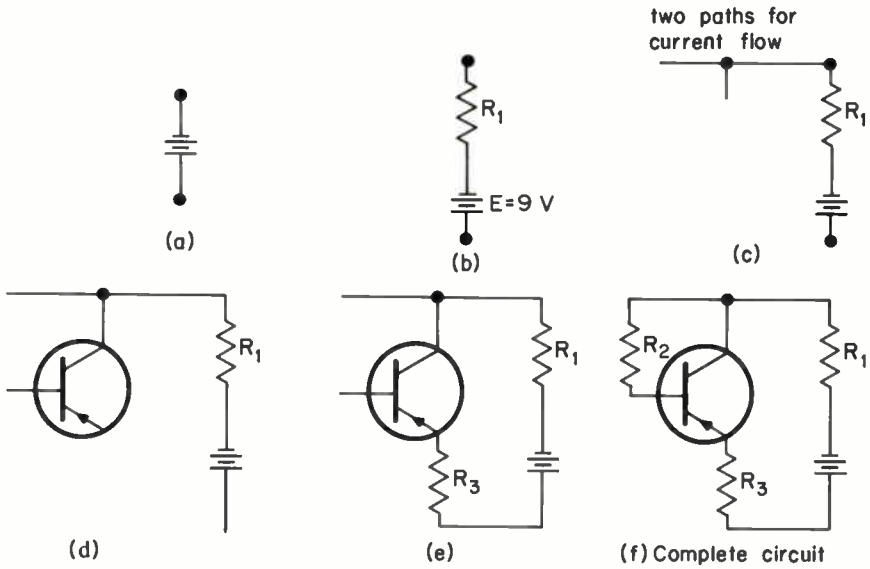
Fig. 49   Tracing out a circuit.

WHAT HAVE YOU LEARNED?

1. Identify the leads of the transistor in Fig. 50.

2. Draw the schematic diagram for the pictorial diagram of Fig. 50. (Use an NPN-type transistor.)
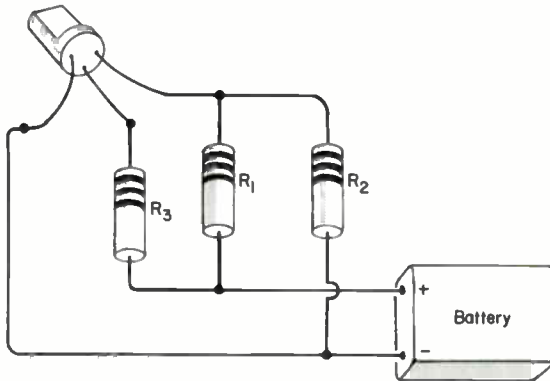
Fig. 50
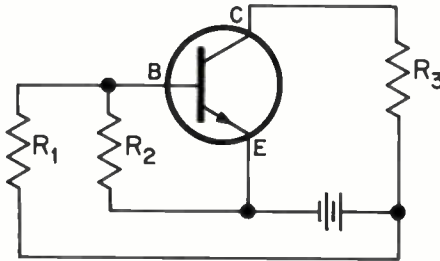
1. See Fig. 51.   2. See Fig. 52.
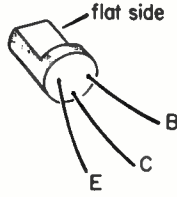
Fig. 51

Fig. 52

21 ANOTHER EXAMPLE OF CIRCUIT TRACING . . . To draw the schematic diagram for Fig. 53, we can again start at the battery. Note first that the positive terminal of B_1 is connected to the positive terminal of B_4, and that a wire M_1 leading off from the battery is also connected to these two terminals. So, we'll first draw the symbols for B_1 and B_4 as shown in Fig. 54(a), and show the two positive terminals connected together and the wire M_1 leading off. We next note in Fig. 53 that the negative terminals of B_2 and B_3 are connected together, with a wire M_2 leading off. We add this information to Fig. 54(a), as shown.
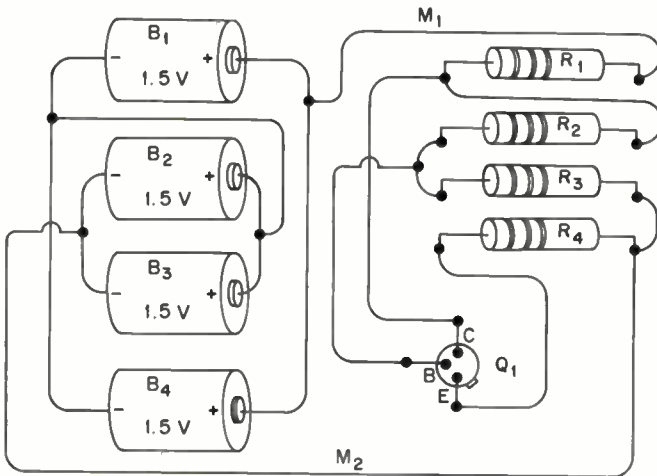
Fig. 53

42   Now we note that the positive terminals of B_2 and B_3 are connected together, and so are the negative terminals of B_1 and B_4. We add this information to our schematic as shown in Fig. 54(b). We further note that there is a wire connecting the positive terminals of B_2-B_3 to the negative terminals of B_1-B_4. We add this connection to Fig. 54(c), which is the complete schematic of the battery. The schematic shows that the cells are connected in a series-parallel arrangement, and will therefore develop an output of 3 V.
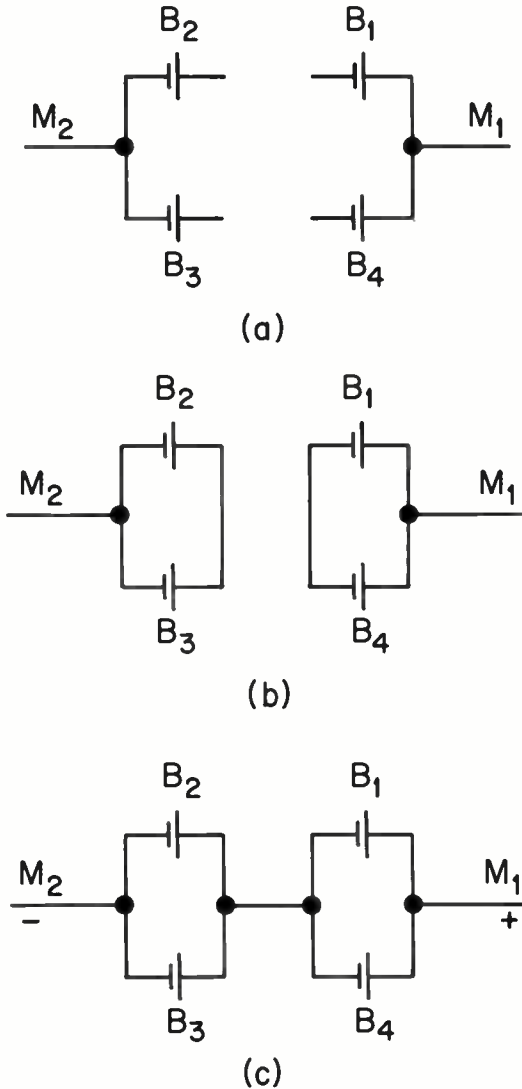
Fig. 54   Steps in drawing the schematic of the battery in Fig. 53.

The battery of Fig. 54(c) is repeated in Fig. 55(a). It's not really necessary to draw the batteries as shown in Fig. 55(a). Now that you know what the voltage is, you can draw the battery symbol as shown in Fig. 55(b). However, in some cases it *is* wise to draw the batteries in their series-parallel connection, for the convenience of the service technician.

(a)   (b)

(c)

(d)

(e)
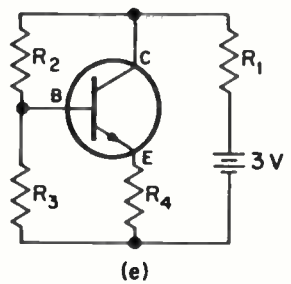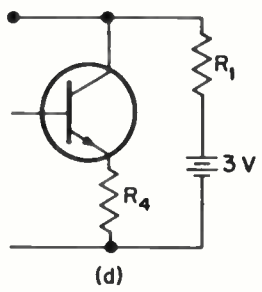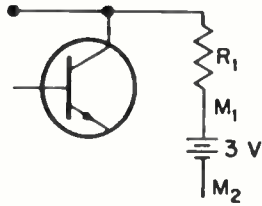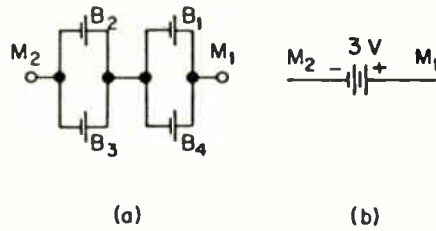
Fig. 55   Steps in drawing the schematic for the component arrangement shown in Fig. 53.

The next step is to trace through the circuit. Start at the positive terminals of the battery supply (wire M_1 in Fig. 53) and go to the first component, which is R_1. Now, connect the other end of R_1 to a junction point, so that current can flow in two directions. (Take the path that goes to the collector of the transistor.) Draw this on your schematic as shown in Fig. 55(c).

Try to complete the path for current—that is, from the positive terminal of the power source, through R_1, through the transistor, through R_4, and back to the negative terminal of the power source. See Fig. 55(d).

Now go back and complete the parallel path. The collector of the transistor is tied to resistor R_1, but note that the collector is also tied to resistor R_2. The other end of R_2 is tied to two points—to resistor R_3, and also to the base of the transistor, so complete this on your diagram. To finish the circuit, note that the other end of R_3 is tied to the negative terminal of the voltage source—or to R_4—which is the same point. This completes the circuit as shown in Fig. 55(e).

WHAT HAVE YOU LEARNED?

1. Using an NPN-type transistor, draw a schematic diagram for the pictorial diagram of Fig. 56. (You'll learn in a later lesson how the battery polarity and transistor-type are related.)
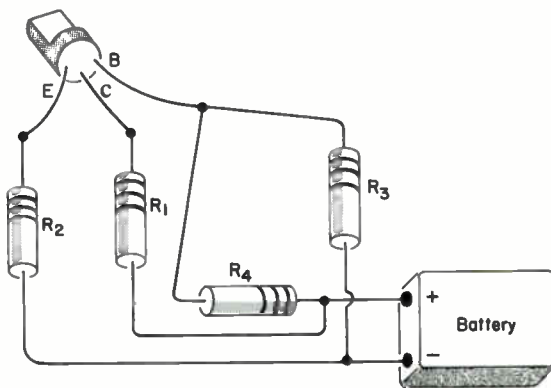
Fig. 56

2. Find two circuits in Fig. 57 that are the same. Are the remaining two circuits also the same?

(a)

(b)

(c)

(d)
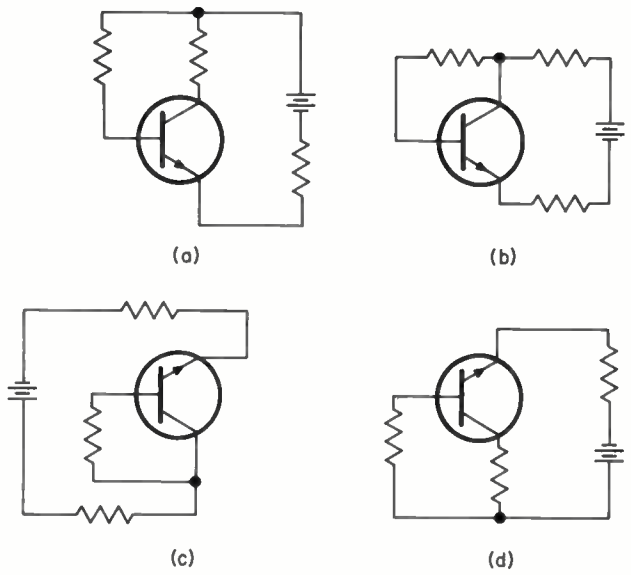
Fig. 57

3. In Fig. 58, match the appropriate schematic diagram (a, b, or c) with the pictorial diagram.

(a)

(b)

(c)
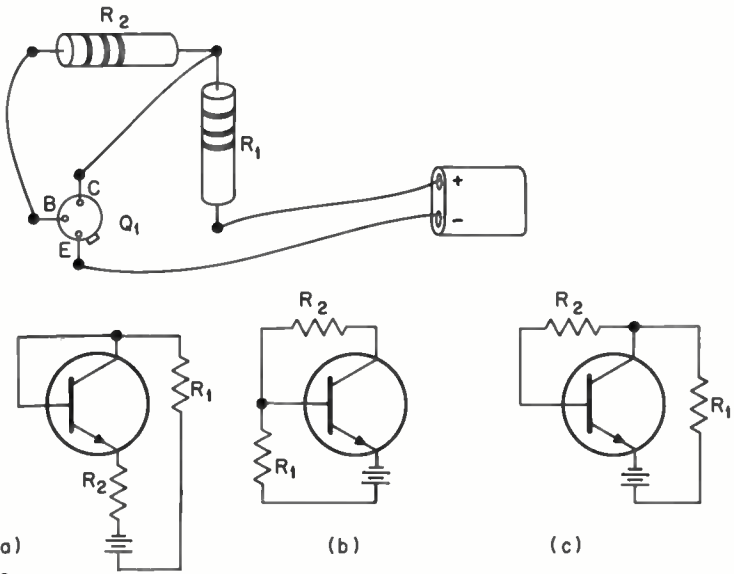
Fig. 58

4. Which schematic diagram in Fig. 59 matches the pictorial diagram?
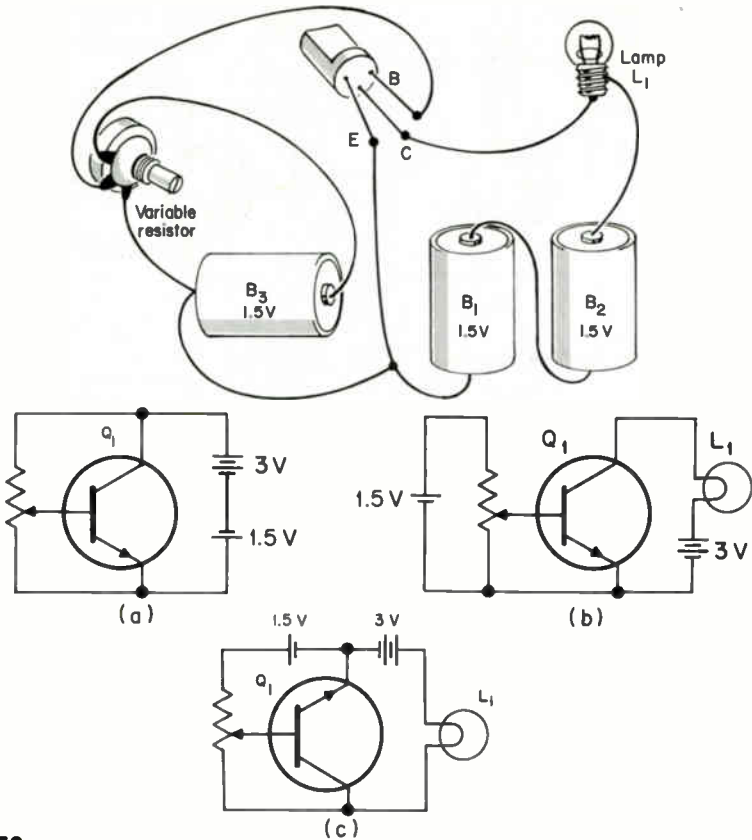
Fig. 59

ANSWERS

1. Either diagram in Fig. 60 is correct.

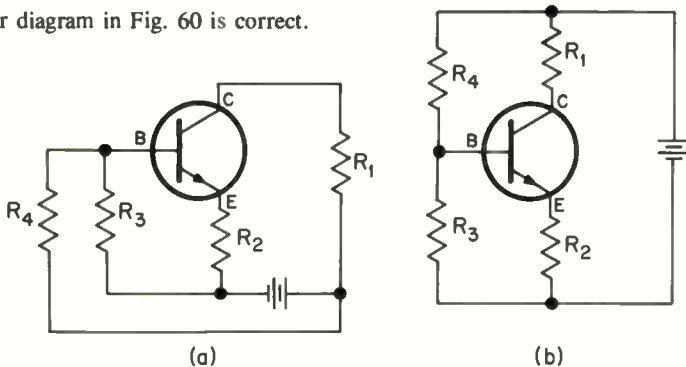**Fig. 60**   (a)   (b)

2. (a) and (d) are the same circuit, and (b) and (c) are the same. . . . . The difference is in the connection of the base resistor.

3. (c)   4. (b)

no set way to draw a particular circuit. For one reason or another, the artist who prepares a given schematic may simply choose to arrange the parts in a different way than another artist would. In other words, there's no "right" way to draw a schematic, so long as the connections are correct and the proper symbols have been used. Of course, some ways are more widely accepted than others. Whichever way you learn to recognize a particular circuit may be the way you'd prefer to see that circuit drawn. For this reason alone, you may find you want to redraw a circuit to better understand it. So never hesitate to redraw an unfamiliar circuit; you may find it fairly simple to interpret once it's in the "position" in which you've learned to recognize it.

Figure 61 shows four versions of a field-effect transistor (FET) circuit. All the circuits are exactly the same "electrically"; they've simply been arranged differently on paper. And these are by no means all the ways in which the schematic could be laid out, and still be perfectly correct so far as the actual circuit is concerned. Again we want to emphasize that the schematic layout seldom mirrors the actual parts layout: its single purpose is to explain the *electrical* connections, using lines and symbols.
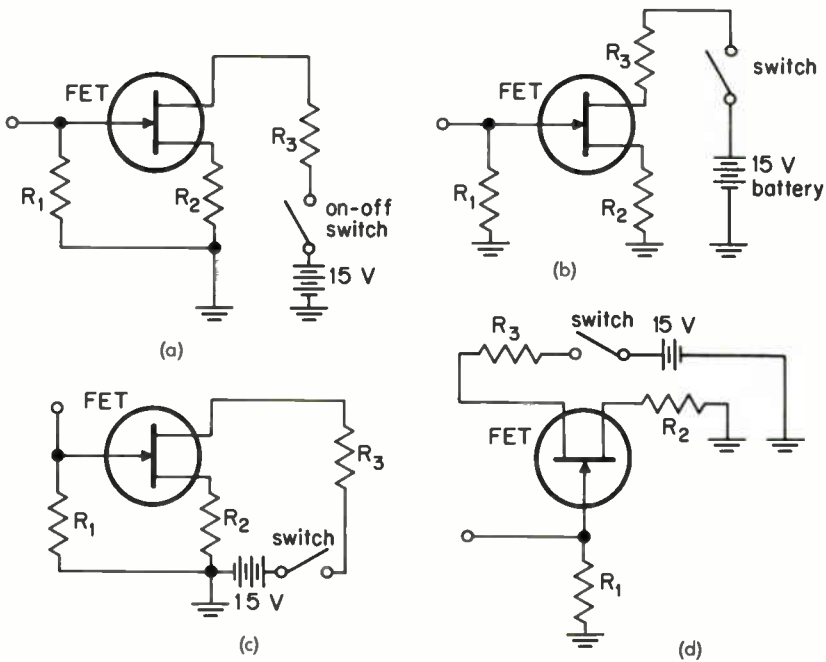
Fig. 61   Some of the various ways in which the same circuit can be drawn, and still be correct.

1. Are all the schematics in Fig. 62 connected alike, or is one different from the others?

(a)   (b)   (c)

(d)   (e)
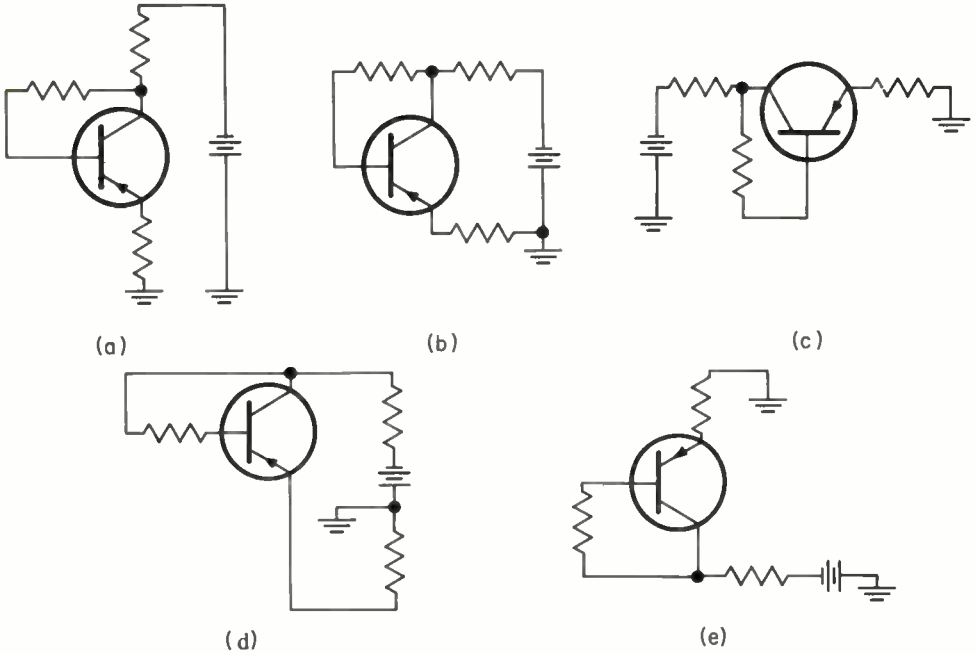
Fig. 62

ANSWERS

1. They're all alike—that is, all represent the same transistor amplifier circuit using a PNP transistor.

INTRODUCTION TO PRINTED CIRCUIT BOARD TRACING

23 POWER SUPPLY . . . Next we want to study the circuit of an electronic power supply built on a printed circuit board. A power supply is a unit that can change the AC power-line voltage into a smooth DC voltage. Batteries supply DC current, but they run down. An electronic power supply that can be plugged in will operate equipment continuously at low cost. Such a power supply can be used

with many circuits, with moderate power requirements, in the 6- to 9-V range.
It can furnish power for a transistor radio, a small transistor tape recorder, and
the like.

The power supply we'll discuss uses a *transformer*, which is a device to step the
AC voltage down to a lower value. It uses four *diodes*—electronic devices that
allow current to flow in only one direction—to change the AC to DC. (This process
is called *rectification*.) Two electrolytic capacitors are used to filter out the ripple
(variations) in the rectified AC. A transistor is used, not only to regulate (hold
steady) the DC output voltage but also to assist in the ripple-smoothing process.
Finally, two resistors are used in conjunction with the diodes in the rectification
process.

A printed circuit board has a conductive material, usually copper foil, on one
side that forms the connecting terminals for the circuit. The copper foil takes the
place of wires in connecting the components of the circuit.

24 CIRCUIT TRACING THE PRINTED CIRCUIT BOARD . . . Figure 63 shows
the components used in the transistor power supply, while Fig. 64 shows the com-
ponents mounted on the board. What's different about this circuit? Look at Fig.
65, which shows the copper foil, or printed circuit, side of the board. (The reverse
side of the board is shown in Fig. 64.) The copper foil takes the place of the wires
that you're accustomed to seeing used to connect the components.
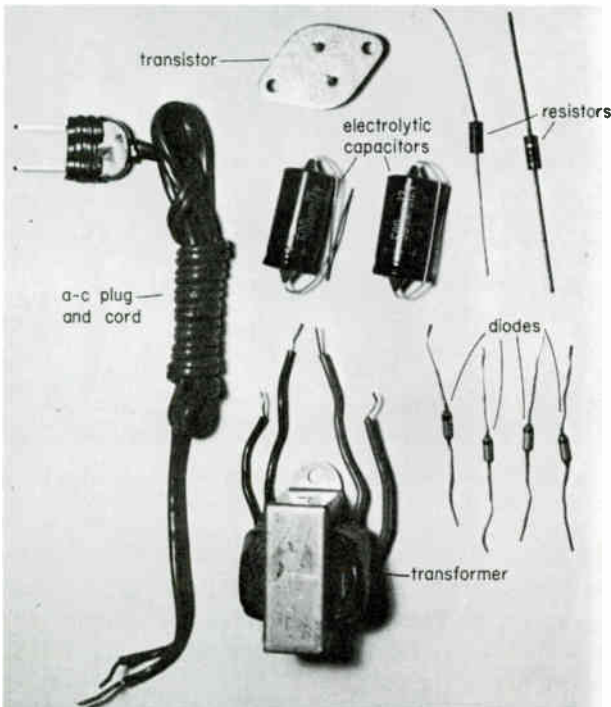
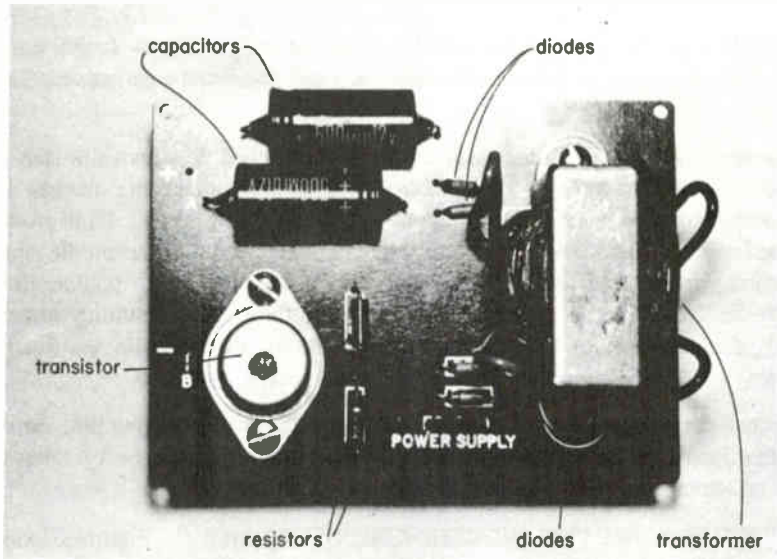**Fig. 63   Components used in a transistor power supply.**

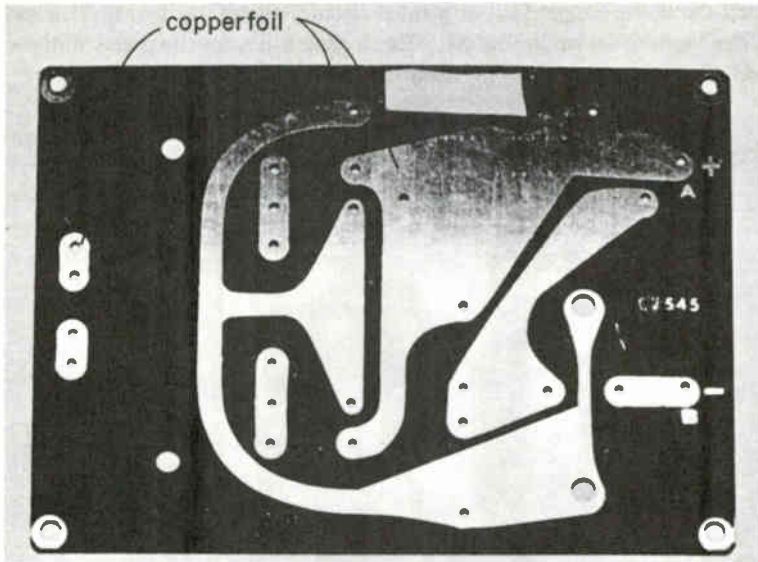Fig. 64   Components for power supply mounted on board.

Fig. 65   Component leads soldered to the copper foil, which takes the place of connecting wires.

Today, very little electronic equipment is manufactured that doesn't use printed circuit (PC) boards. PC boards are rugged and inexpensive, and provide for uniformity during production. Usually, the components are mounted on one side of the board (Fig 66). The leads are then soldered to the copper foil and clipped close on the other side of the board.
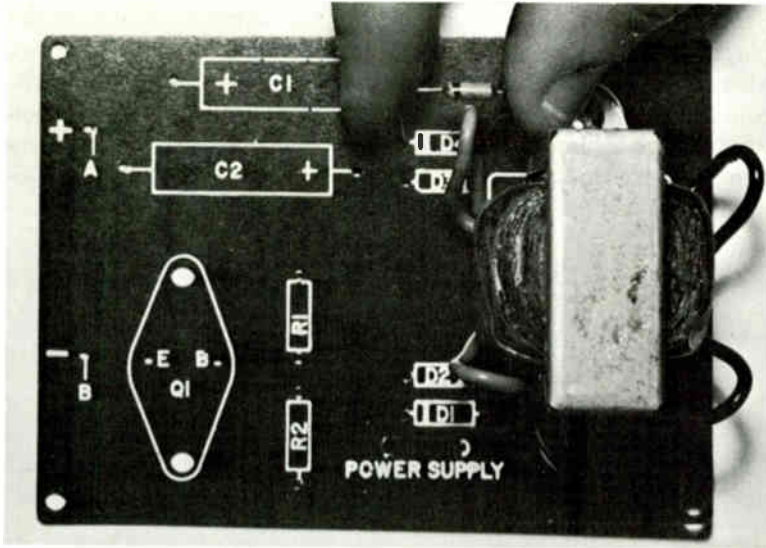
Fig. 66   Mounting the PC components on the board.

Figure 67, finally, shows the components superimposed over the copper foil to help you trace out the circuit. Since the copper foil is a conductor, all of the wires soldered to the same section of copper foil are electrically connected.

printed circuit on front side of board
components on back side of board
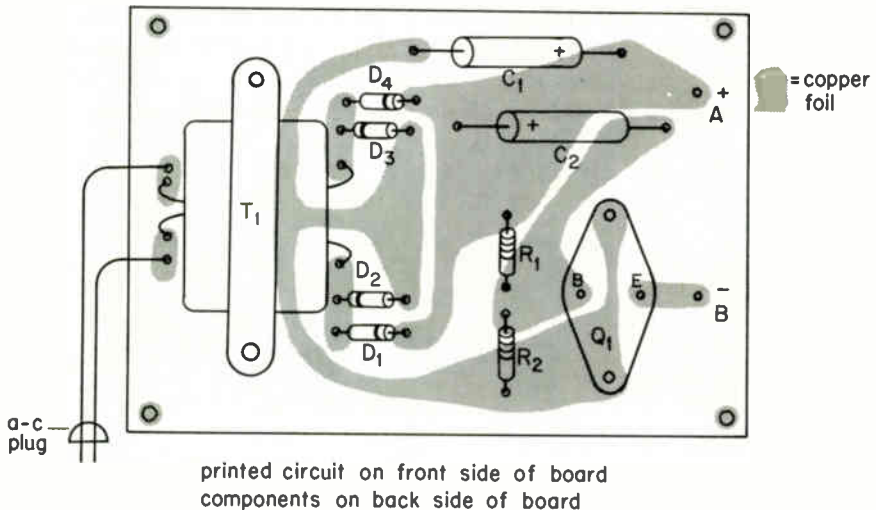
Fig. 67   Overlay showing how components are mounted on the other side of a printed board.

25 TRACING OUT THE CIRCUIT . . . We start our schematic by drawing the AC cord/plug and the transformer. We've done this in Fig. 68, where we also introduce you to the symbol for a transformer. Next, we start with one lead of the transformer (opposite the side where the AC cord is tied), and locate the other components connected to that section of copper foil. Let's start with the top lead from the transformer as seen looking at Fig. 67. This lead is connected to a section of copper foil that has two other components connected: diodes D_4 and D_3.
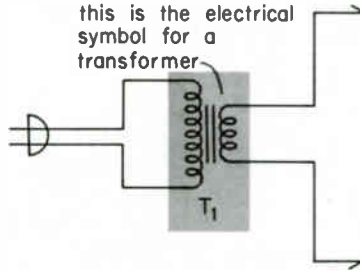
Fig. 68   Schematic drawing for transformer T₁ and AC plug/cord.

You'll recall that we want to trace through a complete path—that is, back to our starting point—before we trace through the parallel branches. So let's draw in diode D_3 on the schematic, but also indicate that there's a junction point here and another path for current to flow. (We'll come back to that later.) The other lead of D_3 is connected to a large section of copper foil, to which a number of other components are connected. Take only one path at a time, as shown in Fig. 69, through resistors R_2 and R_1 and diode D_1, and back to the transformer. Note that we've indicated in Fig. 69 there are a number of parallel paths that have to be completed.
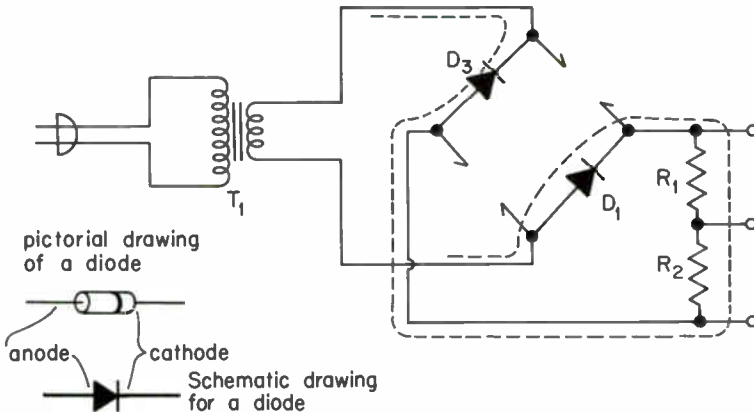

Fig. 69   Schematic with diodes and two resistors added. Diodes are electronic "one-way switches" that allow current to flow through them in one direction only. Thus, they can change alternating current into directional—or one-way—current.

Which path we take next is immaterial, but we've completed the diode connections, as shown in Fig. 70, by adding to our drawing diodes D_2 and D_4. Now, we trace out the connections to PNP-type transistors Q_1 and complete all three leads of the transistor at this time. We complete the schematic diagram by adding the two capacitors C_1 and C_2 to our circuit. Figure 71 shows the complete schematic diagram.
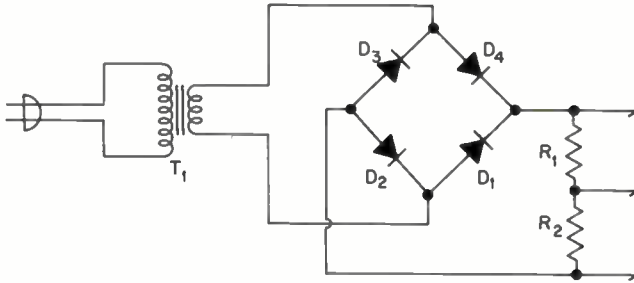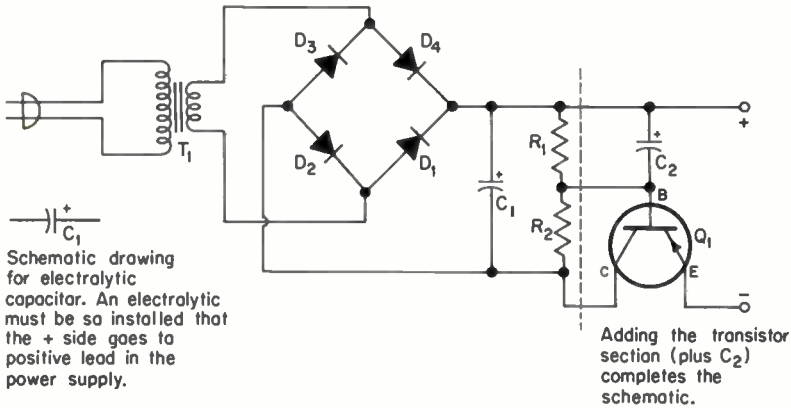

Fig. 70   Diodes D_2 and D_4 added to the schematic.

Schematic drawing
for electrolytic
capacitor. An electrolytic
must be so installed that
the + side goes to
positive lead in the
power supply.

Adding the transistor
section (plus C_2)
completes the
schematic.

Fig. 71   Complete schematic diagram for power supply.

WHAT HAVE YOU LEARNED?

1. List the three advantages of using printed circuit boards.

2. The copper foil on the printed circuit board is a _____.

3. On a printed circuit board, all the components soldered to the same section of the copper foil are _____ _____.

ANSWERS

1. They're rugged and inexpensive, and provide uniformity during production.
2. conductor
3. electrically connected

LESSON 2342C-5
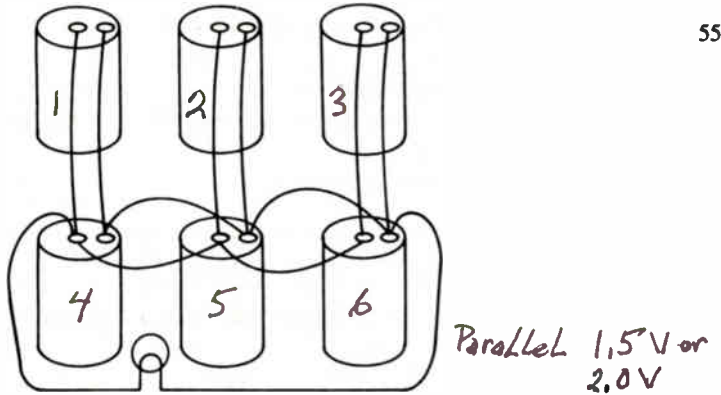## TRACING WIRING ON PRINTED CIRCUIT BOARDS

EXAMINATION

Each examination question is followed by a number of selections. Circle the number in front of the correct selection for each question. When you have finished, transfer your answers to the Answer Sheet provided. Then use the special envelope provided to mail the examination to the school as soon as it is completed.
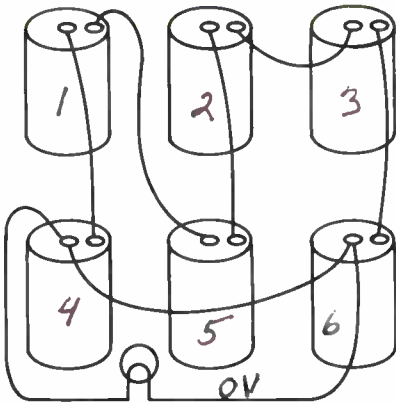
1. Which one of the following is sometimes referred to as an electronic "one-way switch"?
   (1) Battery   (3) Transformer   (5) Electrolytic capacitor
   (2) Diode   (4) Resistor

Note: In answering questions 2-4, choose your answers from the choices given for question 2. (HINT: Be sure to number the cells in Fig. 72 as an aid in converting the pictorials to schematic diagrams. Remember, cells in series increase the voltage, but cells in parallel don't.)
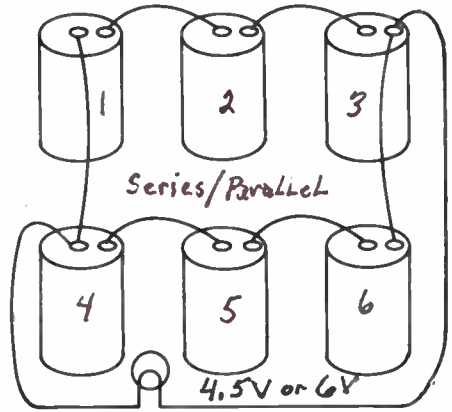
2. In which one of the drawings of Fig. 72 are the cells connected in accordance with the schematic diagram of Fig. 73?
   (1) 1   (3) 3   (5) 5
   (2) 2   (4) 4

3. If a 2-V light bulb is used in Fig. 72, which drawing shows the cells properly connected for operating the light? (Each cell is 2 V.) (1)(*I*)

4. In which of the drawings of Fig. 72 are the cells connected for the maximum voltage (12 V) obtainable from them? (Each cell is a 2-V cell.)
   (4) (4)

5. Which one of the following does *not* describe an advantage of printed circuit boards?
   (1) Rugged
   (2) Inexpensive
   (3) Components can't be mounted on them.
   (4) Provide uniformity during production

6. The copper foil on a printed board is used to
   (1) hold the components together.
   (2) electrically connect the components together.
   (3) electrically isolate the components from one another.
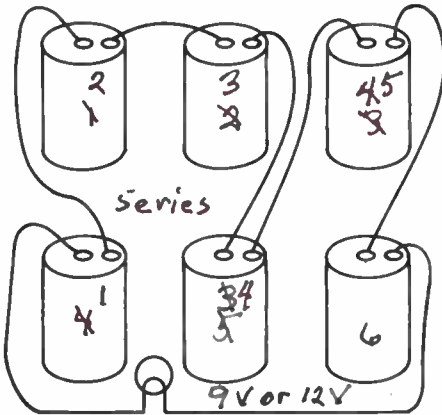   (4) hold all the components together.
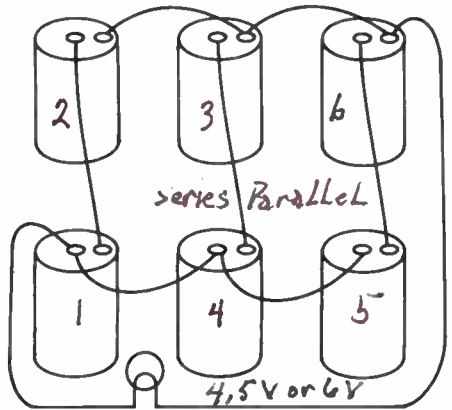
Parallel 1.5 V or 2.0 V

(1)

0V

(2)

Series/Parallel

4.5 V or 6 V

(3)

Series

9 V or 12 V

(4)

series Parallel

4.5 V or 6 V

(5)

Fig. 72

7. The schematic of a particular circuit can be drawn
   (1) only one way.
   (2) using nonstandard symbols.
   (3) in a number of ways, as long as it has all the proper connections and uses the proper symbols.
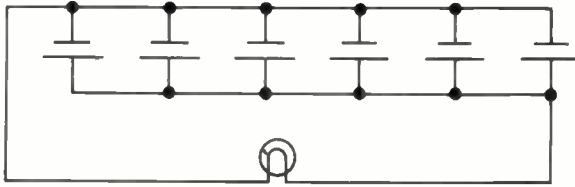   (4) any way you feel like drawing it.

Fig. 73

8. The power-supply unit you studied in this lesson changed
   (1) DC to DC.   (3) AC to AC.
   (2) DC to AC.   (4) AC to DC.

9. What's the function of the electrolytic capacitor connected across the diode bridge in Fig. 71?
   (1) Filters out the ripple in the rectified AC
   (2) Rectifies AC to DC
   (3) Has no purpose
   (4) Supplies voltage to Q_1

10. What other component besides C_1 and C_2 in the power-supply circuit in Fig. 71 helps smooth out the AC ripple?
    (1) The diode bridge
    (2) R_1
   (3) R_2
    (4) Q_1

END OF EXAM

Your next lesson will be on simple mathematics. Sooner or later you will meet technicians who will tell you that you don't need to know mathematics to be an electronics technician. For one thing, knowing a little math makes electronics a lot easier to learn. More important, technicians with the best jobs are always technicians who know their basic math. You will find it easy to learn basic mathematics the CIE way.
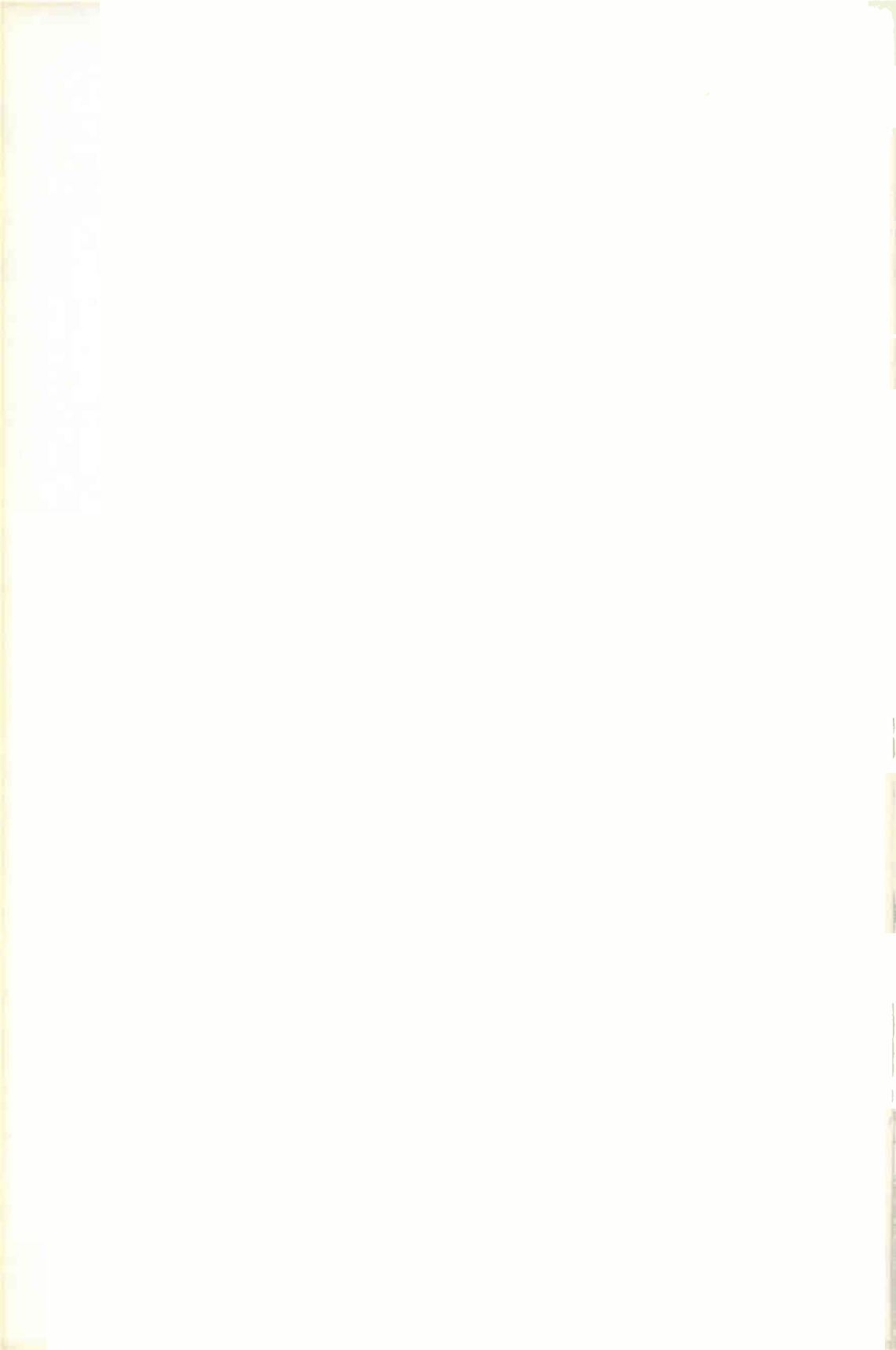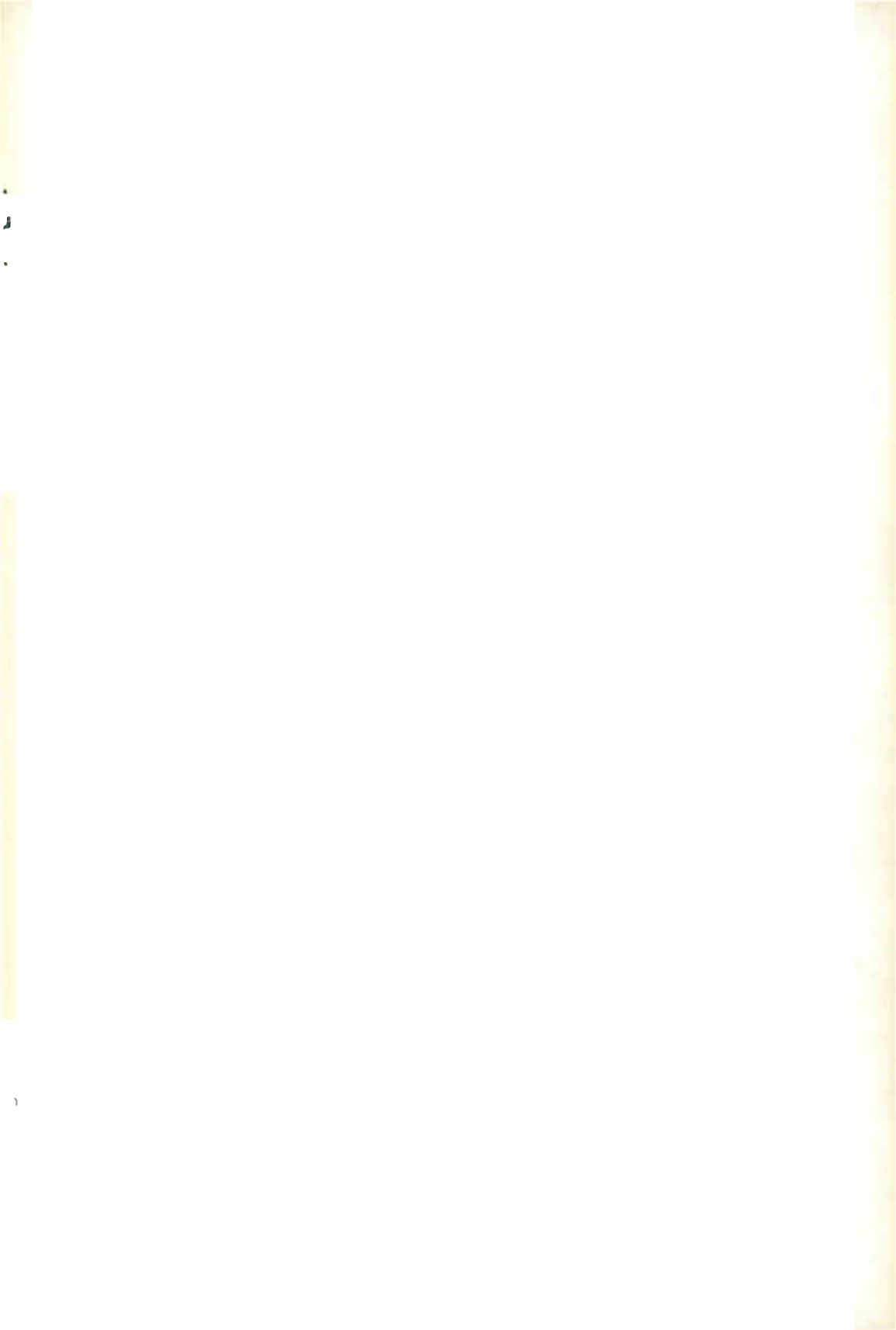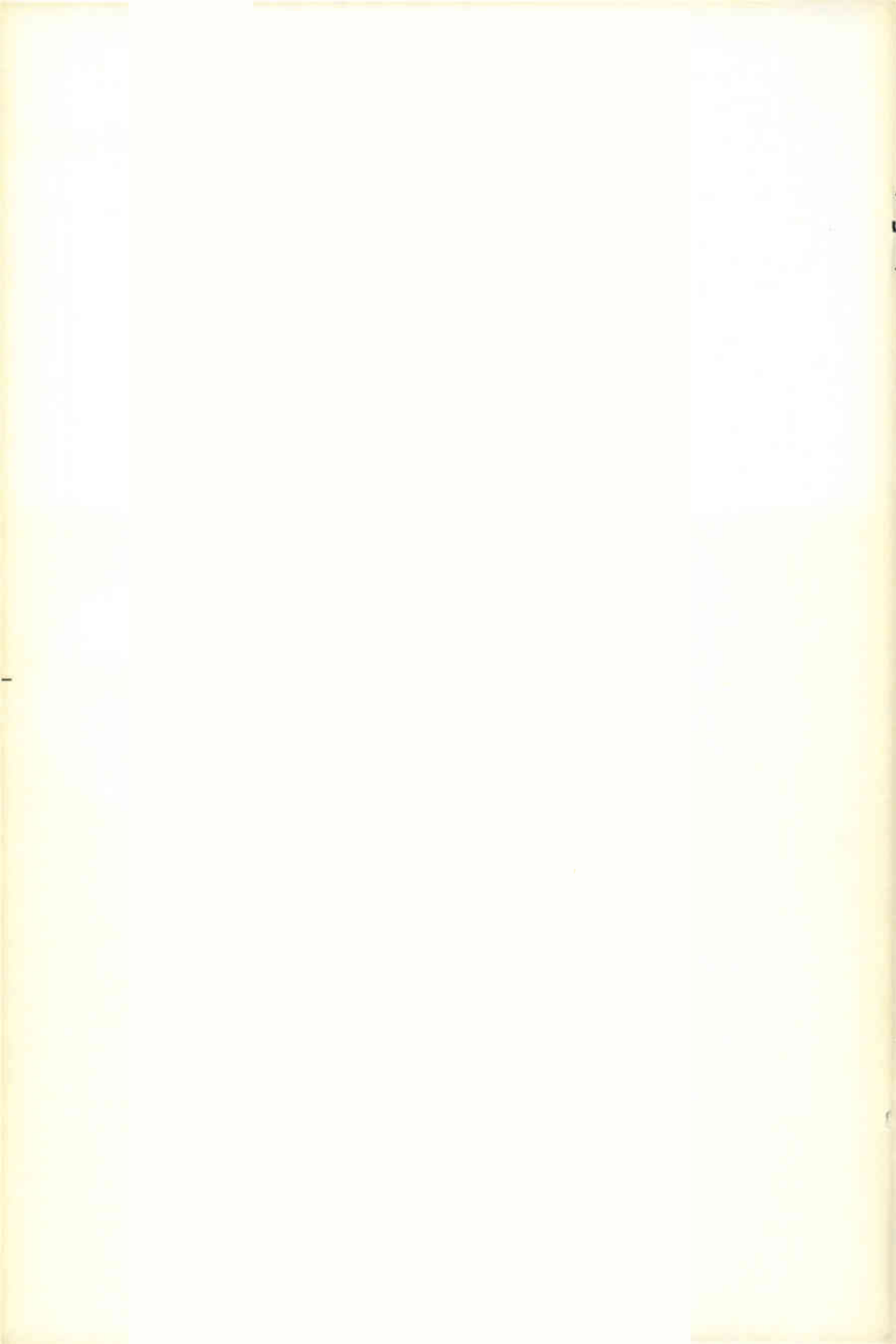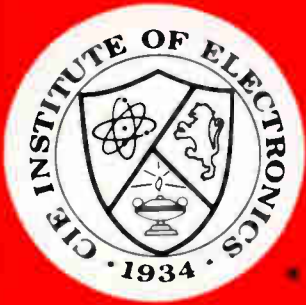
CLEVELAND INSTITUTE OF ELECTRONICS, INC. / CLEVELAND, OHIO

K-110

PACKING LIST

Lesson No.		Quan.	Title or Description
1	2330A	1	Current and Voltage
2	2330B	1	Controlling Current and Voltage
3	2333A	1	Power Distribution
4	2333B	1	Portable Extension Cords
5	2336A	1	Static Electricity
6	2336B	1	Electric Currents and Semiconductor Devices
7	2101A	1	Fractions and Decimal Numbers
8	2101B	1	Reciprocals, Percentage and Powers of Numbers
9	2339A	1	The Three Basics of Electric Circuits: Voltage, Current, and Resistance
10	2339B	1	Ohm's Law, Conductors, and Insulators
11	2342A	1	Connecting and Tracing Battery Circuits
12	2342B	1	Identifying Components
13	2342C	1	Tracing Wiring on Printed Circuit Boards
14	2102A	1	Roots of Numbers, Ratio and Proportion
15	2102B	1	Inverse Proportion and Negative Numbers
16	2323A	1	Parallel Circuits
17	2323B	1	Equivalent Circuits
18	2323C	1	Applications of Kirchhoff's Law
19	2324A	1	Series-Parallel Circuits
20	2324B	1	Voltage and Power