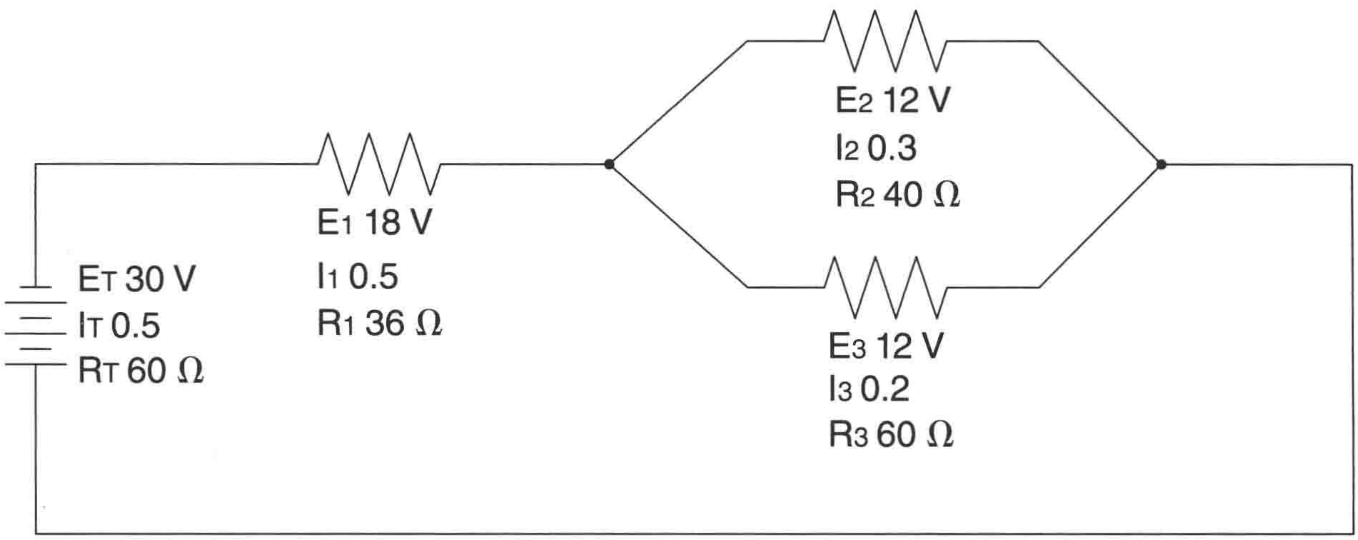


Figure 5-6 All circuit values have been determined.

$$I_3 = \frac{12}{60}$$

$$I_3 = 0.2 \text{ amp}$$

The circuit with all values is shown in Figure 5-6.

Example Circuit #2

The second example circuit is shown in Figure 5-7. The unknown values to be determined in this circuit are:

R_T - Total resistance of the circuit

I_T - Total current in the circuit

I_1 - Current flow through resistor R_1

I_2 - Current flow through resistor R_2

E_1 - Voltage drop across resistor R_1

E_2 - Voltage drop across resistor R_2

I_3 - Current flow through resistor R_3

E_3 - Voltage drop across resistor R_3

E_4 - Voltage drop across resistor R_4

E_5 - Voltage drop across resistor R_5

I_4 - Current flow through resistor R_4

I_5 - Current flow through resistor R_5

The first step in determining the unknown values for this circuit is to trace the current paths to determine which components are connected in series and parallel with each other. Assume that electrons leave the negative battery terminal and return to the positive terminal. Electrons can flow from the battery to the branch containing resistors R_1 and R_2.

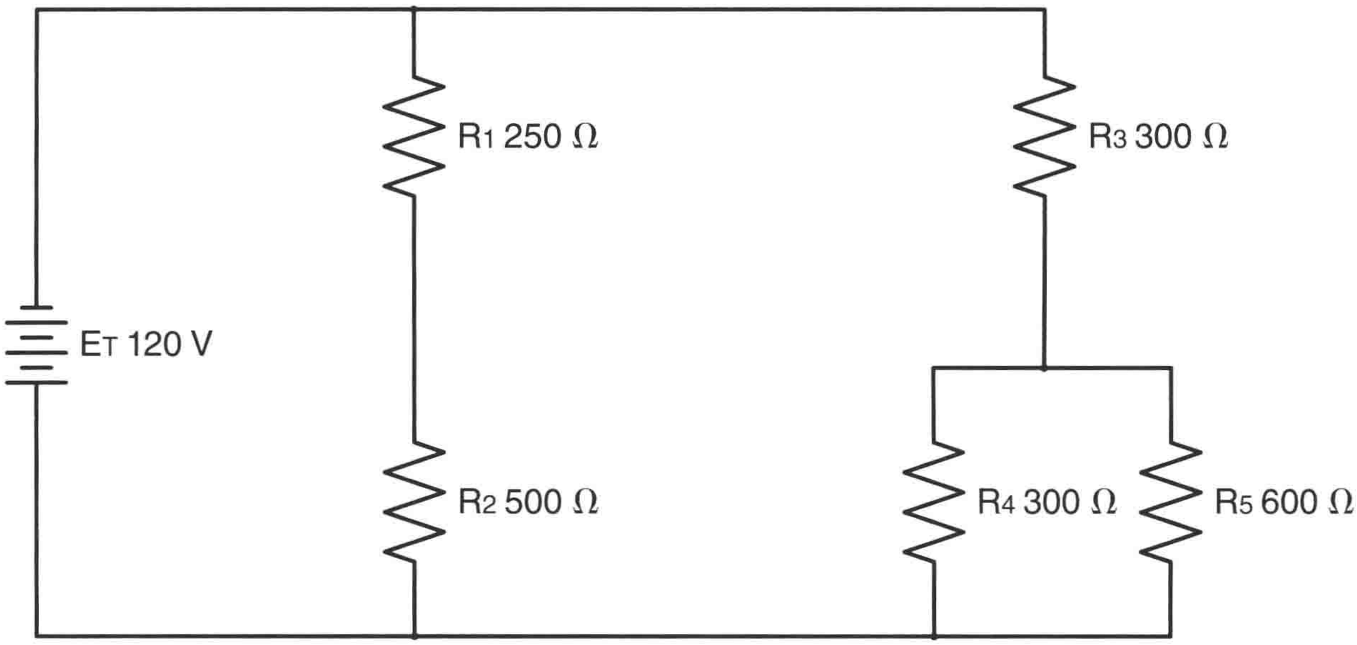


Figure 5-7 Example circuit 2.

Current can then flow through these two resistors and return to the positive battery terminal, as shown in Figure 5-8. Notice that there is only one path through the branch containing these two resistors. The same current must flow through both. Since the same current must flow through both resistors, they are connected in series with each other.

A second current path exists through the branch containing resistors R_3, R_4, and R_5, as shown in Figure 5-9. All of the current of that branch must flow through resistor R_3, but the current then divides through resistors R_4 and R_5. Resistors R_4 and R_5 are connected in parallel with each other because there is more than one path for current flow, but resistor R_3 is connected in series with R_4 and R_5. The branch containing resistors R_1 and R_2 is connected in parallel with the branch containing resistors R_3, R_4, and R_5.

The next step is to find the total resistance of the circuit. This can be accomplished by combining series and parallel connected resistors to form one single resistor. The procedure

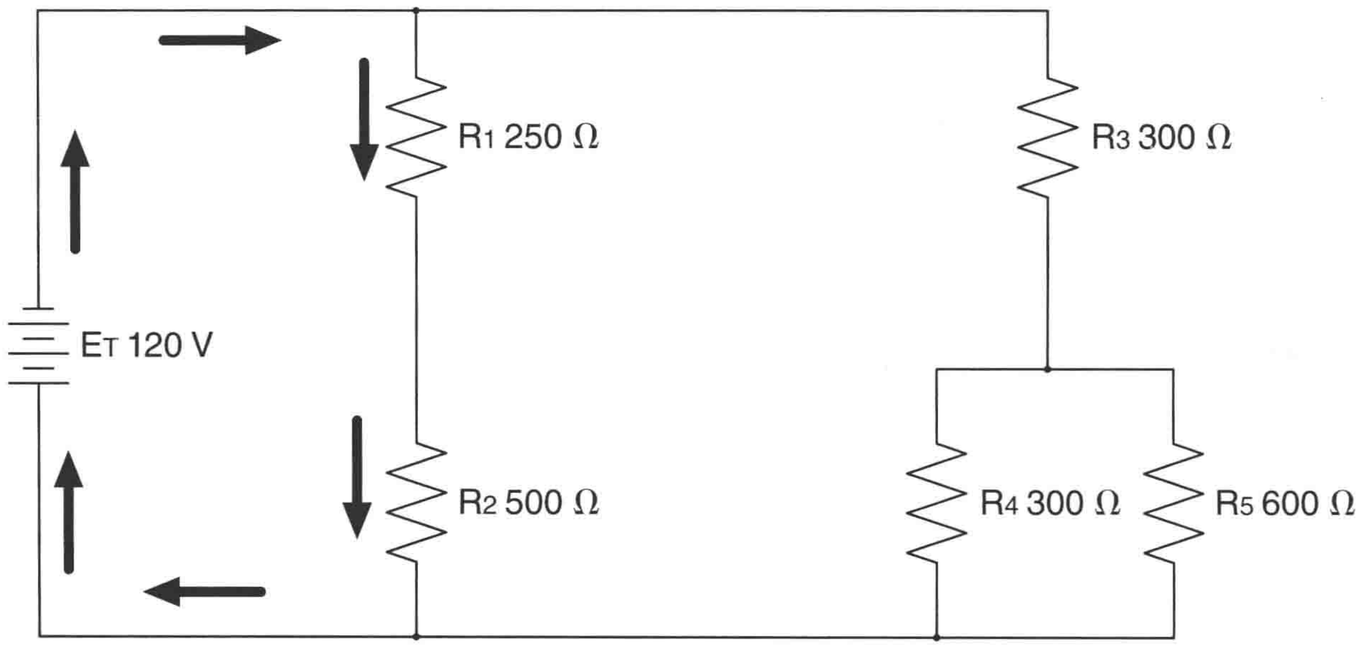


Figure 5-8 Current flows through resistors 1 and 2.

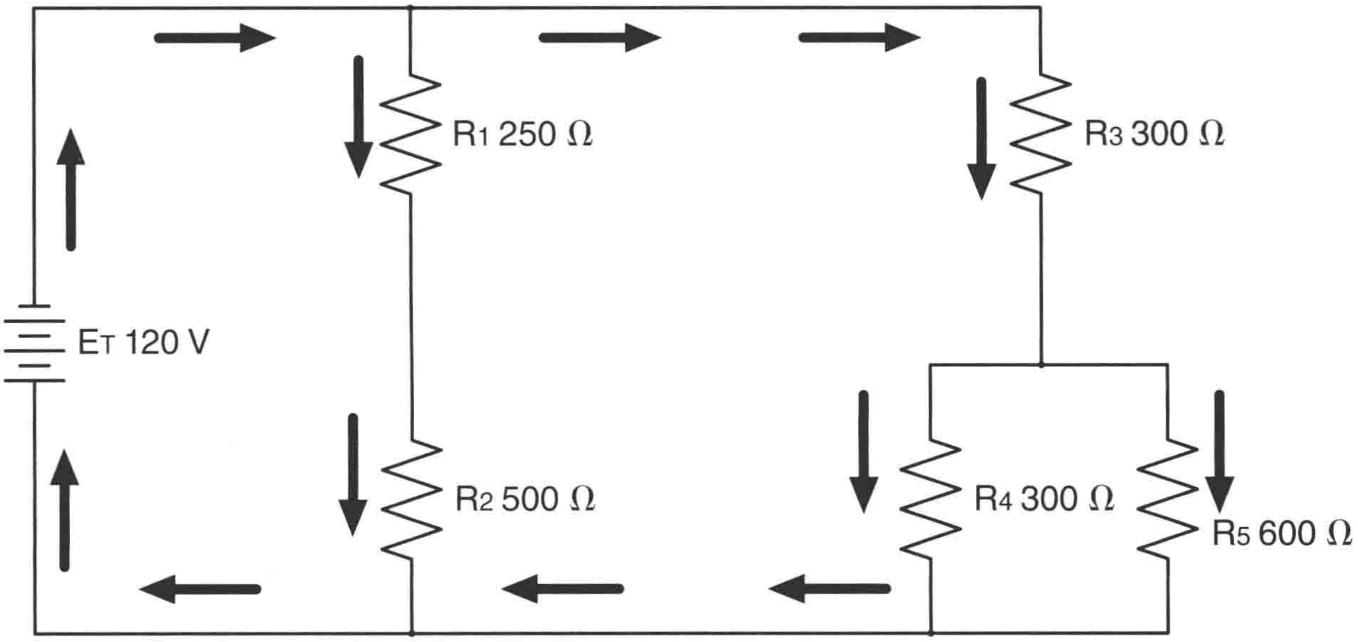


Figure 5-9 A current path also exists through resistors 3, 4, and 5.

is continued until there is a simple series or parallel circuit. The first two resistors to be combined are R_4 and R_5. Since these two resistors are connected in parallel, their total resistance can be determined using the following formula:

$$R_T = \frac{1}{\frac{1}{R_4} + \frac{1}{R_5}}$$

$$R_T = \frac{1}{\frac{1}{300} + \frac{1}{600}}$$

$$R_T = 200\ \Omega$$

This total value will be called R_{C1} (resistance of combination #1). The circuit can be redrawn as shown in Figure 5-10.

Resistors R_1 and R_2 are connected in series with each other. They can be combined into one resistor by adding their values.

$$R_T = R_1 + R_2$$

$$R_T = 750\ \Omega$$

The total value of these two resistors will be shown as R_{C2} (resistance of combination #2).

Resistors R_3 and R_{C1} are also connected in series with each other. They can be combined into one resistor by adding their values.

$$R_T = R_3 + R_{C1}$$

$$R_T = 300 + 200$$

$$R_T = 500\ \Omega$$

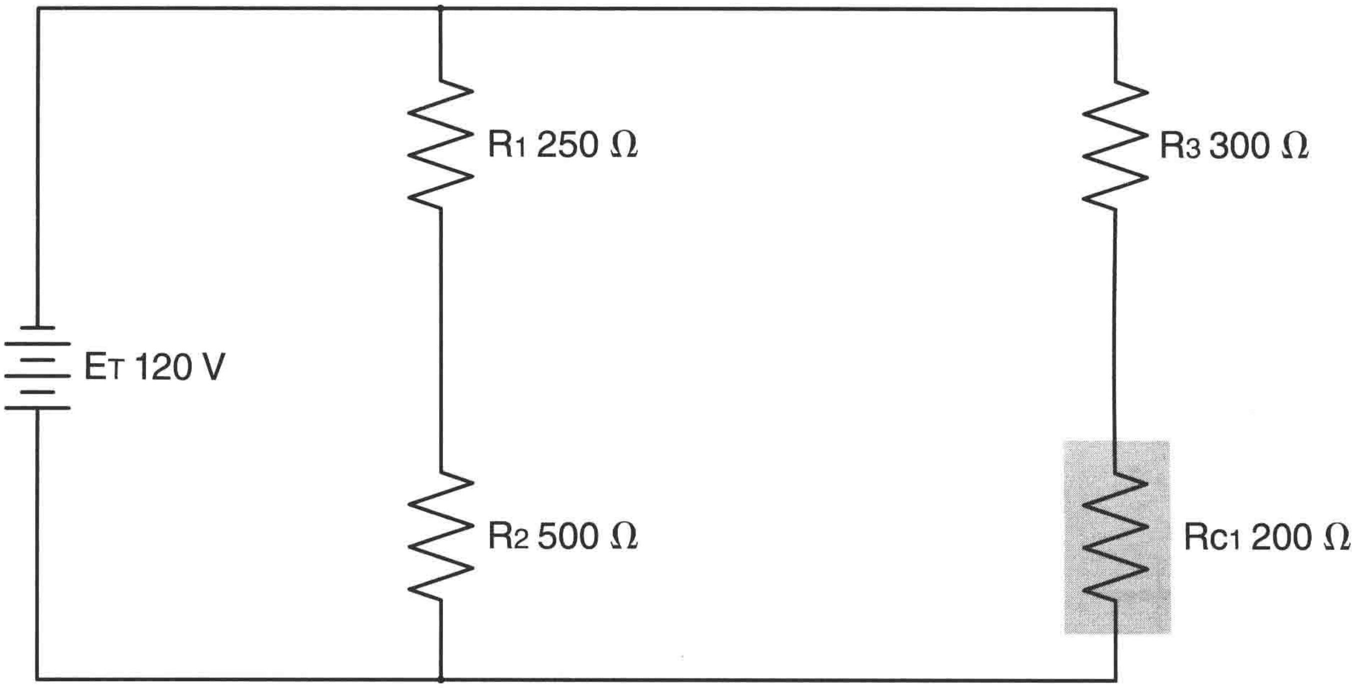


Figure 5-10 Resistors 4 and 5 form one resistor.

The total values of these two resistors will be shown as R_{C3} (resistance of combination #3). The circuit can now be redrawn as a simple parallel circuit, as shown in Figure 5-11.

The total resistance of the circuit can now be determined.

$$R_T = \frac{1}{\frac{1}{750} + \frac{1}{500}}$$

$$R_T = 300\ \Omega$$

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

$$I_T = \frac{120}{300}$$

$$I_T = 0.4 \text{ amp}$$

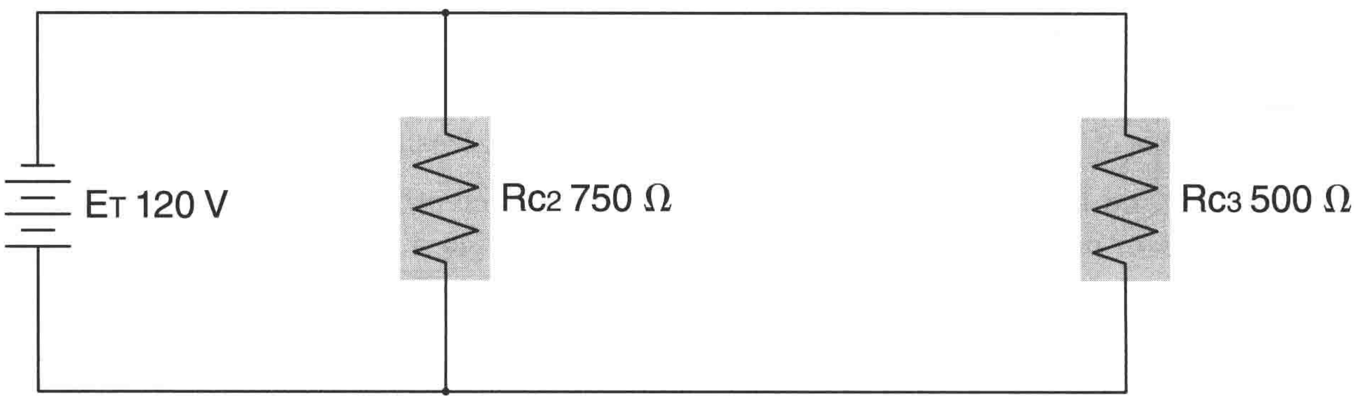


Figure 5-11 The circuit has been reduced to a simple parallel circuit.

In a parallel circuit, the voltage must be the same across all branches. Therefore, a voltage of 120 volts is applied across resistors R_{C2} and R_{C3}. The current flow through these branches can be determined using Ohm's law.

$$I_{C2} = \frac{120}{750}$$

$$I_{C2} = 0.16 \text{ amp}$$

$$I_{C3} = \frac{120}{500}$$

$$I_{C3} = 0.24 \text{ amp}$$

Note that if the currents flowing through resistors R_{C2} and R_{C3} are added together, they will equal the total circuit current ($0.16 + 0.24 = 0.4$). One of the rules for parallel circuits states that the total current of a parallel circuit is equal to the sum of the currents through the branches.

Resistor R_{C2} is, in reality, a combination of resistors R_1 and R_2. The values that apply to R_{C2}, therefore, apply to resistors R_1 and R_2. Since R_1 and R_2 are connected in series, the current flowing through R_{C2} flows through both of them. The voltage drop across R_1 and R_2 can now be determined using Ohm's law.

$$E_1 = 0.16 \times 250$$

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

$$E_2 = 0.16 \times 500$$

$$E_2 = 80 \text{ volts}$$

Note that if the voltage drops across resistors R_1 and R_2 are added together, they will equal the voltage applied across the branch ($40 + 80 = 120$). Recall that one of the rules concerning series circuits states that the sum of the voltage drops must equal the applied voltage.

Resistor R_{C3} is, in reality, the combination of resistors R_3 and R_{C1}. Since R_3 and R_{C1} are connected in series, they will have the same current flowing through them that flows through R_{C3}. The voltage drop across these two resistors can be determined with Ohm's law.

$$E_3 = 0.24 \times 300$$

$$E_3 = 72 \text{ volts}$$

$$E_{C1} = 0.24 \times 200$$

$$E_{C1} = 48 \text{ volts}$$

The values for resistors R_1, R_2, R_3, and R_{C1} are shown in Figure 5-12.

Resistor R_{C1} is, in reality, the combination of resistors R_4 and R_5. The values that apply to resistor R_{C1}, therefore, apply to resistors R_4 and R_5. Since resistors R_4 and R_5 are connected in parallel, the voltage dropped across R_{C1} is dropped across R_4 and R_5. The amount of current flowing through resistors R_4 and R_5 can now be computed.

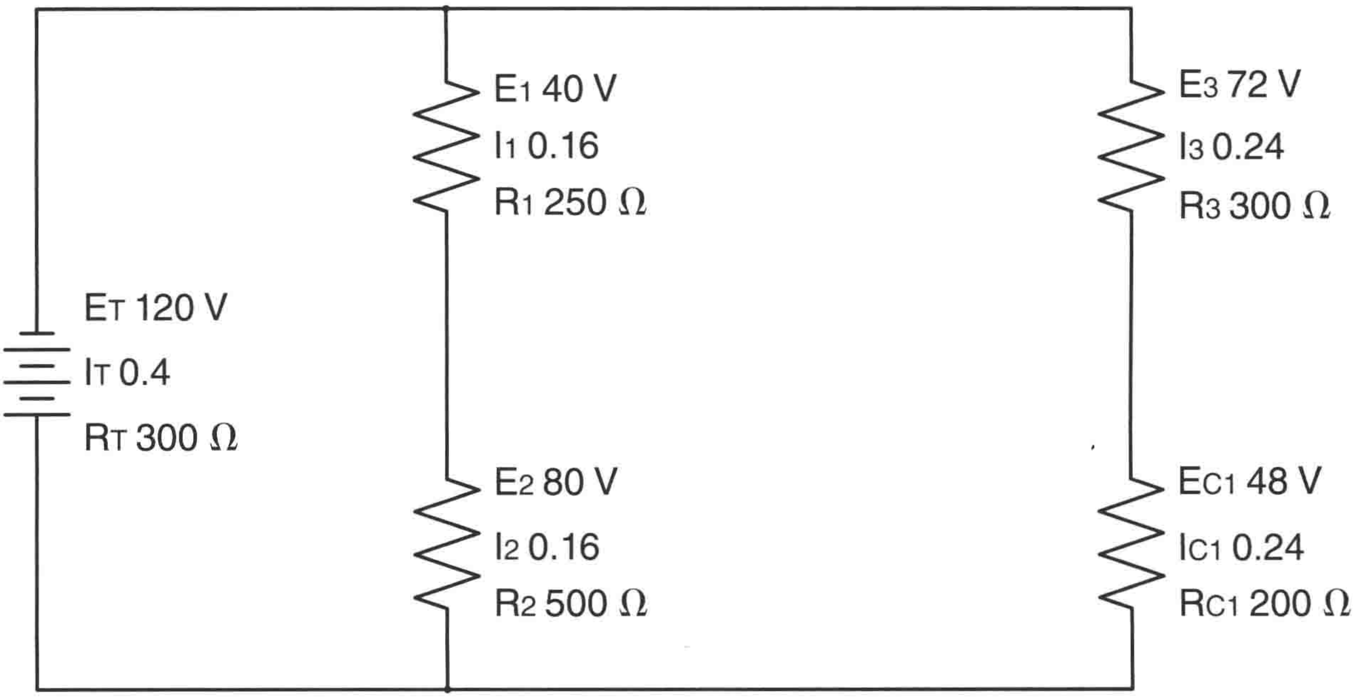


Figure 5-12 The unknown values for R_1, R_2, R_3, and R_{C1} have been determined.

$$I_4 = \frac{48}{300}$$

$$I_4 = 0.16 \text{ amp}$$

$$I_5 = \frac{48}{600}$$

$$I_5 = 0.08 \text{ amp}$$

The circuit with all values is shown in Figure 5-13.

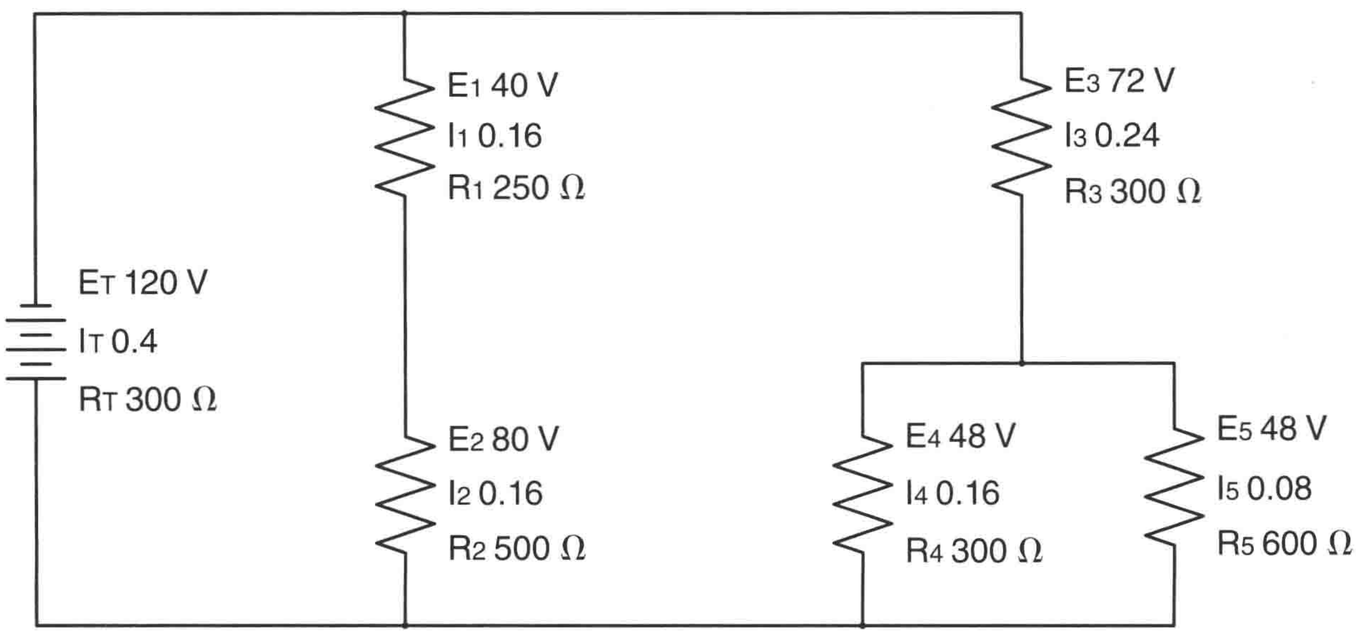


Figure 5-13 All missing circuit values have been determined.

LABORATORY EXERCISE

Name ______________________________ Date __________

Materials Required

1 208 volt AC power supply

1 120 volt AC power supply

2 100 ohm resistors

2 150 ohm resistors

2 250 ohm resistors

1 AC ammeter (in-line or clamp-on may be used. If a clamp-on type is used, a 10:1 scale divider is recommended.)

1 AC voltmeter

1 Ohmmeter

Connecting wires

1. Connect the circuit shown in Figure 5-14. **Make sure that the AC power remains turned off until you are told to turn it on.**
2. Determine the combined resistance of resistors R_2 and R_3. These resistors are connected in series with each other. Therefore, the total resistance is the sum of the two values.

$$R_{C\ 2\&3} = R_2 + R_3$$

$R_{C\ 2\&3}$ __________ Ω

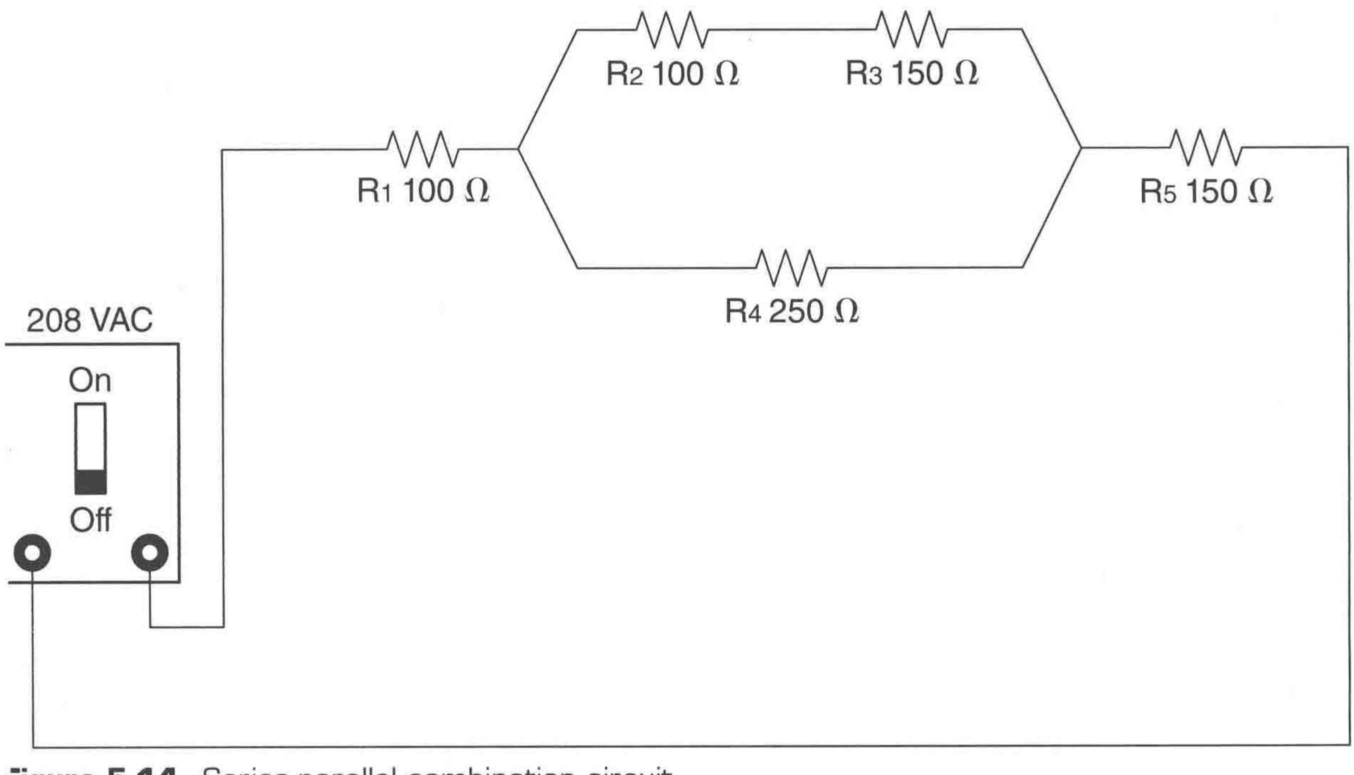


Figure 5-14 Series-parallel combination circuit.

3. Resistors R_2 and R_3 are connected in parallel with resistor R_4. The combined resistance of these three resistors can be determined using the following formula:

$$R_{C\,2,3,4} = \frac{1}{\frac{1}{R_{C\,2,3}} + \frac{1}{R_4}}$$

Alternatively, because the combined resistance of resistors R_2 and R_3 is the same as the value of resistor R_4, the total resistance can be determined using the following formula

$$R_{C\,2,3,4} = \frac{R}{N}$$

where R is the value of the resistors and N is the number of resistors.

$R_{C\,2,3,4}$ = __________ Ω

4. The circuit has now become a simple series circuit with resistors R_1, $R_{C\,2,3,4}$, and R_5 connected in series. Determine the total resistance of the circuit using the following formula:

$$R_T = R_1 + R_{C\,2,3} + R_5$$

R_T = __________ Ω

5. Disconnect the circuit from the power supply and measure the total resistance of the circuit with an ohmmeter. Compare this value with the computed value. Are the values within 5 percent of each other? After making the measurement, reconnect the circuit to the power source but do not turn the power on.

__________ Ω

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

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

I_T = __________ A

7. Resistors R_1 and R_5 are connected in series with the combined resistors $R_{C\,2,3,4}$. Therefore, the total circuit current flows through resistors R_1 and R_5. Determine the voltage drop across these two resistors using Ohm's law.

$$E = I \times R$$

E_1 = __________ volts

E_5 = __________ volts

8. The voltage drop across combined resistors 2, 3, and 4 can be determined using Ohm's law. The total circuit current flows through this combination. The voltage drop across this combination is equal to the total circuit current and the combined resistance of the three resistors. Determine the voltage drop across the combination of resistors.

$E_{C\,2,3,4}$ = __________ volts

9. Resistor R_4 is a single resistor in the combination of resistors 2, 3, and 4. Therefore, the voltage dropped across the combination is dropped across resistor R_4. Determine the amount of current flow through resistor R_4.

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

I_4 = __________ A

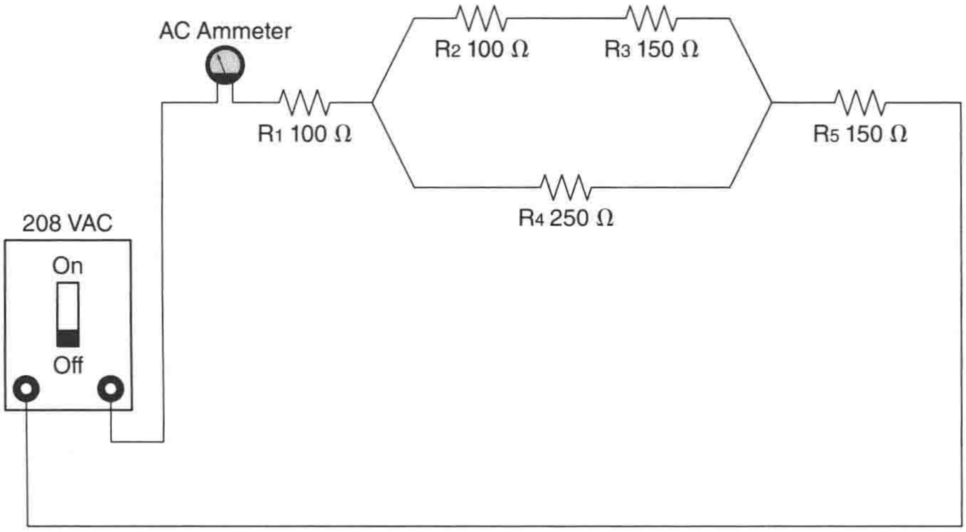


Figure 5-15 Connecting an AC ammeter in the circuit.

10. The voltage dropped across the combined resistors 2, 3, and 4 is also dropped across resistors R_2 and R_3. The current flow through these two resistors can be calculated using the voltage drop across them and the total resistance of the two resistors. Determine the current flow through these resistors using Ohm's law.

    $I_{2\&3}$ = __________ A

11. The voltage drop across resistors R_2 and R_3 can be determined using Ohm's law. Calculate the voltage drop across resistors R_2 and R_3.

    E_2 = __________ volts

    E_3 = __________ volts

12. Connect an ammeter in series with the circuit as shown in Figure 5-15. Turn on the power and measure the total circuit current. **Turn off the power**. Compare the measured value with the value computed in step 6. Are these two values within 5 percent of each other?

    ____

13. Connect an AC voltmeter across resistor R_1 as shown in Figure 5-16. Turn on the power and measure the voltage drop across the resistor. **Turn off the power**. Compare the measured value with the value computed in step 7. Are the two values within 5 percent of each other?

    ____

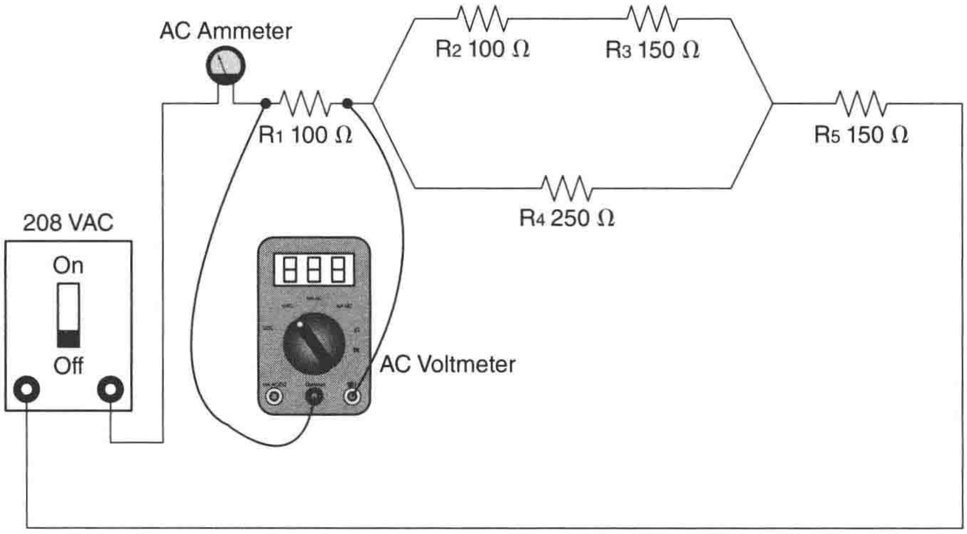


Figure 5-16 A voltmeter measures the voltage drop across resistor R_1.

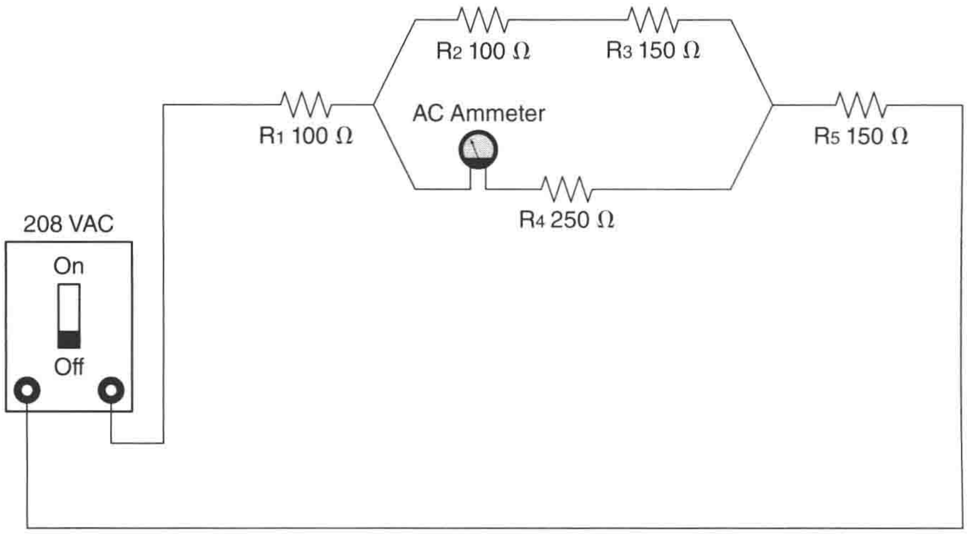


Figure 5-17 The ammeter measures the current flow through resistor R_4.

14. Reconnect the AC voltmeter across resistor R_5. Turn on the power and measure the voltage drop across the resistor. **Turn off the power**. Compare the measured value with the value computed in step 7. Are the two values within 5 percent of each other?

____

15. Reconnect the AC ammeter in the circuit to measure the current flow through resistor R_4 as shown in Figure 5-17. Turn on the power and measure the current. **Turn off the power**. Compare the measured value with the value computed in step 9. Are the two values within 5 percent of each other?

____

16. Connect the AC voltmeter across resistor R_4. Turn on the power and measure the voltage drop across the resistor. **Turn off the power**. Compare the measured value with the value computed in step 8. Are the two values within 5 percent of each other?

____

17. Reconnect the circuit as shown in Figure 5-18. The AC ammeter has been connected in series with resistors R_2 and R_3. Turn on the power and measure the current flow through resistors R_2 and R_3. **Turn off the power**. Compare the measured value with the value computed in step 10. Are the two values within 5 percent of each other?

____

18. Connect an AC voltmeter across resistor R_2. Turn on the power and measure the voltage drop across the resistor. **Turn off the power**. Compare the measured value with the value computed in step 11. Are the two values within 5 percent of each other?

____

19. Connect an AC voltmeter across resistor R_3. Turn on the power and measure the voltage drop across the resistor. **Turn off the power**. Compare the measured value with the value computed in step 11. Are the two values within 5 percent of each other?

____

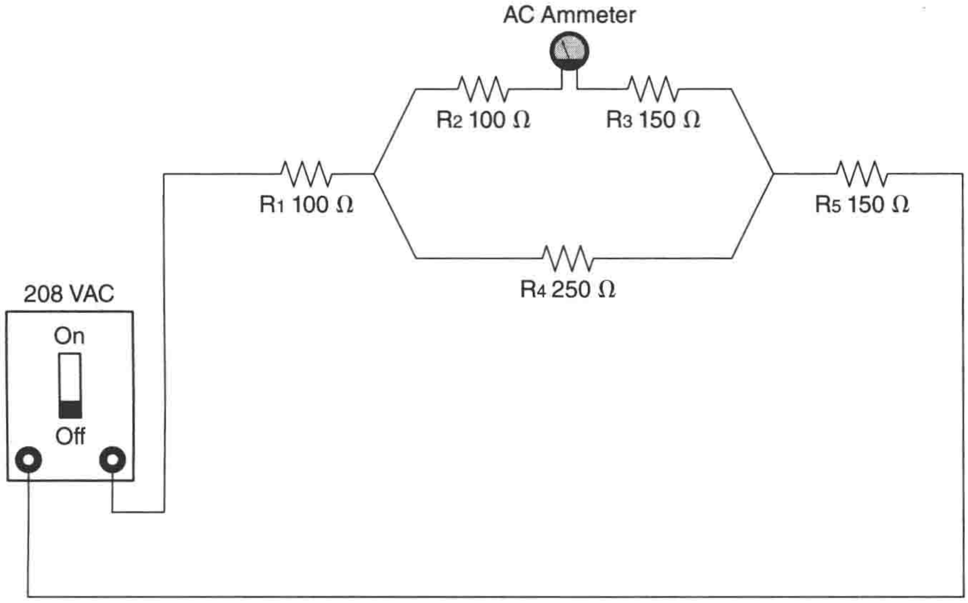


Figure 5-18 The ammeter measures the current flow through resistors R_2 and R_3.

20. Connect the circuit shown in Figure 5-19. Do not turn on the power until you are instructed to do so.
21. Calculate the combined resistance of resistors R_4 and R_5. These two resistors are connected in parallel with each other. The total resistance can be determined using the following formula:

$$R_{4,5} = \frac{1}{\frac{1}{R_4} + \frac{1}{R_5}}$$

$R_{4,5}$ = __________ Ω

22. The combined resistors R_4 and R_5 are connected in series with resistor R_3. Calculate the resistance of the combined resistors $R_{4,5}$ and R_3 with the following formula:

$$R_{3,4,5} = R_3 + R_{4,5}$$

$R_{3,4,5}$ = __________ Ω

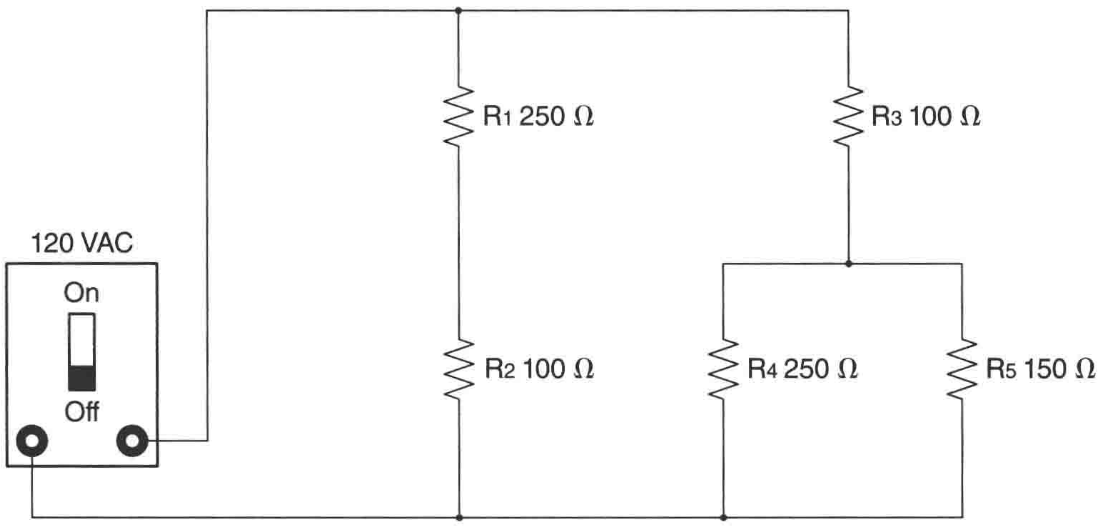


Figure 5-19 Connection schematic for the second combination circuit.

23. Resistors R_1 and R_2 are connected in series. Determine the total combined resistance of resistors R_1 and R_2 using the following formula:

$$R_{1,2} = R_1 + R_2$$

$R_{1,2}$ = __________ Ω

24. The combination or resistors R_1 and R_2 is connected in parallel with the combination of resistors R_3, R_4, and R_5. Calculate the total circuit resistance using the following formula: (Note: Round off the answer to the second decimal place or hundredth of an ohm.)

$$R_T = \frac{1}{\frac{1}{R_{1,2}} + \frac{1}{R_{3,4,5}}}$$

R_T = __________ Ω

25. Disconnect the circuit from the power supply and measure the total resistance of the circuit with an ohmmeter. Compare the measured value with the value calculated in step 24. Are the values within 5 percent of each other?

____

26. Assuming a voltage of 120 volts, calculate the total circuit current using the following formula: (Note: Round the answer off to the second decimal place or hundredth of an amp.)

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

I_T = __________ A

27. In the circuit shown in Figure 5-19, resistors R_1 and R_2 form one branch of a parallel circuit. Therefore, 120 volts are connected across the two series resistors. Because the resistors are connected in series, they will each have the same current. Calculate the current through resistors R_1 and R_2 using the following formula: (Note: Round the answer off to the second decimal place or hundredth of an amp.)

$$I_{1,2} = \frac{E}{R_{1,2}}$$

$I_{1,2}$ = __________ A

28. Because the current flow through resistors R_1 and R_2 is now known, the voltage drop across each resistor can be calculated using Ohm's law.

$$E = I \times R$$

E_1 = __________ volts

E_2 = __________ volts

29. In a series circuit, the sum of the voltage drops must equal the applied voltage. Therefore, the sum of the voltage drops across R_1 and R_2 should equal the voltage applied across the branch. Add the values of E_1 and E_2. Does the sum equal the 120 volts applied across the branch? (Note: There may be a slight difference caused by rounding off values.)

____

____

____

30. The second branch of the circuit comprises resistor R_3 and the combination of resistors R_4 and R_5. Determine the current flow through the second branch using the following formula: (Note: Round the answer off to the second decimal place or hundredth of an amp.)

$$I_{3,4,5} = \frac{E}{R_{3,4,5}}$$

$I_{3,4,5}$ = __________ A

31. The voltage drop across resistor R_3 can be calculated using the following formula:

$$E = I \times R_3$$

E_3 = __________ volts

32. The voltage drop across combination resistor $R_{4,5}$ can be calculated using the following formula: (Note: Round the answer off to the second decimal place or hundredth of a volt.)

$$E_{4,5} = I \times R_{4,5}$$

$E_{4,5}$ = __________ volts

33. Resistors R_3 and combination resistor $R_{4,5}$ are connected in series with each other. Therefore, the sum of the voltage drops should equal the applied voltage of 120 volts. Does the sum of E_3 and $E_{4,5}$ equal the applied voltage of 120 volts? (Note: A slight difference caused by rounding off values may occur.)

____

____

____

34. Resistors R_4 and R_5 are connected in parallel with each other. Therefore, the voltage drop across combination resistor $R_{4,5}$ is dropped across each of the two resistors that comprise the combination. The current flow through each resistor can be determined with Ohm's law.

$$I_4 = \frac{E}{R_4}$$

I_4 = __________ A

$$I_5 = \frac{E}{R_5}$$

I_5 = __________ A

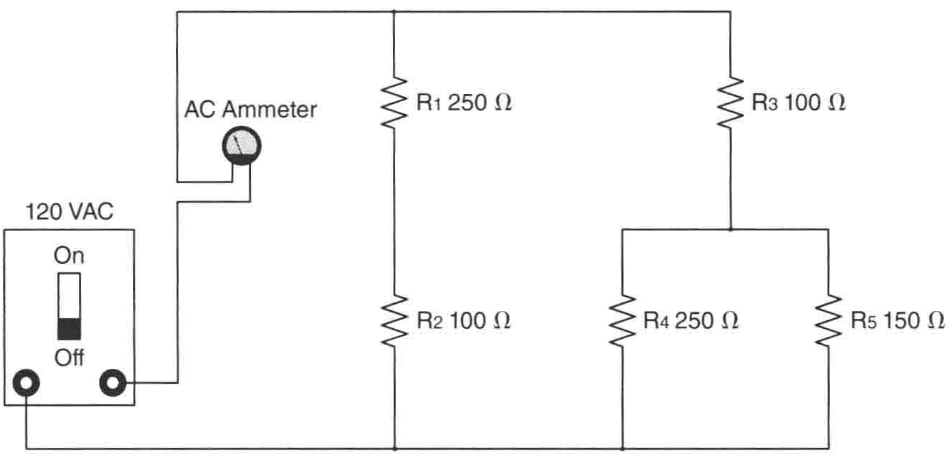


Figure 5-20 The ammeter measures the total circuit current.

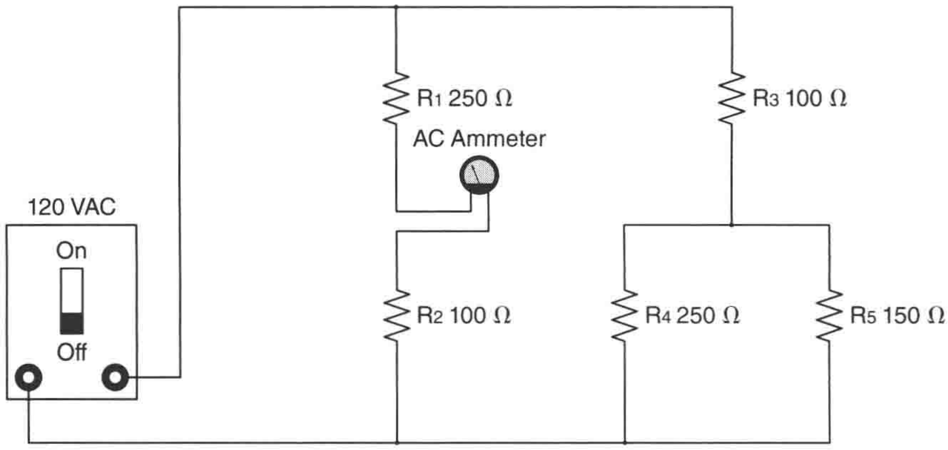


Figure 5-21 The ammeter measures the current through resistors R_1 and R_2.

35. Reconnect the circuit to the power supply and install an AC ammeter in the circuit as shown in Figure 5-20. Turn on the power and measure the total circuit current. **Turn off the power**. Compare the measured value with the value computed in step 26.

    I_T = __________ A

    Are the values within 5 percent of each other? (Note: If there is a significant difference in the measured and calculated values, measure the input voltage with an AC voltmeter. The calculations were made with the assumption that the input voltage is 208 volts. If the voltage is significantly greater, the current will be greater than the calculated value. Also, the measured voltage drops will be greater than calculated. If the input voltage is significantly less, the current and voltage drop measurements will also be less.)

    ____

36. Reconnect the circuit as shown in Figure 5-21. Turn on the power and measure the current flow through resistors R_1 and R_2. **Turn off the power**. Compare the measured value of current with the value computed of current in step 27.

    $I_{1,2}$ = __________ A

    Are the measured and calculated values within 5 percent of each other?

    ____

37. Turn on the power and measure the voltage drop across resistors R_1 and R_2 with an AC voltmeter. **Turn off the power**. Compare the measured values with the values computed in step 28.

    E_1 = __________ volts

    E_2 = __________ volts

    Are the measured and computed values within 5 percent of each other?

    ____

38. Reconnect the circuit as shown in Figure 5-22. Turn on the power and measure the current flow through resistor R_3 and combination resistors R_4 and R_5. **Turn off the power**. Compare the measured value with the value calculated in step 30.

    $I_{3,(4,5)}$ __________ A

    Are the measured and calculated values within 5 percent of each other?

    ____

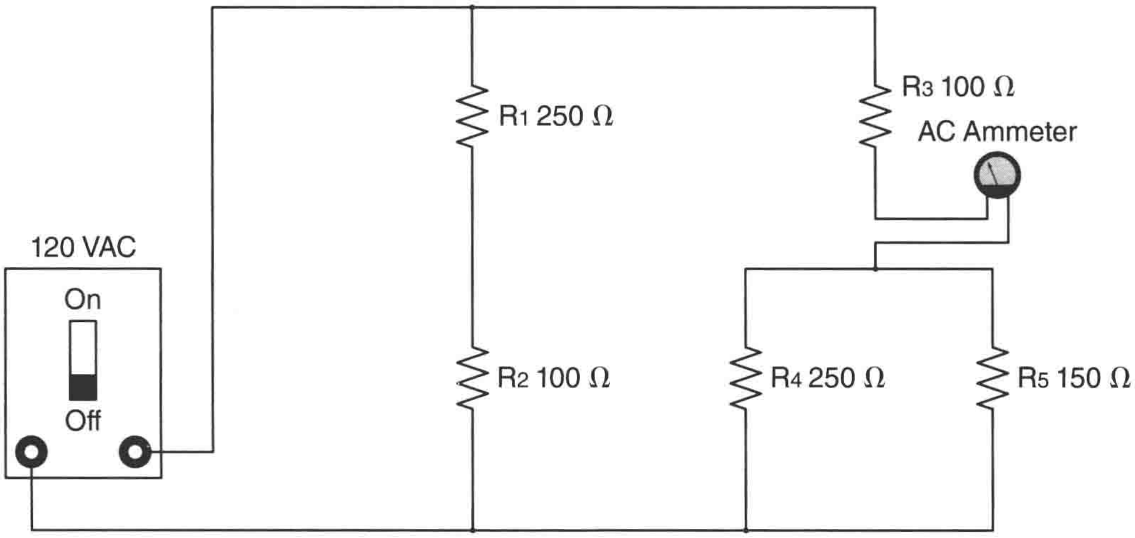


Figure 5-22 The ammeter meter measures the current through the second branch of the circuit.

39. Turn on the power and measure the voltage drop across resistor R_3. **Turn off the power**. Compare the measured value with the value computed in step

    E_3 = __________ volts

    Are the measured and calculated values within 5 percent of each other?

    ____

40. Resistors R_4 and R_5 are connected in parallel with each other and form the combination resistance $R_{4,5}$. The voltage drop across these two resistors will be the same. Turn on the power and measure the voltage drop across these resistors with an AC voltmeter as shown in Figure 5-23. **Turn off the power**. Compare the measured value with the value calculated in step 32.

    $E_{4,5}$ = __________ volts

    Are the measured value and calculated value within 5 percent of each other?

    ____

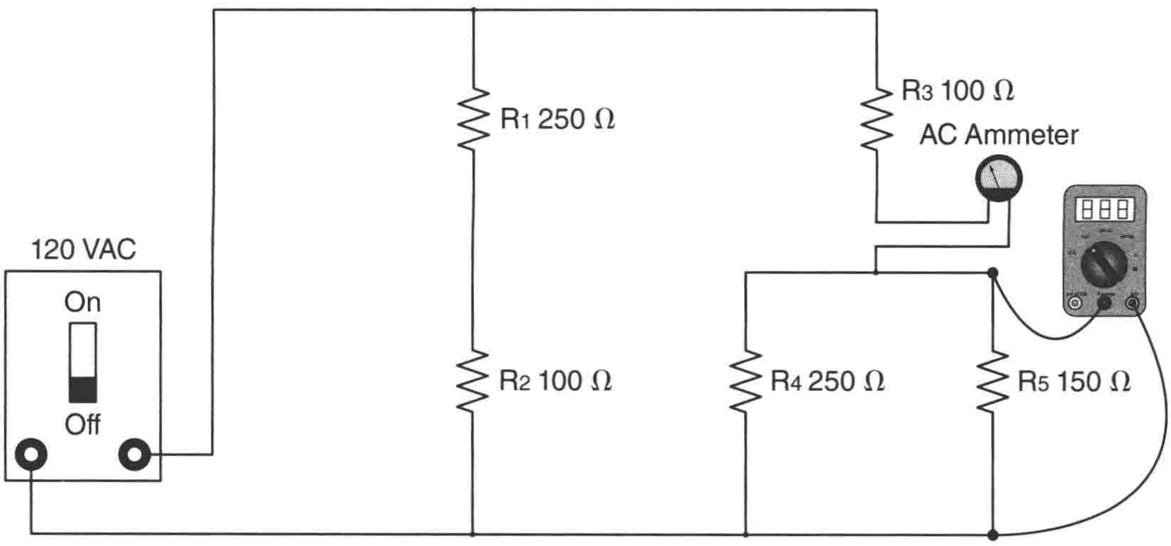


Figure 5-23 The voltmeter measures the voltage drop across resistors R_4 and R_5.

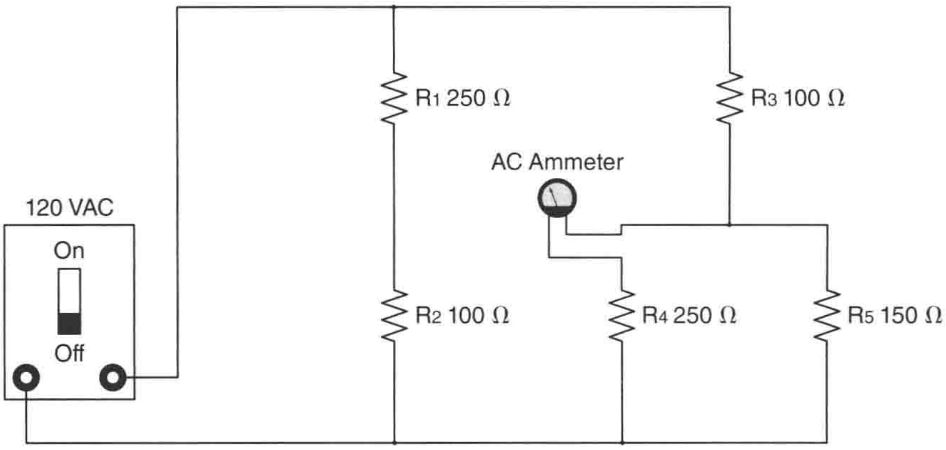


Figure 5-24 The ammeter measures the current flow through resistor R_4.

41. Reconnect the circuit as shown in Figure 5-24. Turn on the power and measure the current through resistor R_4. **Turn off the power**. Compare the measured value with the value calculated in step 34.

    I_4 = __________ A

    Are the measured value and calculated value within 5 percent of each other?

    ____

42. Reconnect the circuit as shown in Figure 5-25. Turn on the power and measure the current flow through resistor R_5. **Turn off the power**. Compare the measured value with the value calculated in step 34.

    I_5 = __________ A

    Are the measured value and calculated value within 5 percent of each other?

    ____

43. Disconnect the circuit and return the components to their proper places.

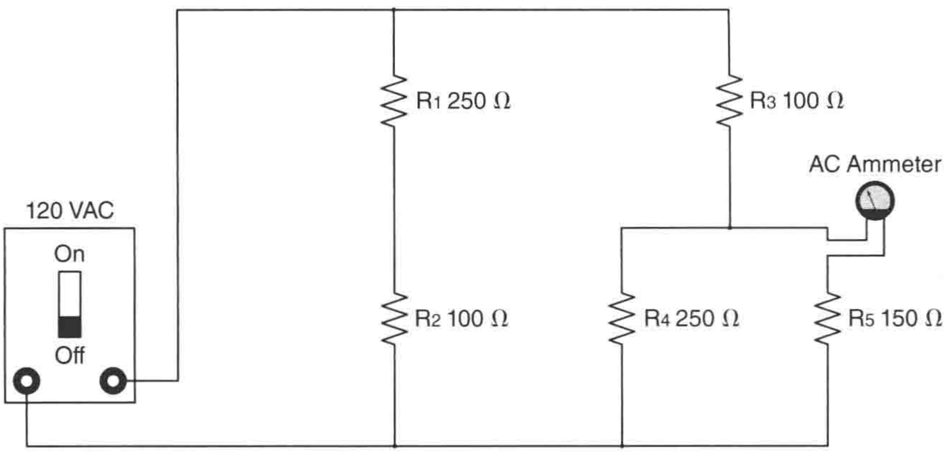


Figure 5-25 The ammeter measures the current flow through resistor R_5.

Review Questions

1. State the three rules for series circuits.

____

____

____

2. State the three rules for parallel circuits.

To answer the following questions, refer to the circuit shown in Figure 5-26.

3. What is the total resistance of resistors R_2 and R_3?

4. What is the total resistance of resistors R_4 and R_5?

5. What is the total resistance of the parallel block containing resistors R_2, R_3, R_4, and R_5?

6. What is the total resistance of this circuit?

7. What is the total amount of current flow in this circuit?

8. How much current flows through resistors R_1 and R_6?

9. What is the voltage drop across resistor R_1?

10. How much voltage is dropped across resistor R_6?

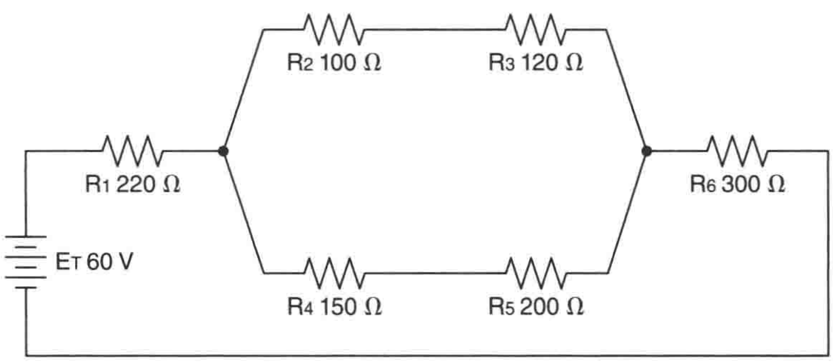


Figure 5-26 Combination circuit.

11. How much voltage is dropped across the parallel block containing resistors R_2, R_3, R_4, and R_5?

____

12. The voltage drop across the parallel block containing resistors R_2, R_3, R_4, and R_5 is dropped across resistors R_2 and R_3. How much current is flowing through resistors R_2 and R_3?

____

13. What is the voltage drop across resistor R_2?

____

14. What is the voltage drop across resistor R_3?

____

15. What is the sum of the voltage drops across R_2 and R_3?

____

16. Is the sum of these two voltage drops approximately equal to the voltage across the parallel block containing resistors R_2, R_3, R_4, and R_5?

____

17. How much current is flowing through resistors R_4 and R_5?

____

18. What is the voltage drop across resistor R_4?

____

19. What is the voltage drop across resistor R_5?

____

20. Is the sum of the two voltage drops across R_4 and R_5 approximately equal to the voltage drop across the parallel block containing resistors R_2, R_3, R_4, and R_5?

____

21. Add the amount of current flowing through R_2 and R_3 to the amount of current flowing through R_4 and R_5. Is the sum of these two currents approximately equal to the total circuit current?

____

Unit 6 Resistor Color Code

Objectives

After studying this unit, you should be able to

- Determine the resistance value by the color bands on the resistor.
- Determine the tolerance range of a resistor.
- Determine the value of a 1 percent resistor with five bands of color.
- Measure resistance with an ohmmeter.

The values of a resistor can often be determined by the color code. Many resistors have bands of color that are used to determine the resistance value, tolerance, and in some cases reliability. The color bands represent numbers. Each color represents a different numerical value. The chart shown in Figure 6-1 lists the color and the number value assigned to that color. The resistor shown below the color chart illustrates how to determine the resistor's value. Resistors can have from three to five bands of color. Resistors that have a tolerance of 20 percent have only three color bands. Most resistors contain four bands of color. For resistors with tolerances that range from 10 percent to 2 percent, the first two color bands represent number values. The third color band is called the multiplier. *Multiply the first*

Color	Number Value	Resistor Tolerance
Black	0	
Brown	1	Brown +/-1%
Red	2	Red +/-2%
Orange	3	Gold +/-5%
Yellow	4	Silver +/-10%
Green	5	No color +/-20%
Blue	6	
Violet	7	Gold (0.1 Multiplier)
Gray	8	Silver (0.01 Multiplier)
White	9	

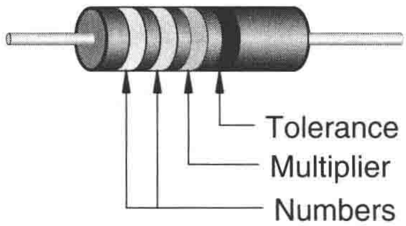


Figure 6-1 Resistor color code chart.

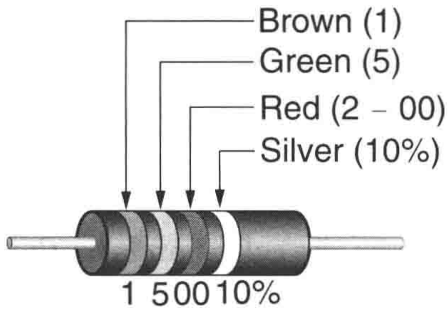


Figure 6-2 Determining resistor values using the color code.

two numbers by 10 the number of times indicated by the number value of the third band. The fourth band indicates the tolerance. For example, assume a resistor has color bands of brown, green, red, and silver, as shown in Figure 6-2. The first two bands represent the numbers 1 and 5 (brown is 1 and green is 5). The third band is red, which has a number value of 2. The number 15 should be multiplied by 10 two times. The value of the resistor is 1500 Ω. Another method that is simpler to understand is to add the number of zeros indicated by the multiplier band to the first two numbers. The multiplier band in this example is red, which has a numeric value of 2. Add two zeros to the first two numbers. The number 15 becomes 1500.

Tolerance

The fourth band is the tolerance band. The tolerance band in this example is silver, which means ±10%. This resistor should be 1500 Ω plus or minus 10 percent. To determine the value limits of this resistor, find 10 percent of 1500.

$$1500 \times 0.10 = 150$$

The value can range from 1500 + 10% or 1500 + 150 = 1650 Ω to 1500 − 10% or 1500 − 150 = 1350 Ω.

Five Band Resistors

Resistors that have a tolerance of ±1% and some military resistors contain five bands of color.

Example #1: The resistor shown in Figure 6-3 contains the following bands of color:

First band = Brown

Second band = Black

Third band = Black

Fourth band = Brown

Fifth band = Brown

The brown fifth band indicates that this resistor has a tolerance of ±1%. To determine the value of a 1 percent resistor, the first three bands are numbers and the fourth band is the multiplier. In this example, the first band is brown, which has a number value of 1.

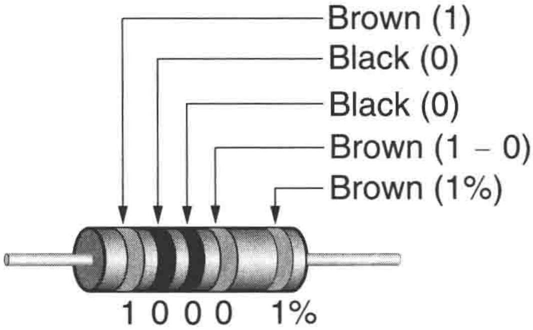


Figure 6-3 Determining the value of a 1 percent resistor.

The next two bands are black, which represent a number value of 0. The fourth band is brown, which means add one zero to the first three numbers. The value of this resistor is 1000 ±1%.

Example #2: A five-band resistor has the following color bands:

First band = Red

Second band = Orange

Third band = Violet

Fourth band = Red

Fifth band = Brown

The first three bands represent number values. Red is 2, orange is 3, and violet is 7. The fourth band is the multiplier; in this case red represents 2. Add two zeros to the number 237. The value of the resistor is 23,700 ohms. The fifth band is brown, which indicates a tolerance of ±1%.

Military resistors often have five bands of color. The ohmic value and tolerance of these resistors are read in the same manner as a resistor with four bands of color. The fifth band can represent different things. A fifth band of orange or yellow is used to indicate reliability. It has been known for many years that if a resistor is going to fail, it will generally fail within so many hours. The military often pays companies to put resistors in a circuit and operate them for so many days. Resistors that do not fail within the test period are considered to be more reliable than untested resistors. Resistors with a fifth band of orange have a reliability good enough to be used in missile systems, and a resistor with a fifth band of yellow can be used in space flight equipment. A military resistor with a fifth band of white indicates the resistor has solderable leads.

Resistors with tolerance ratings ranging from 0.5% to 0.1% will generally have their values printed directly on the resistor.

Gold and Silver as Multipliers

The colors gold and silver are generally found in the fourth band of a resistor, but they can be used in the multiplier band also. When the color gold is used as the multiplier band, it means to *divide* the first two numbers by 10. If silver is used as the multiplier band, it means to *divide* the first two numbers by 100. For example, assume a resistor has color bands of orange, white, gold, and gold. The value of this resistor is 3.9 ohms with a tolerance of ±5%

(orange = 3; white = 9; gold means to divide 39 by 10, which equals 3.9; and gold in the fourth band means 5 percent tolerance).

Standard Resistance Values

Fixed resistors are generally produced in standard values. The higher the tolerance value, the fewer resistance values available. Standard resistor values are listed in the chart shown in Figure 6-4. In the column under 10%, there are only twelve values of resistors listed. These standard values, however, can be multiplied by factors of 10. Also, notice that one of the standard values listed is 33 ohms. There are also standard values in 10 percent resistors of 0.33, 3.3, 330, 3,300, 33,000, 330,000, and 3,300,000 ohms. The 5% column lists twenty four resistor values and the 1% column lists ninety six values. All of the values listed in the chart can be multiplied by factors of 10 to obtain other resistance values.

Power Rating

Resistors also have a power rating in watts, which should not be exceeded or damage will occur to the resistor. The amount of heat that must be dissipated by the resistor can be determined by the use of one of the following formulas:

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

$$P = I^2 R$$

$$P = EI$$

Example:

The resistor shown in Figure 6-5 has a value of 100 Ω and a power rating of 0.5 watt. If the resistor is connected to a 10 volt power supply, will it be damaged?

Solution:

Using the formula shown below, determine the amount of heat that will be dissipated by the resistor.

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

$$P = \frac{100}{100}$$

$$P = 1 \text{ watt}$$

Since the resistor has a power rating of 0.5 watt and the amount of heat that will be dissipated is 1 watt, the resistor will be damaged.

STANDARD RESISTANCE VALUES									
.1%, .25% .5%	1%	.1%, .25% .5%	1%	.1%, .25% .5%	1%	.1%, .25% .5%	1%	.1%, .25% .5%	1%
10.0	10.0	17.2	-	29.4	29.4	50.5	-	86.6	86.6
10.1	-	17.4	17.4	29.8	-	51.1	51.1	87.6	-
10.2	10.2	17.6	-	30.1	30.1	51.7	-	88.7	88.7
10.4	-	17.8	17.8	30.5	-	52.3	52.3	89.8	-
10.5	10.5	18.0	-	30.9	30.9	53.0	-	90.9	90.9
10.6	-	18.2	18.2	31.2	-	53.6	53.6	92.0	-
10.7	10.7	18.4	-	31.6	31.6	54.2	-	93.1	93.1
10.9	-	18.7	18.7	32.0	-	54.9	54.9	94.2	-
11.0	11.0	18.9	-	32.4	32.4	55.6	-	95.3	95.3
11.1	-	19.1	19.1	32.8	-	56.2	56.2	96.5	-
11.3	11.3	19.3	-	33.2	33.2	56.9	-	97.6	97.6
11.4	-	19.6	19.6	33.6	-	57.6	57.6	98.8	-
11.5	11.5	19.8	-	34.0	34.0	58.3	-		
11.7	-	20.0	20.0	34.4	-	59.0	59.0		
11.8	11.8	20.3	-	34.8	34.8	59.7	-		
12.0	-	20.5	20.5	35.2	-	60.4	60.4		
12.1	12.1	20.8	-	35.7	35.7	61.2	-		
12.3	-	21.0	21.0	36.1	-	61.9	61.9		
12.4	12.4	21.3	-	36.5	36.5	62.6	-		
12.6	-	21.5	21.5	37.0	-	63.4	63.4		
12.7	12.7	21.8	-	37.4	37.4	64.2	-		
12.9	-	22.1	22.1	37.9	-	64.9	64.9		
13.0	13.0	22.3	-	38.3	38.3	65.7	-		
13.2	-	22.6	22.6	38.8	-	66.5	66.5		
13.3	13.3	22.9	-	39.2	39.2	67.3	-		
13.5	-	23.2	23.2	39.7	-	68.1	68.1		
13.7	13.7	23.4	-	40.2	40.2	69.0	-		
13.8	-	23.7	23.7	40.7	-	69.8	69.8		
14.0	14.0	24.0	-	41.2	41.2	70.6	-		
14.2	-	24.3	24.3	41.7	-	71.5	71.5		
14.3	14.3	24.6	-	42.2	42.2	72.3	-		
14.5	-	24.9	24.9	42.7	-	73.2	73.2		
14.7	14.7	25.2	-	43.2	43.2	74.1	-		
14.9	-	25.5	25.5	43.7	-	75.0	75.0		
15.0	15.0	25.8	-	44.2	44.2	75.9	-		
15.2	-	26.1	26.1	44.8	-	76.8	76.8		
15.4	15.4	26.4	-	45.3	45.3	77.7	-		
15.6	-	26.7	26.7	45.9	-	78.7	78.7		
15.8	15.8	27.1	-	46.4	46.4	79.6	-		
16.0	-	27.4	27.4	47.0	-	80.6	80.6		
16.2	16.2	27.7	-	47.5	47.5	81.6	-		
16.4	-	28.0	28.0	48.1	-	82.5	82.5		
16.5	16.5	28.4	-	48.7	48.7	83.5	-		
16.7	-	28.7	28.7	49.3	-	84.5	84.5		
16.9	16.9	29.1	-	49.9	49.9	85.6	-		

2%, 5%	10%
10	10
11	-
12	12
13	-
15	15
16	-
18	18
20	-
22	22
24	-
27	27
30	-
33	33
36	-
39	39
43	-
47	47
51	-
56	56
62	-
68	68
75	-
82	82
91	-

Figure 6-4 Standard resistance values.

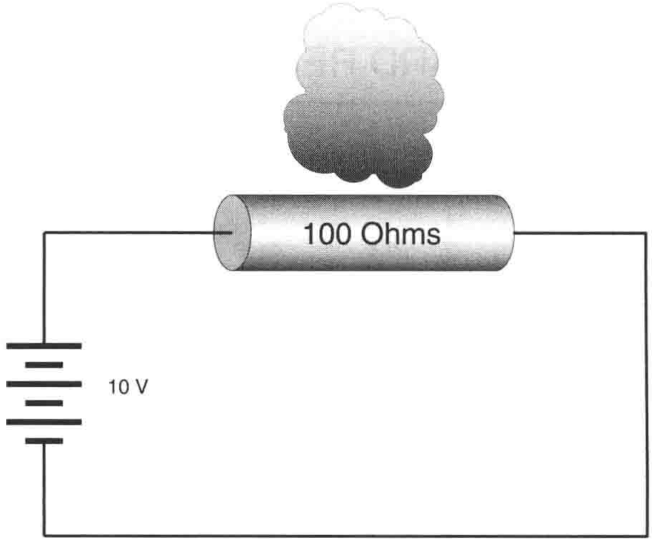


Figure 6-5 Exceeding the power rating causes damage to the resistor.

LABORATORY EXERCISE

Name ______________________________ Date __________

Materials Required

10 color-coded resistors of various values

Ohmmeter

1. Using the table provided in Figure 6-6, list the color of each resistor band in the spaces provided. Then list the resistance value and tolerance according to the color bands. Determine the upper and lower limits of tolerance for each resistor. Next, measure the resistance with an ohmmeter, and, finally, indicate whether the resistor is within its tolerance.

   Example: A resistor has color bands of red, yellow, yellow, and gold. This resistor has been listed on the first line of the chart. After listing the colors and determining the value and tolerance, calculate the upper and lower limit. The example resistor has a marked value of 240,000 Ω with a tolerance of ±5%. The upper and lower limits are determined by the tolerance of the resistor.

   240,000 × 5% (0.05) = 12,000 Ω. Upper limit (240,000 + 12,000 = 252,000 Ω). Lower limit (240,000 − 12,000 = 228,000 Ω). The measured value is determined by measuring the resistance value with an ohmmeter. In this example it is assumed that the ohmmeter measured a resistance of 246,000 Ω. Since this value is within the upper and lower limits, the resistor is within tolerance.

Review Questions

1. A resistor has color bands of orange, orange, orange, and silver. What is the resistance value and tolerance of this resistor?

   ____

FIRST COLOR	SECOND COLOR	THIRD COLOR	FOURTH COLOR	MARKED VALUE	TOLERANCE VALUE	UPPER LIMIT	LOWER LIMIT	MEASURED VALUE	WITHIN TOLERANCE
Red	Yellow	Yellow	Gold	240,000	5%	252,000	228,000	246,000	Yes

Figure 6-6 Determining resistor value.

2. A resistor has color bands of brown, red, black, and gold. What is the resistance and tolerance of this resistor?

___

3. What color bands should be found on a 5100 Ω resistor with a tolerance of ±2%?

___

4. Is it possible to find a resistor with color bands that are orange, blue, brown, and silver?

___

5. A resistor has the following color bands: red, yellow, orange, red, and brown. What is the resistance value and tolerance for this resistor?

___

6. A resistor has the following color bands: green, blue, gold, and red. What is the resistance value and tolerance of this resistor?

___

7. A 14,000 Ω resistor is needed in a circuit. Is it possible to obtain this resistor in a standard value?

___

8. A 470 Ω half-watt resistor is connected across 12 volts. Will this resistor be damaged?

___

9. A resistor has color code bands of orange, orange, red, and red. An ohmmeter is used to check the resistor's value and indicates a value of 3400 Ω. Is the resistor within its tolerance?

___

10. A resistor has color bands of brown, black, black, red, and brown. An ohmmeter indicates that the resistor has a value of 9950 Ω. Is this resistor within its tolerance?

___

SECTION 2 Basic Switch Connections

Unit 7 Single-Pole Switches

Objectives

After studying this unit, you should be able to

- Discuss the operation of a single-pole switch.
- Identify a single-pole switch.
- Define *switch leg.*
- Employ two methods of connecting single-pole switches.
- Determine the amount of current flow in a neutral conductor.

One of the most common jobs of an electrician is to make basic switch connections. There are three main types of switches used when connecting lighting circuits: single-pole, 3-way, and 4-way. Single-pole switches are used when a device, such as a light or receptacle outlet, is to be controlled from one location. Lights are controlled by interrupting the current flow in one of the circuit conductors. In a common 240/120 volt residential or commercial service, a center-tapped transformer is employed to provide 240 or 120 volts (Figure 7-1). The transformer converts the power line voltage (primary) into 240 volts at the secondary. The secondary winding contains a center tap that is grounded. The grounded center tap is generally referred to as the *neutral.* A voltmeter connected across the entire secondary winding will indicate a value of 240 volts. If the voltage is measured from the center tap to either side of the secondary winding, a voltage of 120 volts will be indicated.

Current Relationships

When connecting loads to a center-tapped transformer, the center tap will carry the sum of the unbalanced loads between the other two conductors. In other words, the center tap connection will carry the difference between the other two conductors. Assume that a transformer of this type is connected to a load that produces 10 amperes in each leg (Figure 7-2). Since each of the ungrounded or hot conductors is carrying the same amount of current, the neutral or grounded conductor will carry no current.

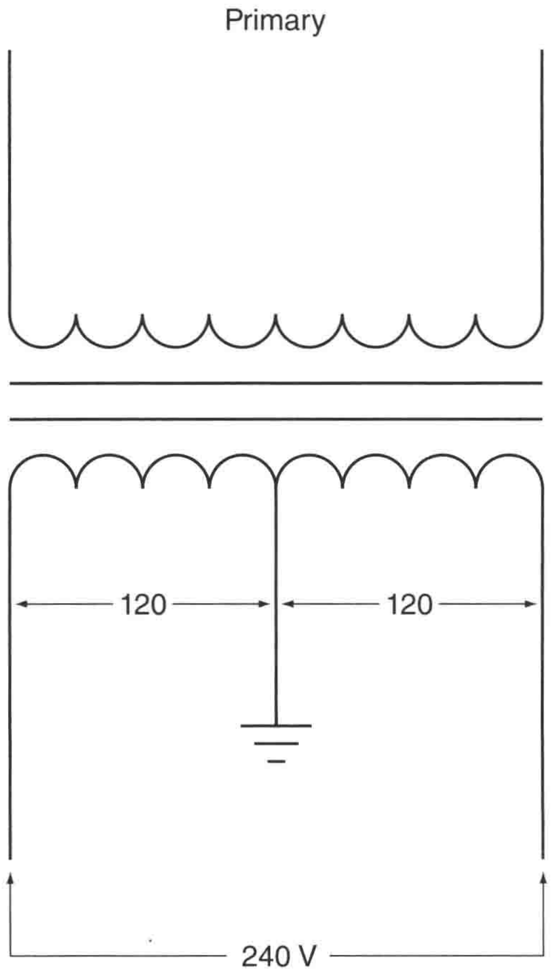


Figure 7-1 Typical 240/120 volt service.

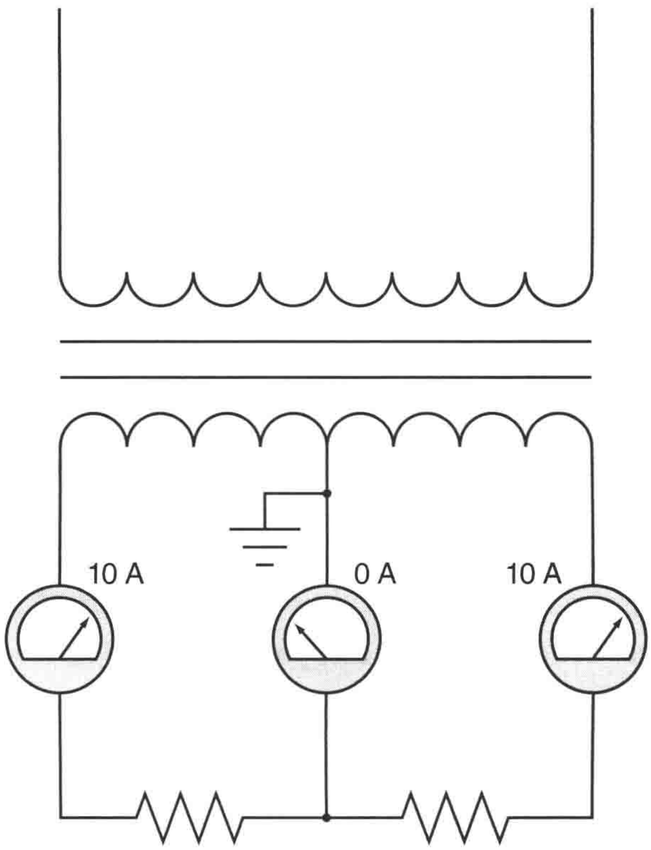


Figure 7-2 A common single-phase service.

Now assume that one of the ungrounded conductors has a current flow of 10 amperes, and the other has a current flow of 7 amperes. The neutral conductor will now carry a current of 3 amperes ($10 - 7 = 3$), as shown in Figure 7-3.

Single-Pole Switch Construction

A single-pole switch contains one movable and one stationary contact (Figure 7-4). This type of switch is designated as single-pole single-throw (SPST). The movable contact is called the switch pole. Since this switch is single-pole, it has only one movable contact. The switch pole will make connection with a stationary contact when switched or *thrown* in only one position. The switch is, therefore, called a single-throw. Single-pole switches can be easily identified by the following:

1. They contain only two terminal screws (Figure 7-5). Switches will often contain an extra green screw used for grounding. The bare copper grounding wire connects to the green screw.
2. The words OFF and ON are shown on the switch lever. The switch contacts will be open (OFF) or closed (ON) when the switch lever is thrown in one position.

Basic Switch Connection

Loads intended to operate on 120 volts are connected between the grounded neutral conductor and the ungrounded hot conductor. These circuits are referred to as *branch circuits.* Branch circuits are protected by fuses or circuit breakers installed at the panel box. A branch circuit that supplies power to one lamp is shown in Figure 7-6.

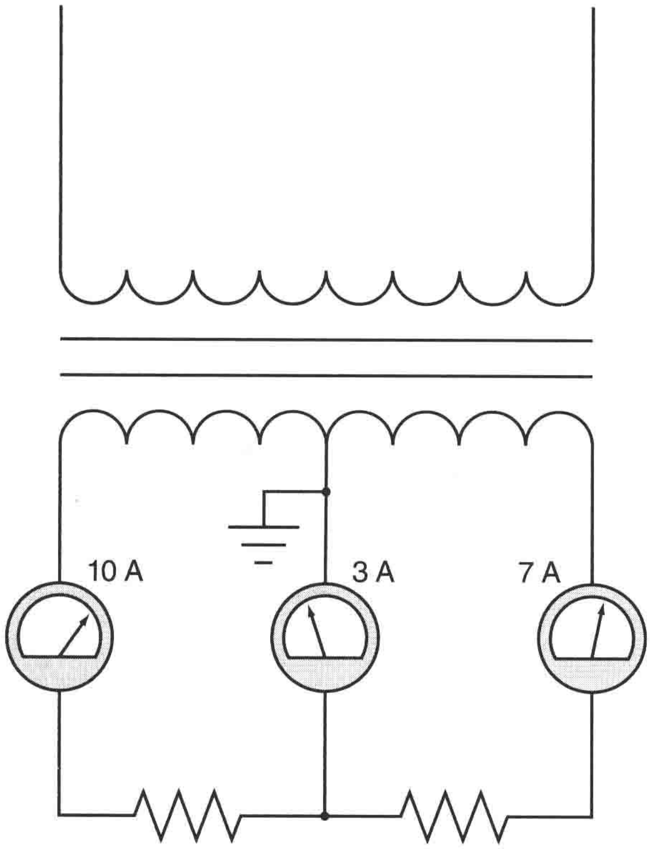


Figure 7-3 The neutral carries the difference between the two hot conductors.

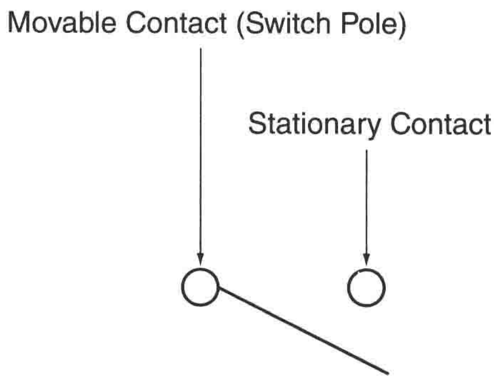


Figure 7-4 Basic construction of a single-pole switch.

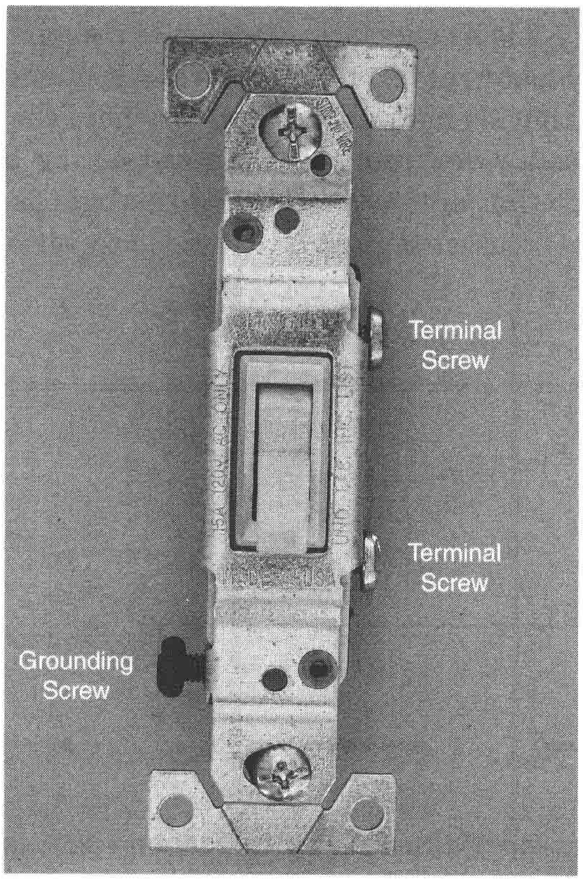


Figure 7-5 A single-pole switch contains only two terminal screws, and the words OFF and ON are shown on the switch lever.

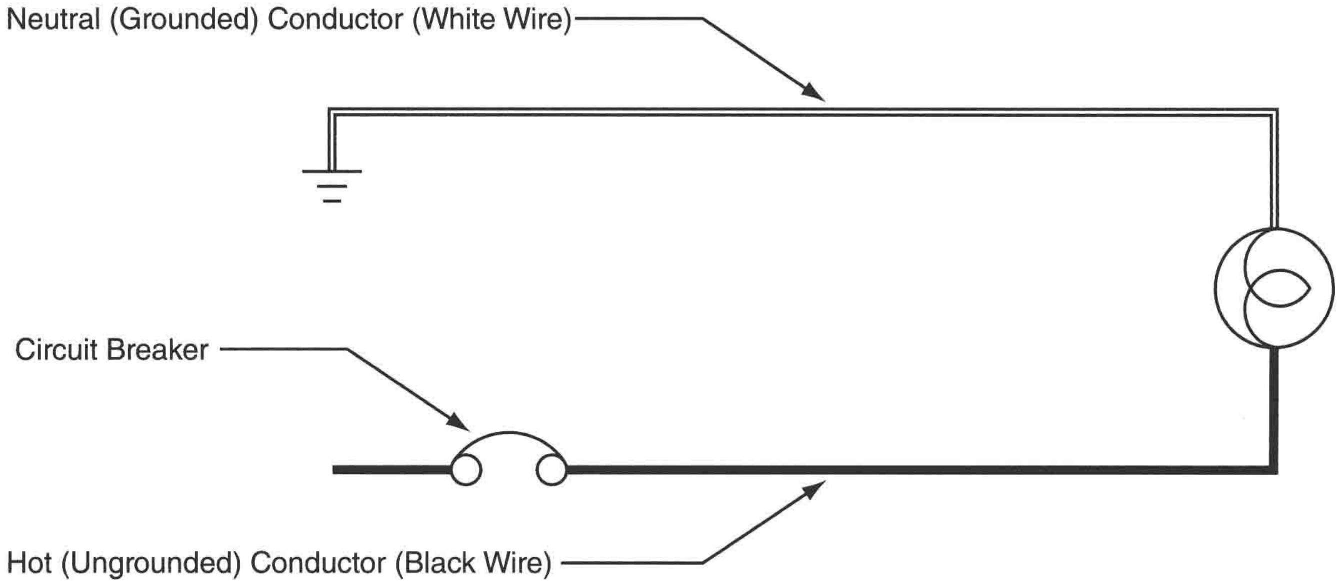


Figure 7-6 Typical lighting branch circuit.

The lamp is controlled by breaking connection between the circuit breaker and lamp (Figure 7-7). Notice that the switch is placed in the hot or ungrounded conductor. The light could be controlled by placing the switch in the neutral conductor, but the *National Electrical Code*® (*NEC*®) does not permit the neutral conductor to be broken. The only exception to this is if both the neutral (grounded) and hot (ungrounded) conductors are broken at the same time. The reason for this is safety. If the switch were to be placed in the neutral conductor, it would turn the lamp on or off, but power would still be connected to the lamp. If a person were to attempt to work on the lamp with the light switched off, he or she would still be working on a *hot* circuit. This could result in a severe electrical shock (Figure 7-8).

The circuit shown in Figure 7-7 is a schematic diagram of a single-pole switch connection. Schematic diagrams show components in their electrical sequence and are used to illustrate circuit logic. However, they do not indicate how or where the components are placed. Switches are generally located away from the light, not at the light. Switches are commonly installed beside a door that enters a room and the light is installed in the ceiling. When this is the case, the hot conductor must be extended to permit the switch to make or break the circuit (Figure 7-9).

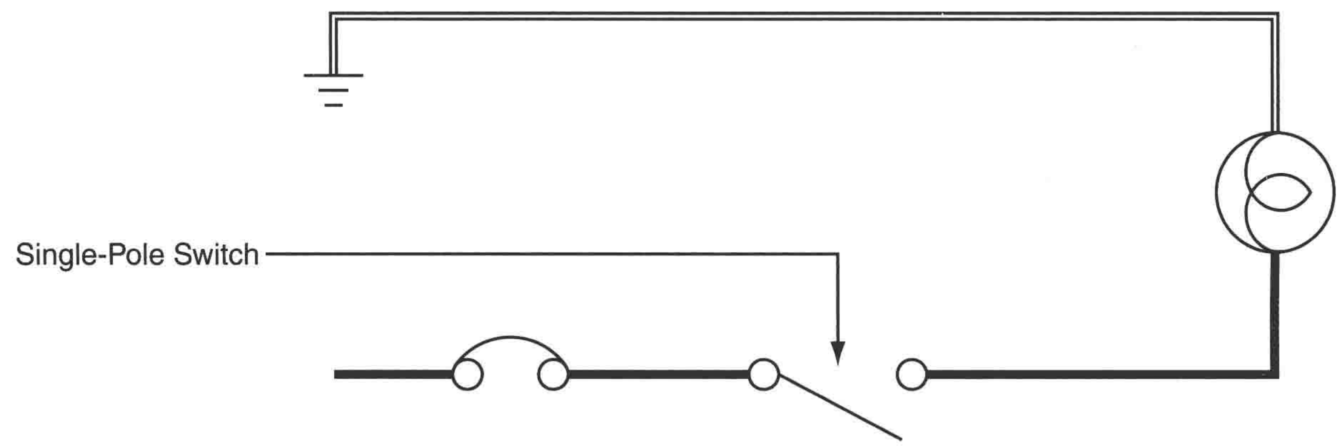


Figure 7-7 The lamp is controlled by breaking the connection between the circuit breaker and the lamp.

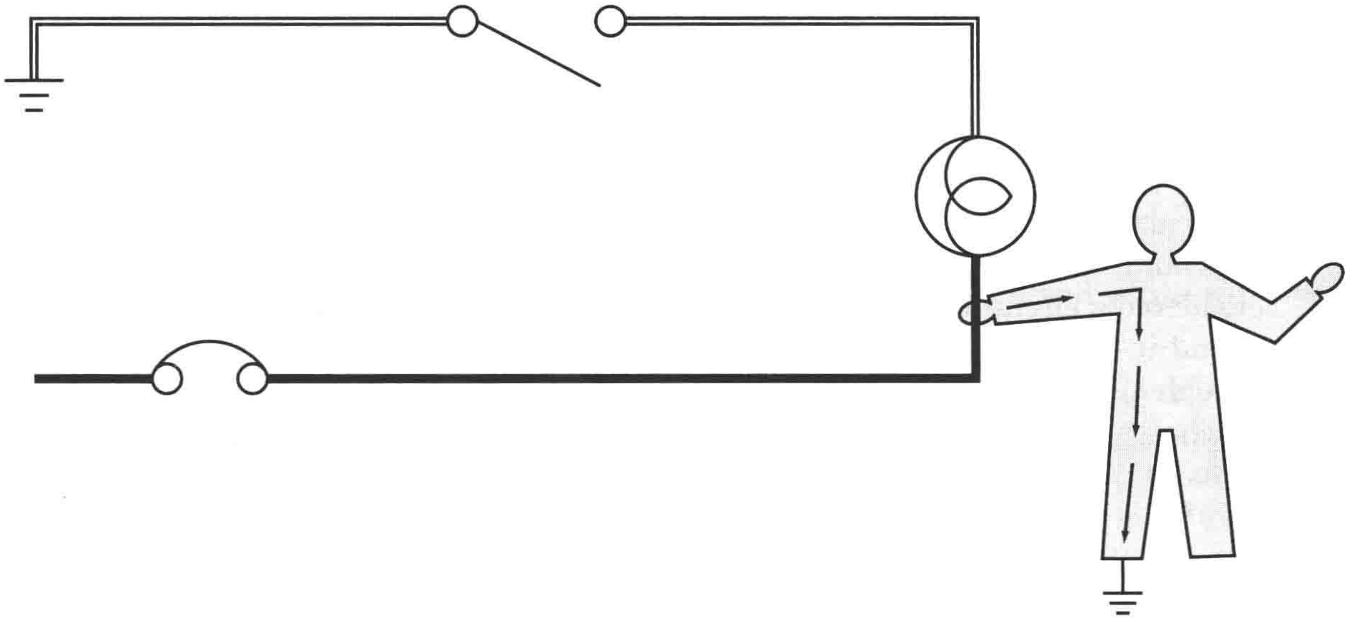


Figure 7-8 Placing the switch in the neutral conductor creates a safety hazard.

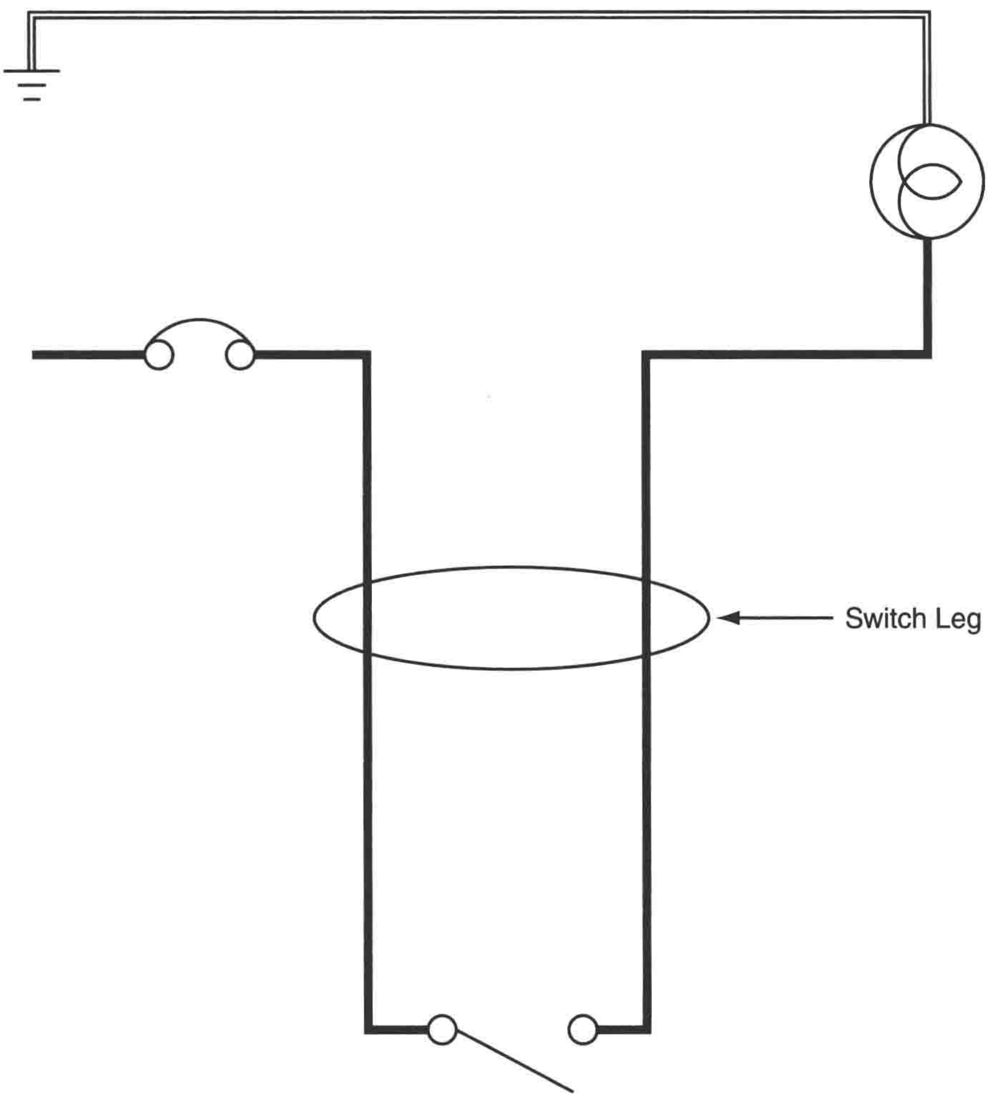


Figure 7-9 A switch leg is an extension of the hot conductor.

Wiring Consideration

When switches are installed in a home or business, several factors must be taken into account.

1. *Switch connections are made using two- and three-conductor cables.* Two-conductor cables actually contain three wires: black, white, and bare copper (Figure 7-10). The black and white wires are actual circuit conductors. The bare copper wire is not considered a circuit conductor because it is there to provide a low-resistance path to ground in the event of a grounded circuit. The bare copper wires connect together throughout the entire building and are connected to green grounding screws on switches and receptacle outlets. Three-conductor cables contain four wires: black, white, red, and bare copper (Figure 7-11). As with two-conductor cables, the bare copper wire is not considered a circuit conductor.
2. *All connections must be made inside a box.* Figure 7-9 shows that a switch leg is an extension of the hot or ungrounded conductor. In reality, this connection must be made inside a box, not in the middle of the conductor.
3. *The white wire is connected to neutral.* The *NEC* requires that the white wire be connected to neutral. For many years the *NEC* permitted white wires to be connected to the hot conductor when they were used as switch legs. The *NEC* now requires that the white wire be reidentified by marking it with colored tape or paint when it is used as a switch leg.
4. *When connection is made to a device such as a lamp or outlet receptacle, the wires must be identified.* This simply means that when connection is made to the lamp, the neutral wire will be white and the hot wire will be red or black. In this way, if an electrician is working on a device, he or she will know immediately which wire is neutral and which is hot.

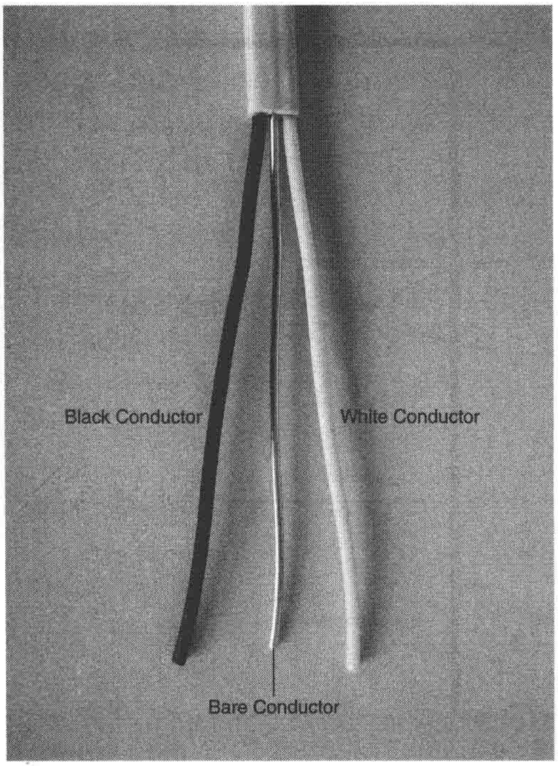


Figure 7-10 Two-conductor cables contain three wires: black, white, and bare copper.

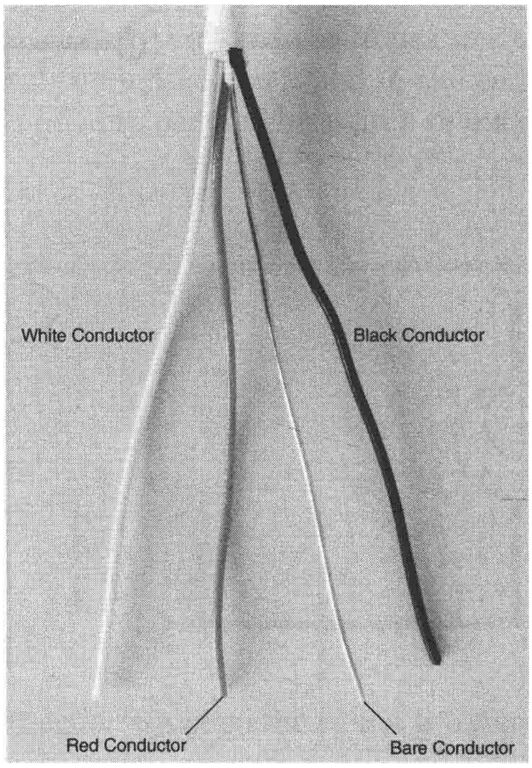


Figure 7-11 Three-conductor cables contain four wires: black, white, red, and bare copper.

Standard Connections for Single-Pole Switches

There are two standard connections used for single-pole switches. One involves bringing power to the switch and then running a two-conductor cable from the switch to the lamp (Figure 7-12). When making this connection, remember that the neutral conductor is never broken. All switching is done in the hot or ungrounded conductor. Therefore, the neutral conductors (white wires) will be connected together inside the switch box, and the hot conductors (black wires) will be connected to the switch. The black and white wires will then be connected to the lamp (Figure 7-13).

The second connection involves supplying power to the light and bringing a switch leg from the light to the switch (Figure 7-14). To make this connection, connect the neutral conductor (white wire in the power cable) directly to the lamp. The *NEC®* requires that the wires that connect to the lamp (device) be identified, so connect the black wire of the switch leg to the other side of the lamp. The white wire of the switch leg is used to carry power down to the switch. Therefore, the white wire of the switch leg connects to the black wire of

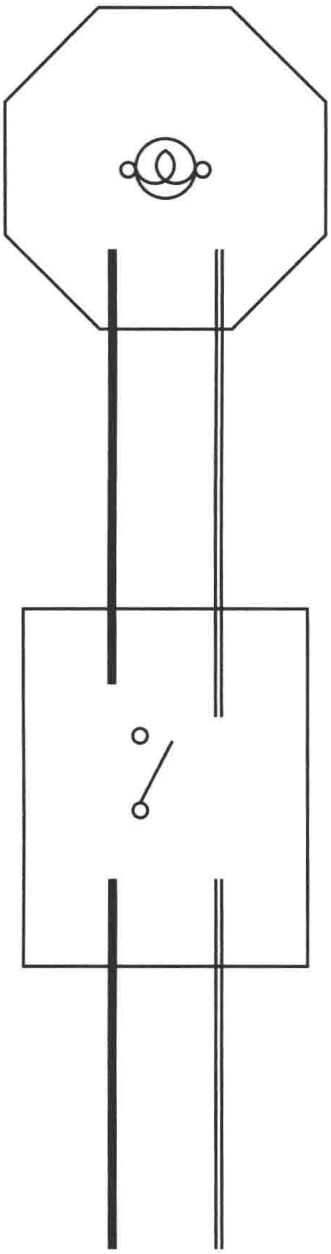


Figure 7-12 Power is supplied to the switch.

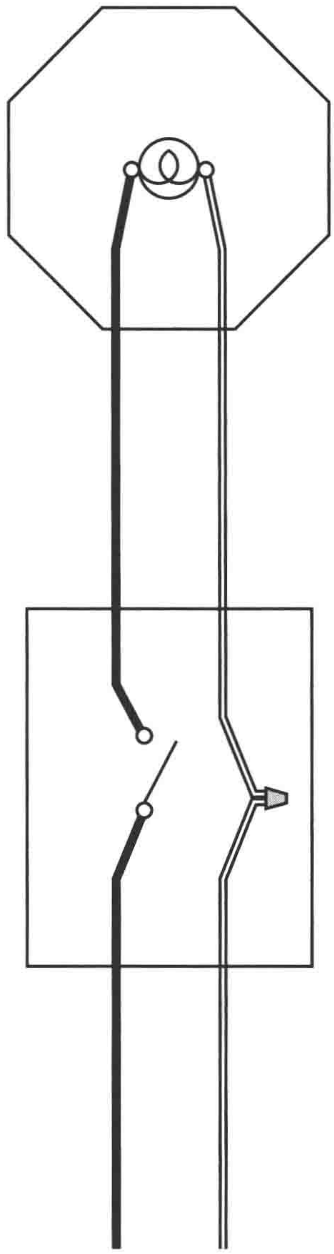


Figure 7-13 The neutral conductor is not broken.

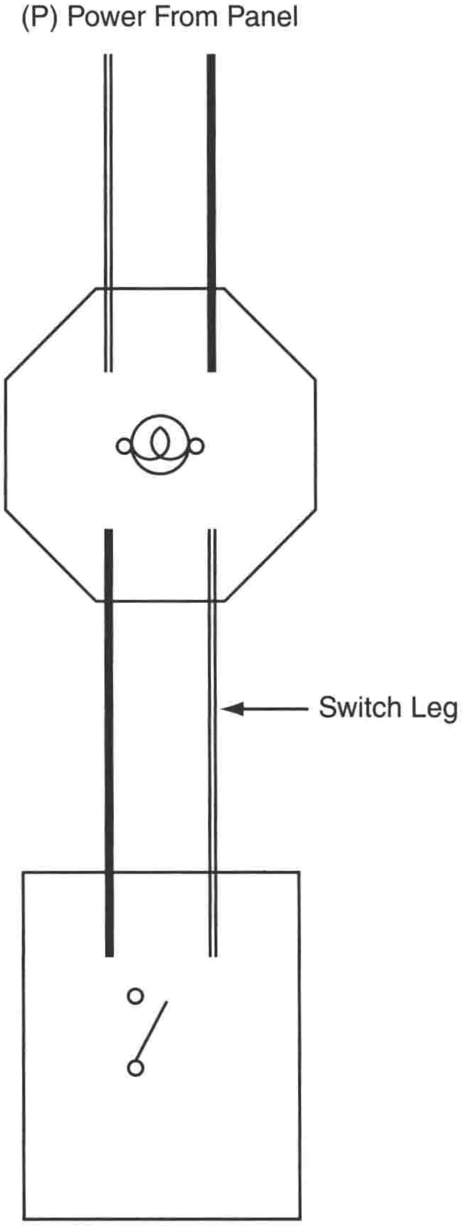


Figure 7-14 Power is brought to the light.

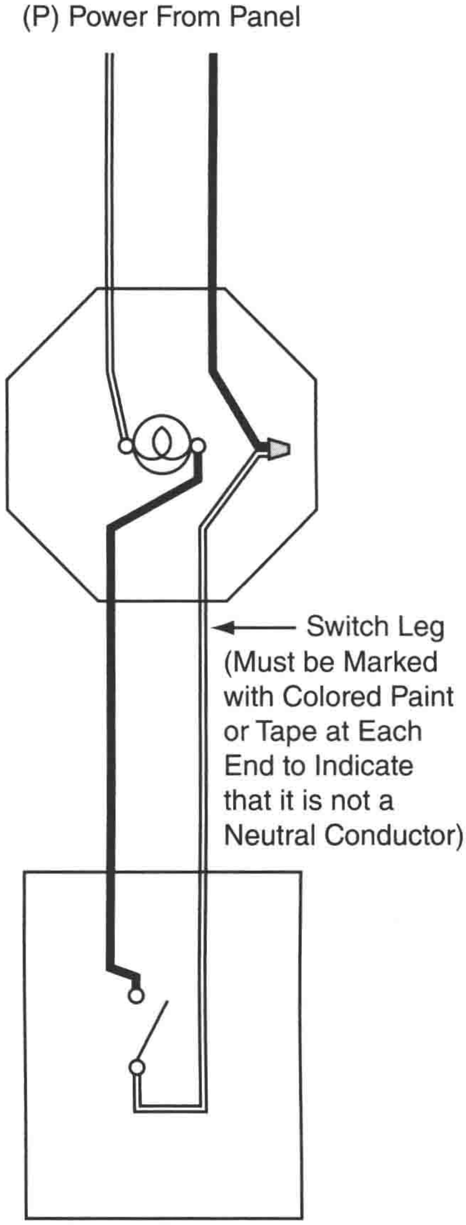


Figure 7-15 The white wire of the switch leg brings power to the switch.

the power cable (Figure 7-15). This is the most common method of making this connection. Be sure to reidentify the white switch leg conductor by marking it in both the light box and the switch box with colored tape or paint.

LABORATORY EXERCISE

Name ______________________________ Date __________

Materials Required

120-volt AC power supply

1 single-pole switch

1 120-volt lamp

1 switch box mounted to a wall stud or on a board

1 standard octagon box mounted on a rafter or on a board

Two-conductor cable (length will be decided by the individual laboratory)

1. Mount the switch box and octagon box as indicated by your instructor.
2. Run a two-conductor cable between the octagon box and the switch box. Be sure to strip the cable at both the octagon box and switch box so that approximately 6 inches of individual wire are available to work with.
3. **Test and verify that the power is turned off.** Connect a two-conductor cable from the power source to the switch box.
4. Connect the circuit shown in Figure 7-16. (Note: The bare grounding wire connection is not shown due to space limitations. The bare grounding wires should connect together in the switch box, and one should be placed under the green screw on the switch if one exists. If the octagon or switch box is metal, a grounding clamp should be used to ground the bare copper wire to the box. If the boxes are made of plastic, fold the bare copper wires in the box so that they are out of the way.
5. Turn on the power and test the circuit by turning the switch on and off.
6. **Turn off the power** and disconnect the circuit.
7. Reroute the power wire so that it enters the octagon box used as the light box.
8. Run a two-conductor cable from the octagon box to the switch box.
9. Connect the circuit illustrated in Figure 7-17.
10. Turn on the power and test the circuit by turning the switch on and off.
11. **Turn off the power** and disconnect the circuit.
12. Return the components to their proper place.

Review Questions

1. How many movable contacts are contained in a single-pole single-throw switch?

____

2. State two characteristics that can be used to identify a single-pole switch.

____

3. What are the three main types of switches used for connecting lighting circuits?

____

4. A 240/120 volt residential service has a load of 12 amperes on one hot leg and 8 amperes on the other. How much current is flowing through the neutral conductor?

____

5. Define *switch leg*.

____

6. Is it permissible to control a light by placing the switch in the hot or ungrounded conductor?

____

7. Many switches contain an extra screw that is green in color. Which wire is connected to this green screw?

____

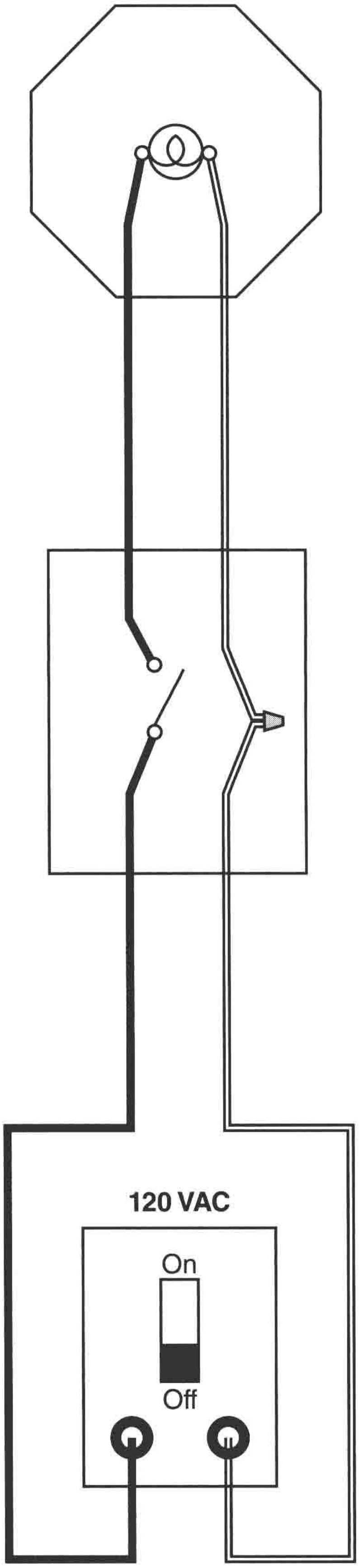


Figure 7-16 Laboratory circuit 1.

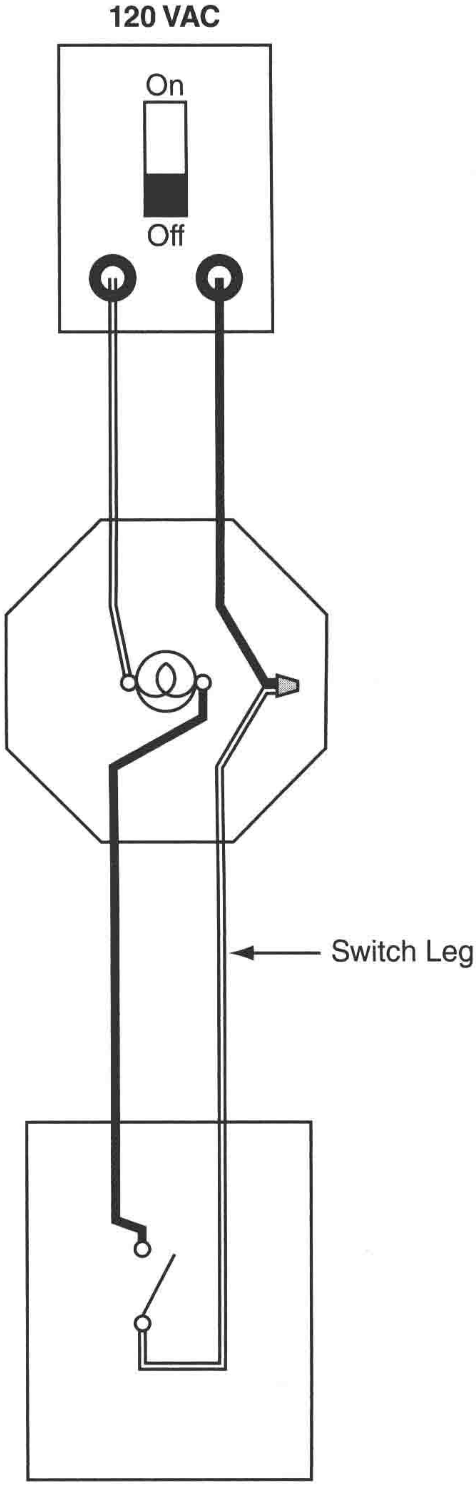


Figure 7-17 Laboratory circuit 2.

Unit 8 3-Way Switches

Objectives

After studying this unit, you should be able to

- Describe the construction of a 3-way switch.
- Determine which terminal is common and which terminals are for travelers.
- Draw a schematic diagram of a 3-way switch connection.
- Connect a 3-way switch circuit to control a lamp from two locations.

Three-way switches are used when it is desirable to control a light or outlet receptacle from two locations. These connections are very common in rooms that have more than one entrance or exit door, in long hallways, and for lights used to illuminate stairs. Making 3-way switch connections is one of the most common jobs for an electrician.

Switch Construction

A 3-way switch is a single-pole double-throw (SPDT) switch. Since the switch is a single-pole, it has only one movable contact (Figure 8-1). Double-throw indicates that the movable contact will make connection with a stationary contact when thrown in either direction. The switch, therefore, contains two stationary contacts. Three-way switches can be identified because they contain three terminal screws. The terminal screw that connects to the movable contact is called the *common* terminal and is generally a different color than the two terminal screws that connect to the stationary contacts (Figure 8-2). Some manufacturers

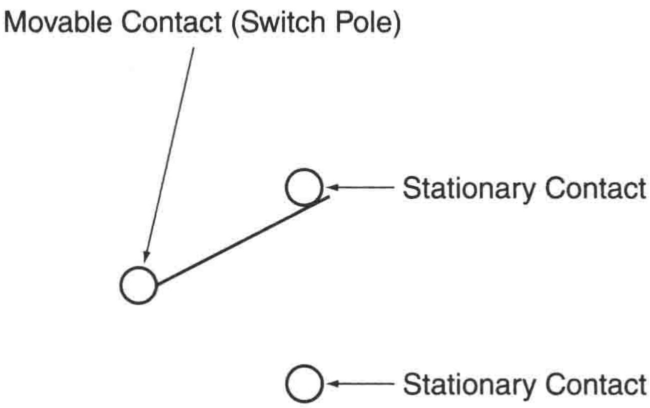


Figure 8-1 A 3-way switch contains one movable and two stationary contacts.

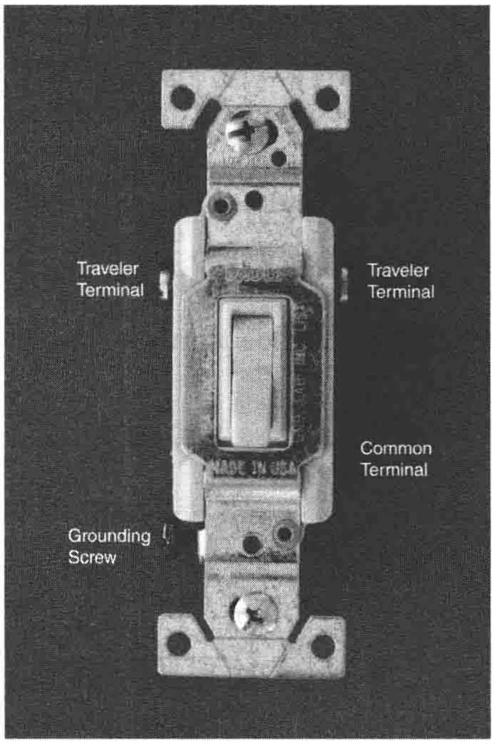


Figure 8-2 The common terminal screw is a different color than the two screws that connect to stationary contacts.

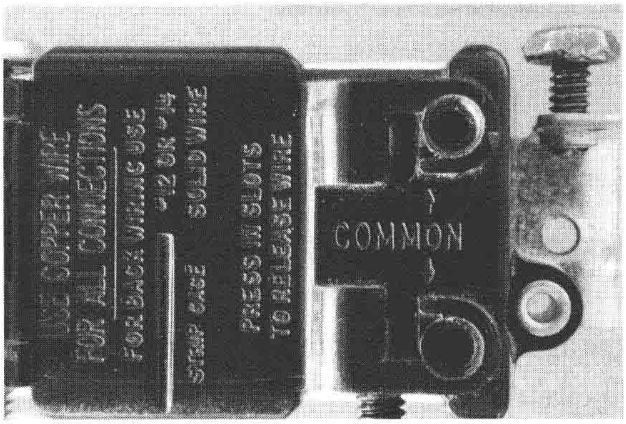


Figure 8-3 Many 3-way switches will have the word *common* written beside the common screen terminal.

also print the word *common* on the back of the switch beside the common screw terminal (Figure 8-3). The common terminal is so well identified because it is necessary to know which terminal is common when connecting a 3-way switch circuit.

Another way of identifying 3-way switches is that they do not have OFF or ON printed on the switch lever as do single-pole switches. Three-way switches can turn a light or receptacle outlet on or off when thrown in either direction.

3-Way Switch Logic

The circuit shown in Figure 8-4 illustrates the logic behind a 3-way switch connection. Notice that the switches are connected in the hot or ungrounded conductor only. The neutral conductor is connected directly to the lamp and is not broken by a switch. The conductors that connect the two switches together are called *travelers*. To understand how this connection works, trace the current path of the hot (ungrounded) conductor from the circuit breaker through the switches, the lamp, and back to neutral. In the circuit shown, a complete path exists from the circuit breaker through the lamp and back to neutral. Therefore, the lamp is turned on with the switches in the position shown in Figure 8-5.

If either of the two 3-way switches is toggled to a different position, the current path will be broken and a circuit will no longer be complete through the lamp, as shown in Figure 8-6. If either of the two switches is again toggled to a different position, the current path will be reestablished through the lamp, as shown in Figure 8-7. Regardless of which switch is toggled to a different position, the light will be alternately turned on or off.

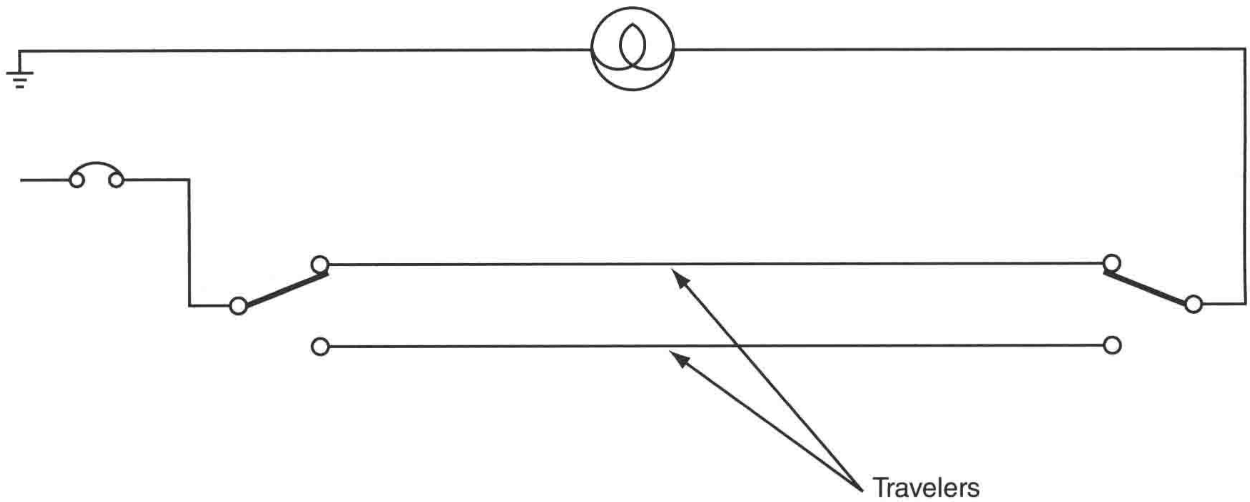


Figure 8-4 A basic 3-way switch connection.

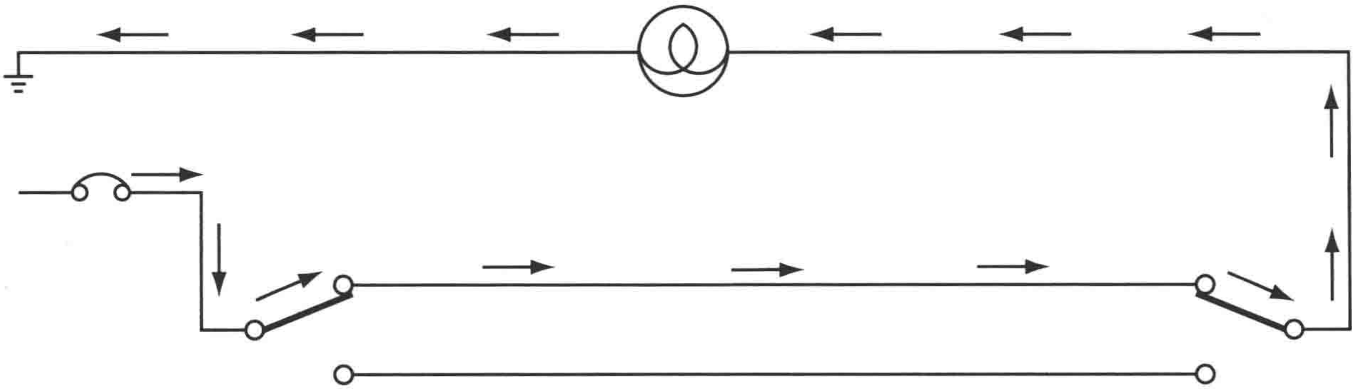


Figure 8-5 A current path exists through the lamp.

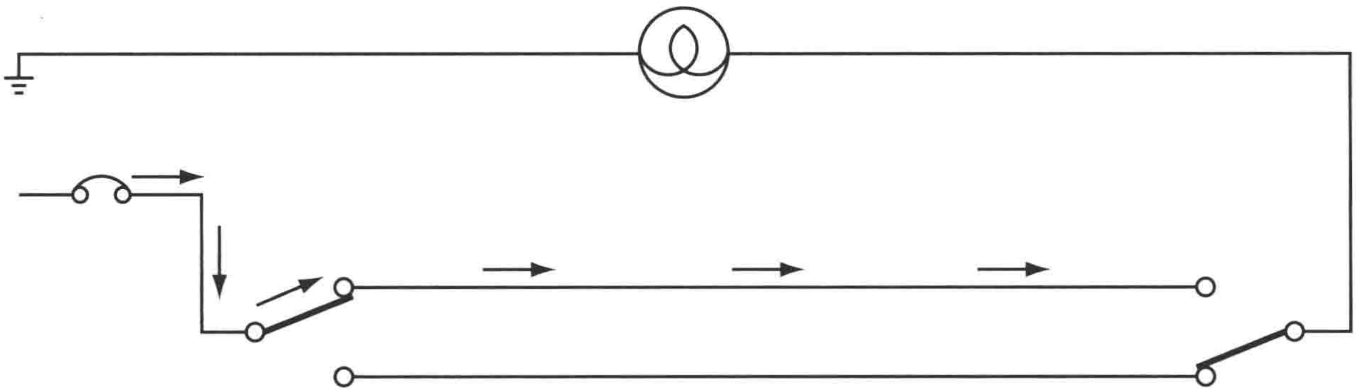


Figure 8-6 The current path is broken.

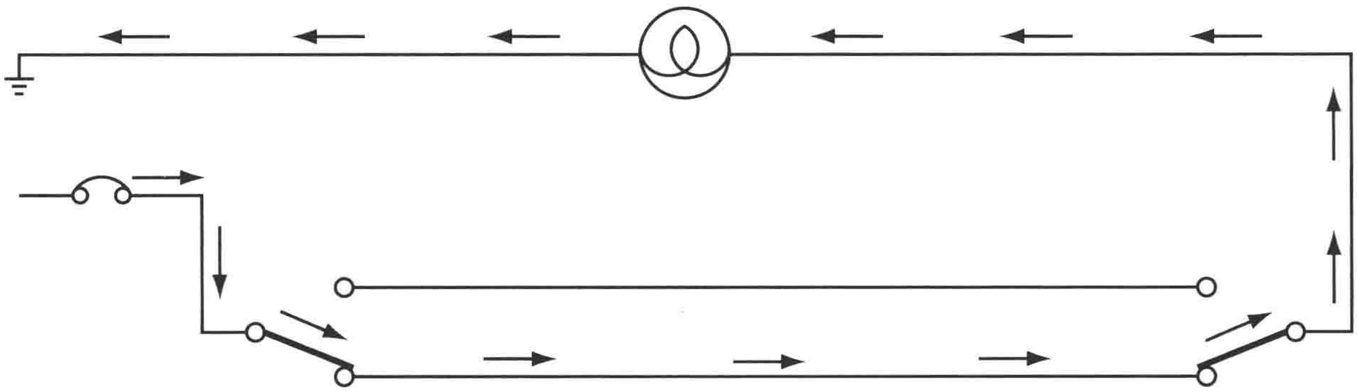


Figure 8-7 The current path is reestablished.

3-Way Switch Connections

Figure 8-5, Figure 8-6, and Figure 8-7 schematically illustrate the logic of a 3-way switch connection. In reality, connection is made with two- and three-conductor cables. When installing the wiring for 3-way switches, a three-conductor cable is connected between the two switches. There are several ways in which 3-way switches can be connected. Making the proper connections is not difficult, however, if the following four rules are followed:

1. **Connect the neutral to the light.** The neutral conductor is not to be broken by a switch. It must be a continuous path from the power panel to the lamp.
2. **Connect the hot conductor to the common terminal of one 3-way switch.**
3. **Connect the other side of the light to the common terminal of the other 3-way switch.**
4. **Connect the travelers.**

Example Connection 1

In the circuit shown in Figure 8-8, power is brought from the panel box to one 3-way switch. A three-conductor cable is connected between the two switches, and a two-conductor cable runs from the other 3-way switch to the lamp. To connect this circuit, follow these four rules for connecting 3-way switches.

1. *Connect the neutral to the light.* The neutral is the white wire of the power cable from the panel box. Neutral conductors should be color-coded white, so connect the neutral conductor to the white wire in the three-conductor cable. Then connect the white wire of the three-conductor cable to the white wire in the two-conductor cable that runs from the second 3-way switch to the light. Connect the lamp to the white wire (Figure 8-9). Note that the neutral conductor is continuous from the power wire to the light. It has not been broken by a switch at any point.
2. *Connect the hot conductor to the common terminal of one 3-way switch.* Since the power cable enters the box of one 3-way switch, the black wire of the power cable will be connected to the common terminal of that 3-way switch (Figure 8-10).
3. *Connect the other side of the light to the common terminal of the other 3-way switch.* The black wire of the two-conductor cable that runs between the switch box and the light is connected to the common terminal of the second 3-way switch (Figure 8-11).
4. *Connect the travelers.* The travelers are used to connect the two remaining terminals on each 3-way switch (Figure 8-12). The red and black conductors of the three-conductor cable are used to make this connection.

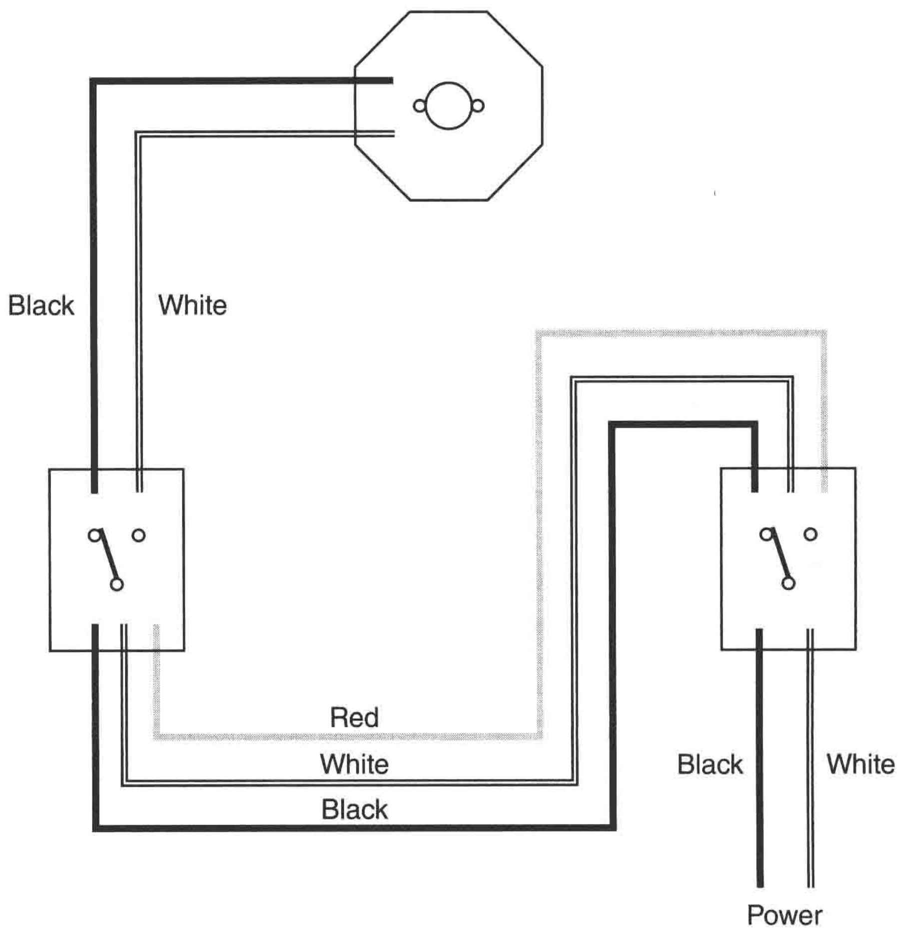


Figure 8-8 Example 1 of 3-way switch.

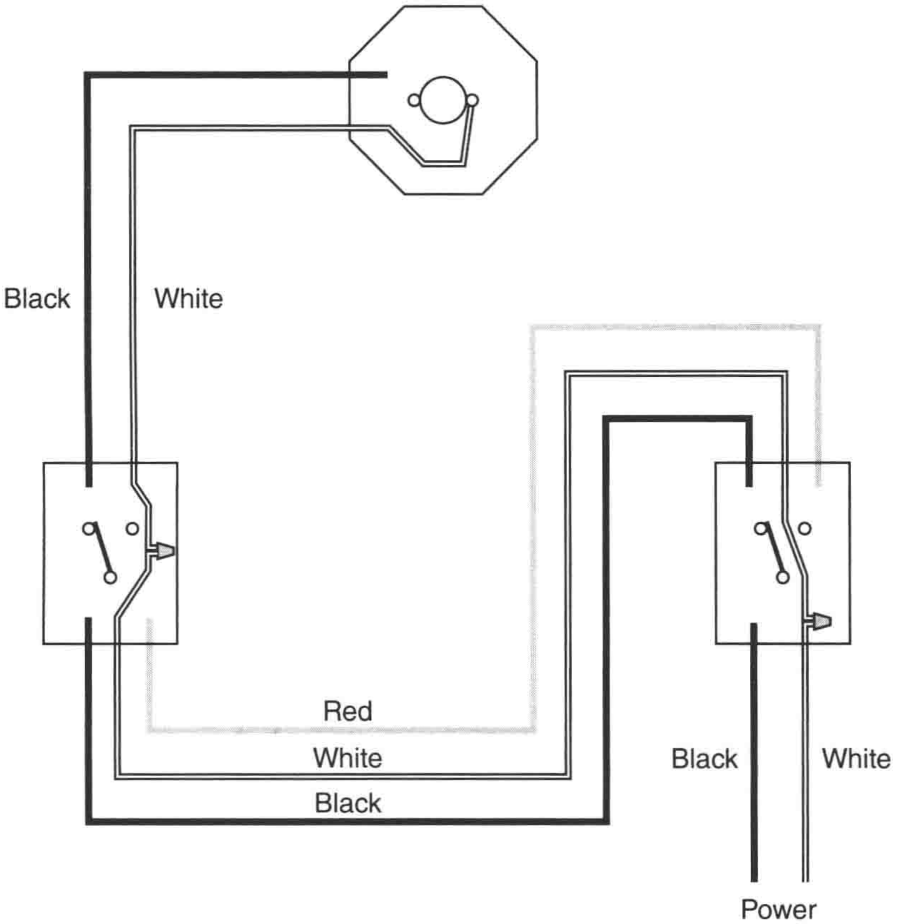


Figure 8-9 Rule 1: Connect the neutral to the light.

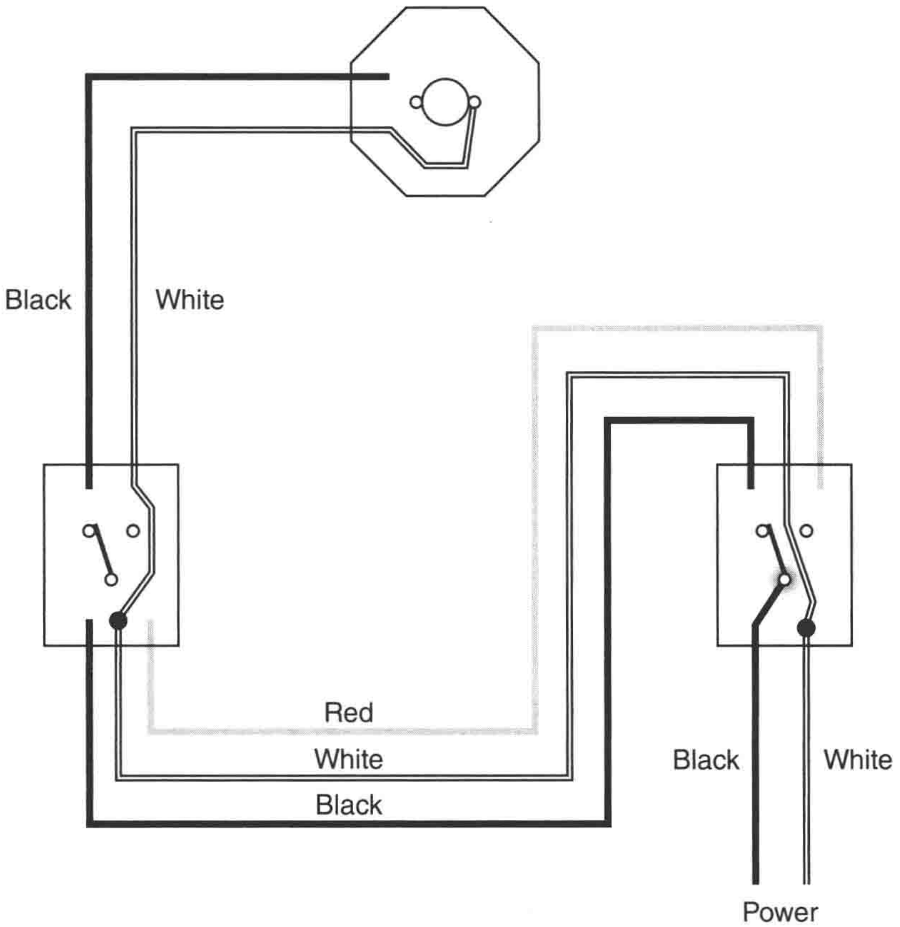


Figure 8-10 Rule 2: Connect the hot conductor to the common terminal of one 3-way switch.

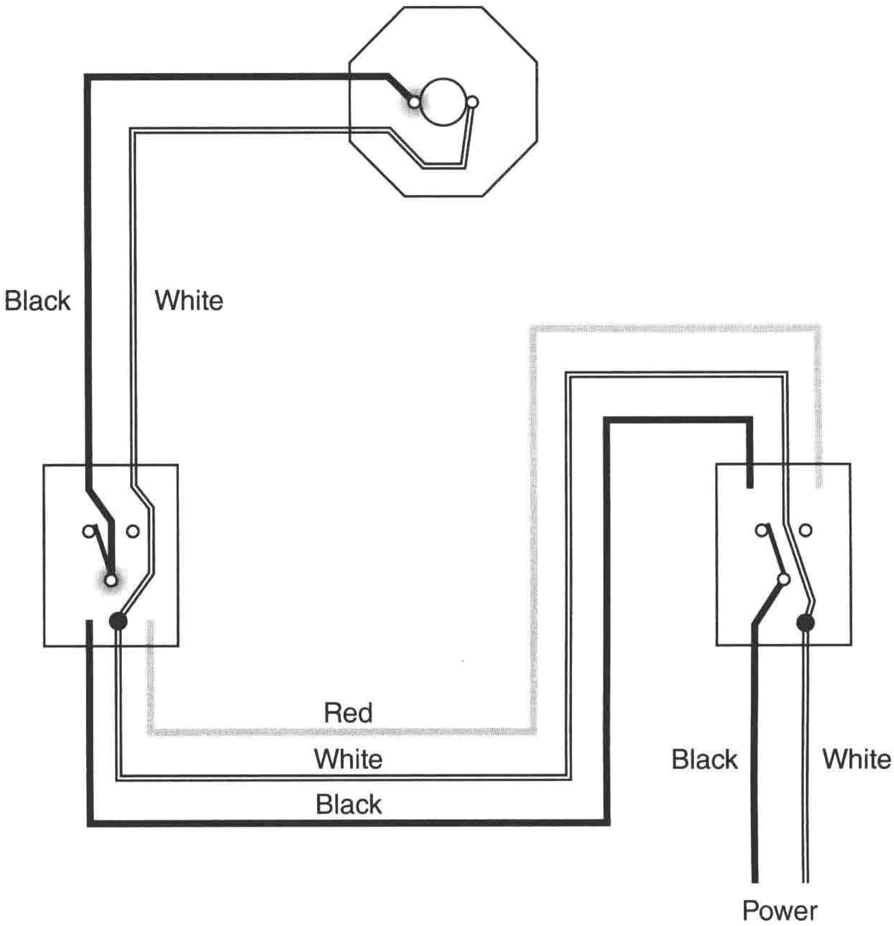


Figure 8-11 Rule 3: Connect the other side of the light to the common terminal of the second 3-way switch.

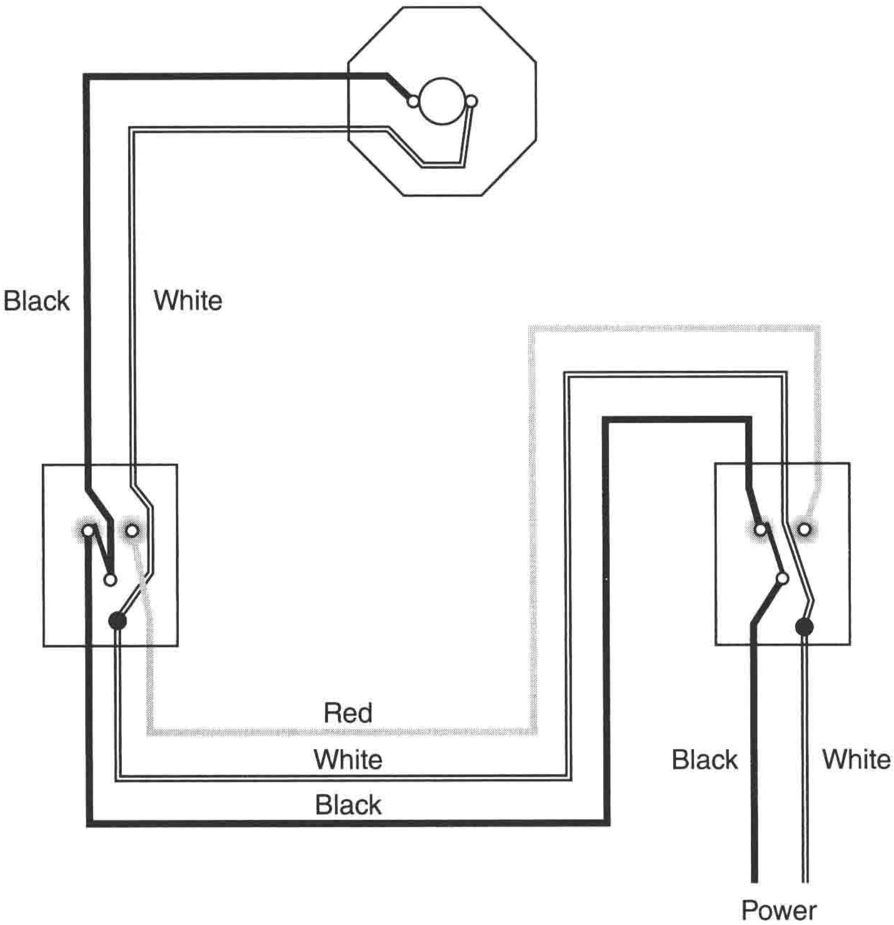


Figure 8-12 Rule 4: Connect the travelers.

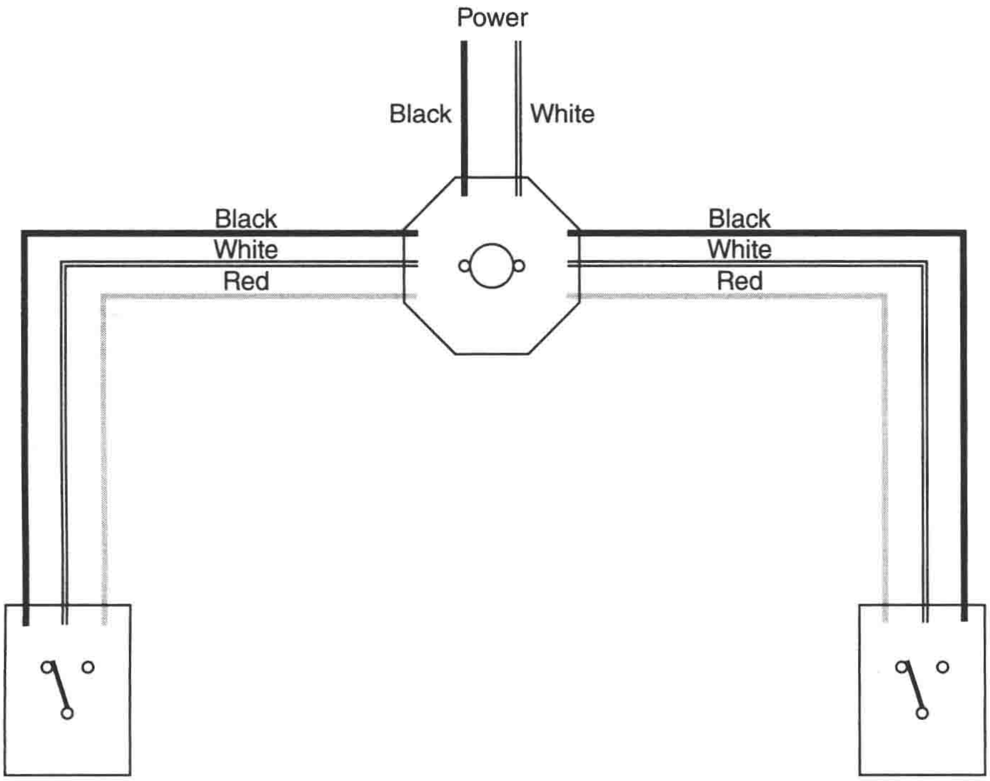


Figure 8-13 Example 2 of 3-way switch.

Example Connection 2

In the next example, power is brought to the light box, and a three-conductor cable is run from the light box to each 3-way switch box (Figure 8-13). The four rules for making 3-way switch connections will be followed.

1. *Connect the neutral to the light.* The neutral is the white wire in the power cable. Connect this wire directly to the light, as in Figure 8-14.

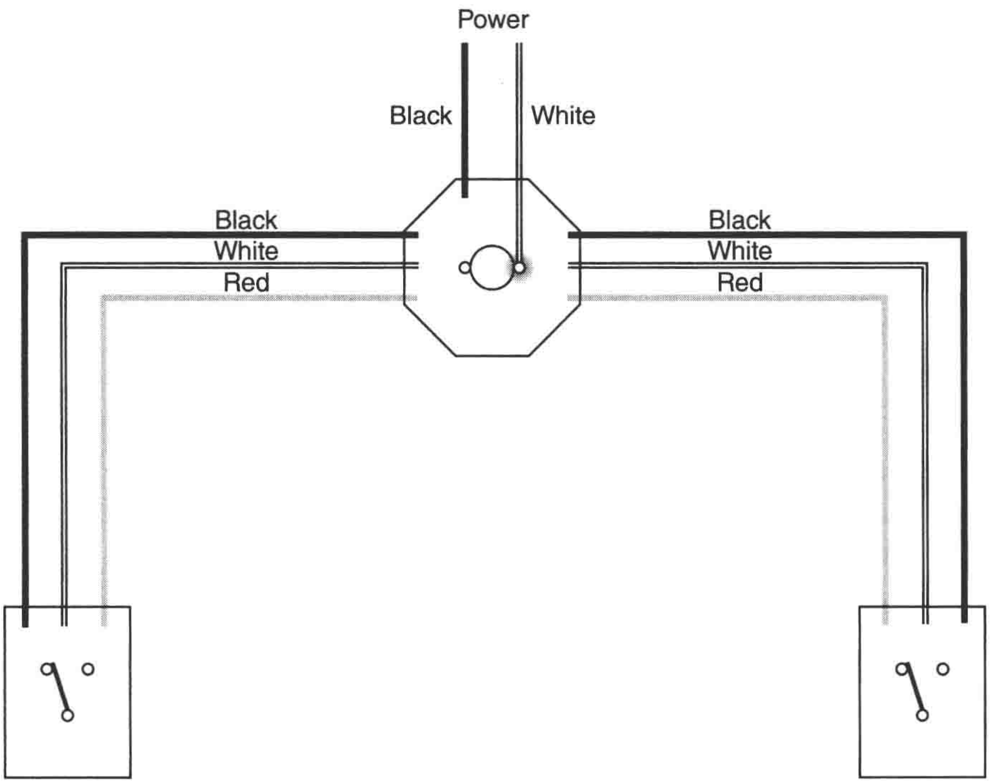


Figure 8-14 The white wire of the power cable is connected to the light.

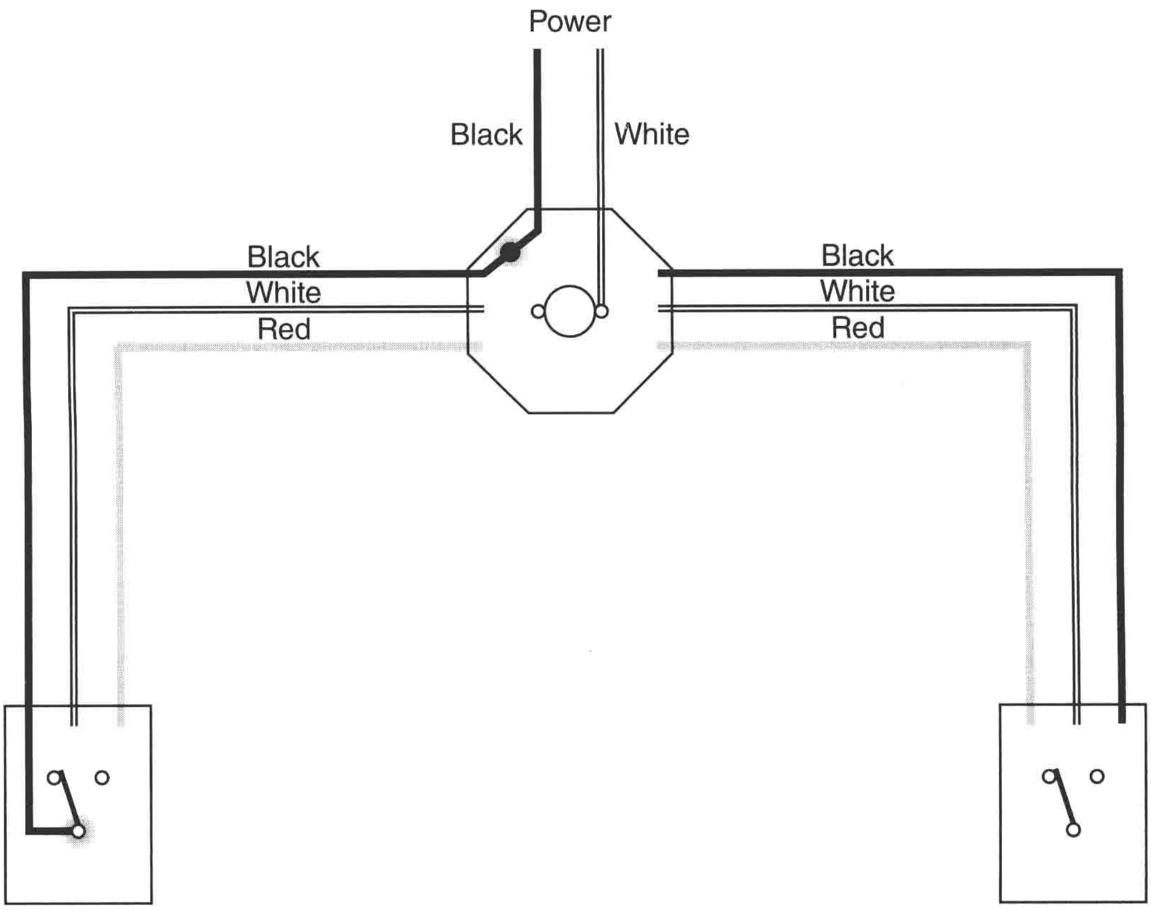


Figure 8-15 The hot conductor is connected to the common terminal of one 3-way switch.

2. *Connect the hot conductor to the common terminal of one 3-way switch.* The black wire of one three-conductor cable will be connected to the hot conductor in the power cable, shown in Figure 8-15. The other end of the black wire will be connected to the common terminal of the 3-way switch. Since the three-conductor cables are used as switch legs, the red or white wires could have been employed to carry the hot wire to the common terminal of the switch. Another helpful rule that can be followed when making 3-way switch connections is to *always* use a black wire to connect to the common terminal of a switch. A black wire can always be used to connect to the common terminal in any type of 3-way switch connection, but this is not true of the white or red wires. When this is done, the electrician will always know which of the wires connects to the common terminal when installing a 3-way switch.
3. *Connect the other side of the light to the common terminal of the other 3-way switch.* The black wire of the other three-conductor cable will be used to make this connection, as shown in Figure 8-16. Notice that the black wire is connected to the common terminal of the switch.
4. *Connect the travelers.* The red and white wires of the three-conductor cables are used as travelers (Figure 8-17). The *NEC*® requires that the white conductor be reidentified by marking it with colored tape or paint because it is a switch leg. The white switch legs should be marked in the light box and each of the switch boxes.

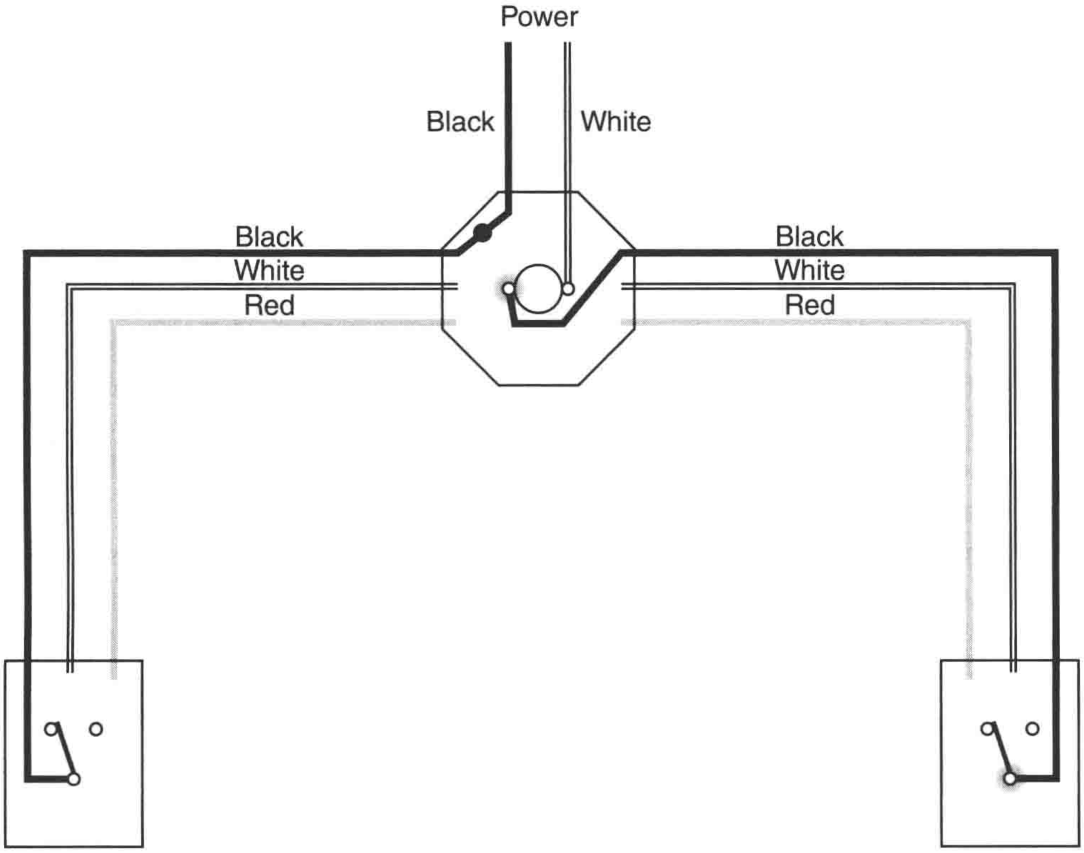


Figure 8-16 The other side of the light is connected to the common terminal of the second 3-way switch.

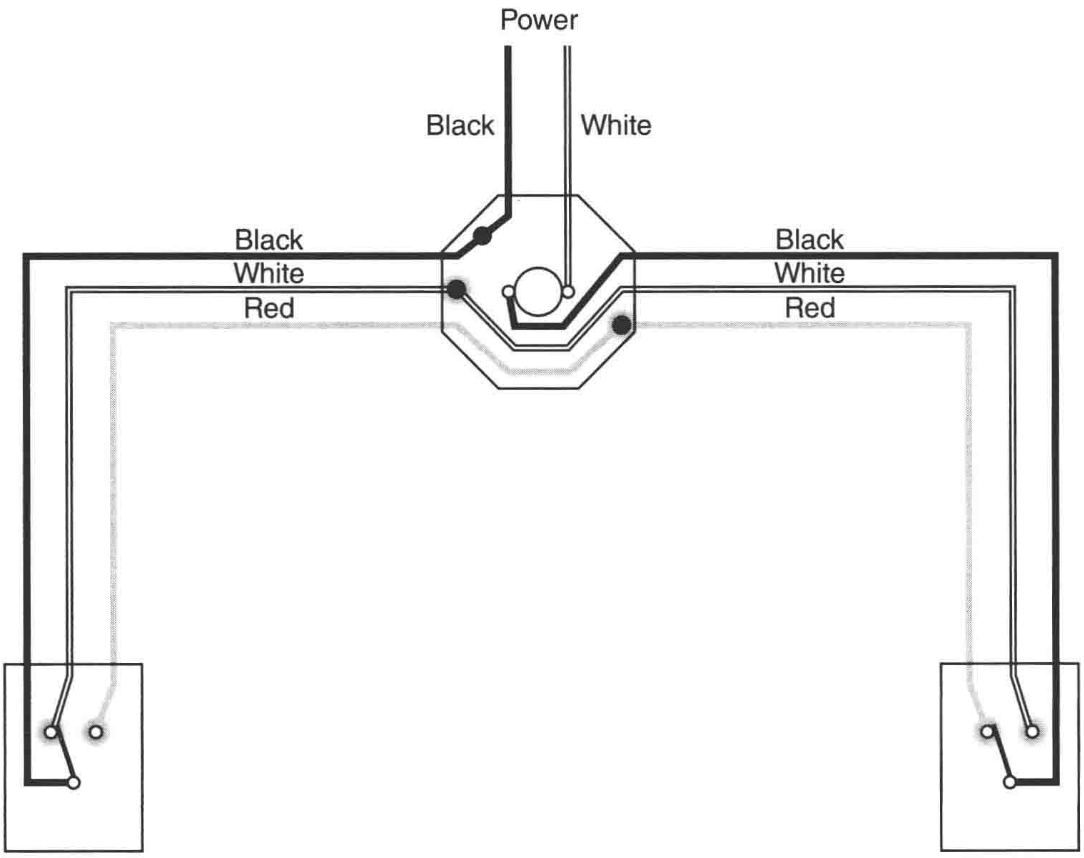


Figure 8-17 The travelers connect the two switches.

Example Connection 3

In this example the power wire is again brought to the light box. A two-conductor cable is run between the light box and one switch box, and a three-conductor cable is connected between the two switch boxes (Figure 8-18). To connect this circuit, the four rules for making 3-way switch connections will again be employed.

1. *Connect the neutral to the light.* The white wire of the power cable is connected directly to the light (Figure 8-19).
2. *Connect the hot conductor to the common terminal of one 3-way switch.* One of the requirements of the *NEC* is that the wires connected to the light must be identified. The neutral conductor must be white and the other wire must be a color other than white or green. Therefore, the black conductor that runs between the light box and the switch box should be connected to the light. That leaves the white wire of the switch leg to carry power to the common terminal of one of the 3-way switches. In the previous example, it was discussed that a black conductor can always be used as the wire that connects to the common terminal of a 3-way switch. To do that, connect the white switch leg in the light box to the hot power wire. Then connect the other end of the white switch leg to the black wire in the three-conductor cable that runs between the two switches. The black wire then connects to the common terminal of the 3-way switch (Figure 8-20).
3. *Connect the other side of the light to the common terminal of the other 3-way switch.* The black conductor of the switch leg that runs from the light box to the switch will be used (Figure 8-21).
4. *Connect the travelers.* The red and white wires of the three-conductor cable are used to connect the traveler terminals of the two switches (Figure 8-22). The white switch leg wire should be reidentified with colored tape or paint at each location.

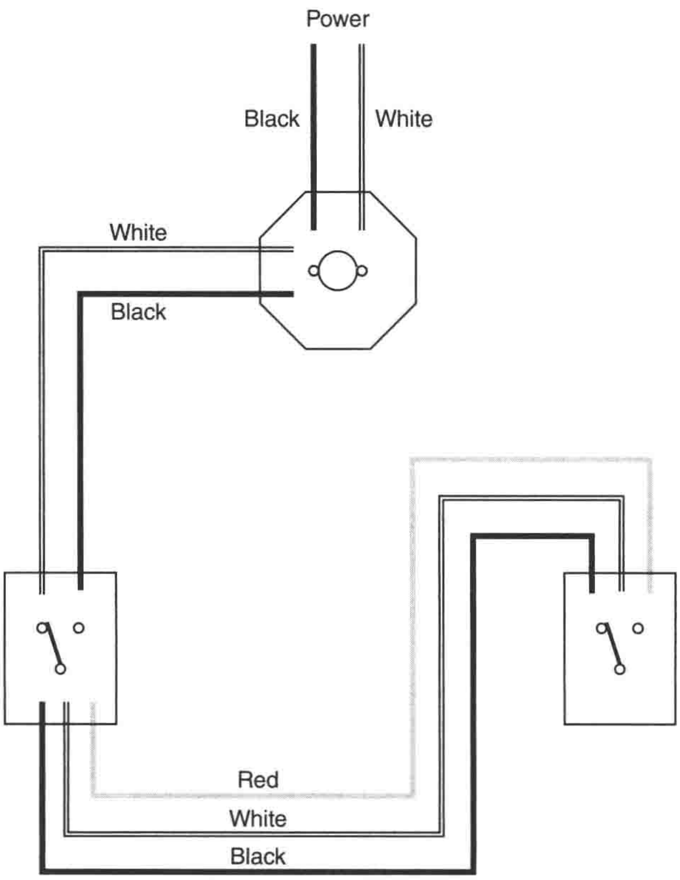


Figure 8-18 Example 3 of 3-way switch.

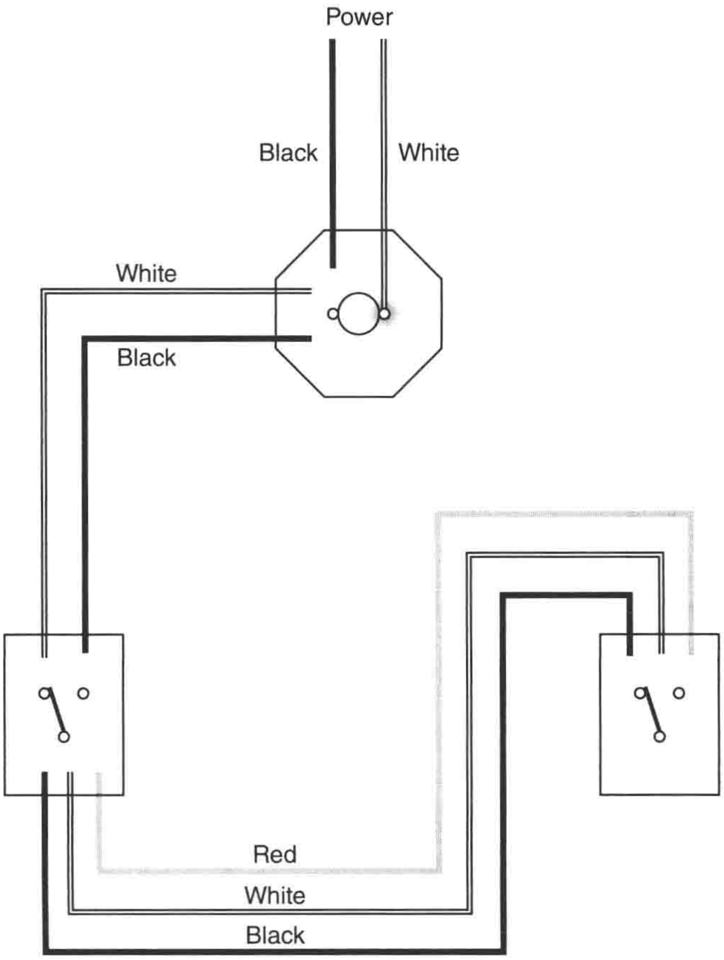


Figure 8-19 The neutral conductor is connected to the light.

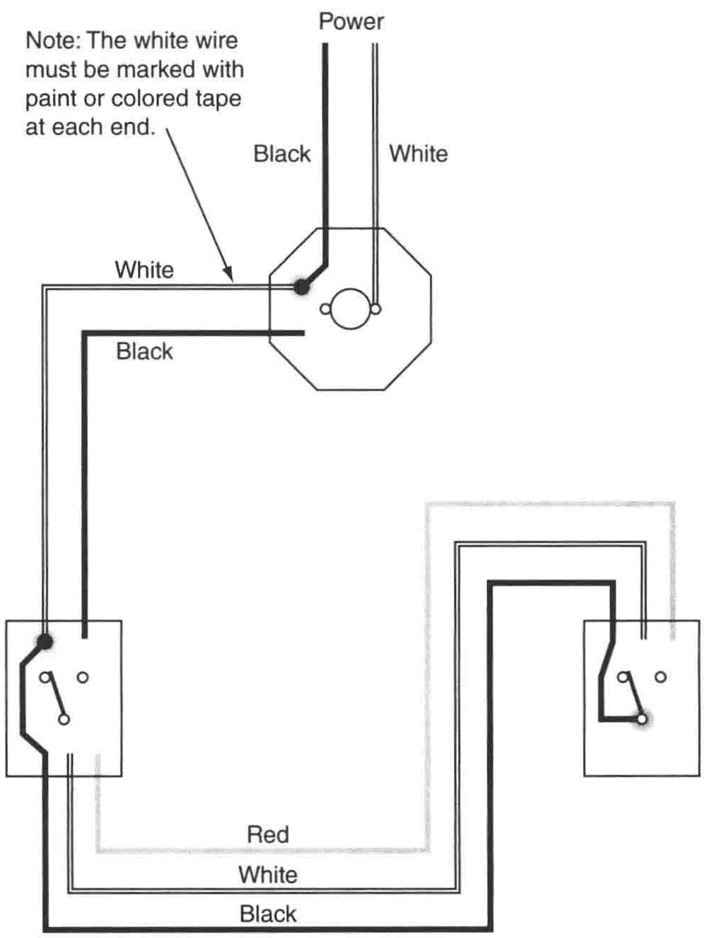


Figure 8-20 The hot wire connects to the common terminal of one 3-way switch.

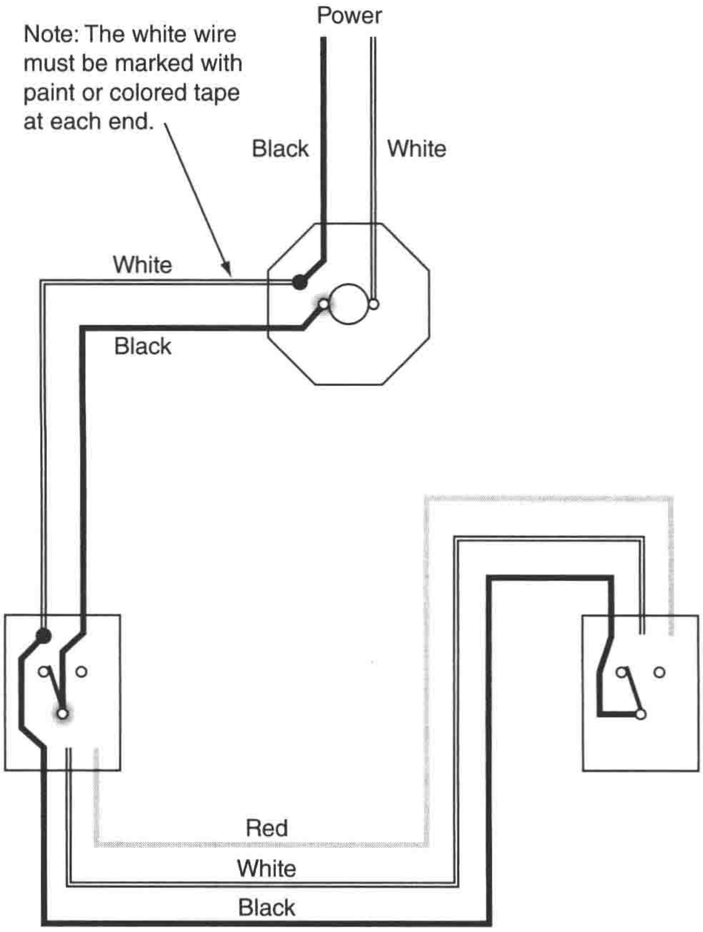


Figure 8-21 The other side of the light is connected to the common terminal of the second 3-way switch.

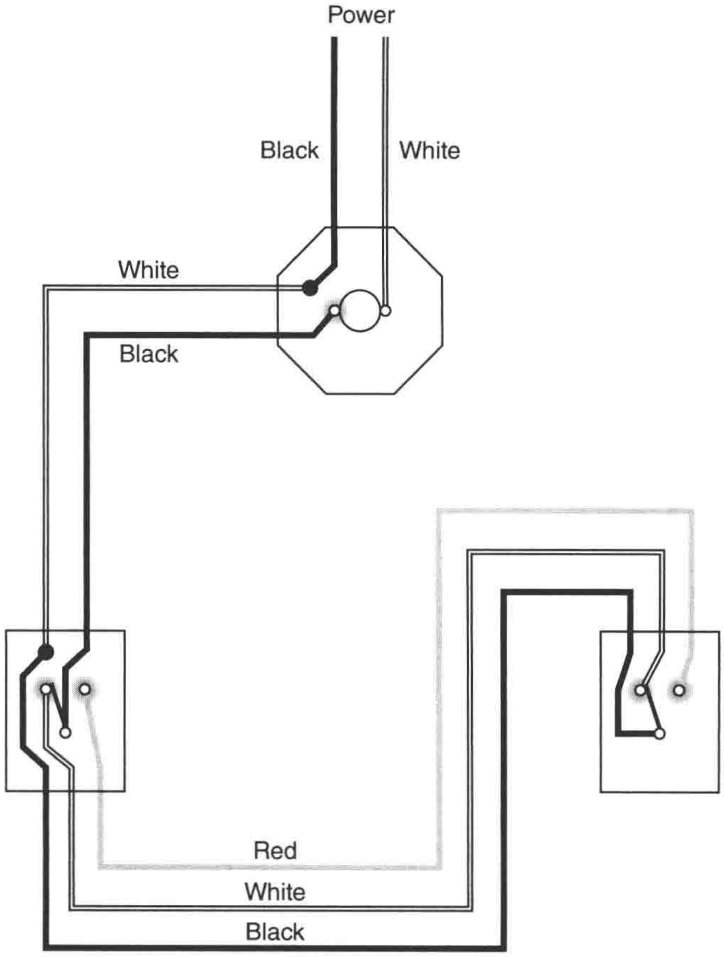


Figure 8-22 Connecting the travelers.

LABORATORY EXERCISE

(See Figure 8-23.)

Materials Required

120-volt AC power supply

1 120-volt lamp (any wattage)

2 3-way switches

2 switch boxes mounted to wall studs or on a board

1 standard octagon box mounted on a rafter or on a board

1 lamp socket that will mount to the octagon box

Two-conductor cable (length will be decided by the individual laboratory)

Three-conductor cable (length will be decided by the individual laboratory)

1. **Test and verify that the power is turned off.**
2. Using the materials listed, mount two switch boxes and one octagon box on a board or wall studs according to the provisions of the laboratory.

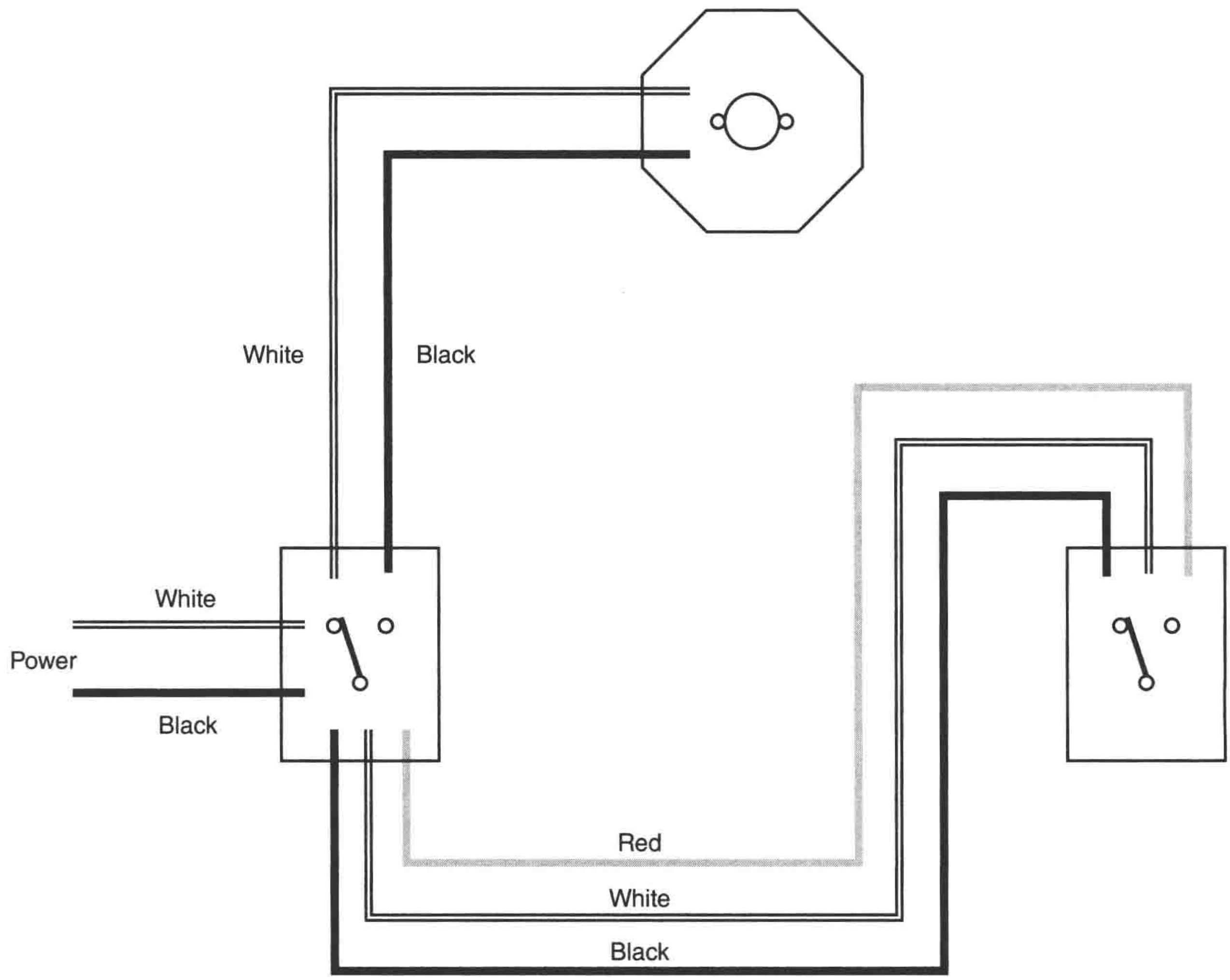


Figure 8-23 Connect the circuit.

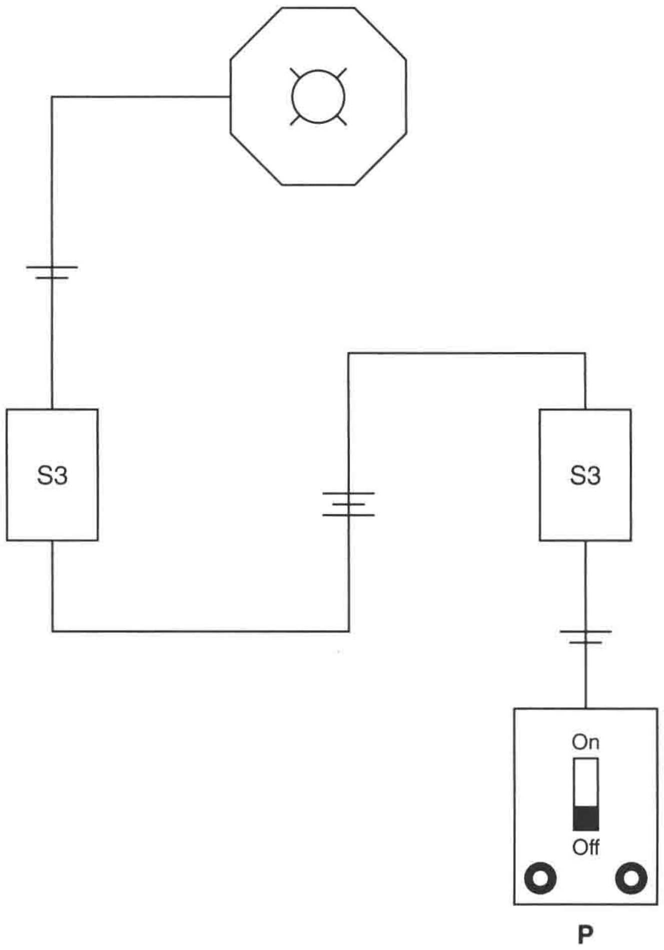


Figure 8-24 First circuit for connection.

3. Connect two- and three-conductor cables between the power supply and the boxes as shown in Figure 8-24. (Note: Blueprints generally indicate electrical cables as lines with hash marks. The same notation will be used in this laboratory exercise. A line with two hash marks indicates a two-conductor cable. A line with three hash marks indicates a three-conductor cable.)
4. Use the four rules for connecting 3-way switches to connect the circuit.
5. Turn on the power and test the circuit by alternately changing the position of each 3-way switch.
6. **Turn off the power** and disconnect the circuit.
7. Reposition the two- and three-conductor cables as shown in Figure 8-25.
8. Use the four rules for connecting 3-way switches to connect the circuit.
9. Turn on the power and test the circuit by alternately changing the position of each 3-way switch.
10. **Turn off the power** and disconnect the circuit.
11. Reposition the two- and three-conductor cables as shown in Figure 8-26.
12. Use the four rules for connecting 3-way switches to connect the circuit.
13. Turn on the power and test the circuit by alternately changing the position of each 3-way switch.
14. **Turn off the power** and disconnect the circuit. Return the components to their proper place.

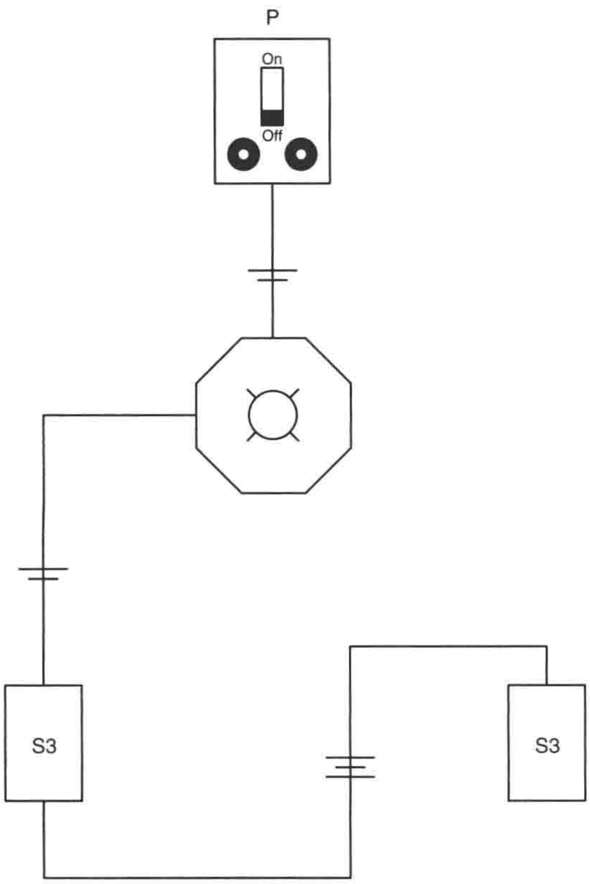


Figure 8-25 Second circuit for connection.

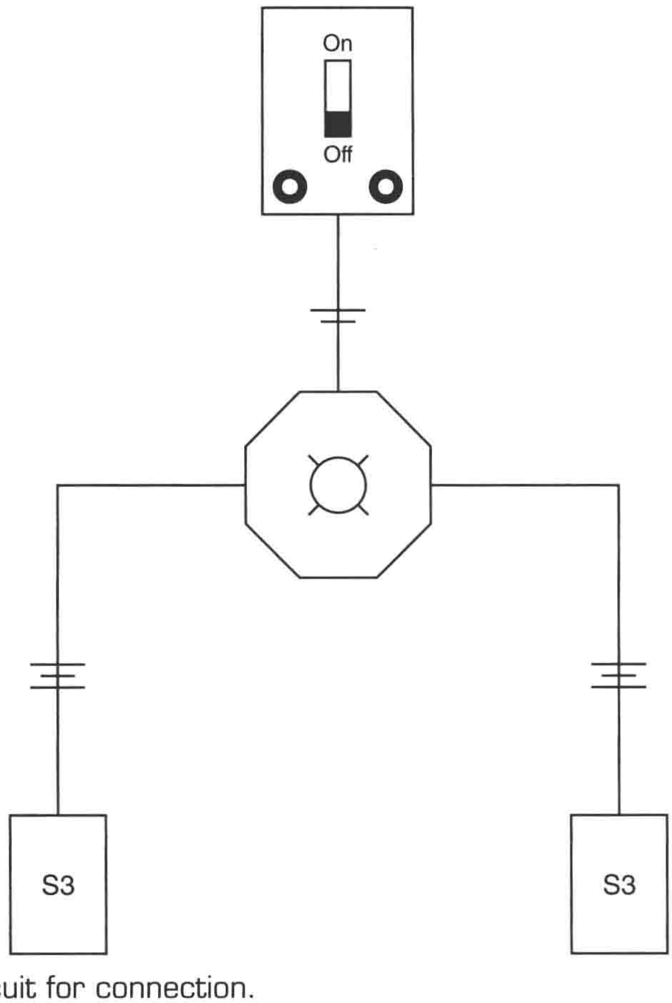


Figure 8-26 Third circuit for connection.

Review Questions

1. How many terminal screws are contained on a 3-way switch?

2. Name two methods commonly employed to identify the common terminal screw on a 3-way switch.

3. List four rules for connecting 3-way switches.

4. What color wire is it possible to always connect to the common terminal of a 3-way switch?

5. Refer to Figure 8-23. Connect the wires for proper switch operation. Connect the circuit so that a black conductor will supply the common terminal on each 3-way switch.

6. According to the *NEC*, when white wires are employed as switch legs, what should be done to reidentify the conductors?

7. What does *SPDT* stand for in reference to switches?

Unit 9 4-Way Switches

Objectives

After studying this unit, you should be able to

- Discuss the operation of a 4-way switch.
- Identify a 4-way switch.
- Draw a schematic illustrating the operation of a 4-way switch.
- Connect a 4-way switch in a circuit.

Four-way switches are used when it is desirable to control a light or outlet receptacle from more than two locations. Two 3-way switches are always used when a device is controlled from more than one location, but the number of switches above two will be 4-way switches. If a light was to be controlled from seven locations, for example, it would require two 3-way switches and five 4-way switches.

Switch Construction

Four-way switches are double-pole double-throw (DPDT) switches. This means that the switch contains two movable (pole) contacts, and each movable contact can make connection to two stationary contacts. A 4-way switch is constructed like a DPDT knife blade switch with the stationary contacts cross-connected (Figure 9-1). Although DPDT switches normally contain six connection terminals, because the stationary contacts are cross-connected, the 4-way switch requires only four terminal connections (Figure 9-2). When the switch lever

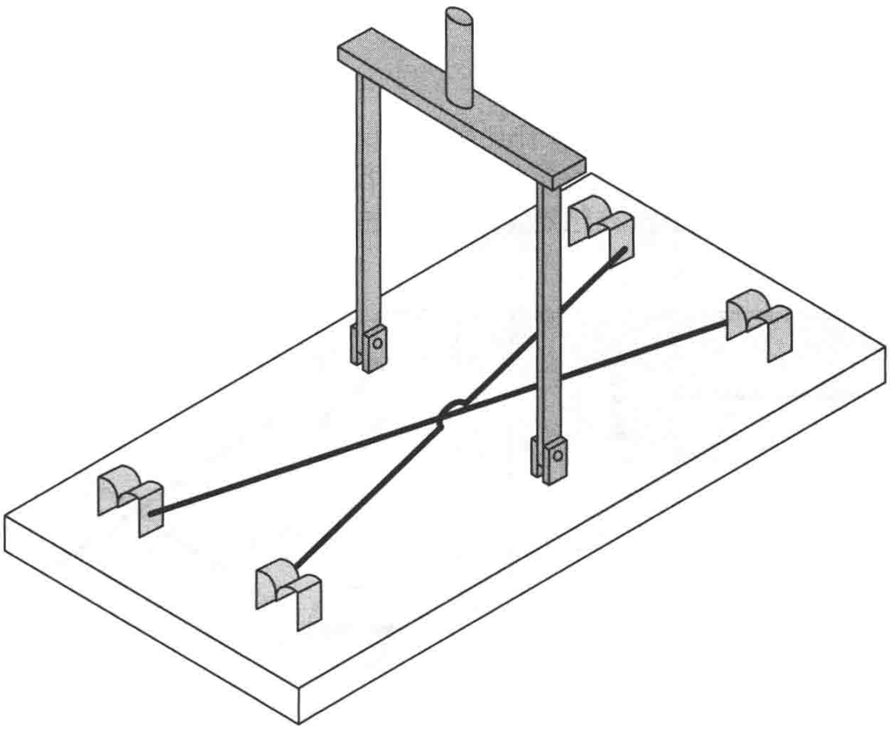


Figure 9-1 A 4-way switch is a double-pole double-throw switch with the stationary contacts cross-connected.

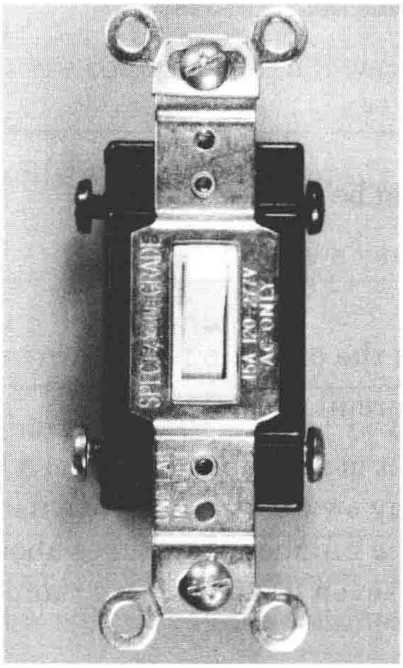


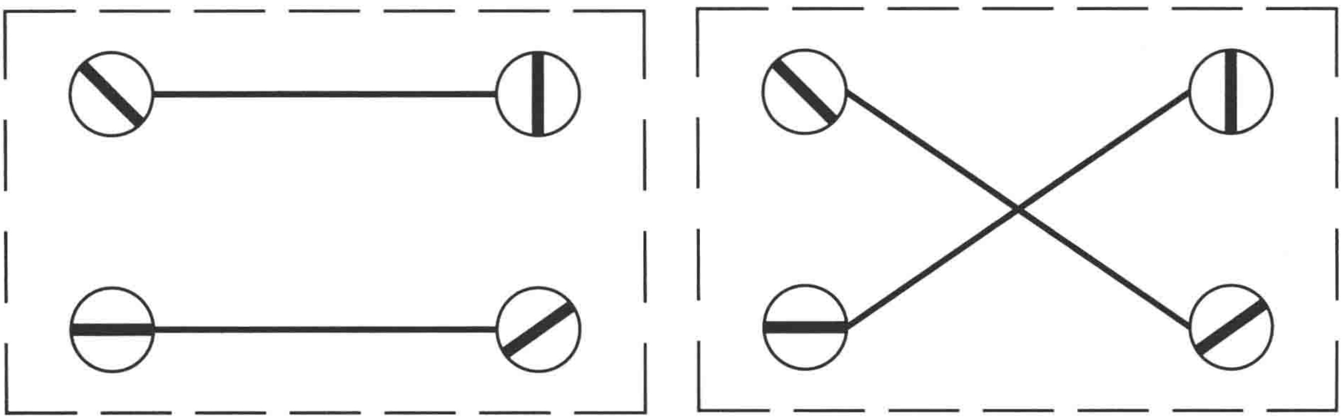
Figure 9-2 The 4-way switch contains four terminal connections.

is in one position, connection will be made straight across the screw terminals as shown in Figure 9-3A. When the switch lever is moved to the other position, the screw terminals are cross-connected as shown in Figure 9-3B.

Four-way switches should not be confused with double-pole single-throw (DPST) switches, which are often used to control the operation of 240 volt devices. DPST switches have four terminal connection screws also. A simple method of identifying the difference between the two switches is that DPST switches have OFF and ON printed on the switch lever and 4-way switches do not.

Basic Switch Logic

The logic for 4-way switches is basically the same as that of 3-way switches discussed in Unit 8. As mentioned previously, when a device is to be controlled from more than one location, two 3-way switches are required. In the circuit shown in Figure 9-4, a light is controlled



(A)
Connection is made straight across the terminal screws.

(B)
Connection is cross-connected between the terminal screws.

Figure 9-3 Switch positions of 4-way switches.

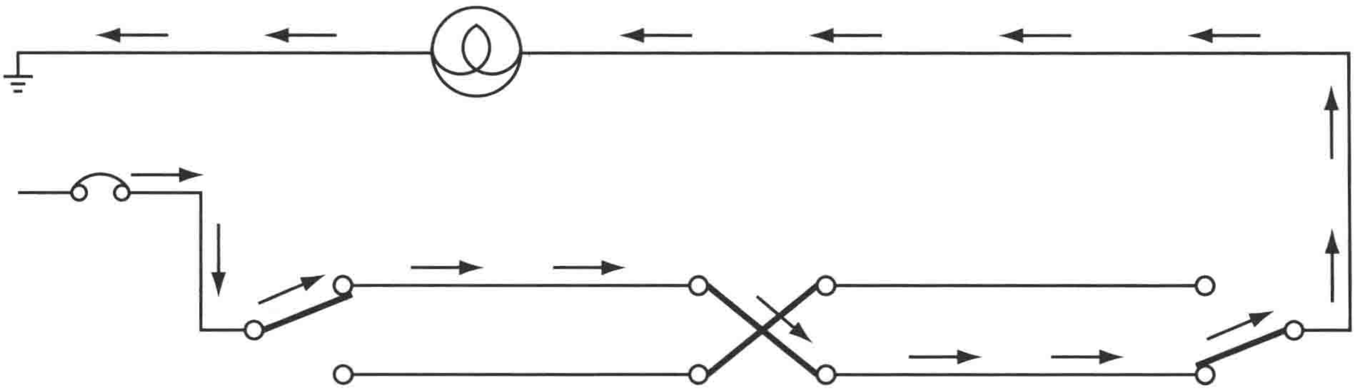


Figure 9-4 A complete circuit exists.

by three switches. Two of the switches are 3-way and the third is a 4-way. Note that the 4-way switch connects in the traveler wires between the two 3-way switches. In the example shown, a complete circuit exists through the lamp. If the switch lever of any of the three switches is changed, the circuit will be broken and the lamp will turn off (Figure 9-5). In this example the lever of the 4-way switch has been changed. There is no longer a complete circuit through the lamp.

Now assume that the lever of one of the 3-way switches is changed (Figure 9-6). A complete circuit again exists through the lamp. Regardless of which switch position is changed, the lamp will toggle from off to on or on to off. Any number of 4-way switches can be connected in the traveler circuit (Figure 9-7). Changing the position of any switch in the circuit will change the lamp from on to off or off to on.

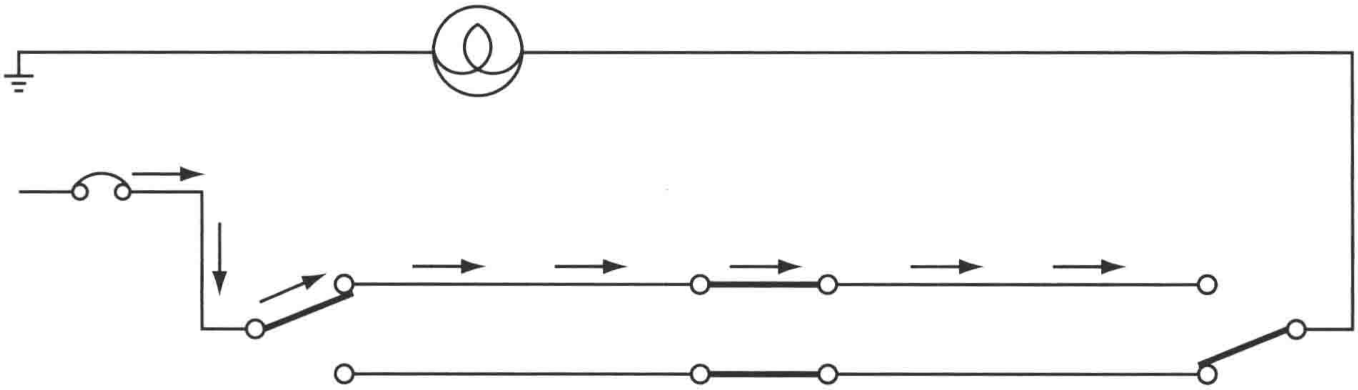


Figure 9-5 The position of the 4-way switch has been changed.

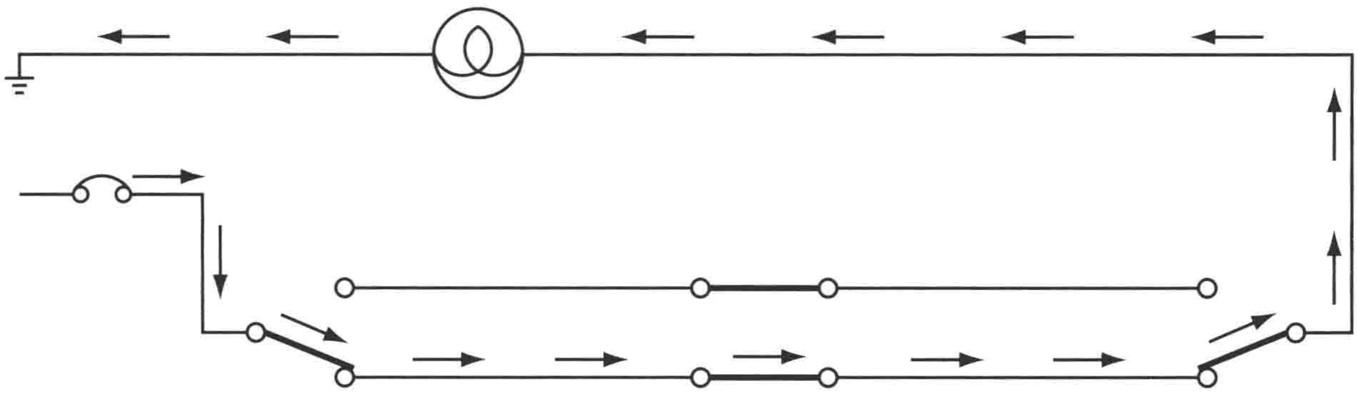


Figure 9-6 The position of a 3-way switch has been changed.

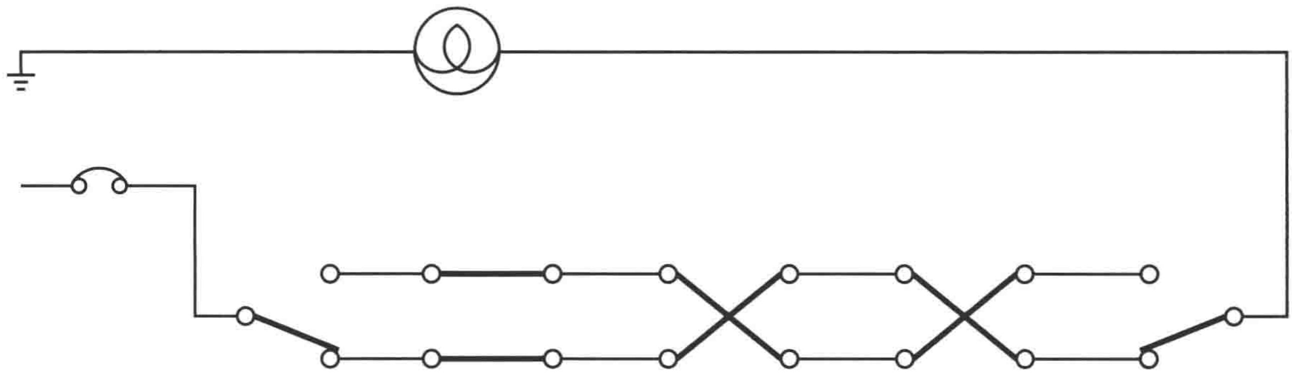


Figure 9-7 Any number of 4-way switches can be connected in the travelers.

Circuit Connections

The schematics shown in Figures 9-4 through 9-7 are used to explain the logic of 4-way switch circuits. In actual practice, connection is made with two- and three-conductor cables. In Unit 8, four rules were given for the connection of 3-way switches. These same four rules can be employed when connecting 4-way switches. The only exception is rule #4, which states "connect the travelers." When connecting 4-way switches, the switch must be connected in the travelers that connect the stationary contact terminals of the two 3-way switches together.

Example Connection 1

In the first example, power is brought to one of the 3-way switch boxes. A three-conductor cable runs from that switch box to the switch box containing the 4-way switch. The

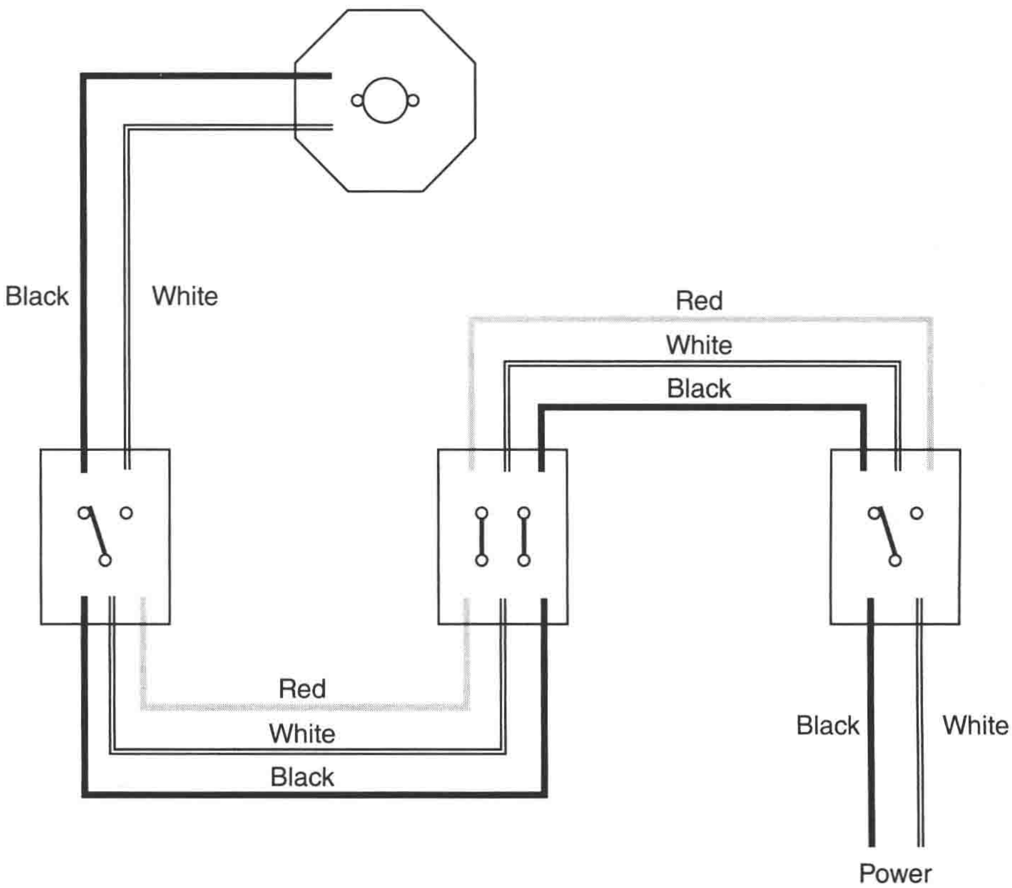


Figure 9-8 Example 1 of 4-way switch.

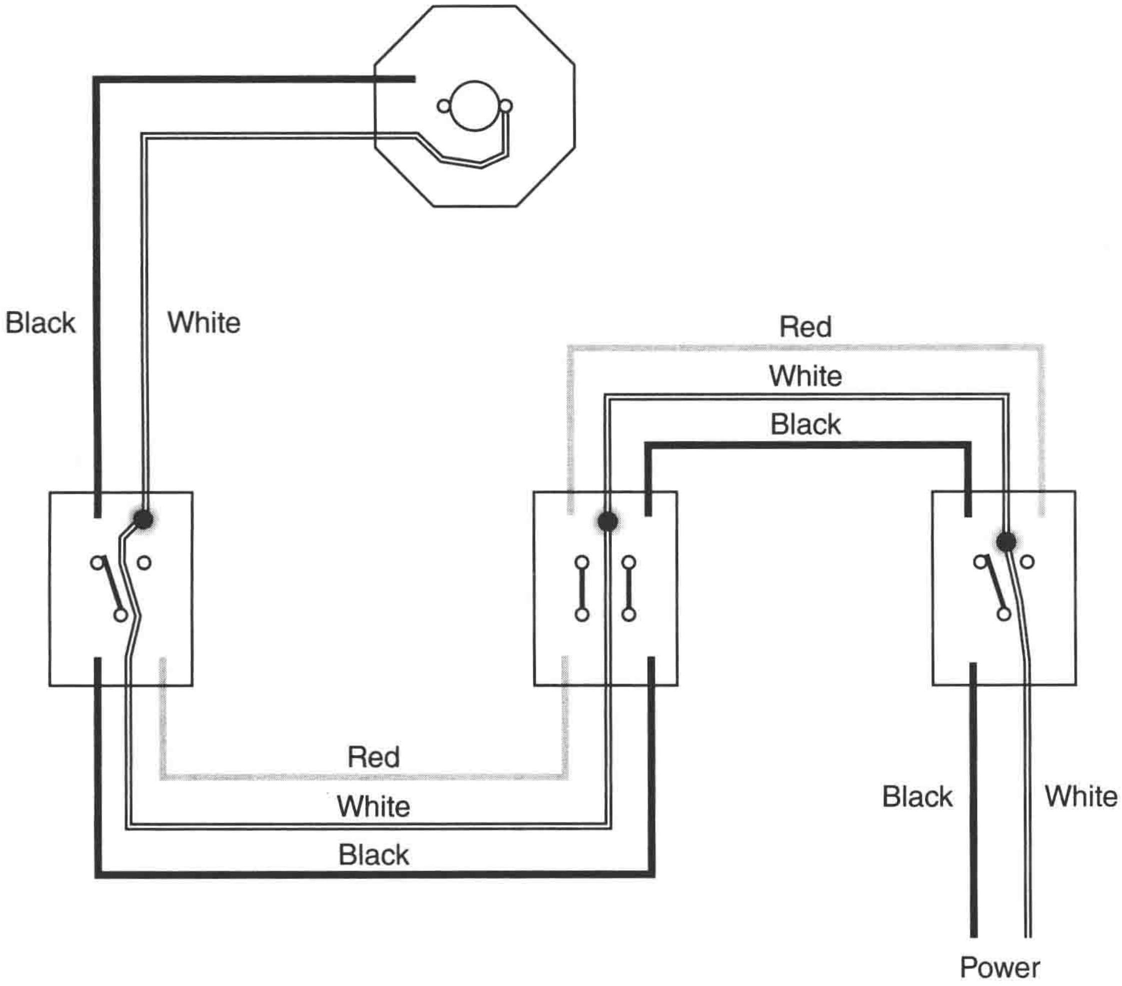


Figure 9-9 The neutral is connected to the lamp.

three-conductor cable proceeds to the second 3-way switch box, and a two-conductor cable runs from that box to the light (Figure 9-8). To connect the circuit, follow the four rules for connecting 3-way switches.

1. *Connect the neutral to the light.* The neutral is the white wire of the two-conductor cable that enters the switch box. It will connect to the white conductor of the three-conductor cable. The two white wires in the 4-way switch box will connect together, and the white wire in the second 3-way switch box will connect to the white wire that runs between the switch box and the lamp box. Then the white wire will connect to one side of the lamp (Figure 9-9).
2. *Connect the hot conductor to the common terminal of one 3-way switch.* Since the black wire of the power cable is hot, it will be connected to the common terminal of the 3-way switch (Figure 9-10).
3. *Connect the other side of the light to the common terminal of the other 3-way switch.* The black wire of the switch leg that runs between the second 3-way switch and the light will be connected to the common terminal of the second 3-way switch. The other end of the black wire will be connected to the other side of the light (Figure 9-11).
4. *Connect the travelers.* The red and black wires of the three-conductor cable will be used to connect the two 3-way switches together. The only difference is that the 4-way switch is connected between the travelers (Figure 9-12).

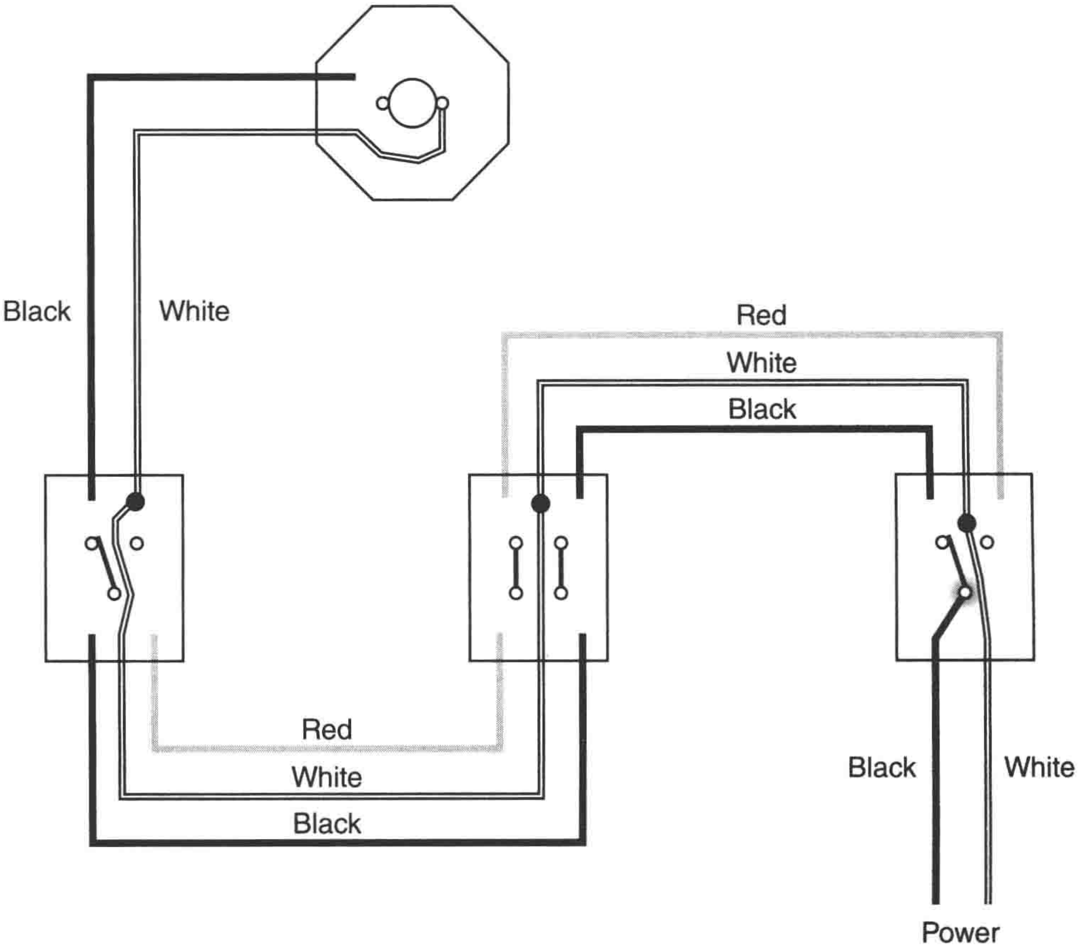


Figure 9-10 The hot conductor connects to the common terminal of one 3-way switch.

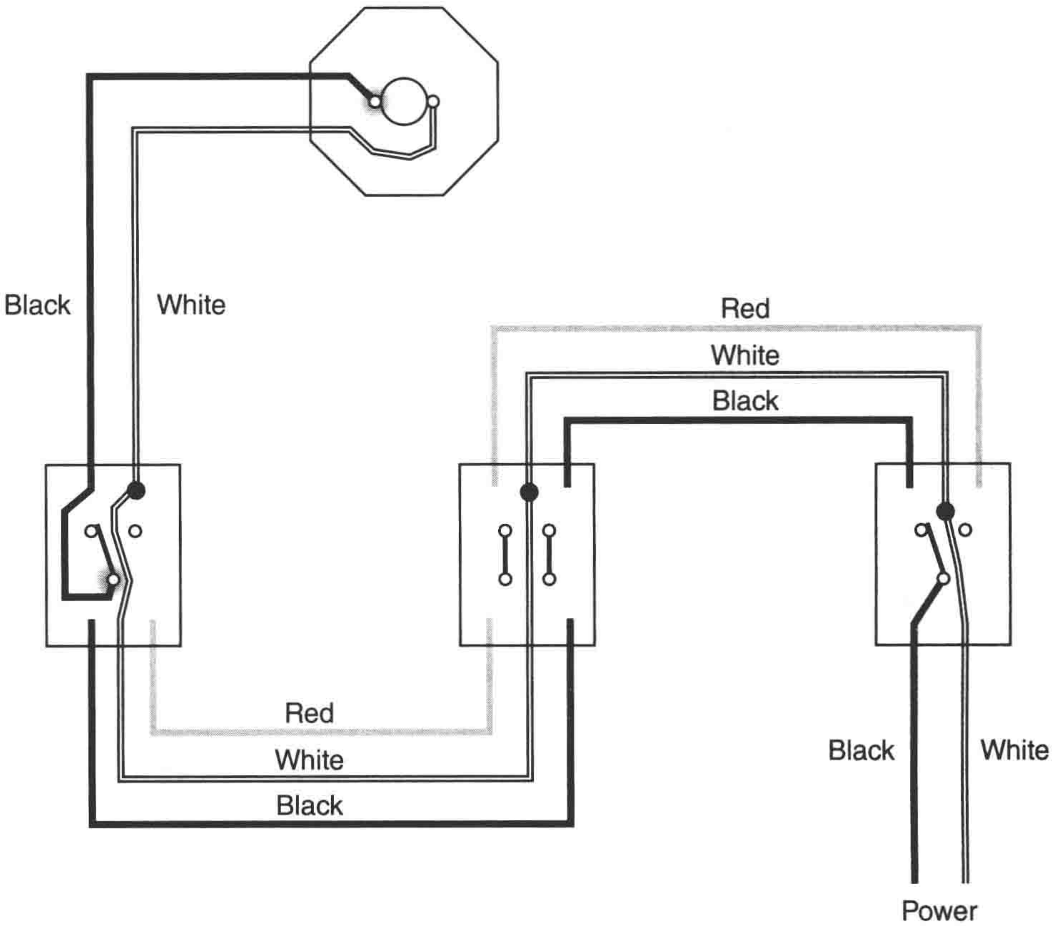


Figure 9-11 The other side of the light is connected to the common terminal of the second 3-way switch.

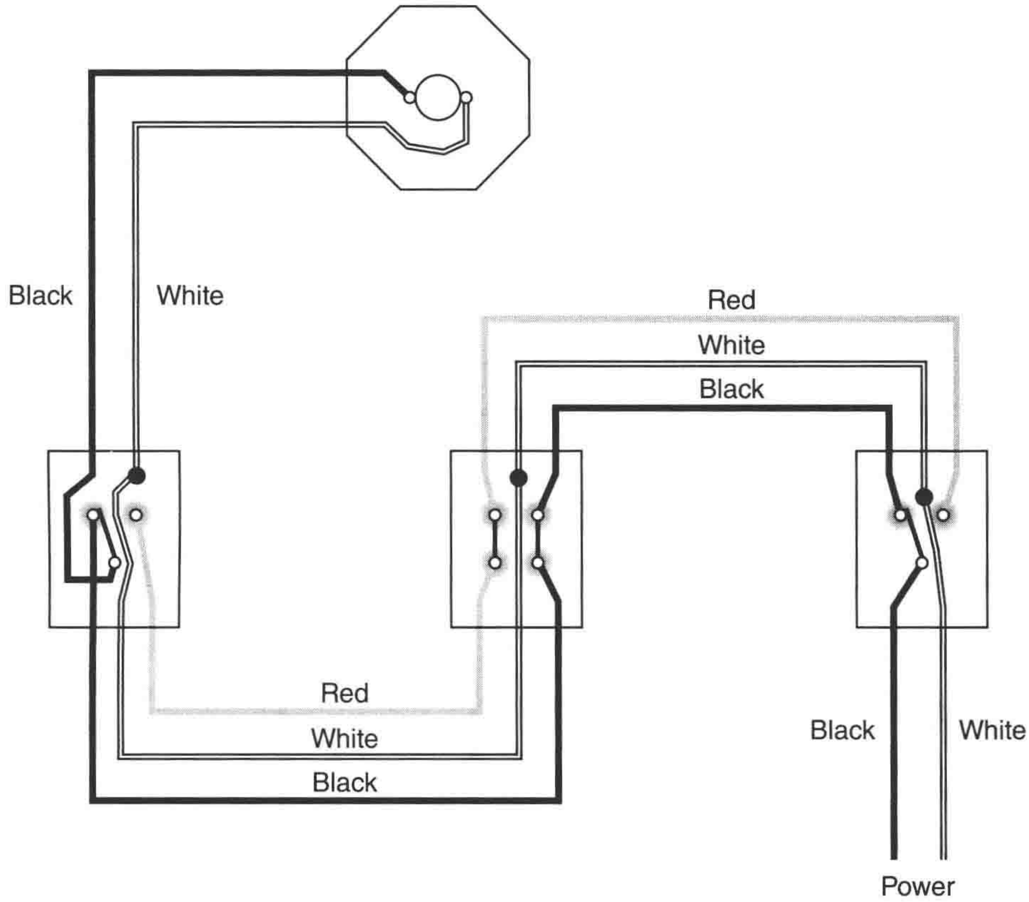


Figure 9-12 The 4-way switch is connected in the travelers.

Example Connection 2

In the second example, a two-conductor cable is connected between the light box and one 3-way switch box. A three-conductor cable runs from the 3-way switch box to the 4-way switch box and on to the second 3-way switch box. The power cable enters the 4-way switch box (Figure 9-13). Although it is seldom that a power cable will be brought to the 4-way switch box, this example is intended to illustrate how the four rules for connecting 3-way switches can be followed to make any 3- or 4-way switch connection.

1. *Connect the neutral to the light.* The white wire of the power cable is connected to the white wire of the three-conductor cable that runs to the 3-way switch box that contains the switch leg to the light (Figure 9-14). The neutral continues through the 3-way switch box and connects to the white wire of the switch leg. It is then connected to one side of the light.
2. *Connect the hot conductor to the common terminal of one 3-way switch.* The black wire of the power cable connects to the black wire of the three-conductor cable that runs to the 3-way switch box that does not contain the switch leg to the light (Figure 9-15). Notice that the common terminal of the switch will be connected to a black wire.
3. *Connect the other side of the light to the common terminal of the other 3-way switch.* The black wire of the switch leg connects to the common terminal of the second 3-way switch and to the other side of the light (Figure 9-16).
4. *Connect the travelers.* In this example, the red and white wires of one three-conductor cable connect to one set of terminals of the 4-way switch, and the red and black wires of the other three-conductor cable connect to the other set of 4-way switch terminals (Figure 9-17). The white wire that is used as a switch leg should be reidentified by marking it with colored tape or paint in each box.

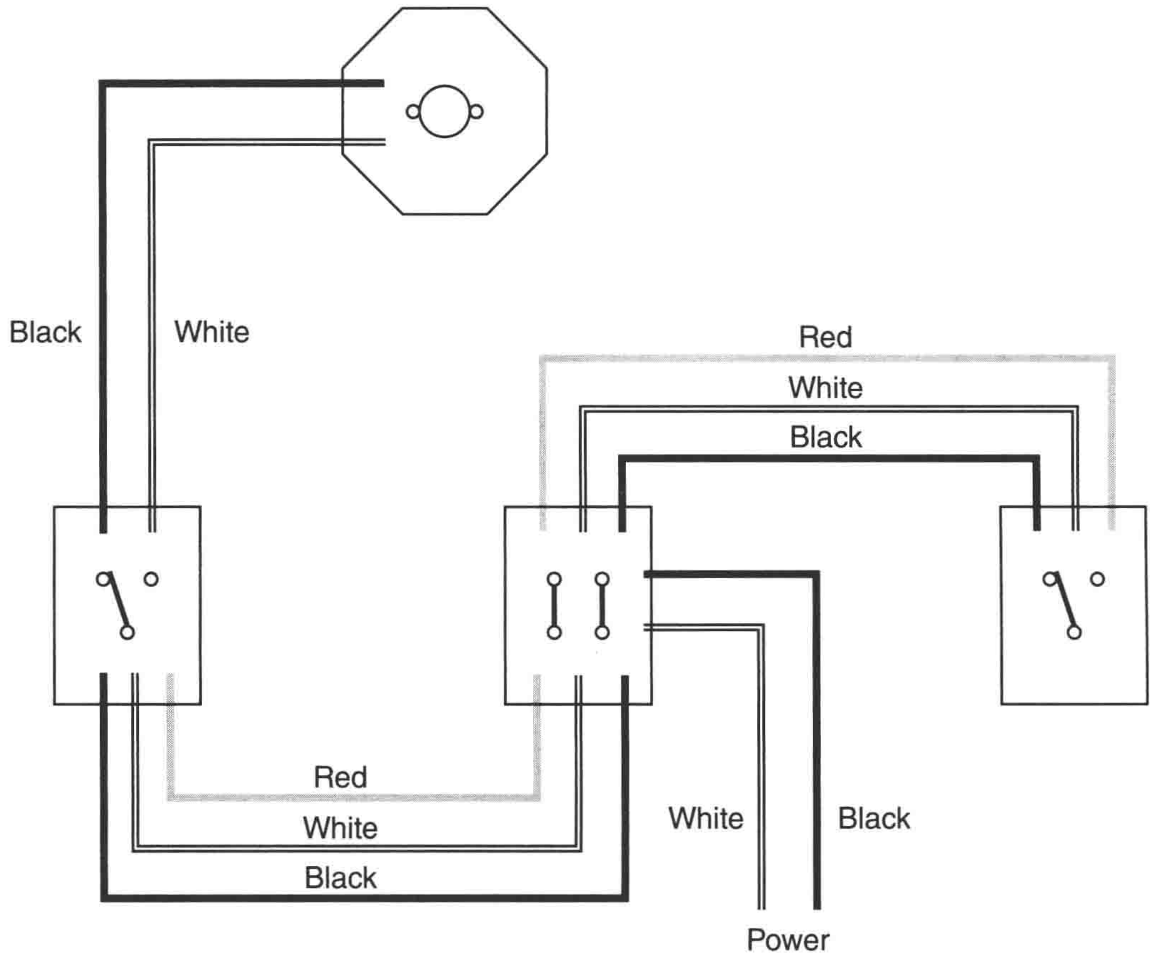


Figure 9-13 Example 2 of 4-way switch.

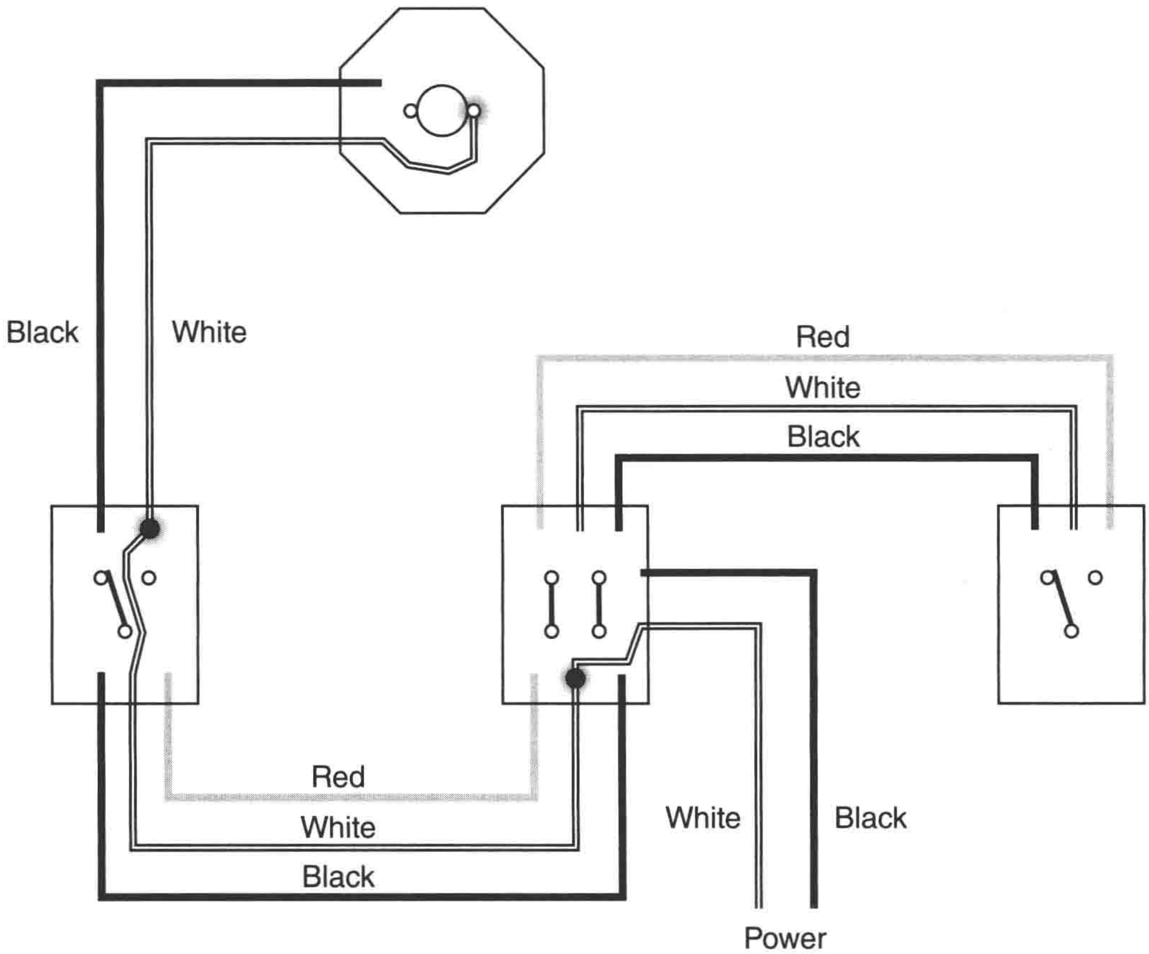


Figure 9-14 The neutral connects to the light.

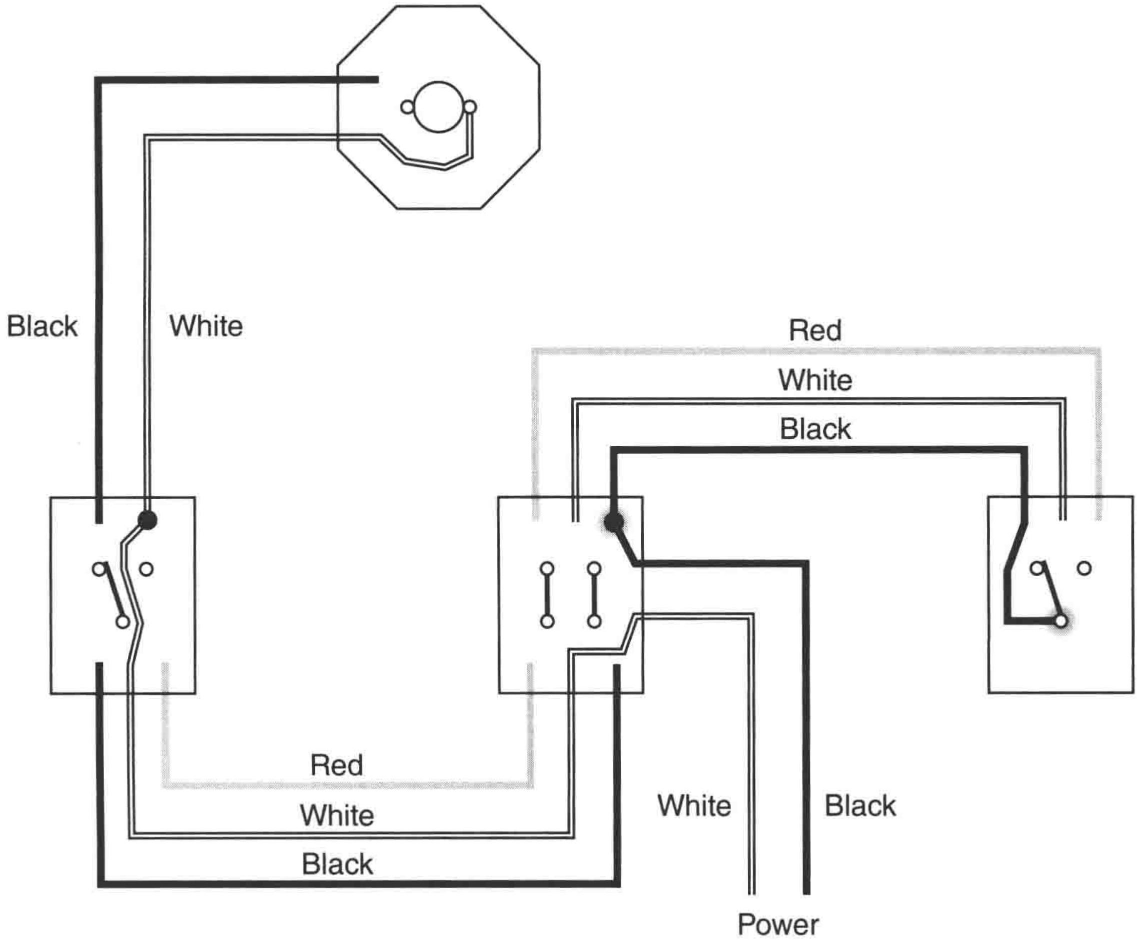


Figure 9-15 The hot conductor connects to the common terminal of one 3-way switch.

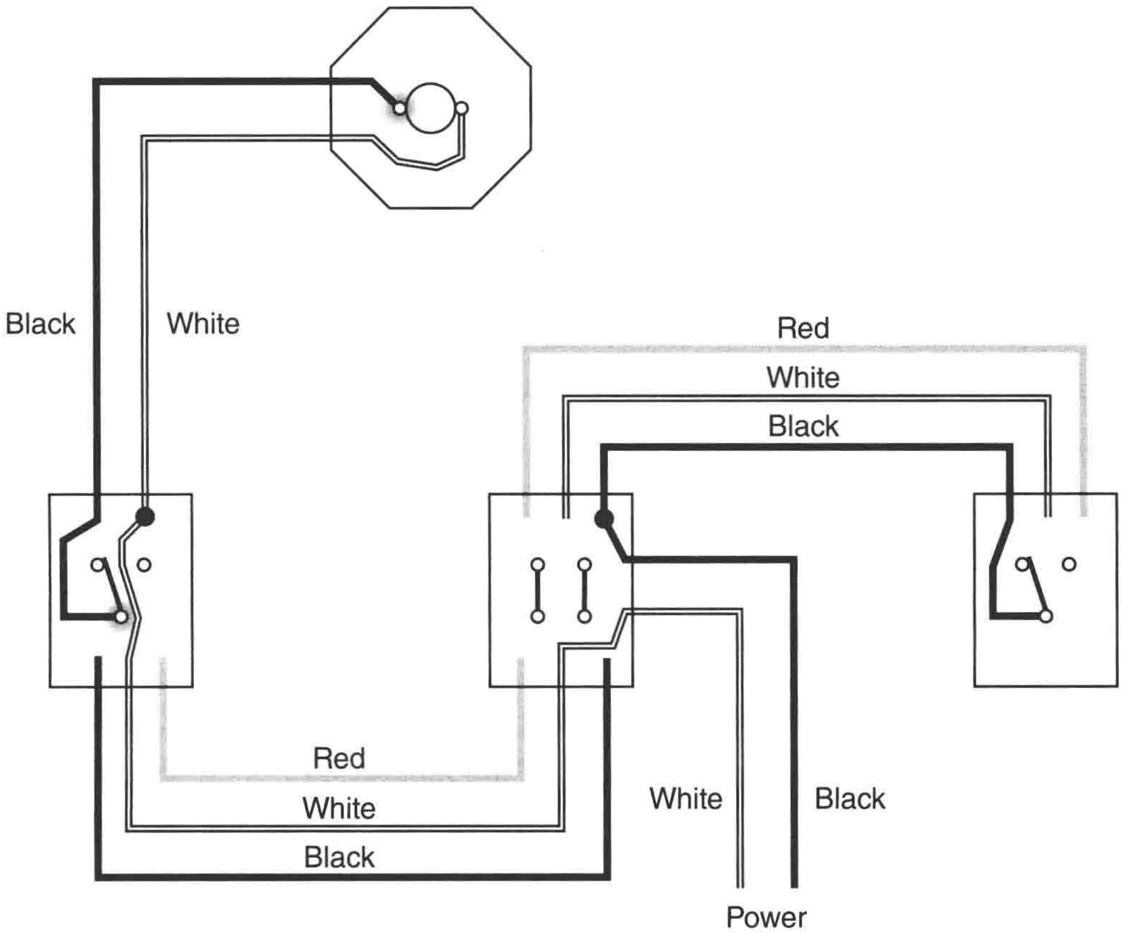


Figure 9-16 The other side of the light connects to the common terminal of the second 3-way switch.

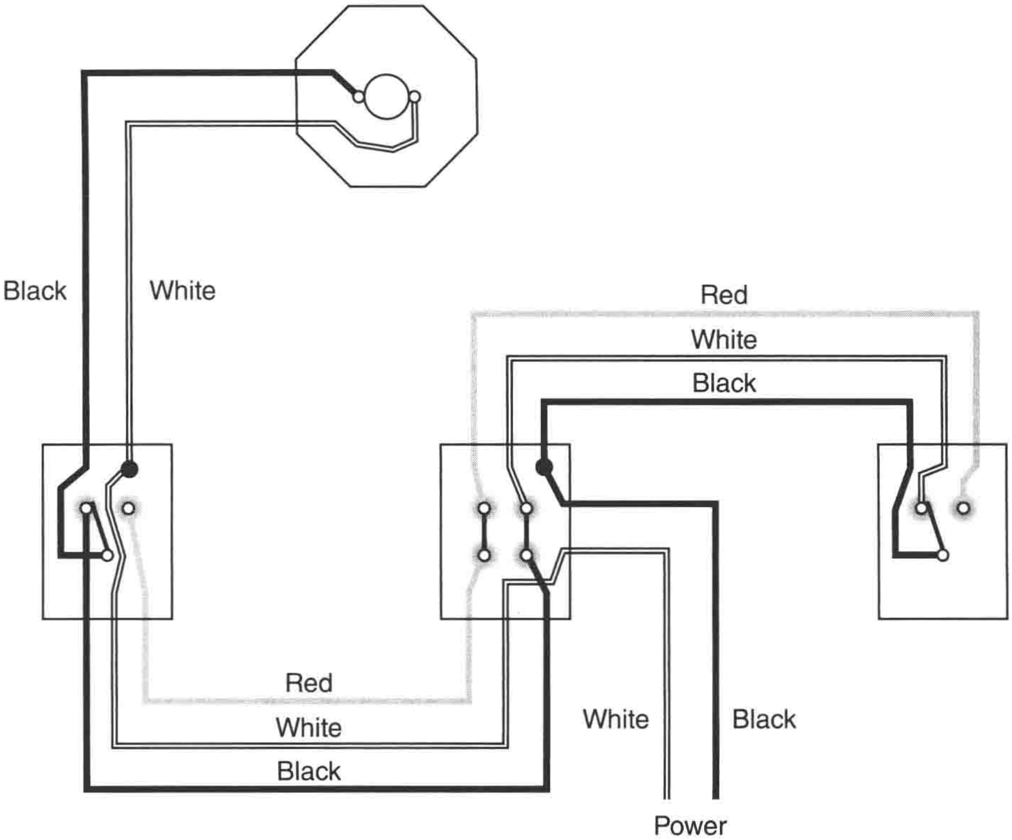


Figure 9-17 The 4-way switch is connected in the travelers.

LABORATORY EXERCISE

Materials Required

120-volt AC power supply

1 120-volt lamp (any wattage)

2 3-way switches

1 4-way switch

3 switch boxes mounted to wall studs or on a board

1 standard octagon box mounted on a rafter or on a board

1 lamp socket that will mount to the octagon box

Two-conductor cable (length will be decided by the individual laboratory)

Three-conductor cable (length will be decided by the individual laboratory)

1. **Test and verify that the power is turned off.**
2. Using the materials list, mount three switch boxes and one octagon box on a board or wall studs according to the provisions of the laboratory.
3. Connect two- and three-conductor cables between the power supply and the boxes as shown in Figure 9-18. (Note: Blueprints generally indicate electrical cables as lines with hash marks. The same notation will be used in this laboratory exercise. A line with two hash marks indicates a two-conductor cable. A line with three hash marks indicates a three-conductor cable.)

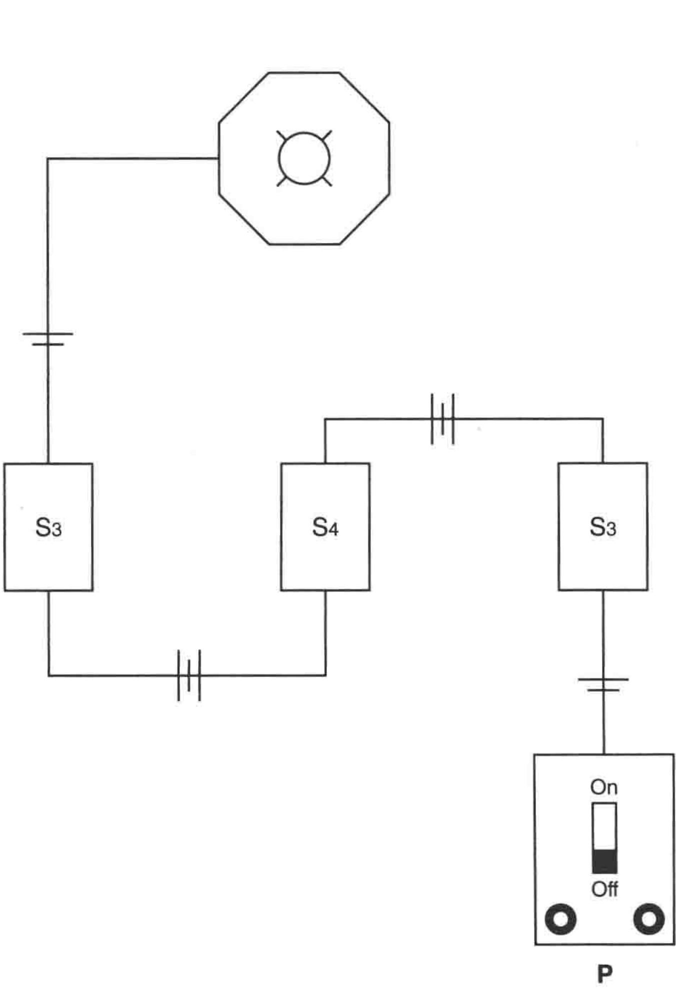


Figure 9-18 First circuit for connection.

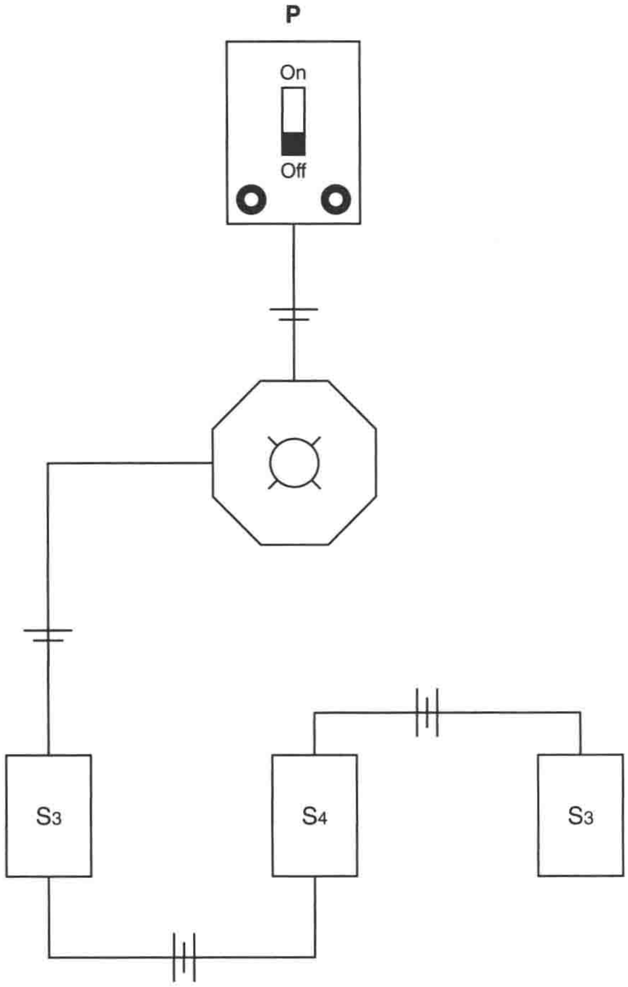


Figure 9-19 Second circuit for connection.

4. Use the four rules for connecting 3-way switches to connect the circuit.
5. Turn on the power and test the circuit by alternately changing the position of each 3-way switch and the 4-way switch.
6. **Turn off the power** and disconnect the circuit.
7. Reposition the two- and three-conductor cables as shown in Figure 9-19.
8. Use the four rules for connecting 3-way switches to connect the circuit.
9. Turn on the power and test the circuit by alternately changing the position of each 3-way switch and the 4-way switch.
10. **Turn off the power** and disconnect the circuit.

Review Questions

1. How many terminal screws are on a 4-way switch?

___

2. A light is to be controlled from eight different locations. How many of each type of switch are required to make this connection?

   Single-pole (S_1) ____________ 3-Way (S_3) ____________ 4-Way (S_4) ____________

___

3. List four rules for connecting 3-way switches.

___

4. What type of switch other than the 4-way contains four terminal screws?

____

5. How can the two switches that contain four terminal screws be distinguished from each other?

____

6. Refer to Figure 9-20. Connect the wires for proper switch operation. Connect the circuit so that a black conductor will supply the common terminal on each 3-way switch.

____

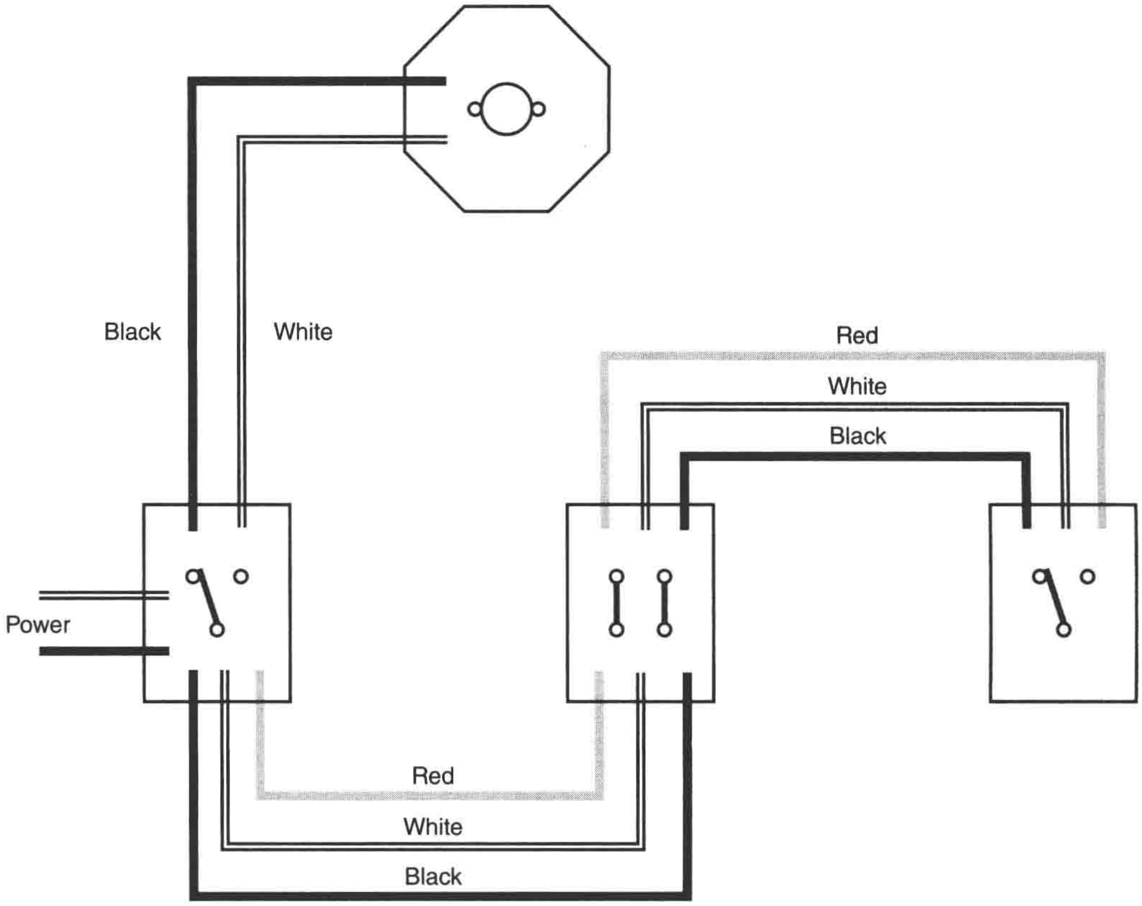


Figure 9-20 Connect the circuit.

SECTION

3

Alternating Current Loads

Unit 10 Inductance

Objectives

After studying this unit, you should be able to

- Determine the impedance of an inductor.
- Determine the inductive reactance of an inductor.
- Determine the Q of an inductor.
- Determine the inductance of an inductor.
- Determine the inductance of coils connected in parallel.
- Determine the inductive reactance of coils connected in parallel.
- Determine the inductance of coils connected in series.
- Determine the inductive reactance of coils connected in series.

Inductance is one of the major types of load in an alternating current circuit. Inductive loads exhibit different characteristics than resistive loads. Some of the characteristics of an inductive circuit are the following:

1. The current is mainly limited by inductive reactance (X_L) instead of resistance.
2. The current lags the applied voltage by 90°.
3. The pure inductive part of the circuit consumes no power.
4. Power in an inductive circuit is measured in VARs (Volt Amps Reactive) instead of watts. VARs is sometimes called wattless power. Watts is a measure of the amount of electrical energy converted into some other form, such as heat or kinetic energy. In a pure inductive circuit, power is stored in a magnetic field during part of the cycle and then returned to the circuit during another part. The electrical energy is not converted to some other form; it is stored and returned.

Impedance

Impedance (Z) is a measure of the total current-limiting effect of the circuit. It can be a combination of resistance, inductive reactance, and capacitive reactance. All inductors have some amount of resistance in the wire used to wind the inductor, but as a general rule, inductors limit current with inductive reactance instead of resistance. To determine the total current-limiting effect of an inductor, the impedance, it is necessary to add the resistance and inductive reactance together. In an AC circuit, however, the inductive part and resistive part are 90° out of phase with each other. To add these two quantities, vector addition must be used. Assume that an inductor has a resistance of 5 Ω and an inductive reactance of 8 Ω. The total current-limiting effect for this inductor can be determined using the formula:

$$Z = \sqrt{R^2 + X_L^{\,2}}$$

$$Z = \sqrt{5^2 + 8^2}$$

$$Z = \sqrt{25 + 64}$$

$$Z = \sqrt{89}$$

$$Z = 9.43\ \Omega$$

This inductor will offer a total current-limiting effect of 9.43 Ω to the circuit.

Q of an Inductor

Q stands for quality. The Q of a coil or inductor can be determined by comparing the resistance and inductive reactance. To determine the Q of an inductor, divide the inductive reactance by the resistance. In the previous example, the coil has a wire resistance of 5 Ω and an inductive reactance of 8 Ω. To determine the Q of this coil, use this formula:

$$Q = \frac{X_L}{R}$$

$$Q = \frac{8}{5}$$

$$Q = 1.6$$

Inductors with a Q of 10 or higher are generally considered to be pure inductors and their resistance is not considered in circuit calculations. Assume that an inductor has a wire resistance of 10 Ω and an inductive reactance of 100 Ω. Now, determine the impedance of this coil:

$$Z = \sqrt{R^2 + X_L^{\,2}}$$

$$Z = \sqrt{10^2 + 100^2}$$

$$Z = \sqrt{100 + 10{,}000}$$

$$Z = \sqrt{10{,}100}$$

$$Z = 100.5\ \Omega$$

As you can see, almost all the current-limiting effect of the coil is caused by inductive reactance. The amount of current limit due to resistance is negligible.

Inductors and Transformers

In the following laboratory experiment, a transformer winding will be used as an inductor. Inductors are also known as "chokes," "reactors," and "coils." The electrical properties of inductors and transformers are not identical, but they are similar. The greatest difference between a true reactor and a transformer is that reactors, or chokes, have the ability to limit inrush current when power is first applied to them. Transformers can exhibit extremely high inrush currents. This different characteristic between the two devices is caused by the type of magnetic core material used to make an inductor or transformer. For the purpose of this experiment, the transformer will be used as an inductor or reactor. It should be understood that although transformers and inductors are both inductive devices, the inductance of a transformer winding may vary with a change of current. True inductors or chokes will retain their inductive value as current changes.

LABORATORY EXERCISE

Name ____ Date __________

Materials Required

2 0.5-kVA control transformers with two windings rated at 240 volts and one winding rated at 120 volts

AC ammeter, in-line or clamp-on. (If a clamp-on type is employed, the use of a 10:1 scale divider is recommended.)

Connecting wires

AC voltmeter

1 120-volt AC power supply

1 208-volt AC power supply

1. With an ohmmeter, measure the resistance of the low-voltage winding marked X_1 and X_2 on the transformer.

   ______________ Ω

2. Connect the circuit shown in Figure 10-1.

> **CAUTION**
>
> Only one winding of the transformer will be connected to power at one time, but all terminals will have voltage across them when the power is turned on. Use extreme caution NOT to touch any terminal on the transformer when the power is on, even if there is no connection made to the terminal.

3. Turn on the power and measure the voltage across terminals X_1 and X_2 with an AC voltmeter.

   ______________ volts

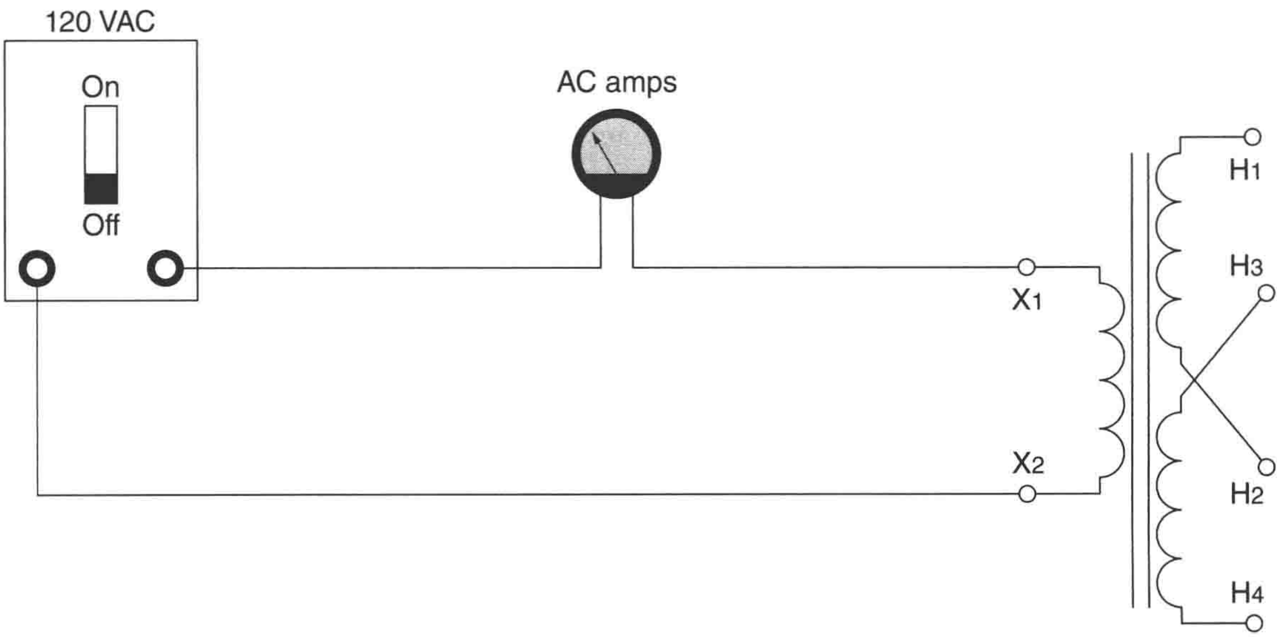


Figure 10-1 The secondary of a control transformer is used as an inductive load.

4. Measure the amount of current flow in the winding.

   ______________ amp(s)

5. **Turn off the power supply.**
6. Determine the total impedance of the inductor using the formula

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

   $Z =$ ______________ Ω

7. Now that the impedance and resistance are known, the inductive reactance of the inductor can be computed using the formula

$$X_L = \sqrt{Z^2 - R^2}$$

   $X_L =$ ______________ Ω

8. Now that the inductive reactance and resistance are known, the Q of the coil can be computed using the formula

$$Q = \frac{X_L}{R}$$

   $Q =$ ______________

9. The inductance (L) of the coil can be computed using the formula

$$L = \frac{X_L}{2\pi f}$$

   where $\pi = 3.1416$

   $f =$ Frequency (60)

   $L =$ ______________ henrys

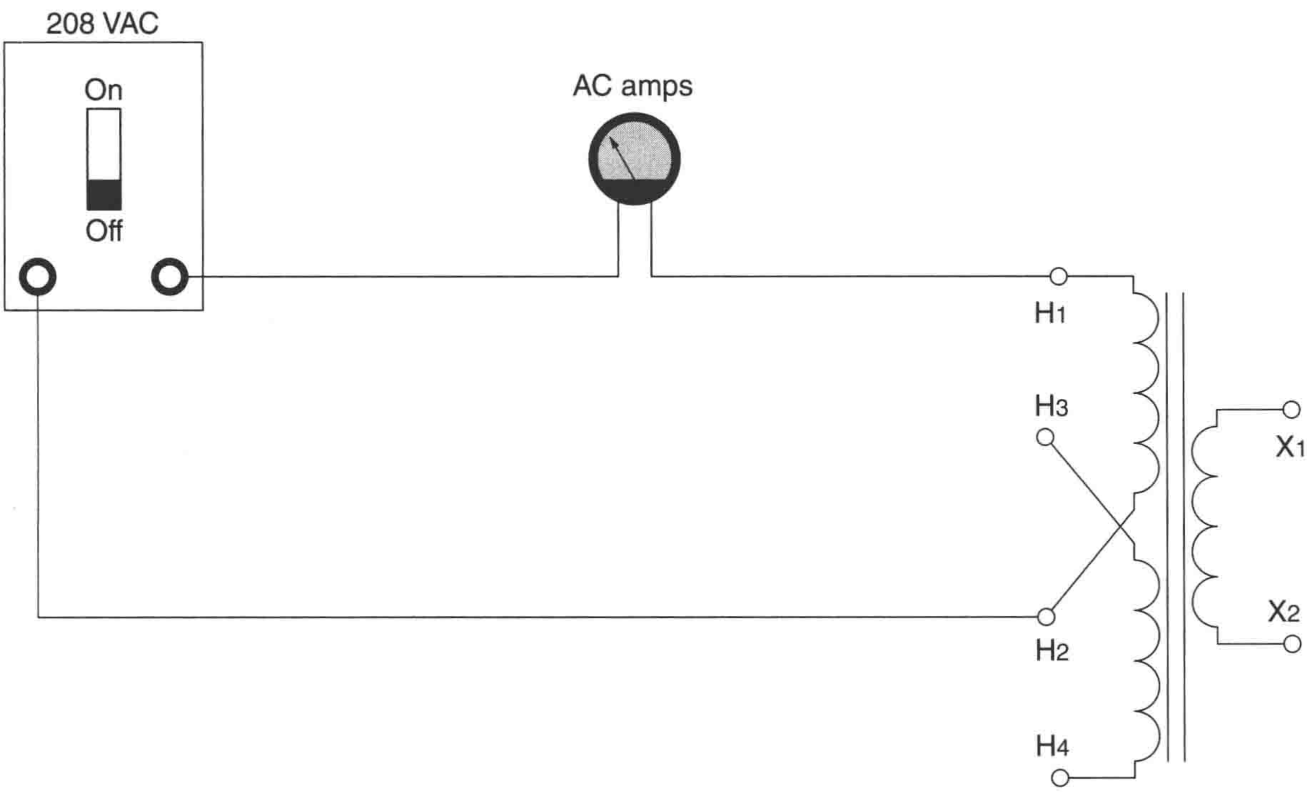


Figure 10-2 The high-voltage winding is connected to 208 volts.

10. Using an ohmmeter, measure the resistance between terminals H_1 and H_2 of the control transformer.

    _______________ Ω

11. Connect the circuit shown in Figure 10-2. Note that H_1 and H_2 are connected to a voltage of 208 VAC.
12. Turn on the power supply and measure the voltage applied to terminals H_1 and H_2 with an AC voltmeter.

    _______________ volts

13. Measure the current flow in the circuit with an AC ammeter.

    _______________ amp(s)

14. **Turn off the power supply.**
15. Using Ohm's law, determine the impedance of the winding.

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

    Z = _______________ Ω

16. Calculate the inductive reactance of the winding.

    $$X_L = \sqrt{Z^2 - R^2}$$

    X_L = _______________ Ω

17. Determine the Q of this inductor.

    $$Q = \frac{X_L}{R}$$

    Q = _______________

18. Calculate the inductance of the coil using the formula

$$L = \frac{X_L}{2\pi f}$$

L = _______________ henry

Inductors Connected in Parallel

When inductors are connected in parallel, the reciprocals of their inductance values add in a similar manner as parallel resistors.

$$L_T = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \frac{1}{L_N}}$$

Since inductive reactance is directly proportional to the amount of inductance in an AC circuit, the reciprocal of the total inductive reactance will be the sum of all the reciprocals of the individual inductive reactances in the circuit.

$$X_{L_T} = \frac{1}{\frac{1}{X_{L_1}} + \frac{1}{X_{L_2}} + \frac{1}{X_{L_3}} + \frac{1}{X_{L_N}}}$$

The next step in completing this experiment is to determine the characteristics of a second 0.5 kVA control transformer. The second transformer will be referred to as transformer #2 and the first transformer will be referred to as transformer #1 for the remainder of this experiment.

19. Using control transformer #2, connect the circuit shown in Figure 10-3.
20. Turn on the power supply and measure the voltage applied to the transformer.

_______________ volts

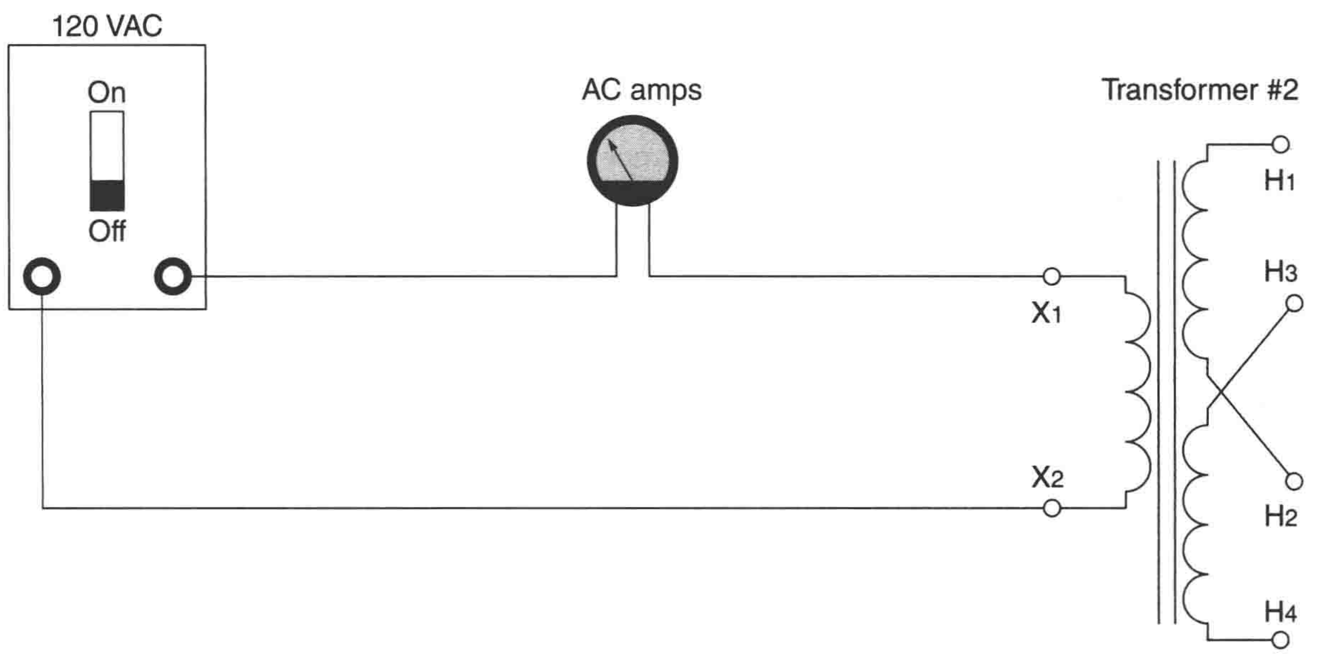


Figure 10-3 Determining the characteristics of the low-voltage winding for the second control transformer.

21. Measure the amount of current flow in the circuit.

_______________ amp(s)

22. Determine the inductive reactance of this winding. (Since it has been shown earlier in this experiment that the impedance and inductive reactance are practically the same, inductive reactance will be determined by using the formula $X_L = \frac{E}{I}$.)

X_L = _______________ Ω

23. Determine the inductance of this winding.

$$L = \frac{X_L}{2\pi f}$$

L = _______________ henry

24. **Turn off the power supply.**

25. Using both transformers, connect the circuit shown in Figure 10-4.

26. Determine the total inductance of the circuit by using the inductance value of winding X_1 and X_2 of transformer #1 as determined in step 9, and the inductance value of winding X_1 and X_2 of transformer #2.

L_T = _______________ henry

27. Calculate the value of X_L for the circuit shown in Figure 10-4. Use the value of L_T as calculated in step 26 for the value of L in the formula.

$$X_L = 2\pi f L$$

X_{L_T} = _______________ Ω

28. Assuming an applied voltage of 120 volts, calculate the amount of current that should flow in this circuit.

$$I_T = \frac{E}{X_{L_T}}$$

I_T = _______________ amp(s)

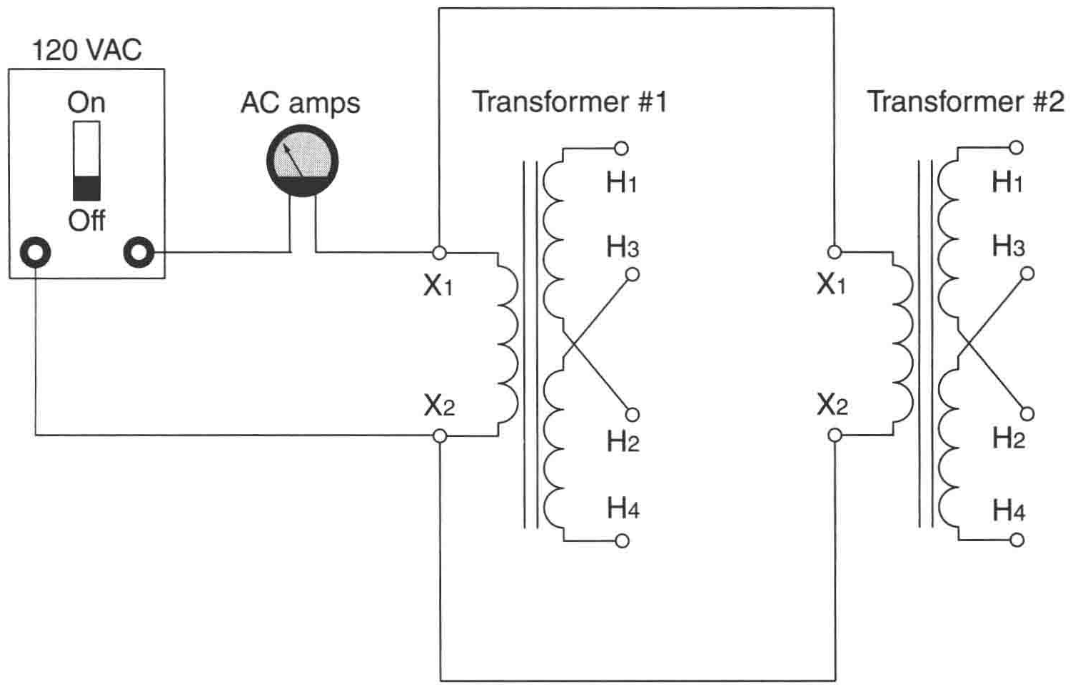


Figure 10-4 Parallel inductors.

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

    $I_{T(measured)}$ = ______________ amp(s)

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

Inductors Connected in Series

When inductors are connected in series, the total inductance is equal to the sum of the individual inductors.

$$L_T = L_1 + L_2 + L_3 + L_N$$

As with series-connected resistors, when inductors are connected in series, the inductive reactance of each inductor will be added together. Therefore, the total inductive reactance will be equal to the sum of all the inductive reactances.

$$X_{L_T} = X_{L_1} + X_{L_2} + X_{L_3} + X_{L_N}$$

31. Connect the circuit shown in Figure 10-5. Note that the power supply has changed to a 208-volt supply.
32. After the connection is completed, turn on the power supply and measure the circuit current.

    I = ______________ amp(s)

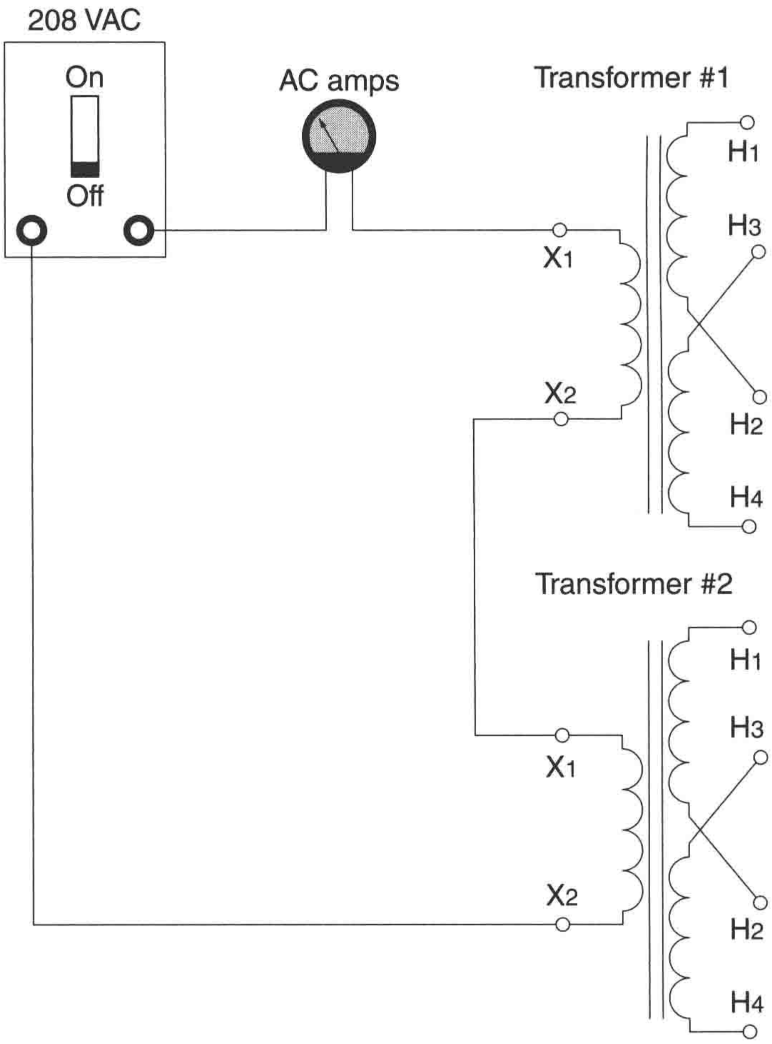


Figure 10-5 Series inductors.

33. Calculate the total inductive reactance of this connection using the current measured in step 32 and the circuit voltage.

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

X_{L_T} = _______________ Ω

34. Calculate the total inductance of the circuit using the calculated value of total inductive reactance.

$$L = \frac{X_L}{2\pi f}$$

L = _______________ henry

35. With an AC voltmeter, measure the amount of voltage across the X_1 and X_2 winding of transformer #1 (Figure 10-6).

$E_{(\text{Transformer \#1})}$ = _______________ volts

36. Use the measured voltage drop in step 35 and the measured current flow in step 32 to calculate the inductive reactance of this winding.

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

$X_{L(\text{Transformer \#1})}$ _______________ Ω

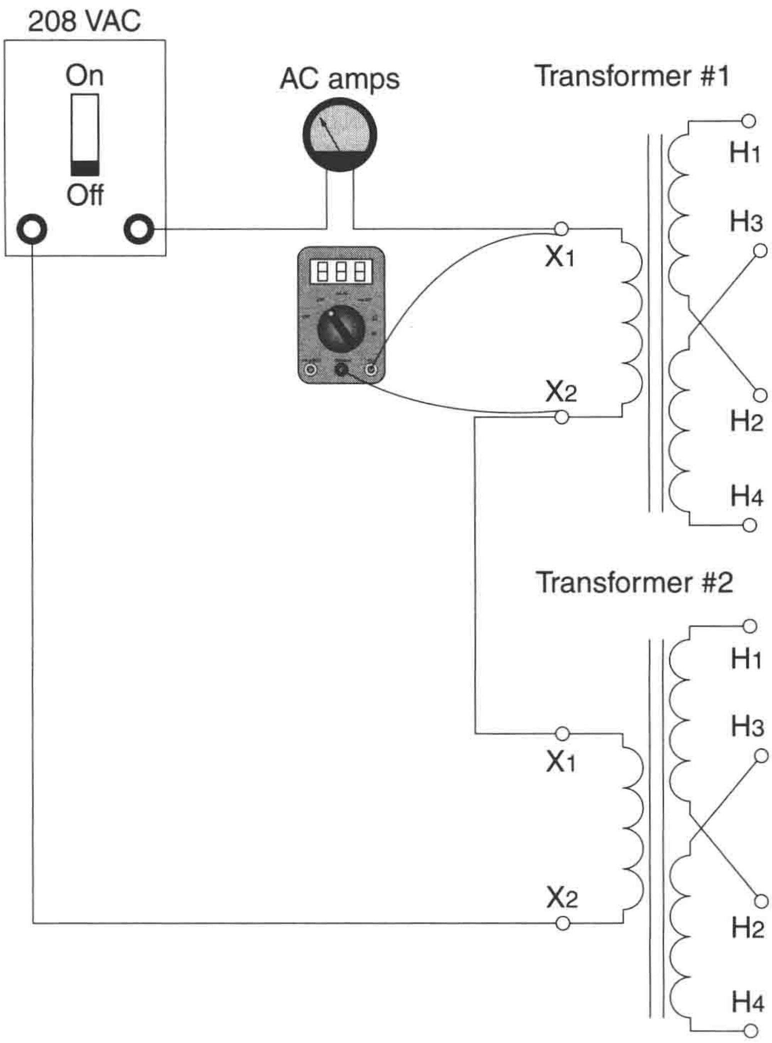


Figure 10-6 Measuring the voltage.

37. Using the value of X_L in step 36, calculate the value of inductance for this winding.

    $L_{(\text{Transformer \#1})}$ ________________ henry

38. With the AC voltmeter, measure the voltage drop across the X_1 and X_2 winding of transformer #2.

    $E_{(\text{Transformer \#2})}$ ________________ volts

39. **Turn off the power supply.**

40. Using the circuit current as measured in step 32, and the voltage drop measured in step 38, calculate the inductive reactance of the winding.

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

    $X_{L(\text{Transformer \#2})}$ ________________ Ω

41. Using the calculated value of inductive reactance for transformer #2, calculate the inductance of the winding for transformer #2.

$$L = \frac{X_L}{2\pi f}$$

    $L_{(\text{Transformer \#2})}$ = ________________ henry

42. Add the inductive reactance values of transformer #1 and transformer #2. Compare the sum with the calculated value of total inductive reactance in step 33. Are the two values approximately the same?

    ____

43. Add the values of inductance for transformer #1 and transformer #2. Compare the sum with the value of total inductance calculated in step 34. Are these two values approximately the same?

    ____

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

NOTE OF EXPLANATION

In some cases the values of inductance for the transformers may be different. For example, the value of inductance for transformer #1 was calculated in step 9 of this experiment. The inductance value for transformer #1 was calculated again in step 37. It is quite possible that these two values are different even if the same transformer was used to make both measurements. The reason for this difference is nonlinearity of the core material. As current flows through the windings of the transformer, the magnetic field causes "magnetic domains" or "magnetic molecules" to align. As more and more magnetic domains align themselves, the core approaches saturation. The closer the core material comes to saturation, the less magnetic effect it exhibits. The magnetic properties of the core material greatly affect the amount of inductance.

Review Questions

1. An inductor has an inductance of 0.65 henry and is connected to a 277 volt, 60 Hz power line. How much current will flow in this circuit? (Assume the wire resistance of the coil to be negligible.)

    ____

2. An ohmmeter is used to measure the wire resistance of a coil at 45 Ω. When connected to a 120 volt, 60 Hz AC circuit, there is a current flow of 1.5 amps. What is the inductive reactance of the coil?

____

3. A coil has an inductive reactance of 75 Ω and a wire resistance of 18 Ω. What is the Q of this coil?

____

4. As a general rule, for an inductor to be considered as a pure inductor, it should have a Q value of what or higher?

____

5. Three choke coils have inductances of 0.56 henry, 0.72 henry, and 0.43 henry. If these coils are connected in series, what would be total inductance of the circuit?

____

6. If the three choke coils in question 5 were to be connected in parallel, what would be the total circuit inductance?

____

7. An inductor is connected in a 240 volt, 60 Hz circuit. The circuit current is 2.5 amperes. If the frequency is changed to 400 Hz, how much current will flow if the voltage remains the same? (Assume the circuit to be a pure inductive circuit.)

____

8. An inductor has an inductive reactance of 124 Ω and a wire resistance of 44 Ω. What is the impedance of the inductor?

____

9. Three inductors are connected in series to a 480 volt, 60 Hz power source. The current flow in the circuit is 0.509 amp. Inductor #1 has an inductance of 1.3 henry, and inductor #2 has an inductance of 0.75 henry. What is the inductance of inductor #3? (Assume all inductors to be pure inductors.)

____

10. Three inductors are connected in a 208 volt, 60 Hz circuit. The circuit current is 1.2 amperes. Inductor #1 has an inductance of 1.2 henry, inductor #2 has an inductance of 1.6 henry, and inductor #3 has an inductance of 1.4 henry. Are these inductors connected in series or parallel?

____

Unit 11 Resistive-Inductive Series Circuits

Objectives

After studying this unit, you should be able to

- Discuss the voltage and current relationship in an RL series circuit.
- Determine the phase angle of current in an RL series circuit.
- Determine the power factor in an RL series circuit.
- Discuss the differences between apparent power, true power, and reactive power.

In an AC circuit containing pure resistance, the current and voltage are in phase with each other. This means that the voltage and current waveforms are identical as far as time is concerned (Figure 11-1). Both the current and voltage will be zero at the same time, both will reach their positive peak at the same time, and both will reach their negative peak at the same time. When the current and voltage are both positive or negative at the same time, volts times amps equals watts.

Watts

Watts is often referred to as true power. To understand true power, you must realize that electricity is a form of pure energy. Energy can be neither created nor destroyed, but its form can be changed. Watts is a measure of the amount of electrical energy changed into some other form. In the case of resistance, electrical energy is converted into thermal energy in the form of heat. In the case of a motor, electrical energy is converted into kinetic energy. There must be some form of energy conversion to have true power or watts.

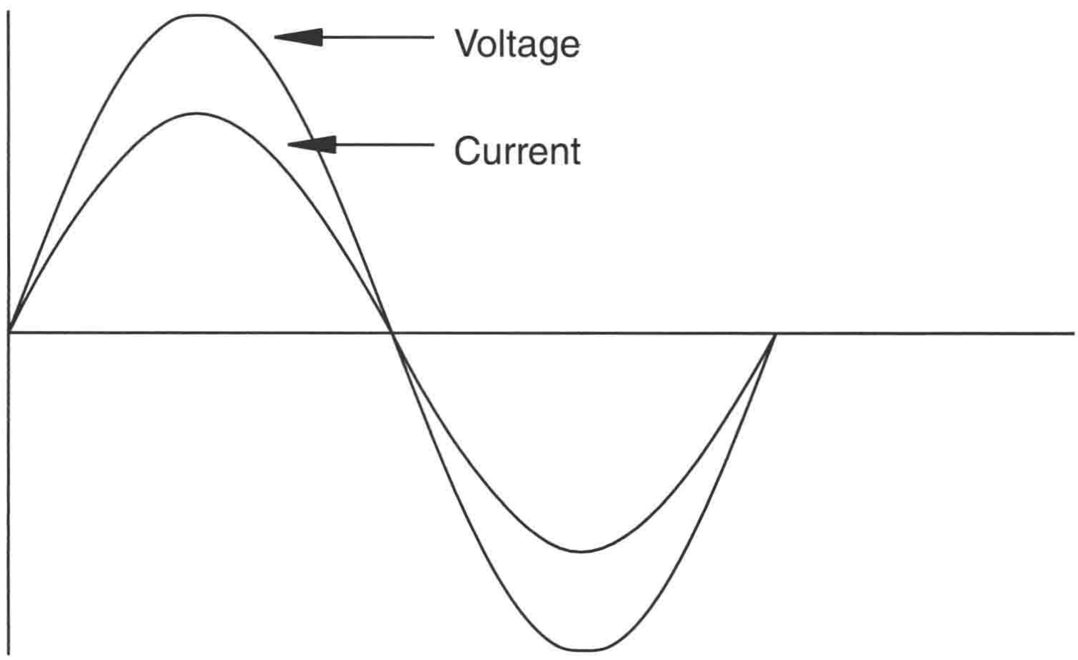


Figure 11-1 The current and voltage are in phase in a pure resistive circuit.

Inductance

In an AC circuit containing a pure inductive load, the current will lag the voltage by 90°, as shown in Figure 11-2. In a circuit of this type, there is no true power or watts because electrical energy is not converted into another form. During periods when the current and voltage are both positive or both negative, energy is stored in the form of an electromagnetic field. As current rises in the inductor, a magnetic field forms around the inductor. During periods when the voltage and current are opposite in polarity, the stored energy is given back to the circuit as the magnetic field collapses and induces a voltage back into itself. The only true power, or watts, in the circuit is caused by losses in the inductor, such as the resistance of the wire, eddy current losses caused by currents being induced into the core material, and hysteresis losses.

VARs

Another electrical term, VARs, is used to describe the power associated with a reactive load. VARs stands for "Volt Amperes Reactive." VARs is to a reactive circuit what watts is to a resistive circuit. Watts can be determined in a resistive circuit by multiplying the voltage drop across the resistor by the amount of current flow through the resistor ($E_R \times I_R$), or by the amount of current flow through the resistor by the resistance ($I_R{}^2 \times R$), or by dividing the voltage drop and the resistance $\left(\frac{E_R{}^2}{R}\right)$. VARs can be determined in a like manner except the inductive values are used instead of resistive values. VARs can be computed by multiplying the voltage drop across the inductor by the current flowing through the inductor ($E_L \times I_L$), or by the current and the inductive reactance of the inductor ($I_L{}^2 \times X_L$), or by the voltage and inductive reactance $\left(\frac{E_L{}^2}{X_L}\right)$.

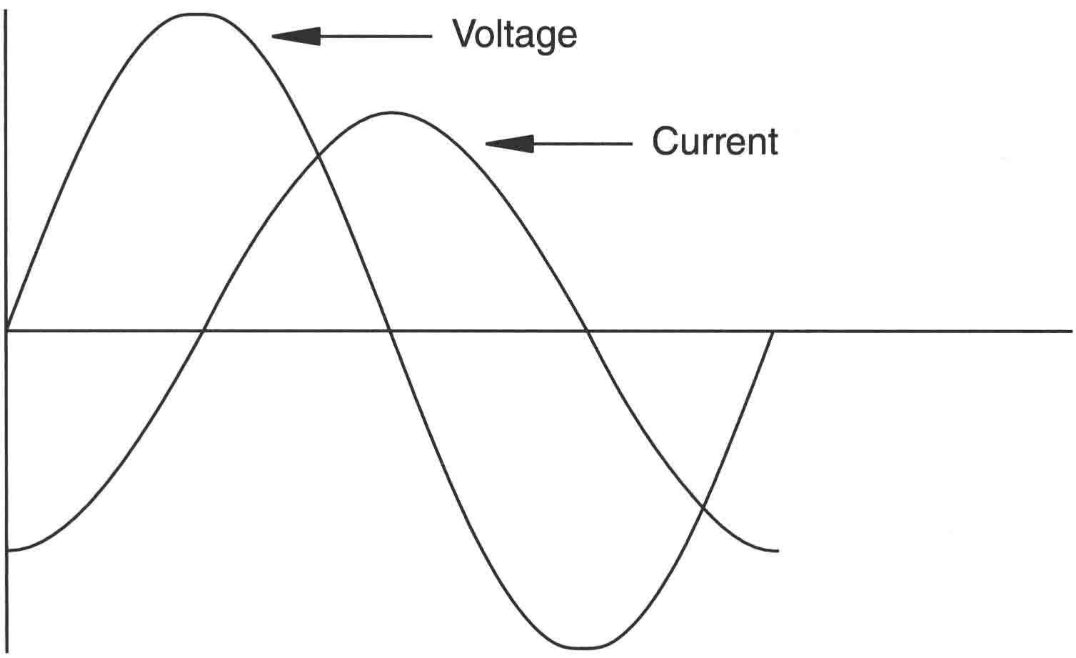


Figure 11-2 In a pure inductive circuit, the current lags the voltage by 90°.

Apparent Power (Volt Amps)

Another electrical quantity that is very similar to watts and VARs is volt amps (VA). Volt amps is generally referred to as apparent power because it is computed in a similar manner as watts and VARs, except that the applied or total circuit values are used instead of resistive or inductive value. Volt amps can be determined by multiplying the total or applied voltage by the total circuit current ($E_T \times I_T$), or by using the total current and circuit impedance ($I_T^2 \times Z$), or by using the applied voltage and impedance $\left(\frac{E_T^{\,2}}{Z}\right)$.

Angle Theta (∅)

When an AC circuit contains elements of both resistance and inductance, the voltage and current will be out of phase by some amount between 0° and 90°. The amount of out-of-phase condition is determined by the values of resistance and inductance and is expressed as angle theta (∅). The power factor is the cosine of angle theta. Angle theta can be computed using the formula $\cos \angle\varnothing = PF$.

Power Factor

Power factor is a ratio of the amount of true power or watts as compared to apparent power or volt amps. Power factor is expressed as a percent. Power companies become upset when the power factor drops to a low percent because they must supply more current than is actually being consumed. Assume that an industrial plant operates on 480 volts three-phase and that the apparent power is 250 kVA. Also assume that a watt meter indicates a true power of 200 kW. The power factor can be determined by dividing the true power by the apparent power.

$$PF = \frac{P}{VA}$$

$$PF = \frac{200{,}000}{250{,}000}$$

$$PF = 0.80 \text{ or } 80\%$$

This indicates that 80% of the supplied energy is actually being consumed. At the present time, the power company is supplying a current of 300.7 amperes.

$$I = \frac{VA}{E \times \sqrt{3}}$$

$$I = \frac{250{,}000}{480 \times 1.732}$$

$$I = 300.7 \text{ amps}$$

If the power factor were to be corrected to 100% or unity, the current would drop to 240.6 amperes.

$$I = \frac{P}{E \times \sqrt{3}}$$

$$I = \frac{200{,}000}{480 \times 1.732}$$

$$I = 240.6 \text{ amps}$$

Power factor correction will be discussed in a later unit.

Example Problem

A series circuit containing a resistor and inductor is shown in Figure 11-3. It is assumed the circuit is connected to 120 VAC with a frequency of 60 Hz. The resistor has a resistance of 24 Ω and the inductor has an inductive reactance of 32 Ω. The following values will be computed:

Z - Total impedance of the circuit

I_T - Total circuit current

E_R - Voltage drop across the resistor

P - True power or watts

E_L - Voltage drop across the inductor

L - Inductance of the inductor

$VARs_L$ - Reactive power

VA - Volt amps or apparent power

PF - Power factor

$\angle\varnothing$ - Angle theta (the angle or degree amount that the current and voltage are out of phase with each other)

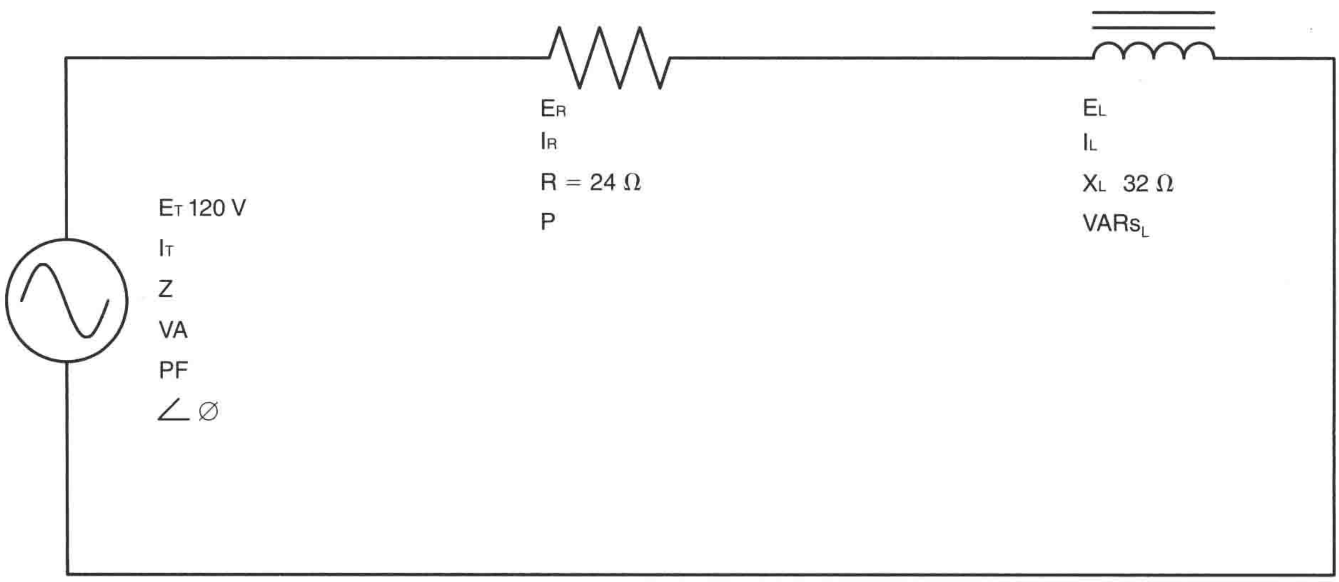


Figure 11-3 RL series circuit.