SECTION 2
Basic Electric Circuits

UNIT 6
Series Circuits

OUTLINE

KEY TERMS

Chassis ground
Circuit breakers
Earth ground
Fuses
Ground point
Series circuit
Voltage drop
Voltage polarity

Anticipatory Set

Prepare students for this lesson by first reviewing the previously learned formulas that will be used in this unit. These include I = E/R, E = I × R, and R = E/I. Review the role of resistors and, if needed, review the practice chart located at the end of Unit 5 and double-check for understanding.

Use the PowerPoint® slides that correspond with *Figures 6–1* through *6–25* on the overhead. Go over each of these carefully, calling on a different student for each blank that is to be filled in.

This is a pivotal point in the learning process. An accounting of all previously learned material is necessary in this unit. A complete working understanding of the material covered up through the end of this unit is crucial to moving forward.

State the objectives and ask for prior knowledge of, or experience with, circuits, circuit boards, and so on.

6-1 Series Circuits

Define a series circuit and remind students that this text bases explanations on the electron theory (have a student explain this theory). Explain how fuses and circuit breakers are used in a series circuit. Ask if anyone has experience with blowing out fuses or tripping circuit breakers (perhaps by plugging in one too many things). Explain why it is not a good idea to bypass these devices with foil, paper clips, pennies, and so on.

6-2 Voltage Drops in a Series Circuit

Define voltage drop, and use PowerPoint slides for *Figure 6–3* through *Figure 6–5* to help explain what this means. Go over each of these figures slowly, checking for understanding as you go.

6-3 Resistance in a Series Circuit

Explain how the total resistance is figured, and remind students that this is in a series circuit. Show this to the class, using the PowerPoint slides for *Figure 6–4* and *Figure 6–5*.

6-4 Calculating Series Circuit Values

Explain the three rules for calculating series circuit values, and refer to PowerPoint slide of *Figure 6–5*. To check for understanding, have students determine what amperage the current is flowing at in *Figure 6–5*. If needed, remind them that I = E/R. Also, have them figure the R_T for the same circuit. Use the PowerPoint slides for *Figure 6–6* and *Figure 6–7* to further illustrate this process. Be sure students understand that the $E_T = E_1 + E_2 + E_3$.

6-5 Solving Circuits

Explain briefly that with any series circuit, if at least two factors are given, the missing factor can be found using the rules for series circuits and Ohm's law. Explain each formula and have students fill in the missing numbers for *Figure 6–8* through *Figure 6–11.* This is an excellent way to test for understanding.

Be sure to explain why you used $P_1 = E_1 \times I_1$ with one set of factors, and $P_2 = E_2^2/R_2$ with another. Explain that the answer will be the same, but one formula is easier to use with decimals than the other. Also, as you progress you may need to do a brief algebra review to figure missing factors for circuits in *Figure 6–12* through *Figure 6–20.* For example, *Figure 6–17* provides P_T, and students will need to do some very basic math to solve for P_1. Show the students that once they have found P_1 and E_1, they can find I, which is a constant throughout a series circuit. To find I, they will need to remember that P = E × I. Write it out for your students on the board or overhead:

$P_1 = E_1 \times I_1$
$0.205 \text{ W} = 6.4 \text{ V} \times I_1$
$0.205 \text{ O}/6.4 \text{ V} = 6.4 \text{ V}/6.4 \text{ V} \times I_1$
$0.032 \text{ A} = I_1$

You may need to remind students that in an equation, whatever you do to one side of the equation, you must also do to the other side. The key here is that I is multiplied by 1, so the answer is simply I.

Have students fill in 0.032 for I_1, I_2, I_3, I_4, and I_T. They now have enough information, using Ohm's law and the three rules for figuring series circuit values, to fill in all the blanks. Prepare some circuits of your own, with just enough information to get them started, and have them do several practice circuit problems before advancing to voltage dividers.

6-6 Voltage Dividers

Explain what a voltage divider is and how it works. Refer to the PowerPoint slide for *Figure 6–22.* Have students draw this circuit, and fill in E_1, E_2, E_3, E_T; I_1, I_2, I_3, I_T; R_1, R_2, R_3, R_T; and P_1, P_2, P_3, P_T. Using 0.015-m for current and the formulas they have learned so far, they should be able to draw this circuit and fill in all the blanks. This is an excellent check for understanding and will let you know if anything needs to be retaught. Also, go over the metric conversion chart again.

6-7 The General Voltage Divider Formula

Explain and demonstrate the formula. Explain that it is closely related to the E-R-I triangle. Have students do some practice problems. As with all other formulas, have students copy this into the front of their notebooks. Also, cover the proper procedure for rounding off numbers. Explain why it is done and how to know whether to carry the answer beyond three places to the right of the decimal.

6-8 Voltage Polarity

Explain this principle, and use the PowerPoint slide for *Figure 6–22* to help illustrate what you are saying. Basic language such as, "the point closest to the negative terminal in any given set of points is always going to be more negative than the point farther away" seems like common sense, but use the PowerPoint slide to check for understanding anyway.

6-9 Using Ground as a Reference

Display the symbols for earth ground and chassis ground on the board or overhead, and explain the difference. Use the automobile chassis as an example of a chassis ground, as is done in the text. For an example of an earth ground, refer back to Unit 3 and the discussion of lightning rods.

Discuss above-ground voltage versus below-ground voltage, with ground serving a type of dividing line or common point of separation. Remind students that an above-ground voltage is positive in respect to ground, and that a below-ground voltage is negative in respect to ground.

Unit Round Up

Do the summary and review in the text orally to assess the students' level of understanding of this unit. Also, provide copies of the circuits chart located is question 1 of the practice problems at the end of the unit of the text for students to complete.

ANSWERS TO PRACTICAL APPLICATIONS

1. 2.88 Ω and 50 W (50 W/12 V = 4.167 A). In a series circuit, the total voltage drops must equal the applied voltage. Therefore, the resistor must have a voltage drop of 12 V (24 V – 12 V). (12 V/4.167 A = 2.88 Ω) (12 V × 4.167 A = 50 W)
2. No. The 100-Ω resistor will have a voltage drop of 114.3 V. (30 Ω + 80 Ω + 100 Ω = 210 Ω)(240 V/210 Ω = 1.143 A)(1.143 A × 100 Ω = 114.3 V)
3. The best meter to use is the voltmeter. The defective lamp can be found by measuring the voltage across each lamp. If the power is turned on, the full 480 volts will be across the defective lamp. The ohmmeter could be used, but it would require turning off the power and measuring the filament resistance of each lamp. This would, of course, be a safer approach, but the problem was to determine the *quickest* way of finding the defective lamp.
4. R_1 = 1.248 ohms and 8494.2 watts; R_2 = 0.267 ohms and 5252 watts.

   The first step is to determine the resistance of the armature at full load (250/165 = 1.515 Ω). Eighty-five percent of the full-load current is 140.25 amperes (165 × 0.85). The amount of resistance needed to obtain this value of current is 1.782 Ω (250/140.25). The ohmic value for resistor R_2 is the difference between the needed value and the armature resistance or 0.267 Ω (1.782 – 1.515). The power dissipation of resistor 2 is 5,252 watts ($140.25^2 \times 0.267$).

   To determine the ohmic value for resistor 1, determine the total resistance needed to limit the current to 50% of the full-load current value [(165 × 0.5 = 82.5 amperes) (250/82.5 = 3.03 Ω)]. The ohmic value for resistor 1 will be the difference between the needed value and the combined resistance value of resistor 2 and the armature (3.03 – 1.782 = 1.248 ohms). [The power dissipation for resistor 1 is 8,494.2 watts ($82.5^2 \times 1.248$).]

UNIT 7
Parallel Circuits

OUTLINE

7-1 Parallel Circuit Values
7-2 Parallel Resistance Formulas

KEY TERMS

Circuit branch	Load
Current dividers	Parallel circuits

Anticipatory Set

Review resistors, Ohm's law, and the rules of series circuits. Explain to students that Units 7 and 8 will call for them to be familiar with all the previously learned formulas and their applications. The new formulas learned in this unit will be used as well in Unit 8.

Instruct students to be ready to write notes concerning parallel circuits into their notebooks. Go over the unit objectives and make students aware of the key terms they will need to learn in this unit.

Prepare some blank parallel circuit diagrams, making them progressively more complex, for students to practice on. Fill in just enough information for the student to start with, and then have them use the formulas to fill in the blanks. These circuit diagrams make excellent warm-up exercises for Unit 7.

7-1 Parallel Circuit Values

Total Current

Define what a parallel circuit is, and either draw *Figure 7–1* on the board, or use the corresponding PowerPoint slide. Students need to *see* this definition, as well as hear it. Using this same slide, explain current adds. This is much easier to understand visually than it is verbally. Have students explain this concept back to you, using the slide as their guide.

Voltage Drop

Use PowerPoint slide 7.2 or draw *Figure 7–2* on the board, and point to the voltage across each branch of the circuit. Have students copy the rule for voltage drop into their notes. Compare this to a series circuit, where the amperage (I) is a constant throughout the circuit. So, if the E_T is known, then E_1, E_2, E_3 . . . E_n can be filled in immediately in a parallel circuit (as I can be, in a series circuit) because they will be the same as E_T.

Total Resistance

This may be a little difficult for students to grasp at first. Explain the rule, and use the water pump and holding tank example. Another example is a garden hose that has holes in it. Without the holes, the overall resistance to the flow of water through the nozzle is much higher than it will be when the hose has holes in it. Every time a new hole is made in the hose, the overall resistance drops again.

Ask students to visualize bending the hose to cut off the water flow. Now the resistance is high. When they open it back up and give the water another outlet (like a parallel circuit), then the overall resistance drops.

So, in a parallel circuit, since the voltage (the pusher of the current) stays constant, with less resistance but the same push, the rate of the flow of that current will increase. This increase is what leads to load. Be sure students can explain this complete process to you before moving on to Section 7-2.

7-2 Parallel Resistance Formulas

Resistors of Equal Value

Explain how the formula works, and emphasize that it can only be used when all resistors are of equal value.

Product over Sum

Go over this slowly, and work a few problems on the board for clarification. Be sure that students understand the substitution process when figuring the overall resistance. Have students do some of these on their own until they are comfortable with the formula.

Reciprocal Formula

Explain that this formula is ideal for situations when a missing resistance value prevents the individual from using the product-over-sum method. Go over this formula carefully, step by step. Have students use the formula to figure out the missing values for *Figure 7–15*. Remind students that once they have found any E value in the circuit, E is a constant in a parallel circuit. Also remind students of Ohm's law, and the R-E-I triangle. Have students draw them on their worksheets for easy reference.

Current Dividers

Explain this process and have students refer to *Figure 7–23* in the text. Take students step by step through the current divider formula. Show them the substitution process ($I_T \times R_T$ for E_T). Before allowing students to look at *Figure 7–25* and the solution, draw this circuit on the board and see if students grasp the substitution process, as well as the concept that I_x represents any location, for current, on the circuit. This applies to R_x as well.

Unit Round Up

Go over the summary in class. Spend as much time as is necessary doing the review, working out the sample problems, and having students fill in the Practice Problem chart. Remember, practice is the best way for students to learn and become comfortable with these processes.

ANSWERS TO PRACTICAL APPLICATIONS

1. Yes, the ceiling fan and light kit can be connected to the existing circuit. The total current draw becomes 11.2 A. (Existing fixture = 120 W or 1 A) (8.6 A – 1 A = 7.6 A) ((4) 60-W lamps = 2 A + 1.6 A for the fan = 3.6 A for ceiling fan and light kit) (7.6 A + 3.6 A = 11.2 A) (15 A × 0.80 = 12 A)
2. The circuit current will be 20.833 A (10,000 W/480 V). The minimum size circuit breaker would have to be not less than 26.041 A (20.833 A/0.8) or a 30-A breaker.
3. Yes, the mirror can be installed on the present circuit. Since the lighted mirror replaces the light fixture with the four 60-watt lamps, that fixture is omitted from the calculation [1000 watts (heater) + 180 watts (fan light fixture) + 320 watts (mirror lamps) = 1500 watts; (1500/120 = 12.5 amperes) 12.5 + 3.2 amps (fan motor) = 15.7 amperes total; 80% of 20 amperes = 16 amperes of continuous load].
4. 75 watts. Since the lamps are on all night, the load is continuous. Therefore, circuit current is limited to a maximum of 16 amperes (20 × 0.80). The maximum wattage is 1920 watts (120 × 16 = 1920 watts). Divide the maximum watts by the number of lamps (1920/24 = 80 watts). The largest standard lamp that can be used is 75 watts.

UNIT 8
Combination Circuits

OUTLINE

8-1 Combination Circuits
8-2 Solving Combination Circuits
8-3 Simplifying the Circuit

KEY TERMS

Combination circuit
Node
Parallel block
Redraw
Reduce
Simple parallel circuit
Trace the current path

Anticipatory Set

This unit could prove to be a very difficult one for some students. It will require a time frame sufficient to include plenty of practice time and algebra review time. As you progress through the unit and the combination circuits become more complex, provide some blank practice circuits for students to work on.

8-1 Combination Circuits

Have students trace, with their fingers, the path of the current as it leaves point A and travels to point B *(Figure 8–1)*. Identify what a node is, as part of a combination circuit, and define combination circuit.

8-2 Solving Combination Circuits

Review the rules for solving series circuits and the rules for solving parallel circuits. Have students make flash cards of these rules on 3 × 5 index cards to keep nearby while solving combination circuits.

8-3 Simplifying the Circuit

This is a crucial concept that must be fully understood in order for Unit 8 to be completed successfully. Go over the reciprocal formula again, and carefully walk students through the first two simpler examples. Then let them wrestle with *Figure 8–9* (or a similar practice example). Provide copies of *Figure 8–9* to students as work sheets. After they have had a reasonable amount of time to solve this circuit, have students explain each step (unless no one solved it, then you will need to solve it with them, and give them another one to try). Make sure that students understand both how to simplify the circuit into a series circuit **and** how to break the circuit back out into a combination circuit, solving for parallel values along the way.

ANSWERS TO PRACTICAL APPLICATIONS

1. Connect a 300-Ω resistor in parallel with the existing 300-Ω resistor. This produces a total resistance of 150 Ω. 150 Ω + 1000 Ω = 1150 Ω. Or, the existing 300-Ω resistor can be replaced with a single 150-Ω resistor.
2. 0.0313 A. The total resistance of the circuit is 2 kΩ (50 V/0.025 A = 2000 Ω). Since the first series resistor is 1000 Ω, the second must be 1000 Ω also. A 1500-Ω resistor connected in parallel with the 1000-Ω resistor equals 600 Ω. Added to 1000 Ω, the total resistance is 1600 Ω. 50 V/1600 Ω = 0.0313 A.
3. The resistance value is 5.139 ohms. The power rating is 3746.3 watts. The first step is to determine the impedance of the motor during starting (240/64 = 3.75 Ω). Next, determine 90% of the circuit rating (30 × 0.9 = 27 amperes). Determine the amount of resistance necessary to limit the circuit current to 27 amperes (240/27 = 8.889 Ω). Subtract the needed resistance from the motor impedance (8.889 – 3.75 = 5.139 Ω). Since the current is limited to 27 amperes, the power rating of the resistor is 3764.3 watts ($27^2 \times 3.139$).
4. The task can be performed in several ways.
   a. Install a transformer that can step the 240-volt service down to 120 volts. This could be accomplished with a 0.5-kVA transformer.
   b. Connect all lamp fixtures in parallel and install lamps rated for 240 volts. These can generally be purchased at electrical supply stores.
   c. Series connect two 120-volt 100-watt lamps. This would provide a voltage of 120 volts to each lamp. Parallel the two sets of series connected lamps.

   Any of these solutions will work. Of the three, installing a transformer is probably the best.

UNIT 9
Kirchhoff's Laws, Thevenin's, Norton's, and Superposition Theorems

OUTLINE

KEY TERMS

Kirchhoff's current law
Kirchhoff's voltage law
Norton's theorem
Superposition theorem
Thevenin's theorem

9-1 Kirchhoff's Laws

Distinguish between voltage and current applications, and demonstrate both of these in action. Have students trace the circuits in the examples given, reminding them that the assumption is that current flow moves from negative to positive. Explain the negative/positive relationship of current entering and leaving a resistor. Practice solving some circuits using Kirchhoff's law and emphasize why you would use these methods, rather than Ohm's law, in these situations. Let students practice using the rules of Kirchhoff's law as long as they need to in order to feel comfortable with the process.

9-2 Thevenin's Theorem

Explain how this works and, if possible, have a black box to use as a visual aid. Talk students through using Thevenin's theorem by doing several on the board. Have students take turns coming to the board and explaining the process. Remind students that they may still use series circuit and parallel circuit rules once a circuit has been simplified. Be sure to go over the Thevenin equivalent circuit.

9-3 Norton's Theorem

Explain how the theorem works, and when it is most helpful in solving combination circuits. Have students practice solving several problems using Norton's theorem. Distinguish it from Kirchhoff's law and Thevenin's theorem, discussing when one is more beneficial to use than the other. Compare the Norton equivalent circuit to the Thevenin equivalent circuit.

Current Sources

Explain the two different ways (voltage or current) that a power source can be identified. Students should be completely familiar, by now, with the V and A indicators for volts and amperes.

Determining the Norton Equivalent Circuit

Explain the process, describing the role of the short circuit as seen in *Figure 9–16*. Make sure students understand how to do this, why this process is useful, and where it will be used.

9-4 The Superposition Theorem

Explain that students will use in this next theorem the three algebraic processes they have already learned. Remind students that in this theorem, as in all the others, the key to simplifying the solving process is circuit reduction. Talk students through this process using circuit diagrams on the board or overhead. You may need to go through this several times before it is clear.

Unit Round Up

Do the summary together, in class. Assign the review for homework to be sure that students can use what they have learned in Unit 9 away from the classroom. Have students solve the practice circuit problems that follow the review questions. Go over all of these in class, having students explain what they did to achieve the answers they came up with. Review all new terms covered in Unit 9.

SECTION 3
Meters and Wire Sizes

UNIT 10
Measuring Instruments

OUTLINE

10-1 Analog Meters
10-2 The Voltmeter
10-3 Multirange Voltmeters
10-4 Reading a Meter
10-5 The Ammeter
10-6 Ammeter Shunts
10-7 Multirange Ammeters
10-8 The Ayrton Shunt
10-9 AC Ammeters
10-10 Clamp-On Ammeters
10-11 DC-AC Clamp-On Ammeters
10-12 The Ohmmeter
10-13 Shunt-Type Ohmmeters
10-14 Digital Meters
10-15 The Low-Impedance Voltage Tester
10-16 The Oscilloscope
10-17 The Wattmeter
10-18 Recording Meters
10-19 Bridge Circuits

KEY TERMS

Ammeter
Ammeter shunt
Analog meters
Ayrton shunt
Bridge circuit
Clamp-on ammeter
Current transformer
D'Arsonval movement
Galvanometers
Moving-coil meter
Multirange ammeters
Multirange voltmeters
Ohmmeter
Oscilloscope
Voltmeter
Wattmeter
Wheatstone bridge

Anticipatory Set

Have as many of these measuring devices as possible in your classroom. The combination of hearing the explanation of how they each work while watching them work is hard to beat as a teaching strategy.

Encourage students to take a few notes about each device, especially the ones they are not familiar with. Those that students are familiar with could be discussed first, especially if Units 8 and 9 were a little difficult. Having devices students are familiar with will allow them to feel that they already know something about the material to be covered in Unit 10. This type of atmosphere always lends itself to better learning.

Begin by going down the list of measuring devices named under Key Terms, and point to the ones you have available. If it is possible to do so, allow students to work these devices in class. As always, go over the unit objectives, and alert students to the key terms they will be responsible for in this unit.

SECTION
2

Basic Switch Connections

Unit 7 Single-Pole Switches

Answers to Review Questions

1. one
2. (1) They contain only two terminal screws. (2) The words “Off” and “On” are visible on the switch lever.
3. Single-pole, 3-way, and 4-way
4. 4 amperes ($12 - 8 = 4$)
5. A switch leg is an extension of the hot or ungrounded conductor.
6. Yes—The *NEC*® does not permit the switch to be placed in the neutral conductor.
7. The green screw connects to the bare copper grounding conductor.

Unit 8 3-Way Switches

Answers to Review Questions

1. 3
2. The terminal screw is generally a different color and the word “common” is often printed on the back of the switch.
3. (1) Connect the neutral to the light.
   (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.
4. Black
5. Refer to Figure IG-1A and Figure IG-1B for suggested connections.
6. The conductors should be reidentified with colored tape or paint.
7. Single-Pole Double-Throw

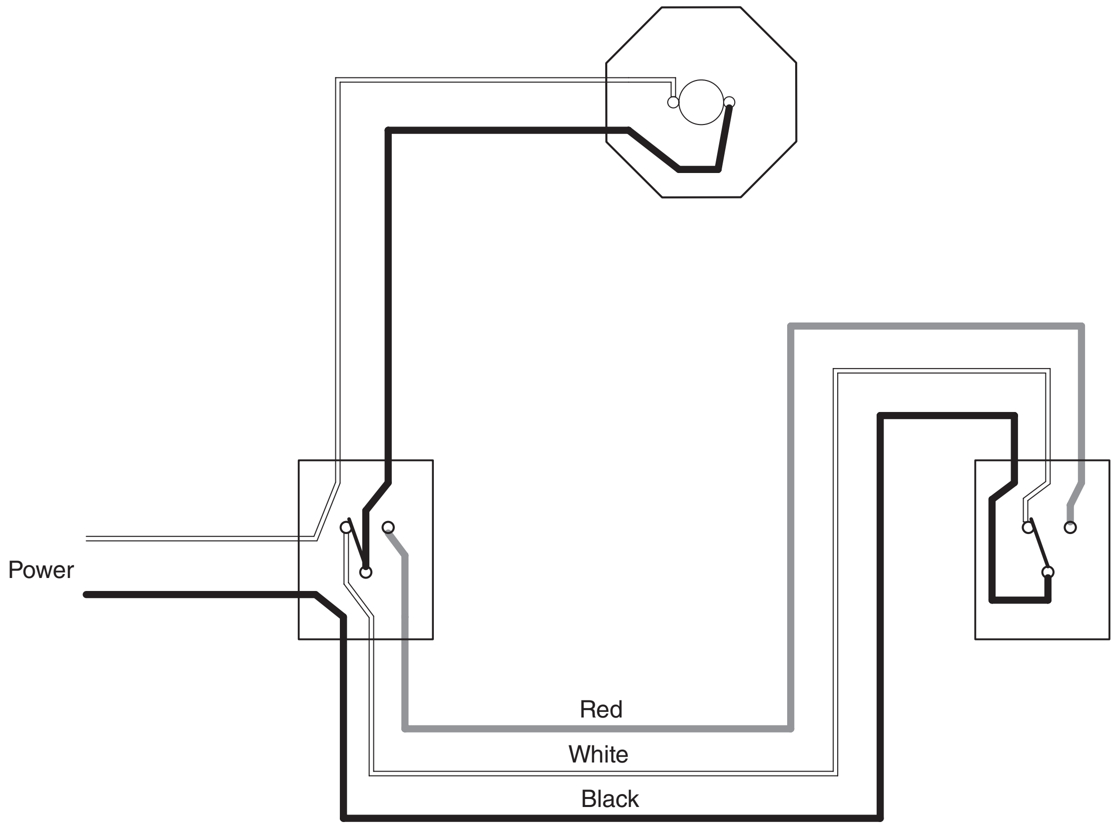

Figure IG-1A Suggested connection A.

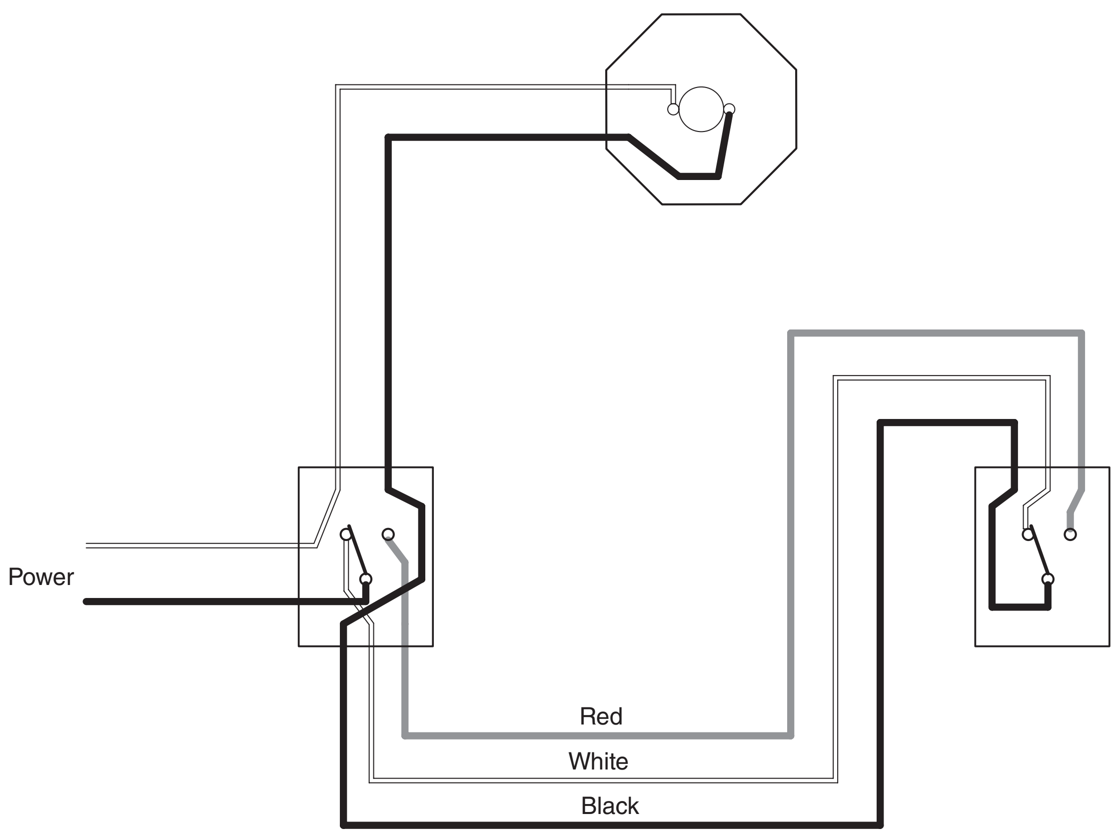

Figure IG-1B Suggested connection B.

Unit 9 4-Way Switches

Answers to Review Questions

1. 4
2. S_1: 0; S_3: 2; S_4: 6
3. (1) Connect the neutral to the light.
   (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.
4. Single-pole double-throw
5. The single-pole double-throw switch contains the words "OFF" and "ON" on the switch lever.
6. Refer to Figure IG-2A and Figure IG-2B for suggested connections.

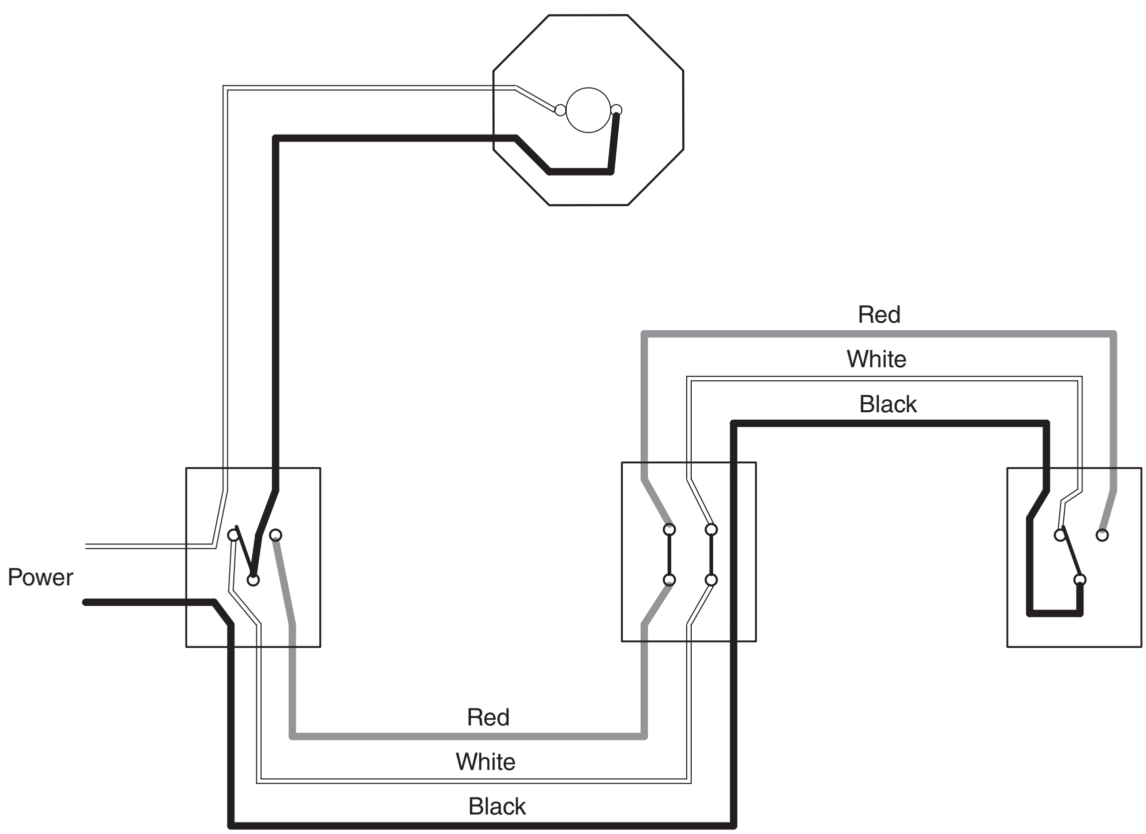

Figure IG-2A Suggested connection A.

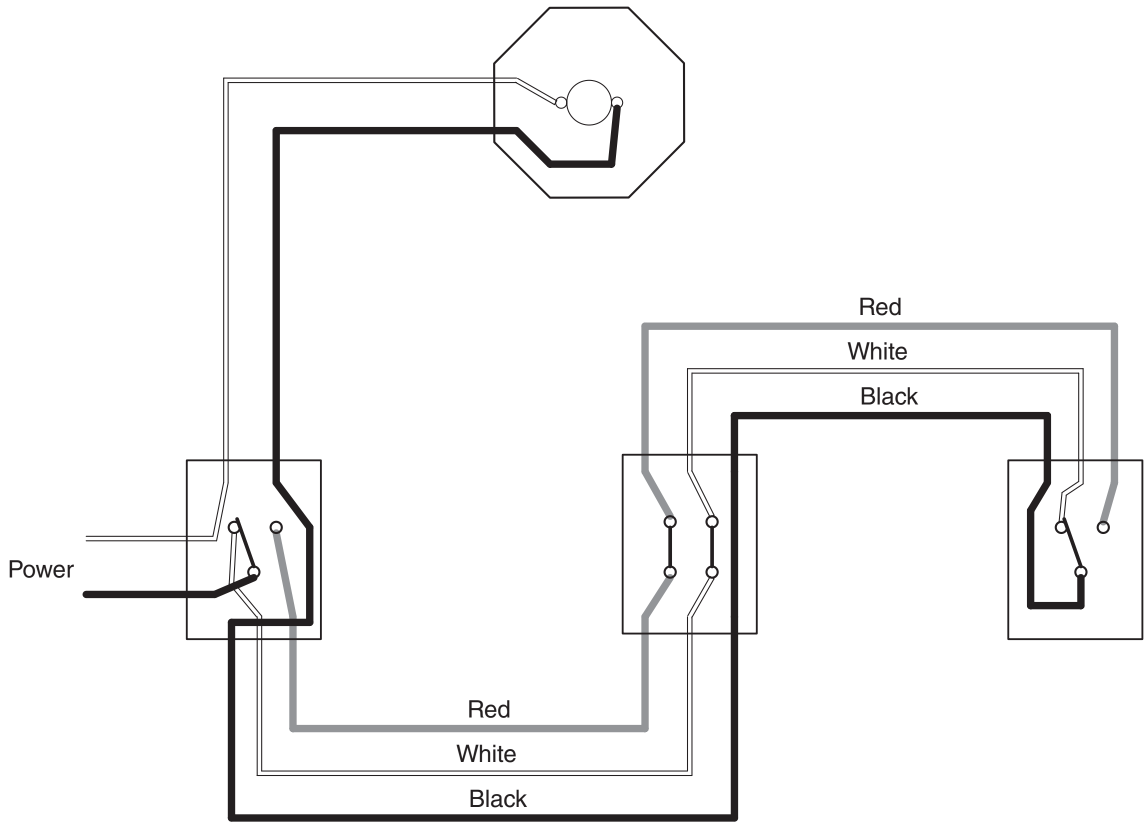

Figure IG-2B Suggested connection B.

SAFETY

1. Think
2. To prevent a current path from being established through the heart
3. 0.100–0.200 A
4. The heart vibrates at a high rate and does not pump blood to the rest of the body.
5. It causes the heart to contract and then relax.

EXERCISE 1

THE POWER SUPPLY

11.

Terminals	Voltage (volts)	AC/DC	Fix/Var (F) (V)	Current (amps)
1-2	208	AC	F	15
1-3	208	AC	F	15
2-3	208	AC	F	15
1-N	120	AC	F	15
2-N	120	AC	F	15
3-N	120	AC	F	15
4-5	208	AC	V	5
4-6	208	AC	V	5
5-6	208	AC	V	5
4-N	120	AC	V	5
5-N	120	AC	V	5
6-N	120	AC	V	5
7-N	120	DC	V	8
8-N	120	DC	F	2

13. No
14. 208 VAC
17. Upscale
19.

Terminals	Voltage (volts)	Fix/Var (F) (V)
1-2	208	F
1-3	208	F
2-3	208	F
1-N	120	F
2-N	120	F
3-N	120	F
4-5	208	V
4-6	208	V
5-6	208	V
4-N	120	V
5-N	120	V
6-N	120	V

23. 140 VDC
25. Yes
27. Yes
28. Polarity-sensitive
31. 145 VDC
33. Fixed
36. 0.4 A
37. 0.4 A

Review Questions

1. 15 A
2. 208 VAC
3. Variable
4. Fixed
5. 120 VAC
6. 2 ADC
7. DC
8. 5 AAC
9. Yes
10. Yes

EXERCISE 2

OHM'S LAW

3. 1.2 A
4. 144 W
6. 1.2 A
9. 2 A
10. 240 W
12. 2 A

Review Questions

1. 7.5 A
2. 900 W
3. 0.833 A
4. 144 Ω
5. 10 A

EXERCISE 3

SERIES CIRCUITS

3. 740 Ω
4. 740 Ω