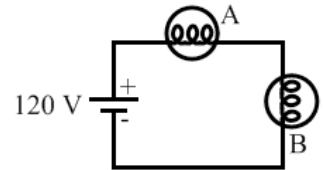


## End-of-Chapter Exercises

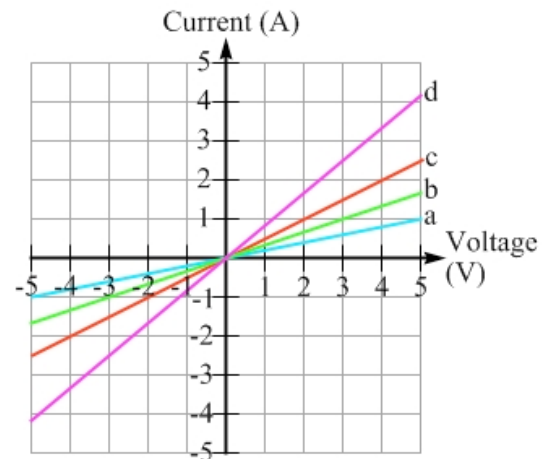
Exercises 1 – 12 are primarily conceptual questions designed to see whether you understand the main concepts of the chapter.

- You are responsible for running the lift at a ski hill, and you can adjust the speed of the lift so there is a smooth flow of skiers up and down the hill. The ski patrol notifies you that one of the trails down the hill (which is in parallel with other trails) needs to be closed temporarily because of an accident. Should you adjust the speed at which the lift carries skiers up the hill? Justify your answer based on an analogy with a circuit.
- Many people think that current gets used up in a circuit, and that in a circuit like that in Figure 18.28, the current through bulb A is different from that through bulb B. (a) Is that true? (b) Use an analogy, such as the fluid analogy or the ski-hill analogy from Section 18.3, to justify your answer to part (a). (c) What gets used up in a circuit?



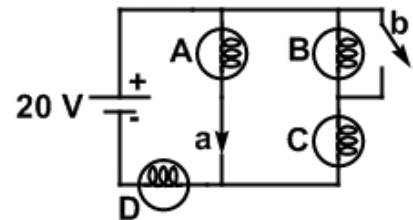
**Figure 18.28:** A circuit with two light bulbs, A and B, and a battery, for Exercise 2.

- You have two resistors. You connect one resistor to a variable power supply (like a battery with a variable emf) and measure the current through it as a function of the potential difference across it. You repeat the process with the second resistor. You then repeat the process with the two resistors connected in parallel, measuring the total current in the circuit as a function of the potential difference across the parallel combination, and do it all a fourth time with the two resistors in series. (a) Which graph in Figure 18.29 goes with which process? (b) What is the resistance of each of the two resistors?



**Figure 18.29:** Graphs of current vs. potential difference for the situations described in Exercises 3 and 4.

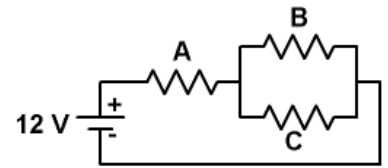
- Four identical light bulbs are arranged in the circuit in Figure 18.30, connected to a 20-volt battery. There are also two switches in the circuit. Switch *a*, in series with bulb A, is initially closed, while switch *b*, in parallel with bulb B, is initially open. Assume that the resistance of each bulb is the same no matter how much current passes through it at all times, that the switches have negligible resistance when they are closed, and that the battery is ideal (no internal resistance). If switch *b* is then closed (and switch *a* remains closed) what happens to the brightness of (a) bulb A? (b) bulb B? (c) bulb C? (d) bulb D?



**Figure 18.30:** A circuit consisting of four identical light bulbs, two switches, and a 20-volt battery. For Exercises 5 – 7.

6. Return to the system described in Exercise 5 and shown in Figure 18.30. In what position should the two switches be to maximize the brightness of (a) bulb A? (b) bulb B? (c) bulb C? (d) bulb D?
7. The four bulbs in Figure 18.30 are identical. Rank the bulbs based on their brightness, from brightest to dimmest, if (a) both switches are closed, (b) switch *a* is closed and switch *b* is open, (c) switch *a* is open and switch *b* is closed, (d) both switches are open.

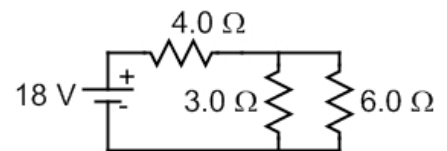
8. As shown in Figure 18.31, three resistors are connected in a circuit with a 12-volt battery. The resistance of resistor C is neither zero nor infinite, but its exact value is unknown. Resistor A has a resistance of  $4.0\ \Omega$ . Resistor B has a resistance of  $3.0\ \Omega$ . (a) Can you say which resistor has the most current through it, or does that depend on the resistance of resistor C? If so, which resistor has the most current through it? (b) Is it possible to rank the resistors based on the potential difference across them? If so, rank them from largest to smallest.



**Figure 18.31:** A circuit with three resistors and a 12-volt battery, for Exercises 8 and 9.

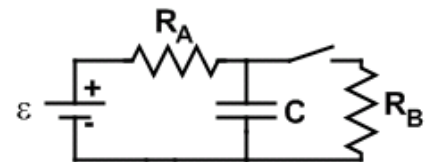
9. Return to the situation shown in Figure 18.31, and described in Exercise 8. If the resistance of resistor C is increased, what happens to the current through (a) resistor A? (b) resistor B? (c) resistor C? (d) the battery? If the current through the battery is  $2.0\ \text{A}$ , what is the resistance of resistor C?

10. Consider the circuit from Essential Question 18.8, which is redrawn in Figure 18.32. (a) Is it possible to add a  $5.0\ \Omega$  resistor to the circuit so that the current through at least one of the original resistors increases? (b) If not, explain why not. If so, determine how many ways there are to do this, draw a circuit diagram for each and, in each diagram, circle the resistor(s) with the increased current.



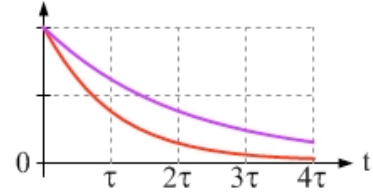
**Figure 18.32:** A circuit consisting of three resistors and an 18-volt battery, for Exercise 10.

11. Consider the RC circuit shown in Figure 18.33. The battery has an emf of  $18\ \text{V}$ ; and resistor A has a resistance of  $3.0\ \text{ohms}$ . At  $t = 0$  the capacitor is uncharged. At some time later, when the potential difference across the capacitor is  $3.0\ \text{V}$ , the switch is closed. This brings resistor B, with a resistance of  $6.0\ \text{ohms}$ , into the circuit. Immediately after the switch is closed, determine: (a) the potential difference across resistor B, (b) the current through resistor A, (c) and the current through resistor B. (d) Describe the effect of closing the switch on the capacitor. In particular, does the rate at which it is charging change? (e) What is going on in the circuit a long time after the switch is closed?



**Figure 18.33:** An RC circuit consisting of a battery, resistor, and capacitor, along with a second resistor that can be added to the circuit by closing a switch. For Exercise 11.

12. A series RC circuit consists of a resistor, a capacitor that is initially uncharged, and a battery. Two graphs are shown for this situation in Figure 18.34. The lower graph is for the initial situation. The upper graph is for a second trial in which either the resistance or the capacitance has been changed. (a) If the graph shows the potential difference across the resistor as a function of time, as the capacitor charges, what was changed before the second trial, the resistance or the capacitance? Explain, and state whether the resistance or capacitance was increased or decreased. (b) Repeat part (a), but now the graph shows the current in the circuit as a function of time, as the capacitor charges, instead.



**Figure 18.34:** The graph shows either the current or the resistor voltage, as a function of time, for a series RC circuit in which the capacitor charges. For Exercise 12.

**Exercises 13 – 19 deal with current, batteries, and resistance.**

13. At a particular point, there is a current  $I$  associated with  $N$  protons flowing past the point in a time  $T$ . Which of the following changes, done individually (not sequentially) corresponds to a doubling of the current? Justify each answer. (a) The velocity of the protons is doubled, so  $N$  protons flow past in a time of  $T/2$ . (b) The number of protons flowing past in the time  $T$  is doubled. (c) Electrons are added to the system so that  $N$  protons and  $N$  electrons, all flowing the same way, pass by in a time  $T$ . (d) The protons are replaced by positive ions that each have a charge of  $+2e$ , flowing past at the same rate the protons were.
14. A current of 2.0 A is directed to the right past a particular point in a circuit. (a) If the charges flowing are electrons, in what direction are the electrons flowing? (b) Assuming all the electrons flow past in the same direction, how many electrons flow past every second? (c) Do all the electrons really flow past in the same direction? If not, what does the answer to part (b) represent?
15. A particular battery is rated at 2800 milliamp-hours. (a) What kind of unit is the milliamp-hour? (b) If this battery is powering a digital camera, which uses a current of 600 mA, how long will the battery last?
16. The wire connecting a wall switch to an overhead light is 2.4 m long. When the light is turned on there is a net flow of electrons in one direction along the wire; in other words, there is a current in the wire. This net flow is actually rather slow. In this case let's say the average speed of the electrons is 0.20 mm/s (this is known as the drift speed). (a) Based on this, what is the average time it takes an electron at the switch to reach the light bulb filament when the switch is closed (and assuming the electrons flow in that direction!)? (b) In your experience, how long does it take the bulb to come on when you close the switch? (c) How do you reconcile the answers from parts (a) and (b)?
17. A particular wire has a circular cross-section and a resistance  $R$ . The wire is then "drawn out" – stretched – until it is four times longer but has the same volume as before. (a) Has its resistance increased, decreased, or stayed the same? (b) What is the resistance of the wire now, in terms of  $R$ ?
18. A nichrome wire has a length of 2.5 m. How long should a copper wire be to have the same resistance as the nichrome wire? The wires have the same cross-sectional area.

19. We can construct a resistor with a resistance that does not change with temperature by joining a material with a positive temperature coefficient to a material with a negative temperature coefficient, if we choose the parameters correctly. For instance, let's say we want to make a resistor with a total resistance of 100 ohms. We will do this by joining together, end-to-end, a length of copper wire (copper has a temperature coefficient of  $+0.0068/^\circ\text{C}$ ) and a length of carbon wire (carbon has a resistivity of  $3.0 \times 10^{-4} \Omega \text{ m}$  and a temperature coefficient of  $-0.00050/^\circ\text{C}$ ). If each wire has a circular cross-section with a radius of 1.25 mm, and we want the resistance to be 100 ohms even if the temperature fluctuates, how long should the two pieces of wire be?

**Exercises 20 – 25 deal with resistors in series or resistors in parallel.**

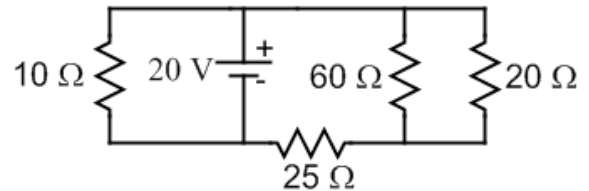
20. **Application: a three-way light bulb.** One way to make a three-way light bulb (a bulb that shines with three different brightnesses, depending on the position of a switch) is to allow connections to the bulb filament so that when the switch is in position 1 the 120 V from the wall socket is connected across the entire filament; in position 2 the 120 V is connected across 40% of the length of the filament; and in position 3 the 120 V is connected across the remaining 60% of the length of the filament. Assume the filament has a uniform cross-section, and that the resistance of the filament is independent of the filament's temperature. (a) Rank the switch positions based on the brightness of the bulb, from brightest to dimmest. (b) If the bulb dissipates 150 W when the switch is in position 2, how much power is dissipated in the other two switch positions?
21. **Application: another three-way light bulb.** A second way to make a three-way light bulb is to have two different filaments. In switch position 1, the wall socket voltage is across one filament, which dissipates 50 W. In position 2, the voltage is across the second filament, which dissipates 100 W. In position 3, the voltage is across both filaments in parallel. (a) What is the resistance of the 50-W filament? (b) What is the resistance of the 100-W filament? (c) What is the equivalent resistance of the two filaments when they are in parallel? (d) What is the power dissipated when the switch is in position 3?
22. You have three identical resistors, one battery, and a number of wires. (a) Show how you can connect the resistors and the battery in a circuit so that the currents through the three resistors are equal (and non-zero!). Is there more than one way to accomplish this? (b) Show how you can connect the resistors and the battery in a circuit so that the current through one of the resistors is twice as large as that through each of the other two resistors. Is there more than one way to accomplish this?
23. You have five identical resistors. You connect one or more of the resistors in some way between point A and point B; one or more in some way between point B and point C; and one or more in some way between point C and point D. There are no other connections between the points, which are all along a straight line in alphabetical order. You then measure the resistance between points A and B to be  $5 \Omega$ , between points B and C to be  $10 \Omega$ , and between points C and C to be  $20 \Omega$ . (a) Find the resistance of each resistor. (b) Sketch a diagram showing how the resistors are connected.
24. You have two identical resistors that are in parallel with one another. When a third identical resistor is wired in parallel with the first two, the equivalent resistance of the set of resistors changes by  $6.0 \Omega$ . (a) Does the equivalent resistance increase or decrease? (b) What is the resistance of one of these resistors?

25. You have  $N$  identical resistors connected in series with a 12-volt battery. The current through each resistor is 0.50 A. When one more resistor, identical to the others, is added to the circuit, in series, the current through each resistor drops to 0.40 A. (a) What is  $N$ ? (b) What is the resistance of each resistor?

**Exercises 26 – 36 involve series-parallel combination circuits.**

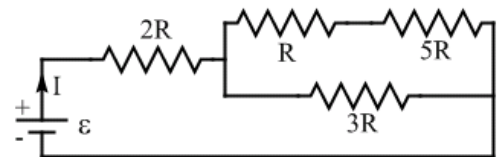
26. You have three resistors, with resistances of  $23\ \Omega$ ,  $47\ \Omega$ , and  $100\ \Omega$ . By using one, two, or all three, list the different equivalent resistance values can you create with these resistors.

27. As shown in Figure 18.35, four resistors are connected in a circuit with a 20-volt battery. (a) Identify two resistors that are either in series or in parallel, and replace them by a single equivalent resistor. Re-draw the circuit. (b) Repeat part (a) twice more until the circuit has been reduced to a single equivalent resistor. (c) Apply Ohm's Law to find the total circuit current. (d) Reverse the order of the steps in the contraction, and expand the circuit back to its original configuration. At each step in the expansion, draw the circuit diagram and label the current through each resistor. Also, label the potential at various points in the circuit, relative to  $V = 0$  at the negative terminal of the battery.



**Figure 18.35:** Four resistors are connected to a battery that has an emf of 20 V. For Exercise 27.

28. Four resistors are connected to a battery that has an emf of  $\epsilon$ , as shown in Figure 18.36. The battery has a current  $I$  passing through it, and provides a total power  $P$  to the circuit. State whether each of the following statements is true or false, and explain your answer. (a) The sum of the currents through the four resistors is equal to  $I$ . (b) The sum of the potential differences across the four resistors is equal to  $\epsilon$ . (c) The sum of the power dissipated in the four resistors is equal to  $P$ .

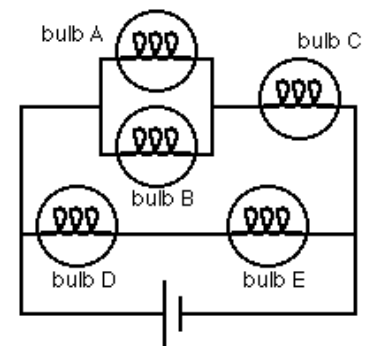


**Figure 18.36:** Four resistors are connected to a battery that has an emf of  $\epsilon$ . For Exercises 28 and 29.

29. Four resistors are connected to a battery that has an emf of  $\epsilon$ , as shown in Figure 18.36. (a) What is the equivalent resistance of the circuit, in terms of  $R$ ? (b) What fraction of  $I$ , the current through the battery, passes through the  $5R$  resistor? (c) Rank the resistors based on the current through them, from largest to smallest. (d) Rank the resistors based on the potential difference across them, from largest to smallest.

30. Figure 18.37 shows five identical light bulbs in a circuit with a battery. Rank the bulbs based on their brightness, from brightest to dimmest.

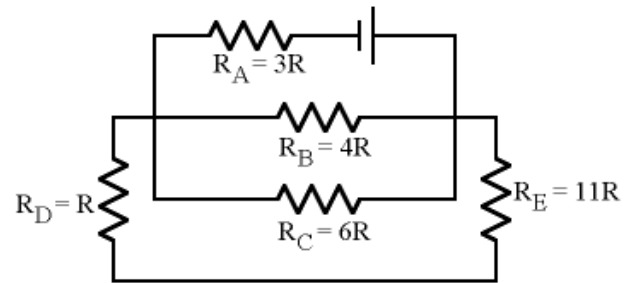
31. Figure 18.37 shows five identical light bulbs in a circuit with a 120-volt battery. Each bulb dissipates 150 W of power if it has a potential difference of 120 V across it. Assume that the resistance of each bulb stays the same no matter what the current is through the bulb. (a) What is the



**Figure 18.37:** Five identical light bulbs are placed in a circuit with a battery. For Exercises 30 and 31.

resistance of one of these bulbs? (b) Is the total power dissipated in this circuit more than or less than 150 W? Justify your answer without explicitly calculating the power. (c) Find the power dissipated in each bulb, and the total power dissipated in the circuit.

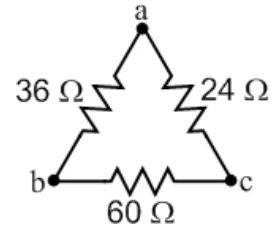
32. Five resistors are wired in a circuit with a single battery, as shown in Figure 18.38. (a) Is resistor A connected in series with resistor B, in parallel with resistor B, or neither? Explain. (b) Rank the resistors based on the current through them, from largest to smallest.



**Figure 18.38:** Five resistors are wired in a circuit with a single battery. For Exercises 32 and 33.

33. Five resistors are wired in a circuit with a single battery, as shown in Figure 18.38. (a) In terms of  $R$ , what is the equivalent resistance of the circuit? (b) If the current through resistor D is  $I_D$ , find the current through each of the other resistors, in terms of  $I_D$ . (c) Rank the resistors based on the potential difference across them, from largest to smallest.

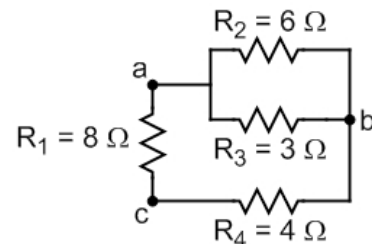
34. Three resistors are connected in an equilateral triangle, as shown in Figure 18.39. A battery is connected to this set of resistors so that its positive terminal is connected by a wire to one of the lettered points, and the negative terminal is connected to another of the lettered points. Consider the following three cases:



- Case 1: Positive terminal connected to a; negative terminal to b.  
Case 2: Positive terminal connected to a; negative terminal to c.  
Case 3: Positive terminal connected to b; negative terminal to c.  
Find the equivalent resistance of the circuit in (a) case 1, (b) case 2, and (c) case 3.

**Figure 18.39:** Three resistors connected in an equilateral triangle, for Exercise 34.

35. Four resistors are connected together in the configuration shown in Figure 18.40. A battery is connected to this set of resistors so that its positive terminal is connected by a wire to one of the lettered points, and the negative terminal is connected to another of the lettered points. Consider the following three cases:



- Case 1: Positive terminal connected to a; negative terminal to b.  
Case 2: Positive terminal connected to a; negative terminal to c.  
Case 3: Positive terminal connected to b; negative terminal to c.  
Rank these cases based on (a) their equivalent resistance; (b) the magnitude of the current through the 4 Ω resistor; (c) the magnitude of the potential difference across the 8 Ω resistor.

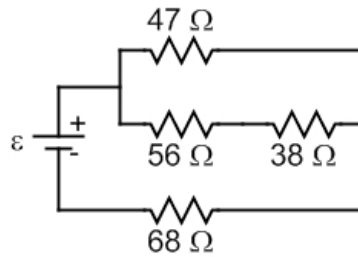
**Figure 18.40:** Four resistors, and three possible locations the terminal of a battery can be connected to. For Exercises 35 and 36.

36. Return to the situation described in Exercise 35, and shown in Figure 18.40. In which of the cases is (a)  $R_2$  in parallel with  $R_3$ ? (b)  $R_1$  in series with  $R_4$ ? (c)  $R_1$  in series with the combination of  $R_2$  and  $R_3$ ? Explain your answer.



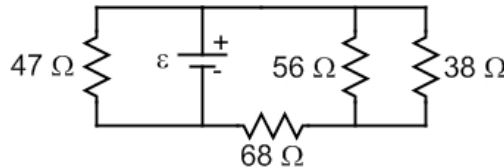
**Exercises 37 – 43 deal with Kirchoff's Rules and multi-loop circuits.**

37. If the current through the  $56\ \Omega$  resistor in Figure 18.41 is 95 milliamps, what is the emf of the battery?



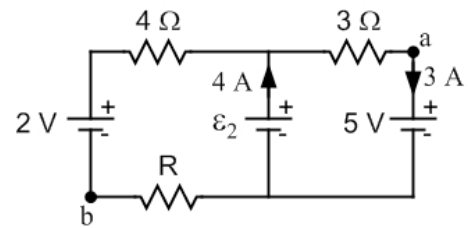
**Figure 18.41:** Four resistors connected in a circuit with a battery of unknown emf, for Exercise 37.

38. The four resistors from Exercise 37 are connected in a different circuit with a different battery, of unknown emf, as shown in Figure 18.42. If the potential difference across the  $56\ \Omega$  resistor is 3.2 V, what is the emf of this battery?



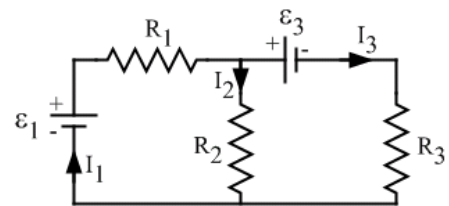
**Figure 18.42:** Four resistors connected in a circuit with a battery of unknown emf, for Exercise 38.

39. Three batteries are connected in a circuit with three resistors, as shown in Figure 18.43. The currents in two of the branches are known and marked correctly on the diagram. (a) Determine the magnitude and direction of the current through the 2-volt battery. (b) Find the emf of the battery in the middle branch of the circuit. (c) Find the value of the resistance  $R$  of the resistor at the bottom left. (d) What is the potential difference,  $V_a - V_b$ , between points  $a$  and  $b$  in the circuit?



**Figure 18.43:** A multi-loop circuit, for Exercise 39.

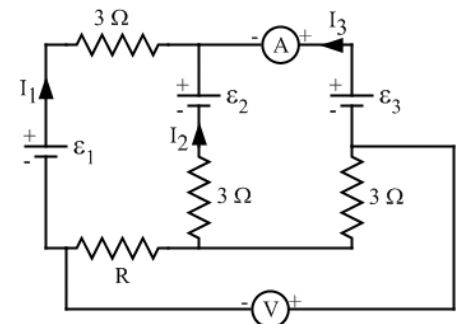
40. The multi-loop circuit in Figure 18.44 is made up of three resistors and two batteries. The various currents in the circuit are labeled. (a) Write out the junction rule at one junction in the circuit. (b) Show that applying the junction rule at the other junction results in the same equation. (c) Apply the loop rule to the inside loop on the left to obtain a loop equation. (d) Apply the loop rule to the inside loop on the right to obtain another loop equation. (e) Apply the loop rule to the outside loop to obtain a third loop equation. (f) Show that one of your loop equations can be obtained by either adding or subtracting the other two loop equations.



**Figure 18.44:** A multi-loop circuit consisting of three resistors and two batteries. For Exercises 40 and 41.

41. Return to the situation described in Exercise 40 and shown in Figure 18.44. The two batteries have emf's of  $\epsilon_1 = 8.0\ \text{V}$  and  $\epsilon_3 = 12.0\ \text{V}$ . If the resistors have resistances of  $R_1 = 4.0\ \Omega$ ;  $R_2 = 6.0\ \Omega$ ; and  $R_3 = 8.0\ \Omega$ , determine the three currents in the circuit.

42. Three  $3.00\ \Omega$  resistors, three batteries, an ammeter, a voltmeter, and one unknown resistor  $R$  are connected in the circuit in Figure 18.45. Assume that the ammeter has negligible resistance and that the voltmeter has infinite resistance. The batteries have emf's of:  $\epsilon_1 =$

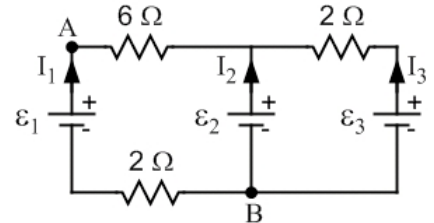


**Figure 18.45:** A multi-loop circuit consisting of three batteries and four resistors, as well as one ammeter and one voltmeter. For Exercise 42.

$20.0\ \text{volts}$ ;  $\epsilon_2 = 5.00\ \text{volts}$ ; and  $\epsilon_3 = 10.0\ \text{volts}$ . The ammeter reads  $+0.650\ \text{A}$ , the positive

value indicating that the current direction shown for  $I_3$  on the diagram is correct. The directions shown for the other two currents may or may not be correct. For parts (a) and (b), include a minus sign if the current is in the direction opposite to that shown on the diagram. (a) What is the value of  $I_2$ ? (b) What is the value of  $I_1$ ? (c) What is the resistance of the unknown resistor  $R$ ? (d) What is the reading on the voltmeter? The voltmeter gives a positive value if the potential at its positive terminal is higher than the potential at its negative terminal.

43. A particular multi-loop circuit consists of three batteries and three resistors, as shown in Figure 18.46. The three currents in the circuit are labeled, but their directions are not necessarily correct. (a) Apply the junction rule to obtain an equation relating the three currents. (b) Based on your junction equation, would you expect one or more of the currents in the circuit to be directed opposite to the direction shown on the diagram? Explain.

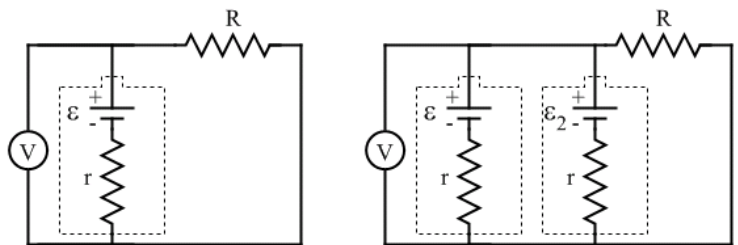


**Figure 18.46:** A particular multi-loop circuit consists of three batteries and three resistors. For Exercises 43 – 45.

44. A particular multi-loop circuit consists of three batteries and three resistors, as shown in Figure 18.46. The battery emf's are  $\epsilon_1 = 10 \text{ V}$ ;  $\epsilon_2 = 2 \text{ V}$ , and  $\epsilon_3 = 6 \text{ V}$ . (a) Solve for the magnitude and direction of the three unknown currents. Note that you should not have to do lots of algebra to solve this problem. (b) What is the potential difference between points A and B in the circuit? Which point is at the higher potential?
45. Return to the situation described in Exercise 44, and shown in Figure 18.46. By adjusting the emf of the second battery (that is, by adjusting  $\epsilon_2$ ) you can set  $I_2 = 0$ . (a) What is  $\epsilon_2$  in this situation? (b) What is the potential difference between points A and B in this situation? Which point is at the higher potential?

**Exercises 46 and 47 deal with the internal resistance of a battery.**

46. A real battery can be modeled as an emf in series with a small internal resistor of resistance  $r$ . The circuit on the left in Figure 18.47 shows one such battery connected in a circuit with a voltmeter and a resistor. When  $R$ , the resistance of the other resistor in the circuit, is very large the voltmeter reads 6.3 V. When  $R$  is  $5.0 \Omega$  the voltmeter reads 5.8 V. What is the battery's internal resistance  $r$ ?



**Figure 18.47:** The circuit at left shows one battery connected in a circuit with a voltmeter and a resistor, while in the circuit at right a second battery, with a different emf, has been added. For Exercises 46 – 47.

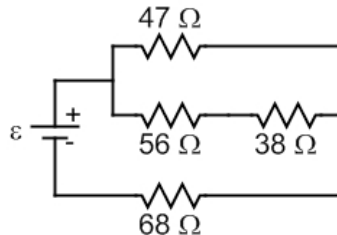
47. As shown in the circuit on the left in Figure 18.47, a resistor  $R$  with a resistance of  $9.80 \Omega$  is connected to a battery with an emf of  $\epsilon = 6.00 \text{ volts}$  and an internal resistance of  $r = 1.00 \Omega$ . (a) What is the current through resistor  $R$ ? (b) The voltmeter measures the terminal voltage on the battery. Assuming the voltmeter has an infinite resistance, what is the terminal voltage? (c) As shown in the figure on the right, a second battery with an unknown emf  $\epsilon_2$  and an internal resistance of  $r = 1.00 \Omega$  is placed in parallel with the first battery. The terminal voltage measured by the voltmeter is now 5.00 V. What is the current through resistor  $R$  now? (d) What is the emf of the second battery?



## General problems and conceptual questions

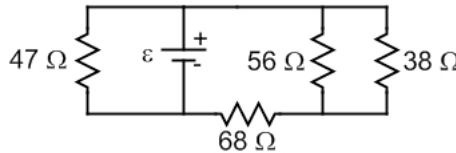
48. A hair dryer is rated at 1850 W. How much does it cost you to use the hair dryer for 10 minutes every day if you are charged 20 cents for every kW-h?
49. A particular 100-W incandescent light bulb costs \$0.50, and can be left on for 1000 hours before burning out. A compact fluorescent light bulb of equal brightness, but with a power rating of 20 W, costs \$4.00, and lasts for 5000 hours. Over the lifetime of the bulb, what is the total energy used by (a) the incandescent bulb? (b) the fluorescent bulb? For providing 5000 hours of light, compare the total energy used by, and total cost, of (c) five 100-W bulbs, and (d) one fluorescent bulb. Assume you are charged 20 cents for every kW-h.
50. Rank the following based on the daily energy cost associated with them. A: a clock radio rated at 5 W (5 watts) that is on 24 hours a day. B: a 300-W television that is on for 3 hours a day. C: a 1000-W microwave oven that is in use for 20 minutes a day. D: a 90-W computer that is on for 8 hours a day.

51. Four resistors are connected to a battery, as shown in Figure 18.48. If the potential difference across through the  $38\ \Omega$  resistor is 2.5 V, what is the emf of the battery?



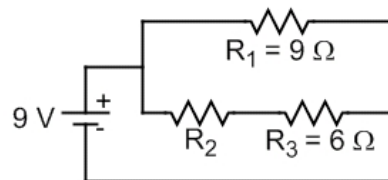
**Figure 18.48:** Four resistors connected in a circuit with a battery of unknown emf, for Exercise 51.

52. The four resistors from Exercise 51 are connected in a different circuit with a different battery, of unknown emf, as shown in Figure 18.49. If the current through the  $38\ \Omega$  resistor is 84 milliamps, what is the current through the  $47\ \Omega$  resistor?



**Figure 18.49:** Four resistors connected in a circuit with a battery of unknown emf, for Exercise 52.

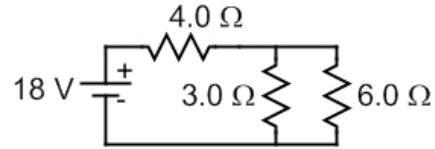
53. Three resistors are connected in a circuit with a 9-volt battery, as shown in Figure 18.50. Resistor 1 has a resistance of  $9\ \Omega$  and resistor 3 has a resistance of  $6\ \Omega$ . The resistance of resistor 2 is some value between  $4\ \Omega$  and  $20\ \Omega$ . (a) Can you tell which resistor has the largest current through it, or does that depend on the value of resistor 2? Explain. (b) If the resistance of resistor 2 is increased, what happens to the current through resistor 1? Explain.



**Figure 18.50:** A circuit consisting of three resistors and a 9-volt battery. For Exercises 53 – 54.

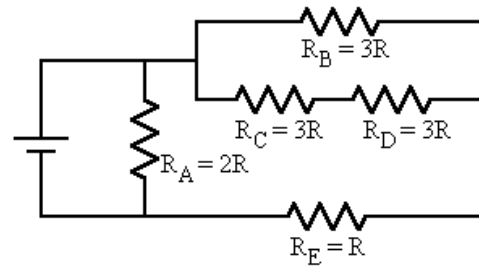
54. Three resistors are connected in a circuit with a 9-volt battery, as shown in Figure 18.50. Resistor 1 has a resistance of  $9\ \Omega$  and resistor 3 has a resistance of  $6\ \Omega$ . The resistance of resistor 2 is  $12\ \Omega$ . (a) What is the equivalent resistance of the circuit? (b) What is the value of the current through resistor 3?

55. Consider the circuit from Essential Question 18.8, which is re-drawn in Figure 18.51. (a) How would you add a  $5.0\ \Omega$  resistor to the circuit so that the current through the  $3.0\ \Omega$  resistor is maximized? (b) By how much does the current through the  $3.0\ \Omega$  resistor increase in that case?



**Figure 18.51:** A circuit consisting of three resistors and an 18-volt battery, for Exercise 55.

56. Figure 18.52 shows a circuit consisting of five resistors and one battery. (a) Find the equivalent resistance of the circuit, in terms of  $R$ . (b) Which resistor has the largest potential difference across it? Briefly justify your answer. (c) Rank the resistors based on the current passing through them, from largest to smallest.

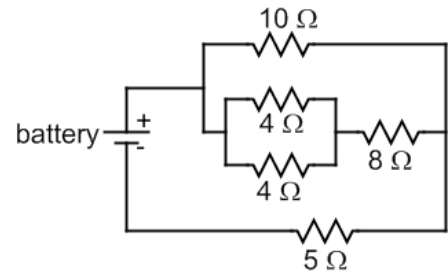


**Figure 18.52:** A circuit consisting of five resistors and a battery, for Exercises 56 and 57.

57. Figure 18.52 shows a circuit consisting of five resistors and one battery. The battery has an emf of  $2.0\ \text{V}$ , and  $R = 2.0\ \Omega$ . Find the current through each resistor.

58. Return to the Answer to Essential Question 18.9. Note that the current through the  $2.0$ -volt battery is passing through the battery from the positive terminal to the negative terminal. The current through the other two batteries is directed from the negative terminal to the positive terminal. (a) What is happening to the  $2.0$ -volt battery in this situation? (b) Find the total power input to the circuit, and the total power dissipated in the circuit. Should we expect these values to be the same?

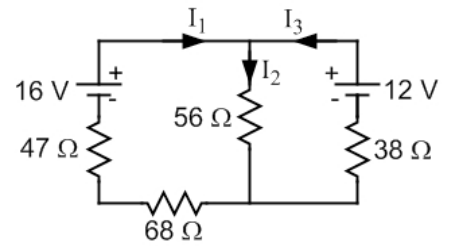
59. Five resistors are connected in a circuit with a battery, as shown in Figure 18.53. (a) Which resistor has the largest current passing through it? Explain. Now compare just the  $8\ \Omega$  resistor and the  $10\ \Omega$  resistor. Of these two resistors, which has the largest (b) current through it? (c) potential difference across it? Justify your answers.



**Figure 18.53:** A circuit consisting of five resistors and a battery. For Exercises 59 and 60.

60. Five resistors are connected in a circuit with a battery, as shown in Figure 18.53. (a) Re-draw the circuit diagram, adding an ammeter to measure the current through the  $5\ \Omega$  resistor, and a voltmeter to measure the potential difference across the  $5\ \Omega$  resistor. (b) If the battery has an emf of  $20\ \text{V}$ , what is the reading on the ammeter? (c) What is the reading on the voltmeter?

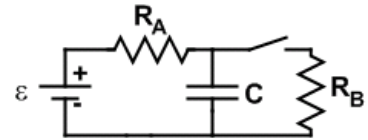
61. Consider the circuit shown in Figure 18.54. (a) Starting at the negative terminal of the 16-V battery, and going clockwise around the loop, write out a loop equation for the inside loop on the left by applying the loop rule. (b) What is the effect of using a different starting point? Write out a loop equation for the same loop, starting at the bottom left corner of the circuit, and going clockwise around the loop. Is this equation equivalent to the equation from (a)? Explain. (c) What is the effect of going counter-clockwise around the loop instead? Write out a loop equation for the same loop, starting at the same place as in (a) but going counter-clockwise. Is this equation equivalent to the equation from (a)? Explain.



**Figure 18.54:** A multi-loop circuit consisting of four resistors and two batteries. For Exercises 61 and 62.

62. Consider the circuit shown in Figure 18.54. Find (a)  $I_1$ , (b)  $I_2$ , and (c)  $I_3$ .
63. A series RC circuit consists of a 12-volt battery, a resistor, capacitor, and a switch, all connected in series. The switch is open and the capacitor is initially uncharged. The switch is closed at  $t = 0$  and the capacitor begins to charge. At  $t = 3.0$  s, the potential difference across the capacitor is 2.0 V. (a) What is the potential difference across the capacitor at  $t = 6.0$  s? (b) At what time is the potential difference across the capacitor equal to 6.0 V? (c) At what time is it equal to 12 V?

64. Consider the RC circuit shown in Figure 18.55. The battery has an emf of 12 V; and the two resistors each have a resistance of 3.0 ohms. At  $t = 0$ , the capacitor is charged, with the top plate positive and the capacitor voltage is equal to 12 V. The capacitance of the capacitor is 1.0 F. (a) Assuming the switch remains open, find the current in the circuit at  $t = 5.0$  s. The switch is then closed. Determine the current through each of the two resistors (b) immediately after the switch is closed, (c) when the capacitor voltage is 9.0 V, and (d) a long time after the switch is closed.



**Figure 18.55:** An RC circuit consisting of a battery, resistor, and capacitor, along with a second resistor that can be added to the circuit by closing a switch. For Exercise 64.

65. Comment on the statements made by three students who are discussing an issue related to DC circuits. The question that they are discussing is whether it is possible to add a resistor to a circuit and increase the current passing through the single battery in the circuit. There is already a non-zero current in the circuit before the resistor is added.

**Terry:** *I don't think that adding a resistor to the circuit makes any difference to the current. The current comes from the battery, and if we don't change the battery then the current stays the same.*

**Sarah:** *I disagree with that. If we connect the resistor in parallel with another resistor in the circuit, then the equivalent resistance of the circuit is going to go down, and the current through the battery is going to go up.*

**Andy:** *No way! I disagree with Terry, too, but I think that if you add a resistor to the circuit that you have to be increasing the total resistance, not decreasing it. That's going to decrease the current, not increase it.*