Summary

A device that transforms another type of energy into electrical energy is called a **source** of **emf**. A battery behaves like a source of emf in series with an **internal resistance**. The emf is the potential difference determined by the chemical reactions in the battery and equals the terminal voltage when no current is drawn. When a current is drawn, the voltage at the battery's terminals is less than its emf by an amount equal to the potential decrease Ir across the internal resistance.

When resistances are connected in **series** (end to end in a single linear path), the equivalent resistance is the sum of the individual resistances:

$$R_{eq} = R_1 + R_2 + \cdots. \tag{19–3}$$

In a series combination, R_{eq} is greater than any component resistance.

When resistors are connected in **parallel**, it is the reciprocals that add up:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots. \tag{19–4}$$

In a parallel connection, the net resistance is less than any of the individual resistances.

Kirchhoff's rules are useful in determining the currents and voltages in circuits. Kirchhoff's **junction rule** is based on conservation of electric charge and states that the sum of all currents entering any junction equals the sum of all currents leaving that junction. The second, or **loop rule**, is based on conservation of energy and states that the algebraic sum of the changes in potential around any closed path of the circuit must be zero.

When capacitors are connected in **parallel**, the equivalent capacitance is the sum of the individual capacitances:

$$C_{eq} = C_1 + C_2 + \cdots. \tag{19–5}$$

When capacitors are connected in **series**, it is the reciprocals that add up:

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots. \tag{19–6}$$

When an ***RC* circuit** containing a resistance R in series with a capacitance C is connected to a dc source of emf, the voltage across the capacitor rises gradually in time characterized by an exponential of the form $(1 - e^{-t/RC})$, where the **time constant**

$$\tau = RC \tag{19–7}$$

is the time it takes for the voltage to reach 63% of its maximum value.

A capacitor discharging through a resistor is characterized by the same time constant: in a time $\tau = RC$, the voltage across the capacitor drops to 37% of its initial value. The charge on the capacitor, and the voltage across it, decrease as $e^{-t/RC}$.

Electric shocks are caused by current passing through the body. To avoid shocks, the body must not become part of a complete circuit by allowing different parts of the body to touch objects at different potentials. Commonly, shocks are caused by one part of the body touching ground ($V = 0$) and another part touching a nonzero electric potential.

An **ammeter** measures current. An analog ammeter consists of a galvanometer and a parallel **shunt resistor** that carries most of the current. An analog **voltmeter** consists of a galvanometer and a series resistor. An ammeter is inserted *into* the circuit whose current is to be measured. A voltmeter is external, being connected in parallel to the element whose voltage is to be measured. Digital meters have greater internal resistance and affect the circuit to be measured less than do analog meters.

Questions

1. Explain why birds can sit on power lines safely, even though the wires have no insulation around them, whereas leaning a metal ladder up against a power line is extremely dangerous.
2. Discuss the advantages and disadvantages of Christmas tree lights connected in parallel versus those connected in series.
3. If all you have is a 120-V line, would it be possible to light several 6-V lamps without burning them out? How?
4. Two lightbulbs of resistance R_1 and R_2 $(R_2 > R_1)$ and a battery are all connected in series. Which bulb is brighter? What if they are connected in parallel? Explain.
5. Household outlets are often double outlets. Are these connected in series or parallel? How do you know?
6. With two identical lightbulbs and two identical batteries, explain how and why you would arrange the bulbs and batteries in a circuit to get the maximum possible total power to the lightbulbs. (Ignore internal resistance of batteries.)
7. If two identical resistors are connected in series to a battery, does the battery have to supply more power or less power than when only one of the resistors is connected? Explain.
8. You have a single 60-W bulb lit in your room. How does the overall resistance of your room's electric circuit change when you turn on an additional 100-W bulb? Explain.
9. Suppose three identical capacitors are connected to a battery. Will they store more energy if connected in series or in parallel?
10. When applying Kirchhoff's loop rule (such as in Fig. 19–36), does the sign (or direction) of a battery's emf depend on the direction of current through the battery? What about the terminal voltage?

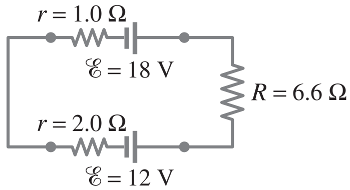

FIGURE 19–36 Question 10.

11. Different lamps might have batteries connected in either of the two arrangements shown in Fig. 19–37. What would be the advantages of each scheme?

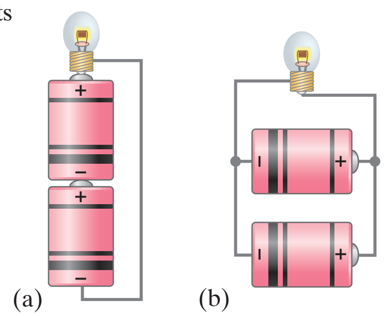

FIGURE 19–37 Question 11.

12. For what use are batteries connected in series? For what use are they connected in parallel? Does it matter if the batteries are nearly identical or not in either case?

13. Can the terminal voltage of a battery ever exceed its emf? Explain.

14. Explain in detail how you could measure the internal resistance of a battery.

15. In an *RC* circuit, current flows from the battery until the capacitor is completely charged. Is the total energy supplied by the battery equal to the total energy stored by the capacitor? If not, where does the extra energy go?

16. Given the circuit shown in Fig. 19–38, use the words "increases," "decreases," or "stays the same" to complete the following statements:

(*a*) If R_7 increases, the potential difference between A and E __________. Assume no resistance in Ⓐ and $\mathscr{E}$.

(*b*) If R_7 increases, the potential difference between A and E __________. Assume Ⓐ and $\mathscr{E}$ have resistance.

(*c*) If R_7 increases, the voltage drop across R_4 __________.

(*d*) If R_2 decreases, the current through R_1 __________.

(*e*) If R_2 decreases, the current through R_6 __________.

(*f*) If R_2 decreases, the current through R_3 __________.

(*g*) If R_5 increases, the voltage drop across R_2 __________.

(*h*) If R_5 increases, the voltage drop across R_4 __________.

(*i*) If R_2, R_5, and R_7 increase, $\mathscr{E}$ $(r = 0)$ __________.

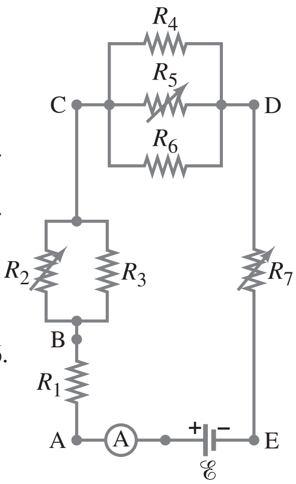

FIGURE 19–38 Question 16. R_2, R_5, and R_7 are *variable* resistors (you can change their resistance), given the symbol -WW-.

17. Design a circuit in which two different switches of the type shown in Fig. 19–39 can be used to operate the same lightbulb from opposite sides of a room.

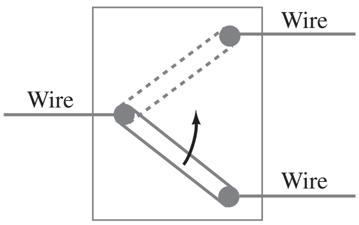

FIGURE 19–39 Question 17.

18. Why is it more dangerous to turn on an electric appliance when you are standing outside in bare feet than when you are inside wearing shoes with thick soles?

19. What is the main difference between an analog voltmeter and an analog ammeter?

20. What would happen if you mistakenly used an ammeter where you needed to use a voltmeter?

21. Explain why an ideal ammeter would have zero resistance and an ideal voltmeter infinite resistance.

22. A voltmeter connected across a resistor always reads *less* than the actual voltage (i.e., when the meter is not present). Explain.

23. A small battery-operated flashlight requires a single 1.5-V battery. The bulb is barely glowing. But when you take the battery out and check it with a digital voltmeter, it registers 1.5 V. How would you explain this?

MisConceptual Questions

1. In which circuits shown in Fig. 19–40 are resistors connected in series?

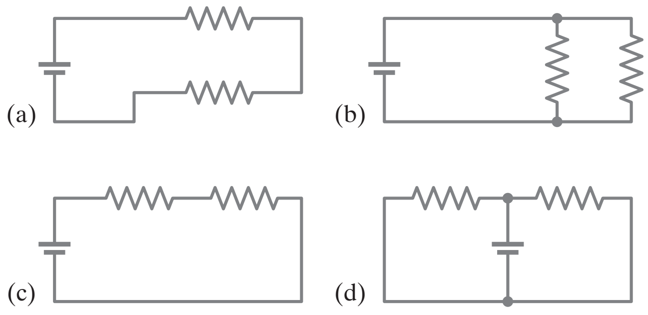

FIGURE 19–40 MisConceptual Question 1.

2. Which resistors in Fig. 19–41 are connected in parallel?

(*a*) All three.
(*b*) R_1 and R_2.
(*c*) R_2 and R_3.
(*d*) R_1 and R_3.
(*e*) None of the above.

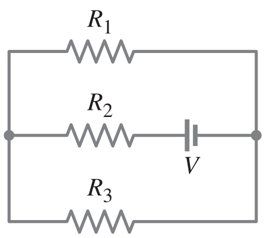

FIGURE 19–41 MisConceptual Question 2.

3. A 10,000-Ω resistor is placed in series with a 100-Ω resistor. The current in the 10,000-Ω resistor is 10 A. If the resistors are swapped, how much current flows through the 100-Ω resistor?

(*a*) >10 A. (*b*) <10 A. (*c*) 10 A.
(*d*) Need more information about the circuit.

4. Two identical 10-V batteries and two identical 10-Ω resistors are placed in series as shown in Fig. 19–42. If a 10-Ω lightbulb is connected with one end connected between the batteries and other end between the resistors, how much current will flow through the lightbulb?

(*a*) 0 A.
(*b*) 1 A.
(*c*) 2 A.
(*d*) 4 A.

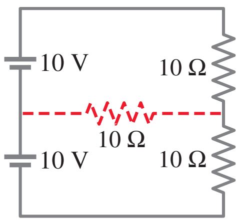

FIGURE 19–42 MisConceptual Question 4.

5. Which resistor shown in Fig. 19–43 has the greatest current going through it? Assume that all the resistors are equal.
(*a*) R_1.
(*b*) R_1 and R_2.
(*c*) R_3 and R_4.
(*d*) R_5.
(*e*) All of them the same.

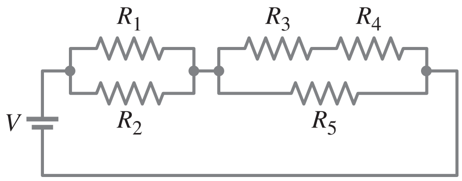

FIGURE 19–43 MisConceptual Question 5.

6. Figure 19–44 shows three identical bulbs in a circuit. What happens to the brightness of bulb A if you replace bulb B with a short circuit?
(*a*) Bulb A gets brighter.
(*b*) Bulb A gets dimmer.
(*c*) Bulb A's brightness does not change.
(*d*) Bulb A goes out.

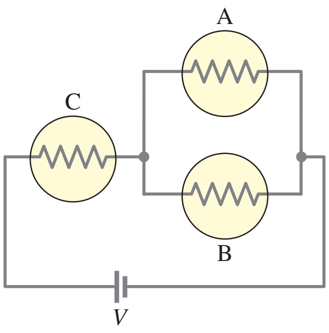

FIGURE 19–44 MisConceptual Question 6.

7. When the switch shown in Fig. 19–45 is closed, what will happen to the voltage across resistor R_4? It will
(*a*) increase. (*b*) decrease. (*c*) stay the same.

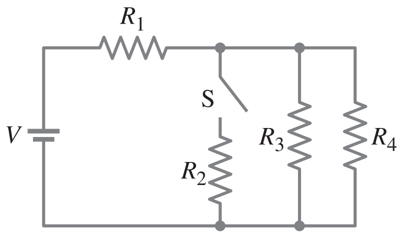

FIGURE 19–45 MisConceptual Questions 7 and 8.

8. When the switch shown in Fig. 19–45 is closed, what will happen to the voltage across resistor R_1? It will
(*a*) increase. (*b*) decrease. (*c*) stay the same.

9. As a capacitor is being charged in an *RC* circuit, the current flowing through the resistor is
(*a*) increasing.
(*b*) decreasing.
(*c*) constant.
(*d*) zero.

10. For the circuit shown in Fig. 19–46, what happens when the switch S is closed?
(*a*) Nothing. Current cannot flow through the capacitor.
(*b*) The capacitor immediately charges up to the battery emf.
(*c*) The capacitor eventually charges up to the full battery emf at a rate determined by *R* and *C*.
(*d*) The capacitor charges up to a fraction of the battery emf determined by *R* and *C*.
(*e*) The capacitor charges up to a fraction of the battery emf determined by *R* only.

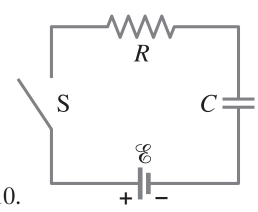

FIGURE 19–46 MisConceptual Question 10.

11. The capacitor in the circuit shown in Fig. 19–47 is charged to an initial value Q. When the switch is closed, it discharges through the resistor. It takes 2.0 seconds for the charge to drop to $\frac{1}{2}Q$. How long does it take to drop to $\frac{1}{4}Q$?
(*a*) 3.0 seconds.
(*b*) 4.0 seconds.
(*c*) Between 2.0 and 3.0 seconds.
(*d*) Between 3.0 and 4.0 seconds.
(*e*) More than 4.0 seconds.

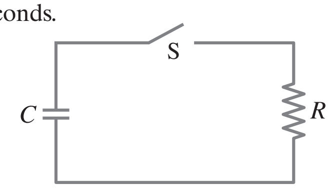

FIGURE 19–47 MisConceptual Question 11.

12. A resistor and a capacitor are used in series to control the timing in the circuit of a heart pacemaker. To design a pacemaker that can double the heart rate when the patient is exercising, which statement below is true? The capacitor
(*a*) needs to discharge faster, so the resistance should be decreased.
(*b*) needs to discharge faster, so the resistance should be increased.
(*c*) needs to discharge slower, so the resistance should be decreased.
(*d*) needs to discharge slower, so the resistance should be increased.
(*e*) does not affect the timing, regardless of the resistance.

13. Why is an appliance cord with a three-prong plug safer than one with two prongs?
(*a*) The 120 V from the outlet is split among three wires, so it isn't as high a voltage as when it is only split between two wires.
(*b*) Three prongs fasten more securely to the wall outlet.
(*c*) The third prong grounds the case, so the case cannot reach a high voltage.
(*d*) The third prong acts as a ground wire, so the electrons have an easier time leaving the appliance. As a result, fewer electrons build up in the appliance.
(*e*) The third prong controls the capacitance of the appliance, so it can't build up a high voltage.

14. When capacitors are connected in series, the effective capacitance is __________ the smallest capacitance; when capacitors are connected in parallel, the effective capacitance is __________ the largest capacitance.
(*a*) greater than; equal to.
(*b*) greater than; less than.
(*c*) less than; greater than.
(*d*) equal to; less than.
(*e*) equal to; equal to.

15. If ammeters and voltmeters are not to significantly alter the quantities they are measuring,
(*a*) the resistance of an ammeter and a voltmeter should be much higher than that of the circuit element being measured.
(*b*) the resistance of an ammeter should be much lower, and the resistance of a voltmeter should be much higher, than those of the circuit being measured.
(*c*) the resistance of an ammeter should be much higher, and the resistance of a voltmeter should be much lower, than those of the circuit being measured.
(*d*) the resistance of an ammeter and a voltmeter should be much lower than that of the circuit being measured.
(*e*) None of the above.

Problems

19–1 Emf and Terminal Voltage

1. (I) Calculate the terminal voltage for a battery with an internal resistance of $0.900\,\Omega$ and an emf of 6.00 V when the battery is connected in series with (*a*) a 71.0-Ω resistor, and (*b*) a 710-Ω resistor.
2. (I) Four 1.50-V cells are connected in series to a 12.0-Ω lightbulb. If the resulting current is 0.45 A, what is the internal resistance of each cell, assuming they are identical and neglecting the resistance of the wires?
3. (II) What is the internal resistance of a 12.0-V car battery whose terminal voltage drops to 8.8 V when the starter motor draws 95 A? What is the resistance of the starter?

19–2 Resistors in Series and Parallel

[In these Problems neglect the internal resistance of a battery unless the Problem refers to it.]

4. (I) A 650-Ω and an 1800-Ω resistor are connected in series with a 12-V battery. What is the voltage across the 1800-Ω resistor?
5. (I) Three 45-Ω lightbulbs and three 65-Ω lightbulbs are connected in series. (*a*) What is the total resistance of the circuit? (*b*) What is the total resistance if all six are wired in parallel?
6. (II) Suppose that you have a 580-Ω, a 790-Ω, and a 1.20-kΩ resistor. What is (*a*) the maximum, and (*b*) the minimum resistance you can obtain by combining these?
7. (II) How many 10-Ω resistors must be connected in series to give an equivalent resistance to five 100-Ω resistors connected in parallel?
8. (II) Design a "voltage divider" (see Example 19–3) that would provide one-fifth (0.20) of the battery voltage across R_2, Fig. 19–6. What is the ratio R_1/R_2?
9. (II) Suppose that you have a 9.0-V battery and wish to apply a voltage of only 3.5 V. Given an unlimited supply of 1.0-Ω resistors, how could you connect them to make a "voltage divider" that produces a 3.5-V output for a 9.0-V input?
10. (II) Three 1.70-kΩ resistors can be connected together in four different ways, making combinations of series and/or parallel circuits. What are these four ways, and what is the net resistance in each case?
11. (II) A battery with an emf of 12.0 V shows a terminal voltage of 11.8 V when operating in a circuit with two lightbulbs, each rated at 4.0 W (at 12.0 V), which are connected in parallel. What is the battery's internal resistance?
12. (II) Eight identical bulbs are connected in series across a 120-V line. (*a*) What is the voltage across each bulb? (*b*) If the current is 0.45 A, what is the resistance of each bulb, and what is the power dissipated in each?
13. (II) Eight bulbs are connected in parallel to a 120-V source by two long leads of total resistance 1.4 Ω. If 210 mA flows through each bulb, what is the resistance of each, and what fraction of the total power is wasted in the leads?
14. (II) A close inspection of an electric circuit reveals that a 480-Ω resistor was inadvertently soldered in the place where a 350-Ω resistor is needed. How can this be fixed without removing anything from the existing circuit?
15. (II) Eight 7.0-W Christmas tree lights are connected in series to each other and to a 120-V source. What is the resistance of each bulb?
16. (II) Determine (*a*) the equivalent resistance of the circuit shown in Fig. 19–48, (*b*) the voltage across each resistor, and (*c*) the current through each resistor.

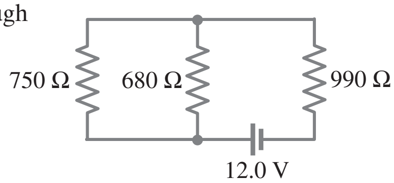

FIGURE 19–48 Problem 16.

17. (II) A 75-W, 120-V bulb is connected in parallel with a 25-W, 120-V bulb. What is the net resistance?
18. (II) (*a*) Determine the equivalent resistance of the "ladder" of equal 175-Ω resistors shown in Fig. 19–49. In other words, what resistance would an ohmmeter read if connected between points A and B? (*b*) What is the current through each of the three resistors on the left if a 50.0-V battery is connected between points A and B?

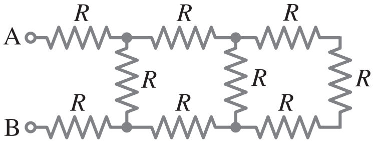

FIGURE 19–49 Problem 18.

19. (II) What is the net resistance of the circuit connected to the battery in Fig. 19–50?

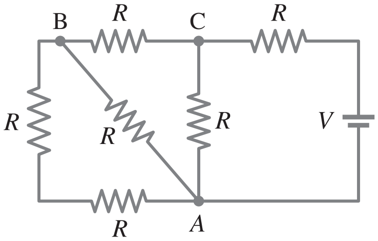

FIGURE 19–50 Problems 19 and 20.

20. (II) Calculate the current through each resistor in Fig. 19–50 if each resistance $R = 3.25\,\mathrm{k\Omega}$ and $V = 12.0\,\mathrm{V}$. What is the potential difference between points A and B?
21. (III) Two resistors when connected in series to a 120-V line use one-fourth the power that is used when they are connected in parallel. If one resistor is 4.8 kΩ, what is the resistance of the other?
22. (III) Three equal resistors (R) are connected to a battery as shown in Fig. 19–51. Qualitatively, what happens to (*a*) the voltage drop across each of these resistors, (*b*) the current flow through each, and (*c*) the terminal voltage of the battery, when the switch S is opened, after having been closed for a long time? (*d*) If the emf of the battery is 9.0 V, what is its terminal voltage when the switch is closed if the internal resistance r is 0.50 Ω and $R = 5.50\,\Omega$? (*e*) What is the terminal voltage when the switch is open?

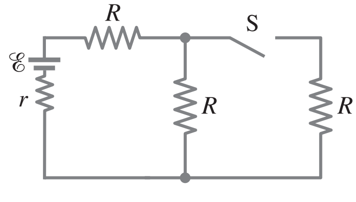

FIGURE 19–51 Problem 22.

23. (III) A 2.5-kΩ and a 3.7-kΩ resistor are connected in parallel; this combination is connected in series with a 1.4-kΩ resistor. If each resistor is rated at 0.5 W (maximum without overheating), what is the maximum voltage that can be applied across the whole network?

24. (III) Consider the network of resistors shown in Fig. 19–52. Answer qualitatively: (*a*) What happens to the voltage across each resistor when the switch S is closed? (*b*) What happens to the current through each when the switch is closed? (*c*) What happens to the power output of the battery when the switch is closed? (*d*) Let $R_1 = R_2 = R_3 = R_4 = 155\,\Omega$ and $V = 22.0$ V. Determine the current through each resistor before and after closing the switch. Are your qualitative predictions confirmed?

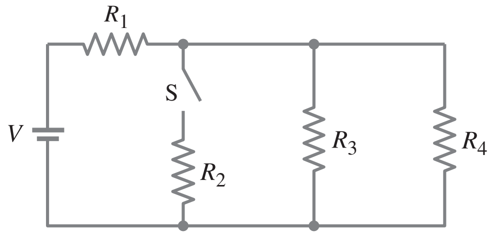

FIGURE 19–52
Problem 24.

19–3 Kirchhoff's Rules

25. (I) Calculate the current in the circuit of Fig. 19–53, and show that the sum of all the voltage changes around the circuit is zero.

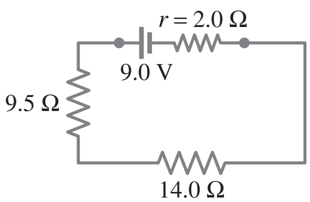

FIGURE 19–53
Problem 25.

26. (II) Determine the terminal voltage of each battery in Fig. 19–54.

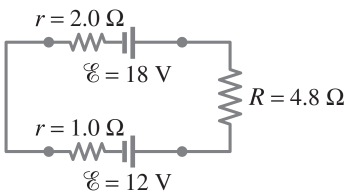

FIGURE 19–54
Problem 26.

27. (II) For the circuit shown in Fig. 19–55, find the potential difference between points a and b. Each resistor has $R = 160\,\Omega$ and each battery is 1.5 V.

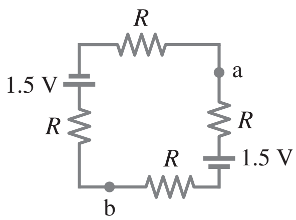

FIGURE 19–55
Problem 27.

28. (II) Determine the magnitudes and directions of the currents in each resistor shown in Fig. 19–56. The batteries have emfs of $\mathscr{E}_1 = 9.0$ V and $\mathscr{E}_2 = 12.0$ V and the resistors have values of $R_1 = 25\,\Omega$, $R_2 = 68\,\Omega$, and $R_3 = 35\,\Omega$. (*a*) Ignore internal resistance of the batteries. (*b*) Assume each battery has internal resistance $r = 1.0\,\Omega$.

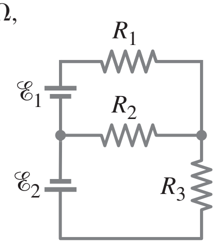

FIGURE 19–56
Problem 28.

29. (II) (*a*) What is the potential difference between points a and d in Fig. 19–57 (similar to Fig. 19–13, Example 19–8), and (*b*) what is the terminal voltage of each battery?

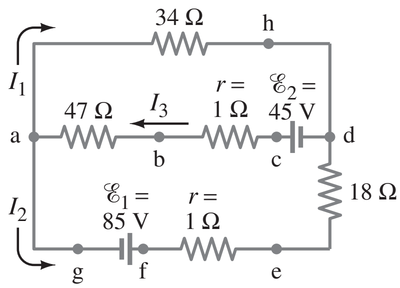

FIGURE 19–57
Problem 29.

30. (II) Calculate the magnitude and direction of the currents in each resistor of Fig. 19–58.

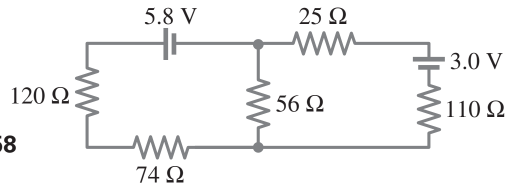

FIGURE 19–58
Problem 30.

31. (II) Determine the magnitudes and directions of the currents through R_1 and R_2 in Fig. 19–59.

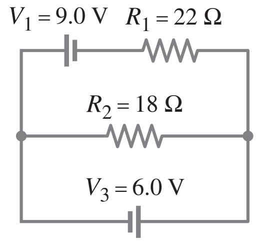

FIGURE 19–59
Problems 31 and 32.

32. (II) Repeat Problem 31, now assuming that each battery has an internal resistance $r = 1.4\,\Omega$.

33. (III) (*a*) A network of five equal resistors R is connected to a battery $\mathscr{E}$ as shown in Fig. 19–60. Determine the current I that flows out of the battery. (*b*) Use the value determined for I to find the single resistor R_{eq} that is equivalent to the five-resistor network.

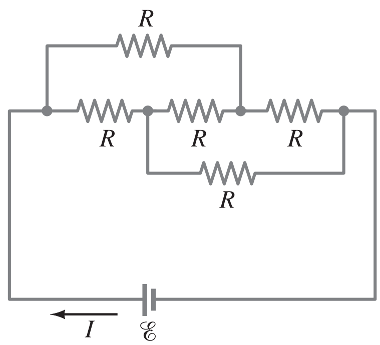

FIGURE 19–60
Problem 33.

34. (III) (*a*) Determine the currents I_1, I_2, and I_3 in Fig. 19–61. Assume the internal resistance of each battery is $r = 1.0\,\Omega$. (*b*) What is the terminal voltage of the 6.0-V battery?

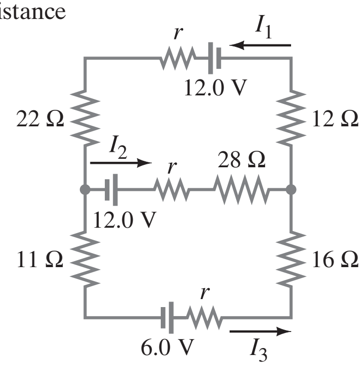

FIGURE 19–61
Problems 34 and 35.

35. (III) What would the current I_1 be in Fig. 19–61 if the 12-Ω resistor is shorted out (resistance = 0)? Let $r = 1.0\,\Omega$.

19–4 Emfs Combined, Battery Charging

36. (II) Suppose two batteries, with unequal emfs of 2.00 V and 3.00 V, are connected as shown in Fig. 19–62. If each internal resistance is $r = 0.350\,\Omega$, and $R = 4.00\,\Omega$, what is the voltage across the resistor R?

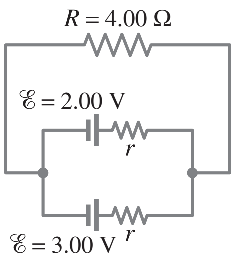

FIGURE 19–62 Problem 36.

37. (II) A battery for a proposed electric car is to have three hundred 3-V lithium ion cells connected such that the total voltage across all of the cells is 300 V. Describe a possible connection configuration (using series and parallel connections) that would meet these battery specifications.

19–5 Capacitors in Series and Parallel

38. (I) (*a*) Six 4.8-μF capacitors are connected in parallel. What is the equivalent capacitance? (*b*) What is their equivalent capacitance if connected in series?

39. (I) A 3.00-μF and a 4.00-μF capacitor are connected in series, and this combination is connected in parallel with a 2.00-μF capacitor (see Fig. 19–63). What is the net capacitance?

40. (II) If 21.0 V is applied across the whole network of Fig. 19–63, calculate (*a*) the voltage across each capacitor and (*b*) the charge on each capacitor.

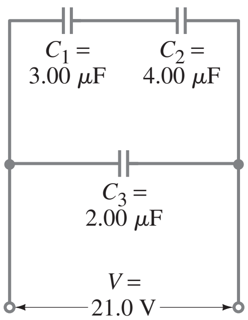

FIGURE 19–63 Problems 39 and 40.

41. (II) The capacitance of a portion of a circuit is to be reduced from 2900 pF to 1200 pF. What capacitance can be added to the circuit to produce this effect without removing existing circuit elements? Must any existing connections be broken to accomplish this?

42. (II) An electric circuit was accidentally constructed using a 7.0-μF capacitor instead of the required 16-μF value. Without removing the 7.0-μF capacitor, what can a technician add to correct this circuit?

43. (II) Consider three capacitors, of capacitance 3200 pF, 5800 pF, and 0.0100 μF. What maximum and minimum capacitance can you form from these? How do you make the connection in each case?

44. (II) Determine the equivalent capacitance between points a and b for the combination of capacitors shown in Fig. 19–64.

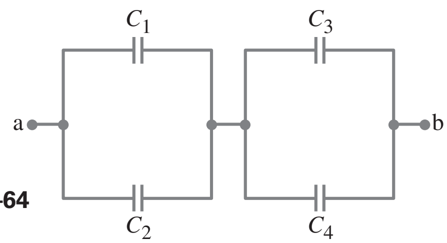

FIGURE 19–64 Problem 44.

45. (II) What is the ratio of the voltage V_1 across capacitor C_1 in Fig. 19–65 to the voltage V_2 across capacitor C_2?

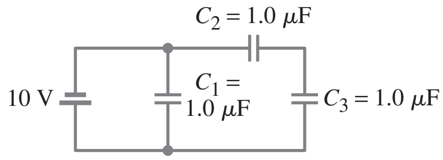

FIGURE 19–65 Problem 45.

46. (II) A 0.50-μF and a 1.4-μF capacitor are connected in series to a 9.0-V battery. Calculate (*a*) the potential difference across each capacitor and (*b*) the charge on each. (*c*) Repeat parts (*a*) and (*b*) assuming the two capacitors are in parallel.

47. (II) A circuit contains a single 250-pF capacitor hooked across a battery. It is desired to store four times as much energy in a combination of two capacitors by adding a single capacitor to this one. How would you hook it up, and what would its value be?

48. (II) Suppose three parallel-plate capacitors, whose plates have areas A_1, A_2, and A_3 and separations d_1, d_2, and d_3, are connected in parallel. Show, using only Eq. 17–8, that Eq. 19–5 is valid.

49. (II) Two capacitors connected in parallel produce an equivalent capacitance of 35.0 μF but when connected in series the equivalent capacitance is only 4.8 μF. What is the individual capacitance of each capacitor?

50. (III) Given three capacitors, $C_1 = 2.0\,\mu$F, $C_2 = 1.5\,\mu$F, and $C_3 = 3.0\,\mu$F, what arrangement of parallel and series connections with a 12-V battery will give the minimum voltage drop across the 2.0-μF capacitor? What is the minimum voltage drop?

51. (III) In Fig. 19–66, suppose $C_1 = C_2 = C_3 = C_4 = C$. (*a*) Determine the equivalent capacitance between points a and b. (*b*) Determine the charge on each capacitor and the potential difference across each in terms of V.

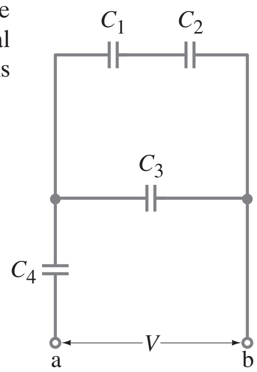

FIGURE 19–66 Problem 51.

19–6 *RC* Circuits

52. (I) Estimate the value of resistances needed to make a variable timer for intermittent windshield wipers: one wipe every 15 s, 8 s, 4 s, 2 s, 1 s. Assume the capacitor used is on the order of 1 μF. See Fig. 19–67.

FIGURE 19–67 Problem 52.

53. (II) Electrocardiographs are often connected as shown in Fig. 19–68. The lead wires to the legs are said to be capacitively coupled. A time constant of 3.0 s is typical and allows rapid changes in potential to be recorded accurately. If $C = 3.0\,\mu\text{F}$, what value must R have? [*Hint*: Consider each leg as a separate circuit.]

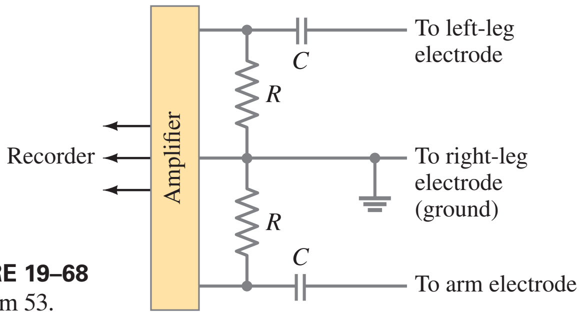

FIGURE 19–68 Problem 53.

54. (II) In Fig. 19–69 (same as Fig. 19–20a), the total resistance is 15.0 kΩ, and the battery's emf is 24.0 V. If the time constant is measured to be 18.0 μs, calculate (*a*) the total capacitance of the circuit and (*b*) the time it takes for the voltage across the resistor to reach 16.0 V after the switch is closed.

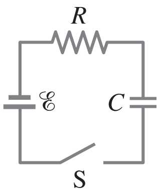

FIGURE 19–69 Problem 54.

55. (II) Two 3.8-μF capacitors, two 2.2-kΩ resistors, and a 16.0-V source are connected in series. Starting from the uncharged state, how long does it take for the current to drop from its initial value to 1.50 mA?

56. (II) The *RC* circuit of Fig. 19–70 (same as Fig. 19–21a) has $R = 8.7\,\text{k}\Omega$ and $C = 3.0\,\mu\text{F}$. The capacitor is at voltage V_0 at $t = 0$, when the switch is closed. How long does it take the capacitor to discharge to 0.25% of its initial voltage?

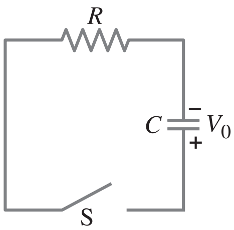

FIGURE 19–70 Problem 56.

57. (III) Consider the circuit shown in Fig. 19–71, where all resistors have the same resistance R. At $t = 0$, with the capacitor C uncharged, the switch is closed. (*a*) At $t = 0$, the three currents can be determined by analyzing a simpler, but equivalent, circuit. Draw this simpler circuit and use it to find the values of I_1, I_2, and I_3 at $t = 0$. (*b*) At $t = \infty$, the currents can be determined by analyzing a simpler, equivalent circuit. Draw this simpler circuit and implement it in finding the values of I_1, I_2, and I_3 at $t = \infty$. (*c*) At $t = \infty$, what is the potential difference across the capacitor?

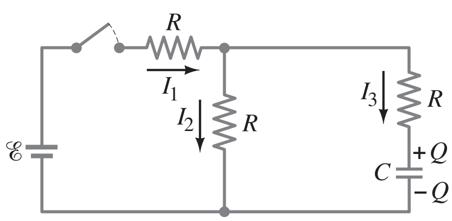

FIGURE 19–71 Problem 57.

58. (III) Two resistors and two uncharged capacitors are arranged as shown in Fig. 19–72. Then a potential difference of 24 V is applied across the combination as shown. (*a*) What is the potential at point a with switch S open? (Let $V = 0$ at the negative terminal of the source.) (*b*) What is the potential at point b with the switch open? (*c*) When the switch is closed, what is the final potential of point b? (*d*) How much charge flows through the switch S after it is closed?

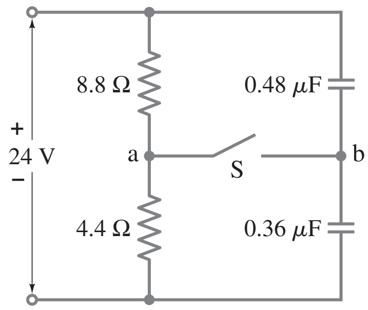

FIGURE 19–72 Problem 58.

19–8 Ammeters and Voltmeters

59. (I) (*a*) An ammeter has a sensitivity of 35,000 Ω/V. What current in the galvanometer produces full-scale deflection? (*b*) What is the resistance of a voltmeter on the 250-V scale if the meter sensitivity is 35,000 Ω/V?

60. (II) An ammeter whose internal resistance is 53 Ω reads 5.25 mA when connected in a circuit containing a battery and two resistors in series whose values are 720 Ω and 480 Ω. What is the actual current when the ammeter is absent?

61. (II) A milliammeter reads 35 mA full scale. It consists of a 0.20-Ω resistor in parallel with a 33-Ω galvanometer. How can you change this ammeter to a voltmeter giving a full-scale reading of 25 V without taking the ammeter apart? What will be the sensitivity (Ω/V) of your voltmeter?

62. (II) A galvanometer has an internal resistance of 32 Ω and deflects full scale for a 55-μA current. Describe how to use this galvanometer to make (*a*) an ammeter to read currents up to 25 A, and (*b*) a voltmeter to give a full-scale deflection of 250 V.

63. (III) A battery with $\mathscr{E} = 12.0\,\text{V}$ and internal resistance $r = 1.0\,\Omega$ is connected to two 7.5-kΩ resistors in series. An ammeter of internal resistance 0.50 Ω measures the current, and at the same time a voltmeter with internal resistance 15 kΩ measures the voltage across one of the 7.5-kΩ resistors in the circuit. What do the ammeter and voltmeter read? What is the % "error" from the current and voltage *without* meters?

64. (III) What internal resistance should the voltmeter of Example 19–17 have to be in error by less than 5%?

65. (III) Two 9.4-kΩ resistors are placed in series and connected to a battery. A voltmeter of sensitivity 1000 Ω/V is on the 3.0-V scale and reads 1.9 V when placed across either resistor. What is the emf of the battery? (Ignore its internal resistance.)

66. (III) When the resistor R in Fig. 19–73 is 35 Ω, the high-resistance voltmeter reads 9.7 V. When R is replaced by a 14.0-Ω resistor, the voltmeter reading drops to 8.1 V. What are the emf and internal resistance of the battery?

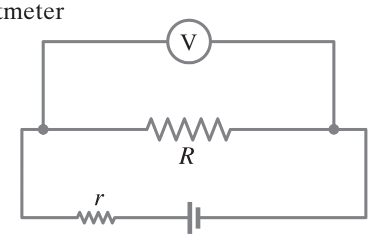

FIGURE 19–73 Problem 66.

General Problems

67. Suppose that you wish to apply a 0.25-V potential difference between two points on the human body. The resistance is about 1800 Ω, and you only have a 1.5-V battery. How can you connect up one or more resistors to produce the desired voltage?

68. A **three-way lightbulb** can produce 50 W, 100 W, or 150 W, at 120 V. Such a bulb contains two filaments that can be connected to the 120 V individually or in parallel (Fig. 19–74). (*a*) Describe how the connections to the two filaments are made to give each of the three wattages. (*b*) What must be the resistance of each filament?

FIGURE 19–74 Problem 68.

69. What are the values of effective capacitance which can be obtained by connecting four identical capacitors, each having a capacitance C?

70. Electricity can be a hazard in hospitals, particularly to patients who are connected to electrodes, such as an ECG. Suppose that the motor of a motorized bed shorts out to the bed frame, and the bed frame's connection to a ground has broken (or was not there in the first place). If a nurse touches the bed and the patient at the same time, the nurse becomes a conductor and a complete circuit can be made through the patient to ground through the ECG apparatus. This is shown schematically in Fig. 19–75. Calculate the current through the patient.

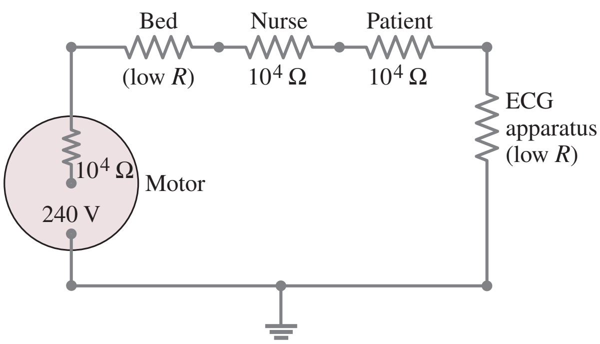

FIGURE 19–75 Problem 70.

71. Suppose that a person's body resistance is 950 Ω (moist skin). (*a*) What current passes through the body when the person accidentally is connected to 120 V? (*b*) If there is an alternative path to ground whose resistance is 25 Ω, what then is the current through the body? (*c*) If the voltage source can produce at most 1.5 A, how much current passes through the person in case (*b*)?

72. One way a multiple-speed ventilation fan for a car can be designed is to put resistors in series with the fan motor. The resistors reduce the current through the motor and make it run more slowly. Suppose the current in the motor is 5.0 A when it is connected directly across a 12-V battery. (*a*) What series resistor should be used to reduce the current to 2.0 A for low-speed operation? (*b*) What power rating should the resistor have? Assume that the motor's resistance is roughly the same at all speeds.

73. A **Wheatstone bridge** is a type of "bridge circuit" used to make measurements of resistance. The unknown resistance to be measured, R_x, is placed in the circuit with accurately known resistances R_1, R_2, and R_3 (Fig. 19–76). One of these, R_3, is a variable resistor which is adjusted so that when the switch is closed momentarily, the ammeter Ⓐ shows zero current flow. The bridge is then said to be balanced. (*a*) Determine R_x in terms of R_1, R_2, and R_3. (*b*) If a Wheatstone bridge is "balanced" when $R_1 = 590\ \Omega$, $R_2 = 972\ \Omega$, and $R_3 = 78.6\ \Omega$, what is the value of the unknown resistance?

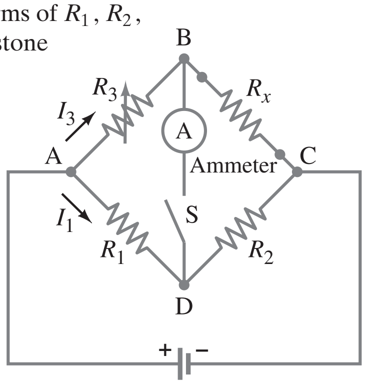

FIGURE 19–76 Problem 73. Wheatstone bridge.

74. The internal resistance of a 1.35-V mercury cell is 0.030 Ω, whereas that of a 1.5-V dry cell is 0.35 Ω. Explain why three mercury cells can more effectively power a 2.5-W hearing aid that requires 4.0 V than can three dry cells.

75. How many $\frac{1}{2}$-W resistors, each of the same resistance, must be used to produce an equivalent 3.2-kΩ, 3.5-W resistor? What is the resistance of each, and how must they be connected? Do not exceed $P = \frac{1}{2}$W in each resistor.

76. A **solar cell**, 3.0 cm square, has an output of 350 mA at 0.80 V when exposed to full sunlight. A solar panel that delivers close to 1.3 A of current at an emf of 120 V to an external load is needed. How many cells will you need to create the panel? How big a panel will you need, and how should you connect the cells to one another?

77. A power supply has a fixed output voltage of 12.0 V, but you need $V_T = 3.5$ V output for an experiment. (*a*) Using the voltage divider shown in Fig. 19–77, what should R_2 be if R_1 is 14.5 Ω? (*b*) What will the terminal voltage V_T be if you connect a load to the 3.5-V output, assuming the load has a resistance of 7.0 Ω?

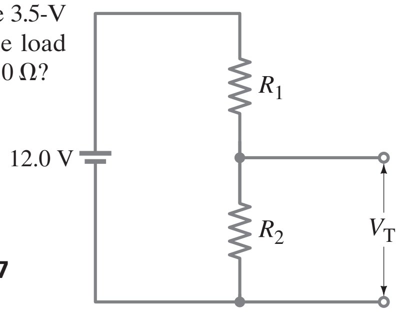

FIGURE 19–77
Problem 77.

78. A battery produces 40.8 V when 8.40 A is drawn from it, and 47.3 V when 2.80 A is drawn. What are the emf and internal resistance of the battery?

79. In the circuit shown in Fig. 19–78, the 33-Ω resistor dissipates 0.80 W. What is the battery voltage?

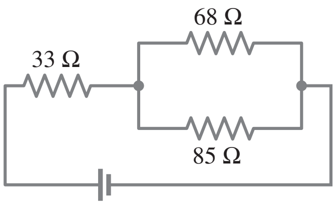

FIGURE 19–78
Problem 79.

80. For the circuit shown in Fig. 19–79, determine (*a*) the current through the 16-V battery and (*b*) the potential difference between points a and b, $V_a - V_b$.

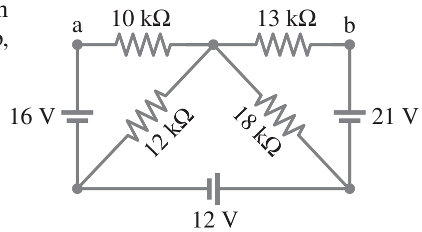

FIGURE 19–79
Problem 80.

81. The current through the 20-Ω resistor in Fig. 19–80 does not change whether the two switches S_1 and S_2 are both open or both closed. Use this clue to determine the value of the unknown resistance *R*.

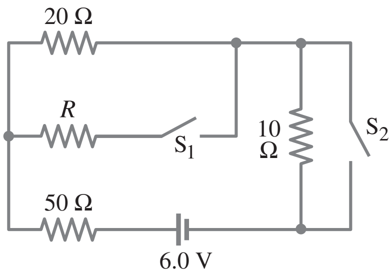

FIGURE 19–80
Problem 81.

82. (*a*) A voltmeter and an ammeter can be connected as shown in Fig. 19–81a to measure a resistance *R*. If *V* is the voltmeter reading, and *I* is the ammeter reading, the value of *R* will not quite be V/I (as in Ohm's law) because some current goes through the voltmeter. Show that the actual value of *R* is

$$\frac{1}{R} = \frac{I}{V} - \frac{1}{R_V},$$

where R_V is the voltmeter resistance. Note that $R \approx V/I$ if $R_V \gg R$. (*b*) A voltmeter and an ammeter can also be connected as shown in Fig. 19–81b to measure a resistance *R*. Show in this case that

$$R = \frac{V}{I} - R_A,$$

where *V* and *I* are the voltmeter and ammeter readings and R_A is the resistance of the ammeter. Note that $R \approx V/I$ if $R_A \ll R$.

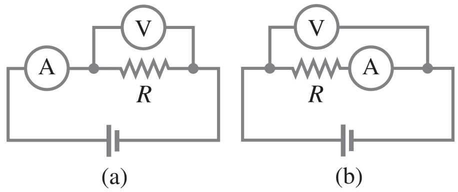

FIGURE 19–81
Problem 82.

83. The circuit shown in Fig. 19–82 uses a neon-filled tube as in Fig. 19–23a. This neon lamp has a threshold voltage V_0 for conduction, because no current flows until the neon gas in the tube is ionized by a sufficiently strong electric field. Once the threshold voltage is exceeded, the lamp has negligible resistance. The capacitor stores electrical energy, which can be released to flash the lamp. Assume that $C = 0.150\,\mu$F, $R = 2.35 \times 10^6\,\Omega$, $V_0 = 90.0$ V, and $\mathscr{E} = 105$ V. (*a*) Assuming the circuit is hooked up to the emf at time $t = 0$, at what time will the light first flash? (*b*) If the value of *R* is increased, will the time you found in part (*a*) increase or decrease? (*c*) The flashing of the lamp is very brief. Why? (*d*) Explain what happens after the lamp flashes for the first time.

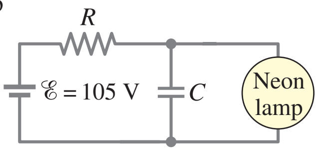

FIGURE 19–82
Problem 83.

84. In Fig. 19–83, let $V = 10.0$ V and $C_1 = C_2 = C_3 = 25.4\,\mu$F. How much energy is stored in the capacitor network (*a*) as shown, (*b*) if the capacitors were all in series, and (*c*) if the capacitors were all in parallel?

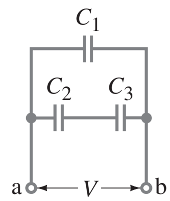

FIGURE 19–83
Problem 84.

85. A 12.0-V battery, two resistors, and two capacitors are connected as shown in Fig. 19–84. After the circuit has been connected for a long time, what is the charge on each capacitor?

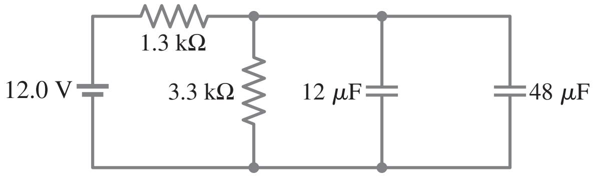

FIGURE 19–84 Problem 85.

86. How much energy must a 24-V battery expend to charge a 0.45-μF and a 0.20-μF capacitor fully when they are placed (*a*) in parallel, (*b*) in series? (*c*) How much charge flowed from the battery in each case?

87. Two capacitors, $C_1 = 2.2\,\mu\text{F}$ and $C_2 = 1.2\,\mu\text{F}$, are connected in parallel to a 24-V source as shown in Fig. 19–85a. After they are charged they are disconnected from the source and from each other, and then reconnected directly to each other with plates of opposite sign connected together (see Fig. 19–85b). Find the charge on each capacitor and the potential across each after equilibrium is established (Fig. 19–85c).

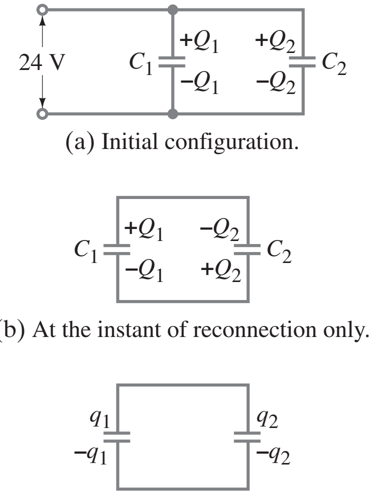

FIGURE 19–85 Problem 87.

88. The switch S in Fig. 19–86 is connected downward so that capacitor C_2 becomes fully charged by the battery of voltage V_0. If the switch is then connected upward, determine the charge on each capacitor after the switching.

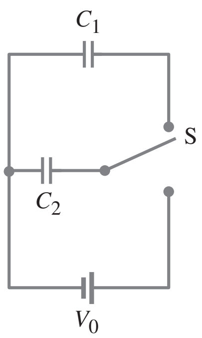

FIGURE 19–86 Problem 88.

89. The performance of the starter circuit in a car can be significantly degraded by a small amount of corrosion on a battery terminal. Figure 19–87a depicts a properly functioning circuit with a battery (12.5-V emf, 0.02-Ω internal resistance) attached via corrosion-free cables to a starter motor of resistance $R_S = 0.15\,\Omega$. Sometime later, corrosion between a battery terminal and a starter cable introduces an extra series resistance of only $R_C = 0.10\,\Omega$ into the circuit as suggested in Fig. 19–87b. Let P_0 be the power delivered to the starter in the circuit free of corrosion, and let P be the power delivered to the circuit with corrosion. Determine the ratio P/P_0.

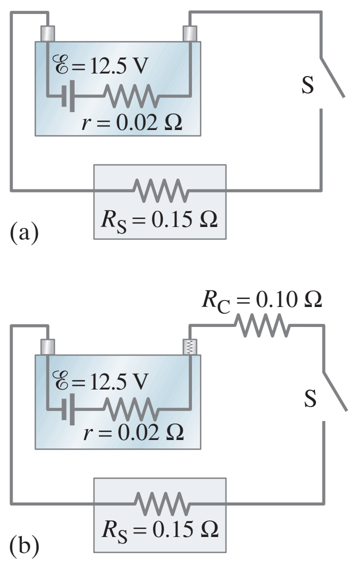

FIGURE 19–87 Problem 89.

90. The variable capacitance of an old radio tuner consists of four plates connected together placed alternately between four other plates, also connected together (Fig. 19–88). Each plate is separated from its neighbor by 1.6 mm of air. One set of plates can move so that the area of overlap of each plate varies from 2.0 cm^2 to 9.0 cm^2. (*a*) Are these seven capacitors connected in series or in parallel? (*b*) Determine the range of capacitance values.

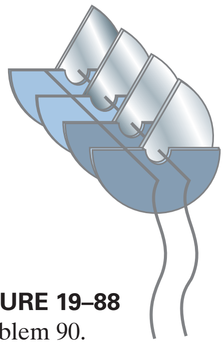

FIGURE 19–88 Problem 90.

91. A 175-pF capacitor is connected in series with an unknown capacitor, and as a series combination they are connected to a 25.0-V battery. If the 175-pF capacitor stores 125 pC of charge on its plates, what is the unknown capacitance?

92. In the circuit shown in Fig. 19–89, $C_1 = 1.0\,\mu\text{F}$, $C_2 = 2.0\,\mu\text{F}$, $C_3 = 2.4\,\mu\text{F}$, and a voltage $V_{ab} = 24\text{ V}$ is applied across points a and b. After C_1 is fully charged, the switch is thrown to the right. What is the final charge and potential difference on each capacitor?

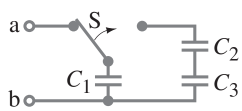

FIGURE 19–89 Problem 92.

Search and Learn

1. Fill in the Table below for a combination of two unequal resistors of resistance R_1 and R_2. Assume the electric potential on the low-voltage end of the combination is V_A volts and the potential at the high-voltage end of the combination is V_B volts. First draw diagrams.

Property	Resistors in Series	Resistors in Parallel
Equivalent resistance		
Current through equivalent resistance		
Voltage across equivalent resistance		
Voltage across the pair of resistors		
Voltage across each resistor	$V_1 =$ $V_2 =$	$V_1 =$ $V_2 =$
Voltage at a point between the resistors		Not applicable
Current through each resistor	$I_1 =$ $I_2 =$	$I_1 =$ $I_2 =$

2. Cardiac defibrillators are discussed in Section 17–9. (*a*) Choose a value for the resistance so that the 1.0-μF capacitor can be charged to 3000 V in 2.0 seconds. Assume that this 3000 V is 95% of the full source voltage. (*b*) The effective resistance of the human body is given in Section 19–7. If the defibrillator discharges with a time constant of 10 ms, what is the effective capacitance of the human body?

3. The circuit shown in Fig. 19–90 is a primitive 4-bit **digital-to-analog converter (DAC)**. In this circuit, to represent each digit (2^n) of a binary number, a "1" has the n^{th} switch closed whereas zero ("0") has the switch open. For example, 0010 is represented by closing switch $n = 1$, while all other switches are open. Show that the voltage V across the 1.0-Ω resistor for the binary numbers 0001, 0010, 0100, and 1001 (which in decimal represent 1, 2, 4, 9) follows the pattern that you expect for a 4-bit DAC. (Section 17–10 may help.)

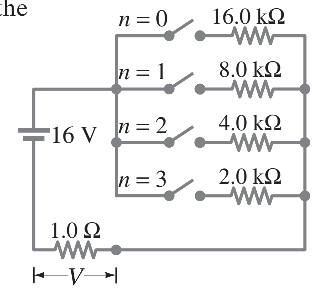

FIGURE 19–90 Search and Learn 3.

ANSWERS TO EXERCISES

A: 6 Ω and 25 Ω.
B: (*b*).
C: (*a*) 60-W bulb; (*b*) 100-W bulb. [Can you explain why? In (*a*), recall $P = I^2R$.]
D: $41I_3 - 45 + 21I_2 - 80 = 0$.
E: 180 A; this high current through the batteries could cause them to become very hot (and dangerous—possibly exploding): the power dissipated in the weak battery would be $P = I^2r = (180\text{ A})^2(0.10\,\Omega) = 3200$ W!
F: (*e*).
G: $\approx$ 500 kΩ.