* **23.** A voltmeter connected across a resistor always reads *less* than the actual voltage across the resistor when the meter is not present. Explain.

* **24.** 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 voltmeter, it registers 1.5 V. How would you explain this?

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 8.50 V when the battery is connected in series with (*a*) an 81.0-Ω resistor, and (*b*) an 810-Ω resistor.

2. (I) Four 1.5-V cells are connected in series to a 12-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 wires?

3. (II) What is the internal resistance of a 12.0-V car battery whose terminal voltage drops to 8.4 V when the starter draws 75 A? What is the resistance of the starter?

4. (II) A 1.5-V dry cell can be tested by connecting it to a low-resistance ammeter. It should be able to supply at least 22 A. What is the internal resistance of the cell in this case, assuming it is much greater than that of the ammeter?

19–2 Resistors in Series and Parallel

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

5. (I) Four 240-Ω lightbulbs are connected in series. What is the total resistance of the circuit? What is their resistance if they are connected in parallel?

6. (I) Three 45-Ω lightbulbs and three 75-Ω lightbulbs are connected in series. (*a*) What is the total resistance of the circuit? (*b*) What is their resistance if all six are wired in parallel?

7. (I) A 650-Ω and a 2200-Ω resistor are connected in series with a 12-V battery. What is the voltage across the 2200-Ω resistor?

8. (I) Given only one 25-Ω and one 35-Ω resistor, list all possible values of resistance that can be obtained.

9. (I) Suppose that you have a 680-Ω, a 940-Ω, and a 1.20-kΩ resistor. What is (*a*) the maximum, and (*b*) the minimum resistance you can obtain by combining these?

10. (II) Suppose that you have a 6.0-V battery and you wish to apply a voltage of only 4.0 V. Given an unlimited supply of 1.0-Ω resistors, how could you connect them so as to make a "voltage divider" that produces a 4.0-V output for a 6.0-V input?

11. (II) Three 240-Ω 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?

12. (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 rated at 3.0 W (at 12.0 V) which are connected in parallel. What is the battery's internal resistance?

13. (II) Eight identical lights are connected in series across a 110-V line. (*a*) What is the voltage across each bulb? (*b*) If the current is 0.50 A, what is the resistance of each bulb, and what is the power dissipated in each?

14. (II) Eight lights are connected in parallel to a 110-V source by two long leads of total resistance $1.6\,\Omega$. If 240 mA flows through each bulb, what is the resistance of each, and what fraction of the total power is wasted in the leads?

15. (II) Eight 7.0-W Christmas tree lights are connected in series to each other and to a 110-V source. What is the resistance of each bulb?

16. (II) A close inspection of an electric circuit reveals that a 480-Ω resistor was inadvertently soldered in the place where a 320-Ω resistor is needed. How can this be fixed without removing anything from the existing circuit?

17. (II) Determine (*a*) the equivalent resistance of the circuit shown in Fig. 19–39, and (*b*) the voltage across each resistor.

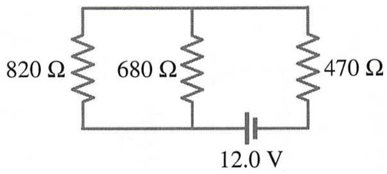
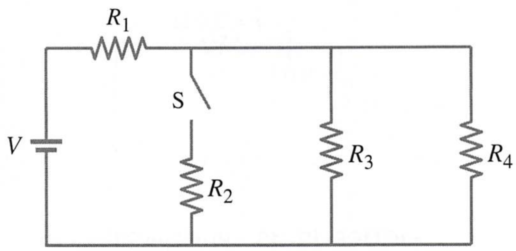


FIGURE 19–39 Problem 17.

18. (II) A 75-W, 110-V bulb is connected in parallel with a 40-W, 110-V bulb. What is the net resistance?

19. (III) Consider the network of resistors shown in Fig. 19–40. 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 $R_1 = R_2 = R_3 = R_4 = 125\,\Omega$ and $V = 22.0$ V. Determine the current through each resistor before and after closing the switch. Are your qualitative predictions confirmed?

FIGURE 19–40 Problem 19.



20. (III) What is the net resistance of the circuit connected to the battery in Fig. 19–41? Each resistance has $R = 2.8\ \text{k}\Omega$.

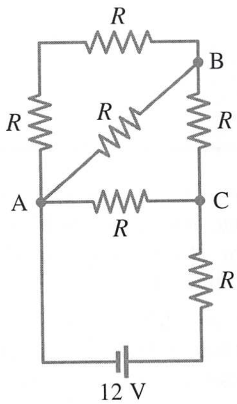


FIGURE 19–41 Problem 20.

21. (III) Three equal resistors (R) are connected to a battery as shown in Fig. 19–42. 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 15.0 V, what is its terminal voltage when the switch is closed if the internal resistance is $0.50\ \Omega$ and $R = 5.50\ \Omega$? (*e*) What is the terminal voltage when the switch is open?

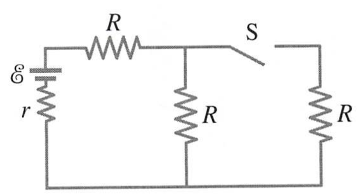


FIGURE 19–42 Problem 21.

22. (III) A 2.8-kΩ and a 2.1-kΩ resistor are connected in parallel; this combination is connected in series with a 1.8-kΩ resistor. If each resistor is rated at $\frac{1}{2}$ W (maximum without overheating), what is the maximum voltage that can be applied across the whole network?

19–3 Kirchhoff's Rules

23. (I) Calculate the current in the circuit of Fig. 19–43 and show that the sum of all the voltage changes around the circuit is zero.

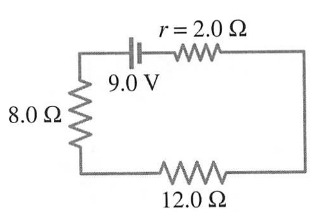


FIGURE 19–43 Problem 23.

24. (II) Determine the terminal voltage of each battery in Fig. 19–44.

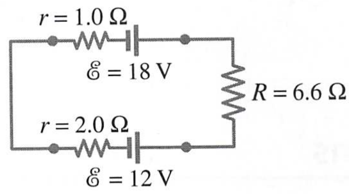


FIGURE 19–44 Problem 24.

25. (II) (*a*) What is the potential difference between points a and d in Fig. 19–45 (same circuit as Fig. 19–13, Example 19–8), and (*b*) what is the terminal voltage of each battery?

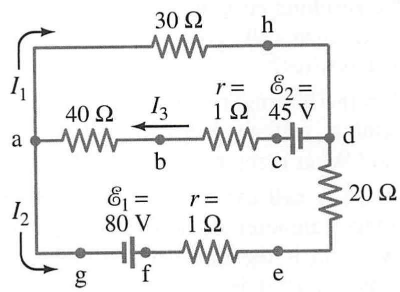


FIGURE 19–45 Problem 25.

26. (II) For the circuit shown in Fig. 19–46, find the potential difference between points a and b. Each resistor has $R = 75\ \Omega$ and each battery is 1.5 V.

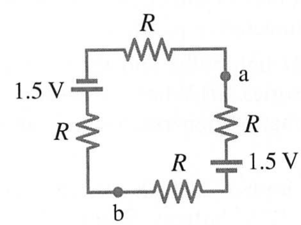


FIGURE 19–46 Problem 26.

27. (II) Determine the magnitudes and directions of the currents through R_1 and R_2 in Fig. 19–47.

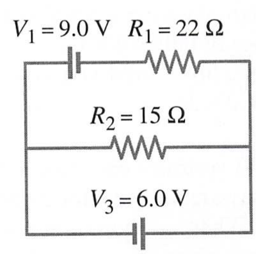


FIGURE 19–47 Problems 27 and 28.

28. (II) Repeat Problem 27, now assuming that each battery has an internal resistance $r = 1.2\ \Omega$.

29. (II) Determine the magnitudes and directions of the currents in each resistor shown in Fig. 19–48. The batteries have emfs of $\mathscr{E}_1 = 9.0\text{ V}$ and $\mathscr{E}_2 = 12.0\text{ V}$ and the resistors have values of $R_1 = 25\,\Omega$, $R_2 = 18\,\Omega$, and $R_3 = 35\,\Omega$.

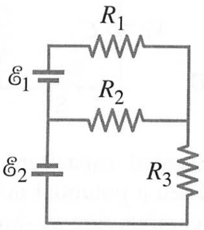


FIGURE 19–48 Problems 29 and 30.

30. (II) Repeat Problem 29, assuming each battery has internal resistance $r = 1.0\,\Omega$.

31. (II) Calculate the currents in each resistor of Fig. 19–49.

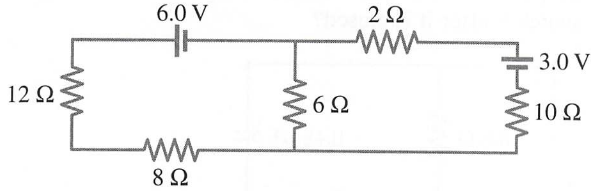


FIGURE 19–49 Problem 31.

32. (III) (*a*) Determine the currents I_1, I_2, and I_3 in Fig. 19–50. Assume the internal resistance of each battery is $r = 1.0\,\Omega$. (*b*) What is the terminal voltage of the 6.0-V battery?

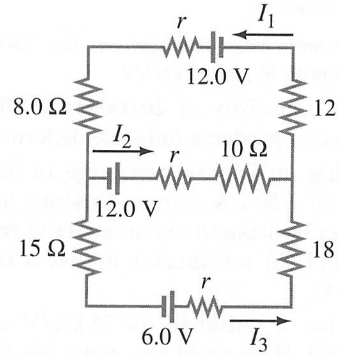


FIGURE 19–50 Problems 32 and 33.

33. (III) What would the current I_1 be in Fig. 19–50 if the 12-Ω resistor is shorted out? Let $r = 1.0\,\Omega$.

* 19–4 Emfs Combined, Battery Charging

*34. (II) Suppose two batteries, with unequal emfs of 2.00 V and 3.00 V, are connected as shown in Fig. 19–51. If each internal resistance is $r = 0.100\,\Omega$, and $R = 4.00\,\Omega$, what is the voltage across the resistor R?

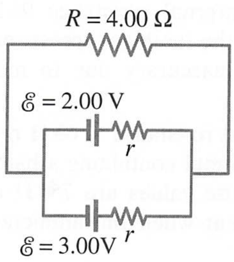


FIGURE 19–51 Problem 34.

19–5 Capacitors in Series and in Parallel

35. (I) (*a*) Six 4.7-μF capacitors are connected in parallel. What is the equivalent capacitance? (*b*) What is their equivalent capacitance if connected in series?

36. (I) You have three capacitors, of capacitance 3200 pF, 7500 pF, and 0.0100 μF. What maximum and minimum capacitance can you form from these? How do you make the connection in each case?

37. (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. 19–52). What is the net capacitance?

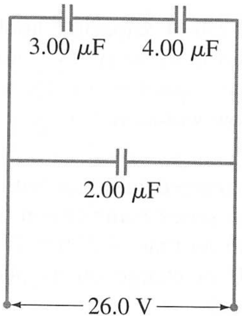


FIGURE 19–52 Problems 37 and 38.

38. (II) If 26.0 V is applied across the whole network of Fig. 19–52, calculate the voltage across each capacitor.

39. (II) The capacitance of a portion of a circuit is to be reduced from 4800 pF to 2900 pF. What capacitance can be added to the circuit to produce this effect without removing existing circuit elements? Must any existing connections be broken in the process?

40. (II) An electric circuit was accidentally constructed using a 5.0-μF capacitor instead of the required 16-μF value. Without removing the 5.0-μF capacitor, what can a technician add to correct this circuit?

41. (II) Determine the equivalent capacitance of the circuit shown in Fig. 19–53.

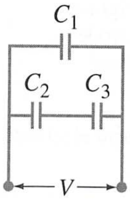


FIGURE 19–53 Problems 41, 42, 43, and 44.

*42. (II) In Fig. 19–53, if $C_1 = C_2 = 2C_3 = 22.6\,\mu\text{F}$, how much charge is stored on each capacitor when $V = 45.0\text{ V}$?

*43. (II) In Fig. 19–53, suppose $C_1 = C_2 = C_3 = 16.0\,\mu\text{F}$. If the charge on C_2 is $Q_2 = 24.0\,\mu\text{C}$, determine the charge on each of the other capacitors, the voltage across each capacitor, and the voltage V across the entire combination.

*44. (II) In Fig. 19–53, let $V = 78\text{ V}$ and $C_1 = C_2 = C_3 = 7.2\,\mu\text{F}$. How much energy is stored in the capacitor network?

*45. (II) A 0.40-μF and a 0.60-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.

46. (II) Three conducting plates, each of area A, are connected as shown in Fig. 19–54. (a) Are the two capacitors formed connected in series or in parallel? (b) Determine C as a function of d_1, d_2, and A. Assume $d_1 + d_2$ is much less than the dimensions of the plates.

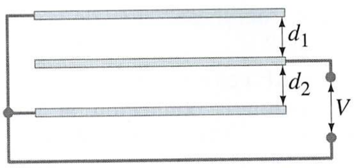


FIGURE 19–54 Problem 46.

47. (II) A circuit contains a single 250-pF capacitor hooked across a battery. It is desired to store three 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. (III) A 185-pF capacitor is connected in series with an unknown capacitance, and as a series combination they are connected to a battery with an emf of 25.0 V. If the 185-pF capacitor stores 125 pC of charge on its plates, what is the unknown capacitance?

19–6 *RC* Circuits

49. (I) Electrocardiographs are often connected as shown in Fig. 19–55. The leads 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.]

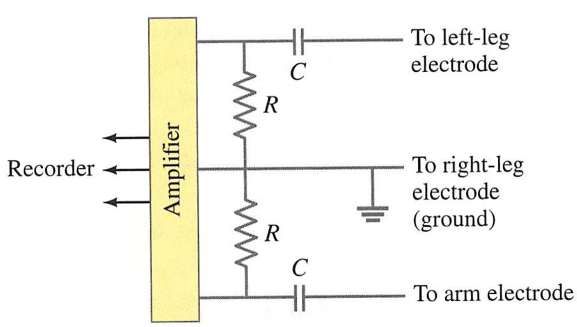


FIGURE 19–55 Problem 49.

50. (II) In Fig. 19–56 (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 35.0 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.

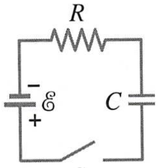


FIGURE 19–56 Problem 50.

51. (II) The RC circuit of Fig. 19–57 (same as Fig. 19–21a) has $R = 6.7\,\text{k}\Omega$ 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 1.0% of its initial voltage?

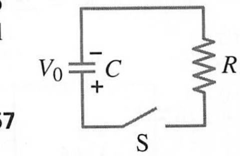


FIGURE 19–57 Problem 51.

52. (III) Two resistors and two uncharged capacitors are arranged as shown in Fig. 19–58. 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?

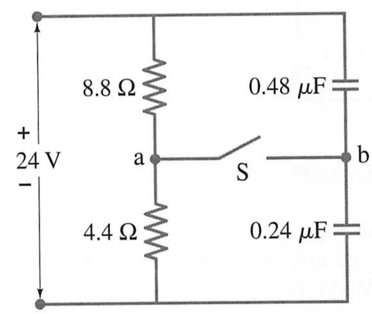


FIGURE 19–58 Problem 52.

* 19–8 Ammeters and Voltmeters

* 53. (I) What is the resistance of a voltmeter on the 250-V scale if the meter sensitivity is 30,000 Ω/V?

* 54. (I) An ammeter has a sensitivity of 20,000 Ω/V. What current in the galvanometer produces full-scale deflection?

* 55. (II) A galvanometer has an internal resistance of 30 Ω and deflects full scale for a 50-μA current. Describe how to use this galvanometer to make (a) an ammeter to read currents up to 30 A, and (b) a voltmeter to give a full-scale deflection of 250 V.

* 56. (II) A galvanometer has a sensitivity of 35 kΩ/V and internal resistance 20.0 Ω. How could you make this into (a) an ammeter that reads 2.0 A full scale, or (b) a voltmeter reading 1.00 V full scale?

* 57. (II) A milliammeter reads 10 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 10 V without taking the ammeter apart? What will be the sensitivity (Ω/V) of your voltmeter?

* 58. (II) A 45-V battery of negligible internal resistance is connected to a 38-kΩ and a 27-kΩ resistor in series. What reading will a voltmeter, of internal resistance 95 kΩ, give when used to measure the voltage across each resistor? What is the percent inaccuracy due to meter resistance for each case?

* 59. (II) An ammeter whose internal resistance is 63 Ω reads 5.25 mA when connected in a circuit containing a battery and two resistors in series whose values are 750 Ω and 480 Ω. What is the actual current when the ammeter is absent?

* 60. (II) A battery with $\mathscr{E} = 12.0\text{ V}$ and internal resistance $r = 1.0\ \Omega$ is connected to two 9.0-kΩ resistors in series. An ammeter of internal resistance $0.50\ \Omega$ measures the current, and at the same time a voltmeter with internal resistance 15 kΩ measures the voltage across one of the 9.0-kΩ resistors in the circuit. What do the ammeter and voltmeter read?

* 61. (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 2.0 V when placed across either resistor. What is the emf of the battery? (Ignore its internal resistance.)

* 62. (III) What internal resistance should the voltmeter of Example 19–15 have to be in error by less than 3%?

* 63. (III) When the resistor R in Fig. 19–59 is 35 Ω, the high-resistance voltmeter reads 9.7 V. When R is replaced by a 9.0-Ω resistor, the voltmeter reading drops to 8.1 V. What are the emf and internal resistance of the battery?

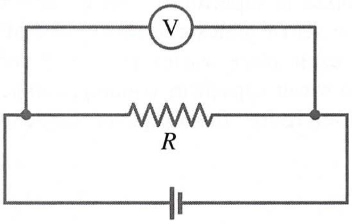


FIGURE 19–59 Problem 63.

General Problems

64. Suppose that you wish to apply a 0.25-V potential difference between two points on the human body. The resistance is about 2000 Ω, and you only have a 9.0-V battery. How can you connect up one or more resistors to produce the desired voltage?

65. 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. (*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?

66. Suppose you want to run some apparatus that is 95 m from an electric outlet. Each of the wires connecting your apparatus to the 120-V source has a resistance per unit length of 0.0065 Ω/m. If your apparatus draws 3.0 A, what will be the voltage drop across the connecting wires and what voltage will be applied to your apparatus?

67. Electricity can be a hazard in hospitals, particularly to patients who are connected to electrodes, such as an ECG. For example, 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, she 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. 19–60. Calculate the current through the patient.

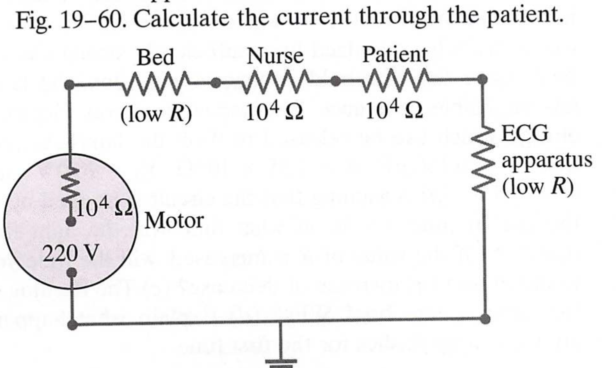


FIGURE 19–60 Problem 67.

68. How much energy must a 45-V battery expend to charge a 0.40-μF and a 0.60-μF capacitor fully when they are placed (*a*) in parallel, (*b*) in series? (*c*) How much charge flowed from the battery in each case?

69. A heart pacemaker is designed to operate at 72 beats/min using a 7.5-μF capacitor in a simple RC circuit. What value of resistance should be used if the pacemaker is to fire (capacitor discharge) when the voltage reaches 63% of maximum?

70. Suppose that a person's body resistance is 950 Ω. (*a*) What current passes through the body when the person accidentally is connected to 110 V? (*b*) If there is an alternative path to ground whose resistance is 45 Ω, what current passes through the person? (*c*) If the voltage source can produce at most 1.5 A, how much current passes through the person in case (*b*)?

71. 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. 19–61). 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. (*a*) Determine R_x in terms of R_1, R_2, and R_3. (*b*) If a Wheatstone bridge is "balanced" when $R_1 = 630\ \Omega$, $R_2 = 972\ \Omega$, and $R_3 = 42.6\ \Omega$, what is the value of the unknown resistance?

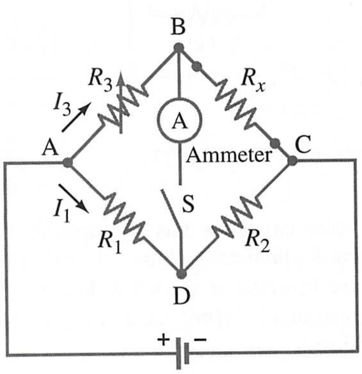


FIGURE 19–61 Problems 71 and 72. Wheatstone bridge.

72. An unknown length of platinum wire 0.920 mm in diameter is placed as the unknown resistance in a Wheatstone bridge (see Problem 71; Fig. 19–61). Arms 1 and 2 have resistance of 38.0 Ω and 46.0 Ω, respectively. Balance is achieved when R_3 is 3.48 Ω. How long is the platinum wire?

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

74. The variable capacitance of an old radio tuner consists of four plates connected together placed alternately between four other plates, also connected together (Fig. 19–62). Each plate is separated from its neighbor by 1.5 mm of air. One set of plates can move so that the area of overlap of each plate varies from $2.0\,\text{cm}^2$ to $9.5\,\text{cm}^2$. (a) Are these seven capacitors connected in series or in parallel? (b) Determine the range of capacitance values.

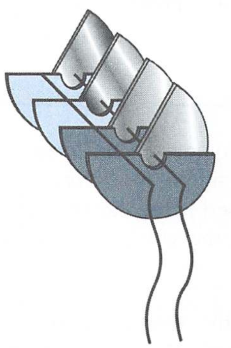


FIGURE 19–62 Problem 74.

75. A battery produces 40.8 V when 7.40 A is drawn from it and 47.3 V when 2.20 A is drawn. What are the emf and internal resistance of the battery?

76. How many $\frac{1}{2}$-W resistors, each of the same resistance, must be used to produce an equivalent 2.2-kΩ, 3.5-W resistor? What is the resistance of each, and how must they be connected? Do not exceed $P = \frac{1}{2}\,\text{W}$ in each resistor.

77. The current through the 4.0-kΩ resistor in Fig. 19–63 is 3.50 mA. What is the terminal voltage V_{ba} of the "unknown" battery? (There are two answers. Why?) [*Hint*: use conservation of energy or Kirchhoff's rules.]

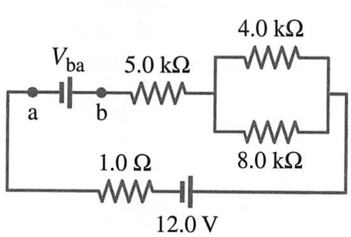


FIGURE 19–63 Problem 77.

78. An air-filled parallel-plate capacitor has capacitance C_0. If two identically sized dielectric slabs of dielectric constants K_1 and K_2 are inserted as shown in Fig. 19–64, what is the new capacitance? [*Hint*: treat this as two capacitors in combination.]

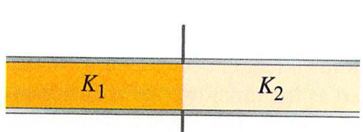


FIGURE 19–64 Problem 78.

79. For the circuit shown in Fig. 19–65, determine (a) the current through the 14-V battery and (b) the potential difference between points a and b, $V_{\text{a}} - V_{\text{b}}$.

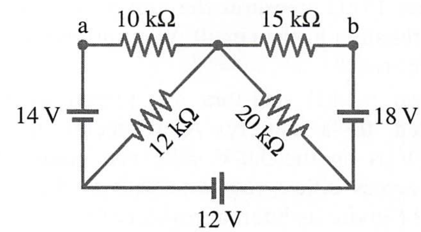


FIGURE 19–65 Problem 79.

80. 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 1.0 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? How can you optimize the output of your solar panel?

81. A power supply has a fixed output voltage of 12.0 V, but you need $V_{\text{T}} = 3.0\,\text{V}$ for an experiment. (a) Using the voltage divider shown in Fig. 19–66, what should R_2 be if R_1 is 10.0 Ω? (b) What will the terminal voltage V_{T} be if you connect a load to the 3.0-V terminal, assuming the load has a resistance of 7.0 Ω?

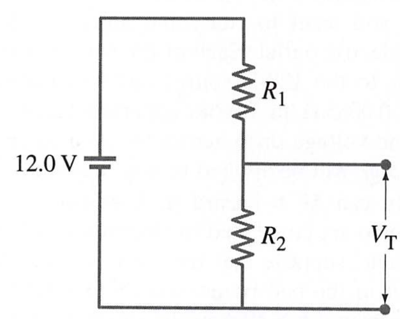


FIGURE 19–66 Problem 81.

82. The circuit shown in Fig. 19–67 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 $C = 0.150\,\mu\text{F}$, $R = 2.35 \times 10^6\,\Omega$, $V_0 = 90.0\,\text{V}$ and $\mathscr{E} = 105\,\text{V}$. ($a$) Assuming that 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.

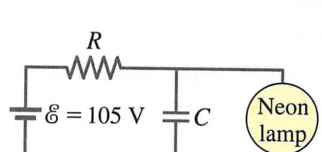


FIGURE 19–67 Problem 82.

83. The current through the 20-Ω resistor in Fig. 19–68 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.

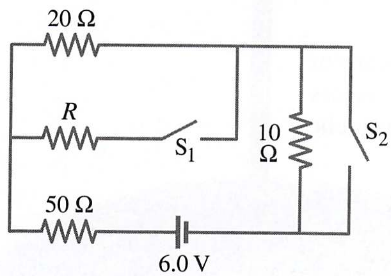


FIGURE 19–68 Problem 83.

84. In the circuit shown in Fig. 19–69, the 33-Ω resistor dissipates 0.50 W. What is the battery voltage?

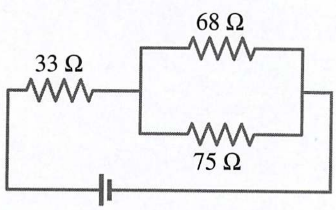


FIGURE 19–69 Problem 84.

85. (*a*) What is the equivalent resistance of the circuit shown in Fig. 19–70? (*b*) What is the current in the 18-Ω resistor? (*c*) What is the current in the 12-Ω resistor? (*d*) What is the power dissipation in the 4.5-Ω resistor?

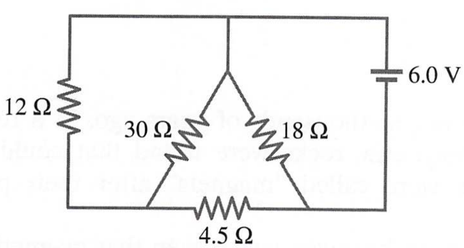


FIGURE 19–70 Problem 85.

* 86. (*a*) A voltmeter and an ammeter can be connected as shown in Fig. 19–71a 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 of the current actually goes through the voltmeter. Show that the actual value of R is given by

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

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. 19–71b 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 $R_A \ll R$.

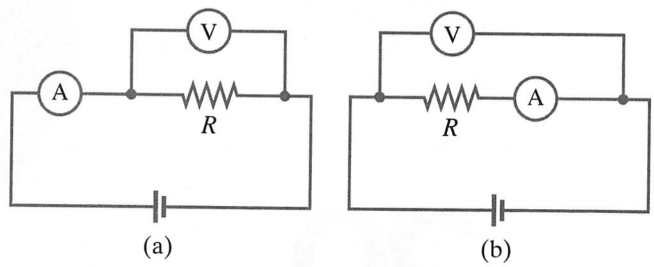


FIGURE 19–71 Problem 86.

87. A flashlight bulb rated at 2.5 W and 3.0 V is operated by a 9.0-V battery. To light the bulb at its rated voltage and power, a resistor R is connected in series as shown in Fig. 19–72. What value should the resistor have?

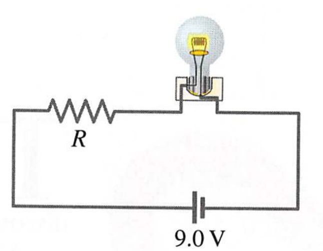


FIGURE 19–72 Problem 87.

Answers to Exercises

A: (*a*) 1.14 A; (*b*) 11.4 V; (*c*) $P_R = 13.1$ W, $P_r = 0.65$ W.
B: Series with $R_1/R_2 = 4.0$.
C: $41I_3 - 45 + 21I_2 - 80 = 0$.
D: 180 A; this high current through the batteries could cause them to become very hot: the power dissipated in the weak battery would be $P = I^2r = (180\text{ A})^2(0.10\ \Omega) = 3200$ W!
E: 12 kΩ.
F: The voltmeter will consist of a resistance $R_{ser} = 300$ kΩ in series with the galvanometer.