PROBLEMS

Section 19.1

•**P29** The capacitor in Figure 19.65 is initially charged, then the circuit is connected. Which graph in Figure 19.66 best describes the current through the bulb as a function of time?

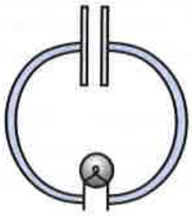

Figure 19.65

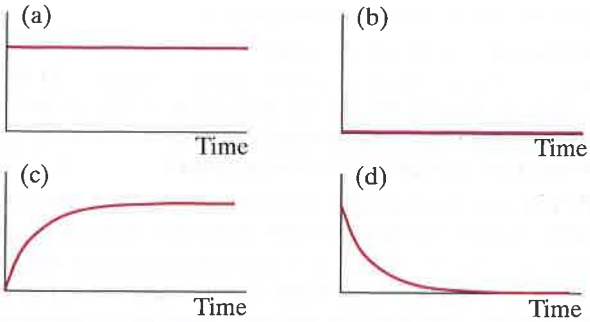

Figure 19.66

•**P30** The capacitor in Figure 19.67 is initially uncharged, then the circuit is connected. Which graph in Figure 19.66 best describes the current through the bulb as a function of time?

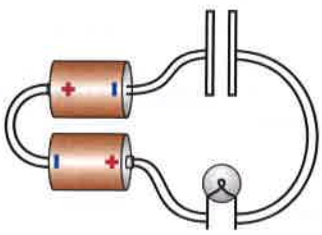

Figure 19.67

•**P31** The capacitor in Figure 19.67 is initially uncharged, then the circuit is connected. Which graph in Figure 19.66 best describes the absolute value of the charge on the left plate as a function of time?

•**P32** The capacitor in Figure 19.68 is initially uncharged, then the circuit is connected. Which graph in Figure 19.66 best describes the magnitude of the fringe field of the capacitor at location A (inside the connecting wire) as a function of time?

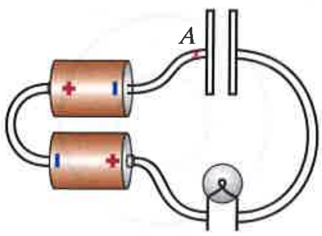

Figure 19.68

•**P33** The capacitor in Figure 19.68 is initially uncharged, then the circuit is connected. Which graph in Figure 19.66 best describes the magnitude of the net electric field at location A (inside the connecting wire) as a function of time?

•**P34** A particular capacitor is initially charged. Then a high-resistance Nichrome wire is connected between the plates of the capacitor, as shown in Figure 19.69. The needle of a compass placed under the wire deflects 20° to the east as soon as the connection is made. After 60 s the compass needle no longer deflects. **(a)** Which of the diagrams in Figure 19.69 best indicates the electron current at three locations in this circuit? (1) 0.01 s after the circuit is connected, (2) 15 s after the circuit is connected, (3) 120 s after the circuit is connected. **(b)** Which of the diagrams in Figure 19.70 best indicates the net electric field inside the wire at three locations in this circuit? (1) 0.01 s after the circuit is connected, (2) 15 s after the circuit is connected, (3) 120 s after the circuit is connected.

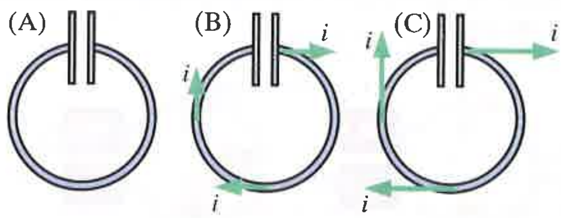

Figure 19.69

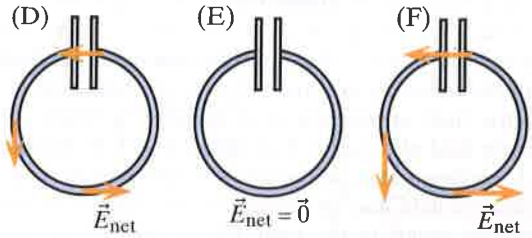

Figure 19.70

•**P35** Which of the following statements about the discharging of a capacitor through a light bulb are correct? Choose all that are true. (1) The fringe field of the capacitor decreases as the charge on the capacitor plates decreases. (2) Electrons flow across the gap between the plates of the capacitor, thus reducing the charge on the capacitor. (3) The electric field at a location inside the wire is due to charge on the surface of the wires and charge on the plates of the capacitor. (4) Electrons in the wires flow away from the negative plate toward the positive plate, reducing the charge on the plates.

•**P36** When a particular capacitor, which is initially uncharged, is connected to a battery and a small light bulb, the light bulb is initially bright but gradually gets dimmer, and after 45 s it goes out. The diagrams in Figure 19.71 show the electric field in the circuit and the surface charge distribution on the wires at three different times (0.01 s, 2 s, and 240 s) after the connection to the bulb is made. The diagrams in Figure 19.71 show the pattern of electric field in the wires and charge on the surface of the wires at three different times (0.01 s, 8 s, and 240 s) after the connection to the battery is made. Which of the diagrams best represents the state of the circuit at each time specified? **(a)** 0.01 s after the connection is made, **(b)** 8 s after the connection is made, **(c)** 240 s after the connection is made

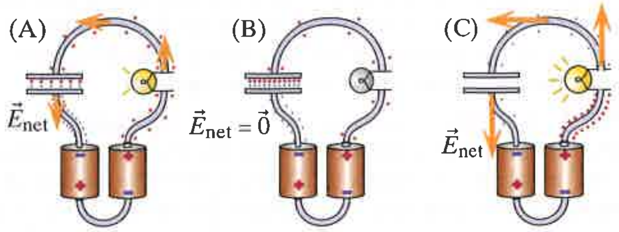

Figure 19.71

•P37 In circuit 1 (Figure 19.72), an uncharged capacitor is connected in series with two batteries and one light bulb. Circuit 2 (Figure 19.72) contains two light bulbs identical to the bulb in circuit 1; in all other respects it is identical to circuit 1. In circuit 1, the light bulb stays lit for 25 s. The following questions refer to these circuits. You should draw diagrams representing the fields and charges in each circuit at the times mentioned, in order to answer the questions.

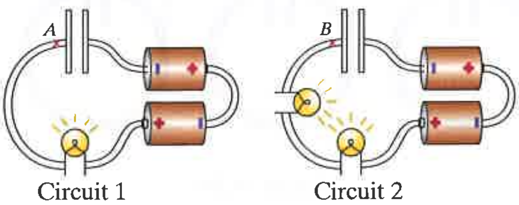

Figure 19.72

(a) One microsecond (1×10^{-6} s) after connecting both circuits, which of the following are true? Choose all that apply: (1) The net electric field at location A in circuit 1 is larger than the net electric field at location B in circuit 2. (2) At location A in circuit 1, electrons flow to the left. (3) At location A in circuit 1, the electric field due to charges on the surface of the wires and batteries points to the right. (4) In circuit 1 the potential difference across the capacitor plates is equal to the emf of the batteries. (5) The current in circuit 1 is larger than the current in circuit 2. **(b)** Two seconds after connecting both circuits, which of the following are true? Choose all that apply: (1) There is more charge on the plates of capacitor 1 than there is on the plates of capacitor 2. (2) There is negative charge on the right plate of the capacitor in circuit 1. (3) At location B in circuit 2 the net electric field points to the right. (4) At location B in circuit 2 the fringe field of the capacitor points to the right. (5) At location A in circuit 1 the fringe field of the capacitor points to the left. **(c)** Which of the graphs in Figure 19.73 represents the amount of charge on the positive plate of the capacitor in circuit 1 as a function of time? **(d)** Which of the graphs in Figure 19.73 represents the current in circuit 1 as a function of time?

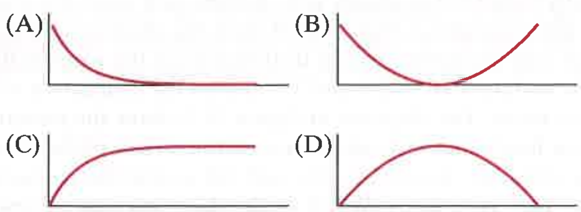

Figure 19.73

•P38 A certain capacitor has rectangular plates 56 cm by 24 cm, and the gap width is 0.20 mm. What is its capacitance? We see that typical capacitances are very small when measured in farads. A 1 F capacitor is quite extraordinary! Apparently it has a very large area A (all wrapped up in a small package), and a very small gap s.

•P39 A certain capacitor has rectangular plates 59 cm by 33 cm, and the gap width is 0.27 mm. If the gap is filled with a material whose dielectric constant is 2.9, what is the capacitance of this capacitor?

•P40 Suppose that you charged a 2.5 F capacitor with two 1.5 V batteries. How much charge would be on each plate in the final state? How many excess electrons would be on the negative plate?

•P41 You connect a 9 V battery to a capacitor consisting of two circular plates of radius 0.08 m separated by an air gap of 2 mm. What is the charge on the positive plate?

•P42 Two circular plates of radius 0.12 m are separated by an air gap of 1.5 mm. The plates carry charge $+Q$ and $-Q$ where $Q = 3.6 \times 10^{-8}$ C. **(a)** What is the magnitude of the electric field in the gap? **(b)** What is the potential difference across the gap? **(c)** What is the capacitance of this capacitor?

•P43 You may have noticed that while discharging a capacitor through a light bulb, the light bulb glows just about as brightly, and for just about as long, as it does while charging the same capacitor through the same bulb. Let E stand for the energy emitted by the light bulb (as light and heat) in the discharging phase, from just before the bulb is connected to the capacitor until the time when there is essentially no more current. In terms of $+E$ or $-E$, what was the energy change of the battery, capacitor, bulb, and surroundings during the charging phase, and during the discharging phase? One answer is already given in the following table:

	Charging	**Discharging**
Battery:		
Bulb:		
Capacitor:		
Surroundings:		$+E$

It is somewhat surprising that we can get this much information out of one simple observation.

••P44 As shown in Figure 19.74, a spherical metal shell of radius r_1 has a charge Q (on its outer surface) and is surrounded by a concentric spherical metal shell of radius r_2 which has a charge $-Q$ (on its inner surface).

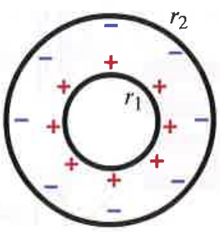

Figure 19.74

(a) Use the definition of capacitance: $Q = C|\Delta V|$ to find the capacitance of this spherical capacitor. (b) If the radii of the spherical shells r_1 and r_2 are large and nearly equal to each other, show that C can be written as $\varepsilon_0 A/s$ (which is also the equation for the capacitance of a parallel-plate capacitor) where $A = 4\pi r^2$ is the surface area of one of the spheres, and s is the small gap distance between them ($r_2 = r_1 + s$).

Section 19.2

•P45 In gold at room temperature, the mobility of mobile electrons is about 4.3×10^{-3} (m/s)/(V/m), and there are about 5.9×10^{28} mobile electrons per cubic meter. Calculate the conductivity of gold, including correct units.

•P46 Consider a silver wire with a cross-sectional area of 1 mm^2 carrying 0.3 A of current. The conductivity of silver is 6.3×10^7 (A/m^2)/(V/m). Calculate the magnitude of the electric field required to drive this current through the wire.

•P47 When a thin-filament light bulb is connected to two 1.5 V batteries in series, the current is 0.075 A. What is the resistance of the glowing thin-filament bulb?

•P48 In copper at room temperature, the mobility of mobile electrons is about 4.5×10^{-3} (m/s)/(V/m), and there are about 8×10^{28} mobile electrons per m^3. Calculate the conductivity σ and include the correct units. In actual practice, it is usually easier to measure the conductivity σ and deduce the mobility u from this measurement.

•P49 (a) A carbon resistor is 5 mm long and has a constant cross section of 0.2 mm^2. The conductivity of carbon at room temperature is $\sigma = 3 \times 10^4$ per ohm·m. In a circuit its potential at one end of the resistor is 12 V relative to ground, and at the other end the potential is 15 V. Calculate the resistance R and the current I. **(b)** A thin copper wire in this circuit is 5 mm long and has a constant cross section of 0.2 mm^2. The conductivity of copper at room temperature is $\sigma = 6 \times 10^7$ ohm^{-1}m^{-1}. The copper wire is in series with the carbon resistor, with one end connected to the 15 V end of the carbon resistor, and the current you calculated in part (a) runs through the carbon resistor wire. Calculate the resistance R of the copper wire and the potential $V_{\text{at end}}$ at the other end of the wire.

You can see that for most purposes a thick copper wire in a circuit would have practically a uniform potential. This is because the small drift speed in a thick, high-conductivity copper wire requires only a very small electric field, and the integral of this very small field creates a very small potential difference along the wire.

•P50 When a single thin-filament bulb is connected to a 1.5 V battery, the current through the battery is about 80 mA. If you add another thin-filament bulb in parallel, the battery current of course increases to 160 mA. Is the battery ohmic? That is, is the current through the battery proportional to the potential difference across the battery?

•P51 A certain ohmic resistor has a resistance of 40 Ω. A second resistor is made of the same material but is three times as long and has half the cross-sectional area. What is the resistance of the second resistor? What is the effective resistance of the two resistors in series?

•P52 In the circuit shown in Figure 19.75, the emf of the battery is 7.9 V. Resistor R_1 has a resistance of 23 Ω, and resistor R_2 has a resistance of 44 Ω. A steady current flows through the circuit. **(a)** What is the absolute value of the potential difference across R_1? **(b)** What is the conventional current through R_2?

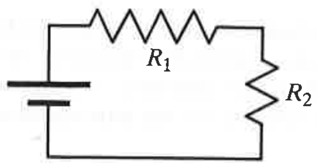

Figure 19.75

•P53 When a thick-filament bulb is connected to one flashlight battery, the current is 0.20 A. When you use two batteries in series, the current is not 0.40 A but only 0.33 A. Briefly explain this behavior.

•P54 In Figure 19.76 the resistance R_1 is 10 Ω, R_2 is 5 Ω, and R_3 is 20 Ω. If this combination of resistors were to be replaced by a single resistor with an equivalent resistance, what should that resistance be?

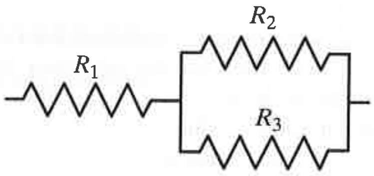

Figure 19.76

•P55 Suppose that you charge a 1 F capacitor in a circuit containing two 1.5 V batteries, so the final potential difference across the plates is 3 V. How much charge is on each plate? How many excess electrons are on the negative plate?

•P56 In the circuit shown in Figure 19.77 the emf of the battery is 7.4 V. Resistor R_1 has a resistance of 31 Ω , resistor R_2 has a resistance of 47 Ω, and resistor R_3 has a resistance of 52 Ω. A steady current flows through the circuit.

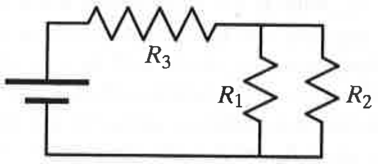

Figure 19.77

(a) What is the equivalent resistance of R_1 and R_2? **(b)** What is the equivalent resistance of all three resistors? **(c)** What is the conventional current through R_3?

•P57 Consider a copper wire with a cross-sectional area of 1 mm^2 (similar to your connecting wires) and carrying 0.3 A of current, which is about what you get in a circuit with a thick-filament bulb and two batteries in series. Calculate the strength of the very small electric field required to drive this current through the wire.

••P58 The conductivity of tungsten at room temperature, 1.8×10^7 (A/m^2)/(V/m), is significantly smaller than that of copper. At the very high temperature of a glowing light-bulb filament (nearly 3000 kelvins), the conductivity of tungsten is 18 times smaller than it is at room temperature. The tungsten filament of a thick-filament bulb has a radius of about 0.015 mm. Calculate the electric field required to drive 0.20 A of current through the glowing bulb and show that it is very large compared to the field in the connecting copper wires.

••P59 A circuit consists of a battery, whose emf is K, and five Nichrome wires, three thick and two thin as shown in

Figure 19.78. The thicknesses of the wires have been exaggerated in order to give you room to draw inside the wires. The internal resistance of the battery is negligible compared to the resistance of the wires. The voltmeter is not attached until part (e) of the problem.

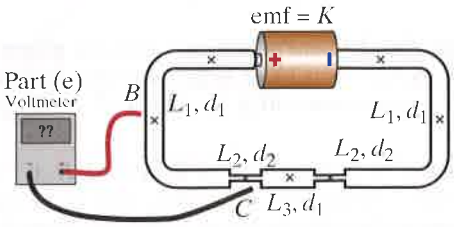

Figure 19.78

(a) Draw and label appropriately the electric field at the locations marked × inside the wires, paying attention to appropriate relative magnitudes of the vectors that you draw. **(b)** Show the approximate distribution of charges for this circuit. Make the important aspects of the charge distribution very clear in your drawing, supplementing your diagram if necessary with very brief written descriptions on the diagram. Make sure that parts (a) and (b) of this problem are consistent with each other. **(c)** Assume that you know the mobile-electron density n and the electron mobility u at room temperature for Nichrome. The lengths (L_1, L_2, L_3) and diameters (d_1, d_2) of the wires are given on the diagram. Calculate accurately the number of electrons that leave the negative end of the battery every second. Assume that no part of the circuit gets very hot. Express your result in terms of the given quantities (K, L_1, L_2, L_3, d_1, d_2, n, and u). Explain your work and identify the principles you are using. **(d)** In the case that $d_2 \ll d_1$, what is the *approximate* number of electrons that leave the negative end of the battery every second? **(e)** A voltmeter is attached to the circuit with its + lead connected to location B (halfway along the leftmost thick wire) and its − lead connected to location C (halfway along the leftmost thin wire). In the case that $d_2 \ll d_1$, what is the approximate voltage shown on the voltmeter, including sign? Express your result in terms of the given quantities (K, L_1, L_2, L_3, d_1, d_2, n, and, u).

••P60 Using thick connecting wires that are very good conductors, a Nichrome wire ("wire 1") of length L_1 and cross-sectional area A_1 is connected in series with a battery and an ammeter (this is circuit 1). The reading on the ammeter is I_1. Now the Nichrome wire is removed and replaced with a different wire ("wire 2"), which is 2.5 times as long and has 5.5 times the cross-sectional area of the original wire (this is circuit 2).

In the following questions, a subscript 1 refers to circuit 1, and a subscript 2 refers to circuit 2. It will be helpful to write out your solutions to the following questions algebraically before doing numerical calculations. (*Hint:* Think about what is the same in these two circuits.) **(a)** What is the value of I_2/I_1, the ratio of the conventional currents in the two circuits? **(b)** What is the value of R_2/R_1, the ratio of the resistances of the wires? **(c)** What is the value of E_2/E_1, the ratio of the electric fields inside the wires in the steady state?

•••P61 A long iron slab of width w and height h emerges from a furnace, as shown in Figure 19.79. Because the end of the slab near the furnace is hot and the other end is cold, the electron mobility increases significantly with the distance x.

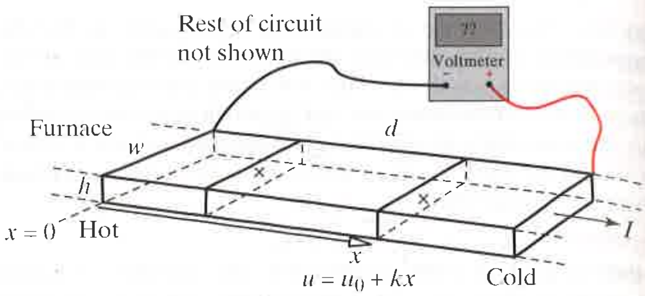

Figure 19.79

The electron mobility is $u = u_0 + kx$, where u_0 is the mobility of the iron at the hot end of the slab. There are n iron atoms per cubic meter, and each atom contributes one electron to the sea of mobile electrons (we can neglect the small thermal expansion of the iron). A steady-state conventional current runs through the slab from the hot end toward the cold end, and an ammeter (not shown) measures the current to have a magnitude I in amperes. A voltmeter is connected to two locations a distance d apart, as shown. **(a)** Show the electric field inside the slab at the two locations marked with ×. Pay attention to the relative magnitudes of the two vectors that you draw. **(b)** Explain why the magnitude of the electric field is different at these two locations. **(c)** At a distance x from the left voltmeter connection, what is the magnitude of the electric field in terms of x and the given quantities w, h, d, u_0, k, n, and I (and fundamental constants)? **(d)** What is the sign of the potential difference displayed on the voltmeter? Explain briefly. **(e)** In terms of the given quantities w, h, d, u_0, k, n, and I (and fundamental constants), what is the magnitude of the voltmeter reading? Check your work. **(f)** What is the resistance of this length of the iron slab?

Section 19.4

••P62 A battery with negligible internal resistance is connected to a resistor. The power produced in the battery and the power dissipated in the resistor are both P_1. Another resistor of the same kind is added, so the circuit consists of a battery and two resistors in series. **(a)** In terms of P_1, now how much power is dissipated in the first resistor? **(b)** In terms of P_1, now how much power is produced in the battery? **(c)** The circuit is rearranged so that the two resistors are in parallel rather than in series. In terms of P_1, now how much power is produced in the battery?

••P63 Two flashlight batteries in series power a circuit consisting of four ohmic resistors as shown in Figure 19.80, connected by copper wires with negligible resistance. The internal resistance of the batteries is negligible. Two magnetic compasses are placed underneath the wires, initially pointing northward before closing the circuit. A very-high-resistance voltmeter is connected as shown. The resistance R_1 is 20 Ω, R_2 is 20 Ω, R_3 is 30 Ω, and R_4 is 15 Ω.

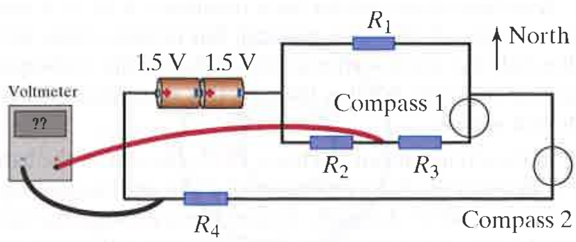

Figure 19.80

(a) Starting from fundamental principles, write equations that could be solved to determine the conventional current through each resistor, and show the directions of these currents on the diagram. Explain where each of your equations comes from. Do not use equations for parallel and series resistances (but you are free to use such equations to check your work if you like). If these equations are solved, we find that the current through R_1 is 0.073 A and the current through R_4 is 0.102 A. **(b)** Sketch the positions of the compass needles. Compass 1 deflects by 3 degrees. What is the deflection angle of compass 2? **(c)** The resistors are made of a material that has 8×10^{28} free electrons per cubic meter and a mobility of 3×10^{-5} (m/s)/(N/C). Find E_2, the magnitude of the electric field in resistor R_2, which is in the form of a short wire with a constant cross-sectional area of 6×10^{-10} m^2. **(d)** Is the field E_1 in resistor R_1 larger, smaller, or the same as E_2? **(e)** What is the length of resistor R_2? **(f)** What does the voltmeter read, including sign? **(g)** How much energy in joules is expended by the batteries in moving a singly charged ion from one end of one of the batteries to the other end of that same battery? **(h)** How much power output is there from one of the batteries?

••P64 Consider the two circuits depicted in Figure 19.81. In circuit 1, ohmic resistor R_1 dissipates 5 W; in circuit 2, ohmic resistor R_2 dissipates 20 W. The wires and batteries have negligible resistance. The circuits contain 10 V batteries.

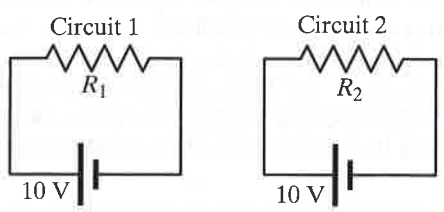

Figure 19.81

(a) What is the resistance of R_1 and of R_2? **(b)** Resistor R_1 is made of a very thin metal wire that is 3 mm long, with a diameter of 0.1 mm. What is the electric field inside this metal resistor? **(c)** The same resistors are used to construct circuit 3 (Figure 19.82), using the same 10 V battery as before. Make a complete accurate graph of potential versus location for circuit 3. Label the y axis numerically. Be sure to explain the significant features of your graph.

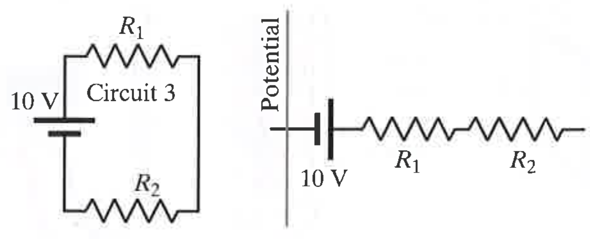

Figure 19.82

(d) On a copy of the diagram of circuit 3, place +'s and −'s to indicate the distribution of surface charge everywhere on the circuit. Assume that both resistors are far from the battery. **(e)** In circuit 3, calculate the number of electrons entering R_1 every second and the number of electrons entering R_2 every second. **(f)** What is the power output of the battery in circuit 3?

••P65 Work and energy with a capacitor: A capacitor with capacitance C has an amount of charge q on one of its plates, in which case the potential difference across the plates is $\Delta V = q/C$ (definition of capacitance). The work done to add a small amount of charge dq when charging the capacitor is $dq(\Delta V) = dq(q/C)$. Show by integration that the amount of work required to charge up the capacitor from no charge to a final charge Q is $\frac{1}{2}(Q^2/C)$. Since this is the amount of work required to charge the capacitor, it is also the amount of energy stored in the capacitor. Substituting $Q = C\Delta V$, we can also express the energy as $\frac{1}{2}C(\Delta V)^2$.

••P66 A circuit is made of two 1.5 V batteries and three light bulbs as shown in Figure 19.83.

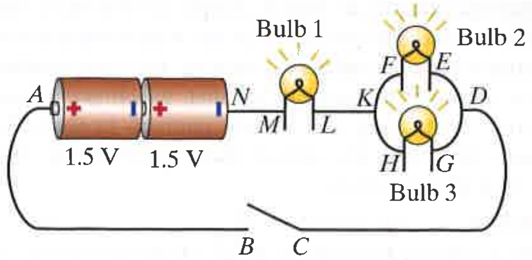

Figure 19.83

When the switch is closed and the bulbs are glowing, bulb 1 has a resistance of 10 Ω, bulb 2 has a resistance of 40 Ω, bulb 3 has a resistance of 30 Ω, and the copper connecting wires have negligible resistance. You can also neglect the internal resistance of the batteries. **(a)** Make a copy of the circuit diagram. With the switch open, indicate the approximate surface charge with +'s and −'s on your diagram. **(b)** With the switch open, find the potential differences $V_B - V_C$ and $V_D - V_K$. **(c)** After the switch is closed and the steady state is established, the currents through bulbs 1, 2, and 3 are I_1, I_2, and I_3, respectively. Write loop and node equations that could be solved to determine these three unknown currents, but do not solve the equations. Label on the diagram what current directions, loops, and nodes you are using, and explain which equation is which. In order to learn about the general approach, do not use equations for series and parallel resistance in this problem. (You can use these equations to check your work.) **(d)** In terms of the unknown currents I_1, I_2, and I_3, what is the potential difference $V_C - V_F$ (with the switch closed)? **(e)** In terms of the unknown currents I_1, I_2, and I_3, how much power is delivered by the batteries (with the switch closed)? **(f)** Solve your equations and give values for I_1, I_2, and I_3. **(g)** How many electrons leave the battery at location N every second? **(h)** What is the numerical value of $V_C - V_F$? **(i)** What is the numerical value of the power delivered by the batteries? **(j)** The tungsten filament in the 40 Ω bulb is 8 mm long and has a cross-sectional area of 2×10^{-10} m^2. How big is the electric field inside this metal filament?

Section 19.5

•P67 A certain 6 V battery delivers 12 A when short-circuited. How much current does the battery deliver when a 1 Ω resistor is connected to it?

••P68 **(a)** You short-circuit a 9 V battery by connecting a short wire from one end of the battery to the other end. If the current in the short circuit is measured to be 18 A, what is the internal resistance of the battery? **(b)** What is the power generated by the battery? **(c)** How much energy is dissipated in the internal resistance every second? (Remember that one watt is one joule per second.) **(d)** This same battery is now connected to a 10 Ω resistor. How much current flows through this resistor? **(e)** How much power is dissipated in the 10 Ω resistor? **(f)** The leads to a voltmeter are placed at the two ends of the battery of this circuit containing the 10 Ω resistor. What does the meter read?

••P69 A 9 V battery is connected to a 100 Ω resistor, and a voltmeter shows the potential difference across the battery to be 6.7 V. **(a)** What is the internal resistance of the battery? **(b)** If the resistor is replaced by a very low-resistance wire, what does the voltmeter read? **(c)** What is the current through this wire?

••P70 **(a)** Suppose that you connect two identical flashlight batteries in series to get a 3 V emf. Write a loop equation to show that the maximum (short-circuit) current these batteries can deliver is exactly the same as the maximum current from one battery. **(b)** Alternatively, suppose that you connect two identical flashlight batteries in parallel, which gives you just a 1.5 V emf. Write loop and node equations to show that the maximum (short-circuit) current these batteries can deliver is double that of one battery.

Section 19.6

•P71 You connect an ammeter to a 1.5 V battery whose internal resistance is 0.1 ohm. **(a)** What does the ammeter read? **(b)** Replace the ammeter with a voltmeter. What does the voltmeter read?

••P72 A 40-cm-long high-resistance wire with rectangular cross section 7 mm by 3 mm is connected to a 12 V battery through an ammeter, as shown in Figure 19.84. The resistance of the wire is 50 Ω. The resistance of the ammeter and the internal resistance of the battery can be considered to be negligibly small compared to the resistance of the wire.

Leads to a high-resistance voltmeter are connected as shown, with the − lead connected to the inner edge of the wire, at the top (location A), and the + lead connected to the outer edge of the wire, at the bottom (location C). The distance d along the wire between voltmeter connections is 5 cm.

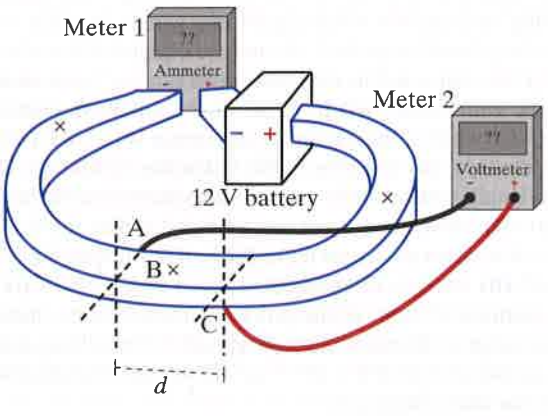

Figure 19.84

(a) On a copy of the diagram, show the approximate distribution of charge. **(b)** On a copy of the diagram, draw the electric field inside the wire at the 3 locations marked ×. **(c)** What is the magnitude of the electric field at location B? **(d)** What does the voltmeter read, both magnitude and sign? **(e)** What does the ammeter read, both magnitude and sign? **(f)** In a 60 s period, how many electrons are released from the − end of the battery? **(g)** There are 1.5×10^{26} free electrons per cubic meter in the wire. What is the drift speed v of the electrons in the wire? **(h)** What is the mobility u of the material that the wire is made of? **(i)** Switch meter 1 from being an ammeter to being a voltmeter. Now what do the two meters read? **(j)** The 12 V battery is removed from the circuit and both the ammeter and voltmeter are connected in parallel to the battery. The voltmeter reads 1.8 V, and the ammeter reads 20.4 A. What is the internal resistance of the battery?

••P73 Two resistors each with resistance of 4×10^6 Ω are connected in series to a 60 V power supply whose internal resistance is negligible. You connect a voltmeter across one of these resistors, and this voltmeter has an internal resistance of 1×10^6 ohms. What is the reading on the voltmeter?

Section 19.7

•P74 A 20 Ω resistor and a 2 F capacitor are in series with a 9 V battery. What is the initial current when the circuit is first assembled? What is the current after 50 s?

••P75 A resistor with resistance R and an air-gap capacitor of capacitance C are connected in series to a battery (whose strength is "emf"). **(a)** What is the final charge on the positive plate of the capacitor? **(b)** After fully charging the capacitor (so there is no current), a sheet of plastic whose dielectric constant is K is inserted into the capacitor and fills the gap. Explain why a current starts running in the circuit. You can base your explanation either on electric field or on electric potential, whichever you prefer. **(c)** What is the initial current through the resistor just after inserting the sheet of plastic? **(d)** What is the final charge on the positive plate of the capacitor after inserting the plastic?

••P76 The deflection plates in an oscilloscope are 10 cm by 2 cm with a gap distance of 1 mm. A 100 V potential difference is suddenly applied to the initially uncharged plates through a 1000 Ω resistor in series with the deflection plates. How long does it take for the potential difference between the deflection plates to reach 95 V?

••P77 A capacitor consists of two rectangular metal plates 3 m by 4 m, placed a distance 2.5 mm apart in air (Figure 19.85). The capacitor is connected to a 9 V power supply long enough to charge the capacitor fully, and then the battery is removed.

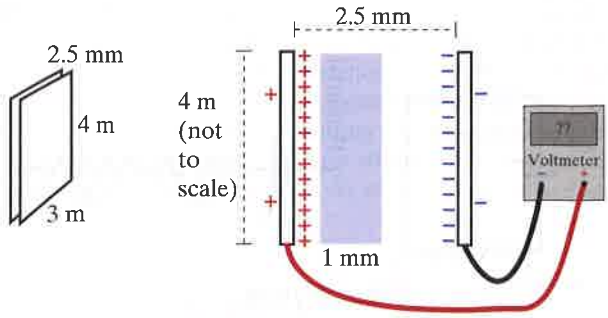

Figure 19.85

(a) Show that there will not be a spark in the air between the plates. **(b)** How much charge is on the positive plate of the capacitor?

With the battery still disconnected, you insert a slab of plastic 3 m by 4 m by 1 mm between the plates, next to the positive plate, as shown in Figure 19.85. This plastic has a dielectric constant of 5. **(c)** After inserting the plastic, you connect a voltmeter to the capacitor. What is the initial reading of the voltmeter? **(d)** The voltmeter has a resistance of 100 MΩ (1×10^8 Ω). What does the voltmeter read 3 s after being connected?

Section 19.11

•P78 For the circuit shown in Figure 19.86, which consists of batteries with known emf and ohmic resistors with known resistance, write the correct number of energy-conservation and current node rule equations that would be adequate to solve for the unknown currents, but do not solve the equations. Label nodes and currents on the diagram, and identify each equation (energy or current, and for which loop or node).

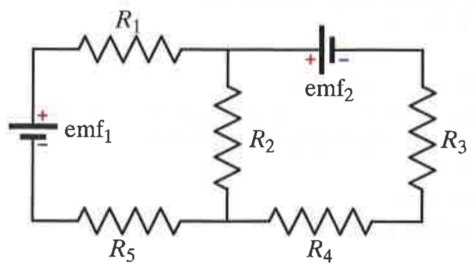

Figure 19.86

••P79 A circuit consists of two batteries (with negligible internal resistance), six ohmic resistors, and connecting wires that have negligible resistance. The resistance R_1 is 10 Ω, R_2 is 20 Ω, R_3 is 30 Ω, R_4 is 12 Ω, R_5 is 15 Ω, and R_6 is 20 Ω. Unknown currents I_1, I_2, I_3, I_4, I_5, and I_6 have their directions marked on the circuit diagram in Figure 19.87.

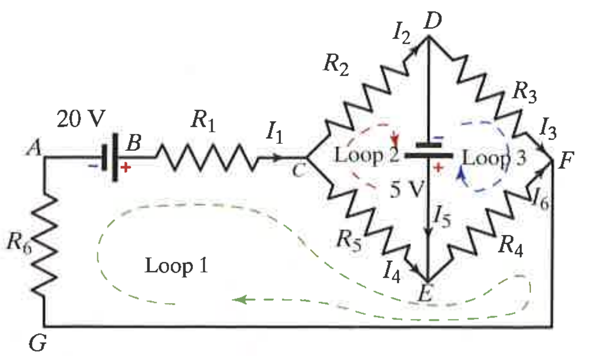

Figure 19.87

(a) Write down a set of equations that could be solved for the six unknown currents. Make sure you can explain how you got these equations. **(b)** When a correct set of equations is solved, the currents are as follows (to the nearest milliampere): $I_1 = 0.4394$ A, $I_2 = 0.3312$ A, $I_3 = 0.0065$ A, $I_4 = 0.1082$ A, $I_5 = 0.3247$ A, $I_6 = 0.4329$ A. Check your equations by substituting in these numbers. **(c)** Suppose that you connect the negative lead of a voltmeter to location G and the positive lead of the voltmeter to location C. What does the voltmeter read, including both magnitude and sign? **(d)** What is the power output of the 5 V battery? **(e)** Resistor R_4 is made of a very thin metal wire that is 3 mm long, with a diameter of 0.1 mm. What is the electric field inside this metal resistor?

••P80 A circuit contains two batteries (with negligible internal resistance) and five ohmic resistors (Figure 19.88). The connecting wires have negligible resistance. The letters A through H are shown to make it possible to refer to specific parts of the circuit.

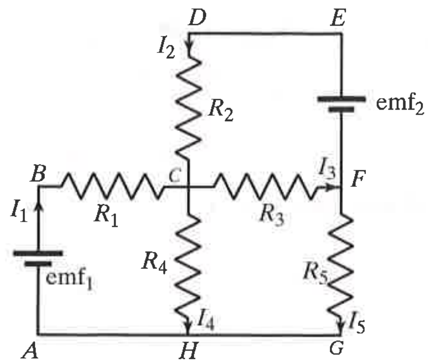

Figure 19.88

(a) Write all the equations necessary to solve for the unknown currents I_1, I_2, I_3, I_4, and I_5, whose directions are indicated on the circuit diagram. Do not solve the equations, but do explain very clearly what your equations are based on, and to what they refer.

Assume that a computer program has solved your equations in terms of the known battery voltages and known resistances, so that the currents I_1, I_2, I_3, I_4, and I_5 are known. **(b)** In terms of the known quantities, calculate $V_D - V_A$, and check that your sign makes sense. **(c)** In terms of the known quantities, calculate the power produced in battery number 2.

ANSWERS TO CHECKPOINTS

1 Consider the very first short time interval—say, 0.01 s. At the beginning of this interval both capacitors have very little charge. The electric field in the wires is due almost entirely to the battery and surface charge on the wires, and is the same in both cases. Thus the number of electrons flowing onto the left plate and off of the right plate is approximately the same in the first 0.01 s. At the end of this time interval, both capacitors have nearly the same small amount of charge, q. This is the situation illustrated in Figure 19.89.

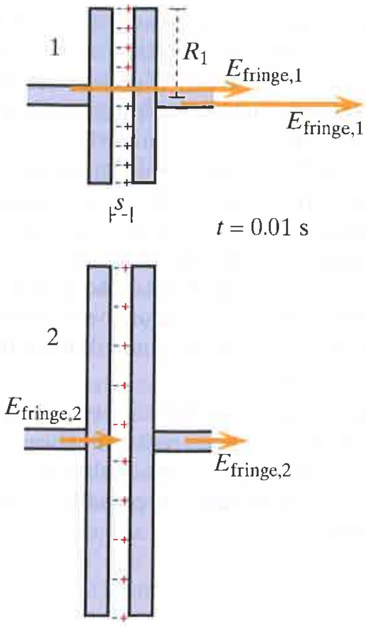

Figure 19.89

The fringe field of the smaller capacitor is this:

$$E_{\text{fringe},1} \approx \frac{q/A}{\varepsilon_0}\left(\frac{s}{2R_1}\right) = \frac{1}{\varepsilon_0}\frac{q}{\pi R_1^2}\left(\frac{s}{2R_1}\right)$$

The fringe field of the larger capacitor is smaller, since $R_2 > R_1$:

$$E_{\text{fringe},2} = \frac{1}{\varepsilon_0}\frac{q}{\pi R_2^2}\left(\frac{s}{2R_2}\right) < E_{\text{fringe},1}$$

The smaller fringe field of the large capacitor means a larger *net* field and larger drift speed, so the current flowing onto the large capacitor has decreased less than the current flowing onto the small capacitor. See further discussion in Section 19.7.

2 30 Ω; 18.8 Ω; 8.3 Ω; R is not constant, and the bulb filament is not ohmic for this range of currents

3 7.5 Ω; 0.4 A

4 4.5 W

5 nearly 0; nearly 0; nearly 0

6 A voltmeter has very high resistance, so the current is extremely small; the voltmeter reads 3 V (+3 − 3 = 0 round-trip potential difference).

7 $q/m = aL/\Delta V$

8 −8.0 V; 3.2 W; 4.8 W