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:

$$R_{eq} = R_1 + R_2 + \cdots. \quad \textbf{(19–3)}$$

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:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots. \quad \textbf{(19–4)}$$

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:

$$C_{eq} = C_1 + C_2 + \cdots. \quad \textbf{(19–5)}$$

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

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots. \quad \textbf{(19–6)}$$

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**

$$\tau = RC \quad \textbf{(19–7)}$$

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?

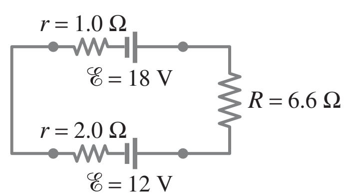

FIGURE 19–36 Question 10.

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?

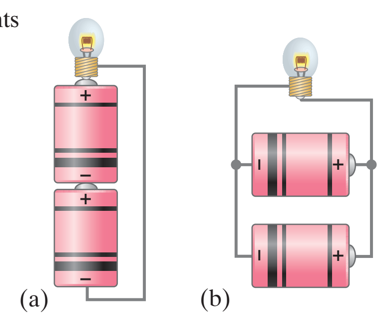

FIGURE 19–37 Question 11.

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?