Power utilities use large electric generators to provide the 120 volts delivered to home outlets. The alternating potential difference between the two holes in the outlet averages 120 volts. When the prongs of a plug are inserted into the outlet, an average electric "pressure" of 120 volts is placed across the circuit connected to the prongs. This means that 120 joules of energy is supplied to each coulomb of charge that is made to flow in the circuit.

There is often some confusion between charge flowing *through* a circuit and voltage being impressed *across* a circuit. To distinguish between these ideas, consider a long pipe filled with water. Water will flow *through* the pipe if there is a difference in pressure *across* the pipe or between its ends. Water flows from the high-pressure end to the low-pressure end. Only the water flows, not the pressure. Similarly, you say that charges flow *through* a circuit because of an applied voltage *across* the circuit.* You don't say that voltage flows through a circuit. Voltage doesn't go anywhere, for it is the charges that move. Voltage causes current.

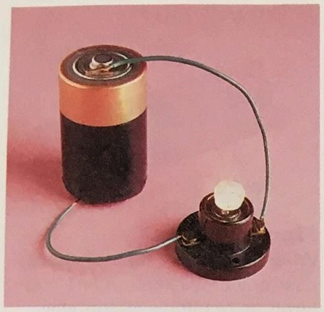

Figure 34.3 ▲
Each coulomb of charge that is made to flow in a circuit that connects the ends of this 1.5-volt flashlight cell is energized with 1.5 joules.

34.4 Electric Resistance

The amount of charge that flows in a circuit depends on the voltage provided by the voltage source. The current also depends on the resistance that the conductor offers to the flow of charge—the **electric resistance.** This is similar to the rate of water flow in a pipe, which depends not only on the pressure difference between the ends of the pipe but on the resistance offered by the pipe itself. The resistance of a wire depends on the *conductivity* of the material used in the wire (that is, how well it conducts) and also on the thickness and length of the wire.

Thick wires have less resistance than thin wires. Longer wires have more resistance than short wires. In addition, electric resistance depends on temperature. The greater the jostling about of atoms within the conductor, the greater resistance the conductor offers to the flow of charge. For most conductors, increased temperature means increased resistance.** The resistance of some materials becomes zero at very low temperatures. These are the superconductors discussed briefly in Chapter 32.

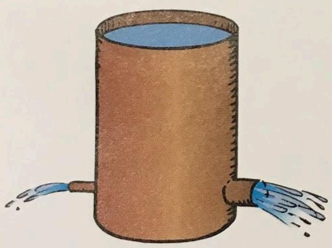

Figure 34.4 ▲
For a given pressure, more water passes through a large pipe than a small one. Similarly, for a given voltage, more electric current passes through a large-diameter wire than a small-diameter one.

1 Explore | 2 Develop | 3 Apply

3 Problem-Solving Exercises in Physics *16-1*

* It is conceptually simpler to say that current flows through a circuit, but don't say this around somebody who is "picky" about grammar, for the expression *current flows* is redundant. More properly, charge flows, which *is* current.

** Carbon is an interesting exception. At high temperatures, electrons are shaken from the carbon atom, which increases electric current. Carbon's resistance decreases with increasing temperature. This behavior, along with its high melting temperature, accounts for the use of carbon in arc lamps.

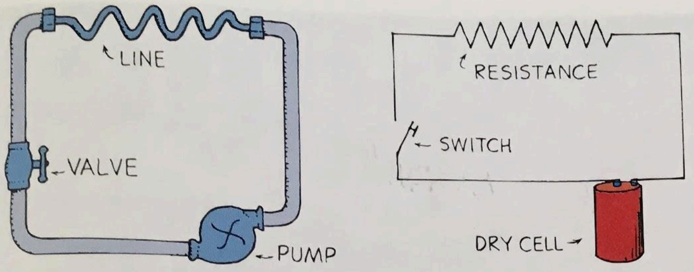

Figure 34.5 ▲
Analogy between a simple hydraulic circuit and an electric circuit.

Electric resistance is measured in units called **ohms,*** after Georg Simon Ohm, a German physicist who tested different wires in circuits to see what effect the resistance of the wire had on the current.

34.5 Ohm's Law

Ohm discovered that the current in a circuit is directly proportional to the voltage impressed across the circuit, and is inversely proportional to the resistance of the circuit. In short,

$$\text{current} = \frac{\text{voltage}}{\text{resistance}}$$

This relationship among voltage, current, and resistance is called **Ohm's law.****

The relationship among the units of measurement for these three quantities is

$$1 \text{ ampere} = 1 \frac{\text{volt}}{\text{ohm}}$$

So for a given circuit of constant resistance, current and voltage are proportional. This means that you'll get twice the current for twice the voltage. The greater the voltage, the greater the current. But if the resistance is doubled for a circuit, the current will be half what it would be otherwise. The greater the resistance, the less the current. Ohm's law makes good sense.

* The Greek letter capital Ω (omega) is usually used as a symbol for ohm.

** Many texts use *V* for voltage, *I* for current, and *R* for resistance, and express Ohm's law as $V = IR$. It then follows that $I = V/R$, or $R = V/I$, so if any two variables are known, the third can be found.

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Figure 34.6 ▲
Resistors. The stripes are color coded to indicate the resistance in ohms.

> **LINK TO ELECTROCHEMISTRY**
>
> **Electrolysis**
>
> Electrochemistry is about electrical energy and chemical change. Molecules in a liquid can be broken apart and separated by the action of electric current. This is *electrolysis.* A common example is passing an electric current through water, separating water into its hydrogen and oxygen components. This common process is also at work when a car battery is recharged. Electrolysis is also used to produce metals from ores. Aluminum is a familiar metal produced by electrolysis. Aluminum is common today, but before the advent of its production by electrolysis in 1886, aluminum was much more expensive than silver or gold!

Using specific values, a potential difference of 1 volt impressed across a circuit that has a resistance of 1 ohm will produce a current of 1 ampere. If a voltage of 12 volts is impressed across the same circuit, the current will be 12 amperes.

The resistance of a typical lamp cord is much less than 1 ohm, while a typical lightbulb has a resistance of about 100 ohms. An iron or electric toaster has a resistance of 15 to 20 ohms. The low resistance permits a large current, which produces considerable heat. Inside electric devices such as radio and television receivers, the current is regulated by circuit elements called *resistors,* whose resistance may range from a few ohms to millions of ohms.

Questions

1. What is the resistance of an electric frying pan that draws 12 amperes of current when connected to a 120-volt circuit?
2. How much current is drawn by a lamp that has a resistance of 100 ohms when a voltage of 50 volts is impressed across it?

Answers

1. The resistance is 10 ohms.

$$\text{resistance} = \frac{\text{voltage}}{\text{current}} = \frac{120 \text{ volts}}{12 \text{ amperes}} = 10 \text{ ohms}$$

An electric device is said to *draw* current when voltage is impressed across it, just as water is said to be drawn from a well or a faucet. In this sense, to draw is not to attract, but to *obtain.*

2. The current is 0.5 ampere.

$$\text{current} = \frac{\text{voltage}}{\text{resistance}} = \frac{50 \text{ volts}}{100 \text{ ohms}} = 0.5 \text{ ampere}$$

34.6 Ohm's Law and Electric Shock

What causes electric shock in the human body—current or voltage? The damaging effects of shock are the result of current passing through the body. From Ohm's law, we can see that this current depends on the voltage applied, and also on the electric resistance of the human body.

The resistance of your body depends on its condition and ranges from about 100 ohms if you're soaked with salt water to about 500 000 ohms if your skin is very dry. If you touched the two electrodes of a battery with dry fingers, the resistance your body would normally offer to the flow of charge would be about 100 000 ohms. You usually would not feel 12 volts, and 24 volts would just barely tingle. If your skin were moist, on the other hand, 24 volts could be

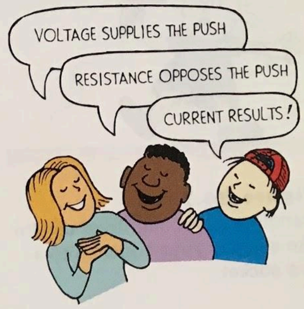

Table 34.1
Effect of Various Electric Currents on the Body

Current in amperes	Effect
0.001	Can be felt
0.005	Painful
0.010	Involuntary muscle contractions (spasms)
0.015	Loss of muscle control
0.070	If through the heart, serious disruption; probably fatal if current lasts for more than 1 second

Questions

1. If the resistance of your body were 100 000 ohms, what would be the current in your body when you touched the terminals of a 12-volt battery?
2. If your skin were very moist so that your resistance was only 1000 ohms, and you touched the terminals of a 24-volt battery, how much current would you draw?

Answers

1. The current in your body, quite harmless, would be

$$\text{current} = \frac{\text{voltage}}{\text{resistance}} = \frac{12\ \text{V}}{100\ 000\ \Omega} = 0.000\ 12\ \text{A}$$

2. You would draw $\frac{24\ \text{V}}{1000\ \Omega}$, or 0.024 A, a dangerous amount of current!

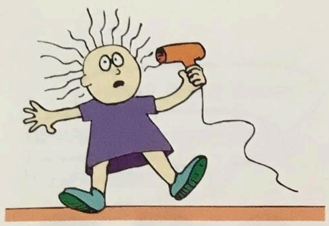

Figure 34.7 ▲
Handling a wet hair dryer can be like sticking your fingers into a live socket.

quite uncomfortable. Table 34.1 describes the effects of different amounts of current on the human body.

Many people are killed each year by current from common 120-volt electric circuits. If you touch a faulty 120-volt light fixture with your hand while you are standing on the ground, there is a 120-volt "electric pressure" between your hand and the ground. The soles of your shoes normally provide a very large resistance between your feet and the ground, so the current would probably not be enough to do serious harm. But if you are standing barefoot in a wet bathtub connected through its plumbing to the ground, the resistance between you and the ground is very small. Your overall resistance is lowered so much that the 120-volt potential difference may produce a harmful current through your body.

Drops of water that collect around the on/off switches of devices such as a hair dryer can conduct current to the user. Although distilled water is a good insulator, the ions in ordinary water greatly reduce the electric resistance. These ions are contributed by dissolved materials, especially salts. There is usually a layer of salt left from perspiration on your skin, which when wet lowers your skin resistance to a few hundred ohms or less. Handling electric devices while taking a bath is extremely dangerous.

Figure 34.8 ▲
The bird can stand harmlessly on one wire of high potential, but it had better not reach over and grab a neighboring wire! Why not?

You have seen birds perched on high-voltage wires. Every part of their bodies is at the same high potential as the wire, and they feel no ill effects. For the bird to receive a shock, there must be a *difference* in electric potential between one part of its body and another part. Most of the current will then pass along the path of least electric resistance connecting these two points.

Suppose you fall from a bridge and manage to grab onto a high-voltage power line, halting your fall. So long as you touch nothing else of different potential, you will receive no shock at all. Even if the wire is thousands of volts above ground potential and even if you hang by it with two hands, no charge will flow from one hand to the other. This is because there is no appreciable difference in electric potential between your hands. If, however, you reach over with one hand and grab onto a wire of different potential, ZAP!!

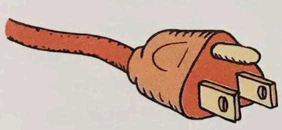

Figure 34.9 ▲
The third prong connects the body of the appliance directly to ground. Any charge that builds up on an appliance is therefore conducted to the ground.

Mild shocks occur when the surfaces of electric appliances are at an electric potential different from that of the surfaces of other nearby devices. If you touch surfaces of different potentials, you become a pathway for current. Sometimes the effect is more than mild. To prevent this problem, the outsides of electric appliances are connected to a ground wire, which is connected to the round third prong of a three-wire electric plug (Figure 34.9). All ground wires in all plugs are connected together through the wiring system of the house. The two flat prongs are for the current-carrying double wire. If the live wire accidentally comes in contact with the metal surface of an appliance, the current will be directed to ground rather than shocking you if you handle it.

One effect of electric shock is to overheat tissues in the body or to disrupt normal nerve functions. It can upset the nerve center that controls breathing. In rescuing victims, the first thing to do is clear them from the electric power supply with a wooden stick or some other nonconductor so that you don't get electrocuted yourself. Then apply artificial respiration.