The intermittent windshield wipers of a car can also use an RC circuit. The RC time constant, which can be changed using a multi-positioned switch for different values of R with fixed C, determines the rate at which the wipers come on.

PHYSICS APPLIED
Windshield wipers on "intermittent"

EXERCISE G A typical turn signal flashes perhaps twice per second, so its time constant is on the order of 0.5 s. Estimate the resistance in the circuit, assuming a moderate capacitor of $C = 1\,\mu\text{F}$.

PHYSICS APPLIED
Heart pacemaker

An important medical use of an RC circuit is the electronic heart pacemaker, which can make a stopped heart start beating again by applying an electric stimulus through electrodes attached to the chest. The stimulus can be repeated at the normal heartbeat rate if necessary. The heart itself contains *pacemaker* cells, which send out tiny electric pulses at a rate of 60 to 80 per minute. These signals induce the start of each heartbeat. In some forms of heart disease, the natural pacemaker fails to function properly, and the heart loses its beat. Such patients use *electronic pacemakers* which produce a regular voltage pulse that starts and controls the frequency of the heartbeat. The electrodes are implanted in or near the heart (Fig. 19–24), and the circuit contains a capacitor and a resistor. The charge on the capacitor increases to a certain point and then discharges a pulse to the heart. Then it starts charging again. The pulsing rate depends on the time constant RC.

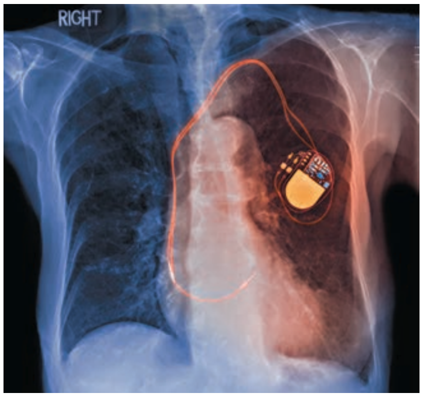


FIGURE 19–24 Electronic battery-powered pacemaker can be seen on the rib cage in this X-ray (color added).

19–7 Electric Hazards

PHYSICS APPLIED
Dangers of electricity

Excess electric current can overheat wires in buildings and cause fires, as discussed in Section 18–6. Electric current can also damage the human body or even be fatal. Electric current through the human body can cause damage in two ways: (1) heating tissue and causing burns; (2) stimulating nerves and muscles, and we feel a "shock." The severity of a shock depends on the magnitude of the current, how long it acts, and through what part of the body it passes. A current passing through vital organs such as the heart or brain is especially damaging.

A current of about 1 mA or more can be felt and may cause pain. Currents above 10 mA cause severe contraction of the muscles, and a person may not be able to let go of the source of the current (say, a faulty appliance or wire). Death from paralysis of the respiratory system can occur. Artificial respiration can sometimes revive a victim. If a current above about 80 to 100 mA passes across the torso, so that a portion passes through the heart for more than a second or two, the heart muscles will begin to contract irregularly and blood will not be properly pumped. This condition is called **ventricular fibrillation**. If it lasts for long, death results. Strangely enough, if the current is much larger, on the order of 1 A, death by heart failure may be less likely,† but such currents can cause serious burns if concentrated through a small area of the body.

It is current that harms, but it is voltage that drives the current. The seriousness of an electric shock depends on the current and thus on the applied voltage and the effective resistance of the body. Living tissue has low resistance because the fluid of cells contains ions that can conduct quite well. However, the outer layer of skin, when dry, offers high resistance and is thus protective. The effective resistance between two points on opposite sides of the body when the skin is dry is on the order of 10^4 to $10^6\,\Omega$. But when the skin is wet, the resistance may be $10^3\,\Omega$ or less. A person who is barefoot or wearing thin-soled shoes will be in good contact with the ground, and touching a 120-V line with a wet hand can result in a current

$$I = \frac{120\text{ V}}{1000\,\Omega} = 120\text{ mA}.$$

As we saw, this could be lethal.

†Larger currents apparently bring the entire heart to a standstill. Upon release of the current, the heart returns to its normal rhythm. This may not happen when fibrillation occurs because, once started, it can be hard to stop. Fibrillation may also occur as a result of a heart attack or during heart surgery. A device known as a *defibrillator* (described in Section 17–9) can apply a brief high current to the heart, causing complete heart stoppage which is often followed by resumption of normal beating.

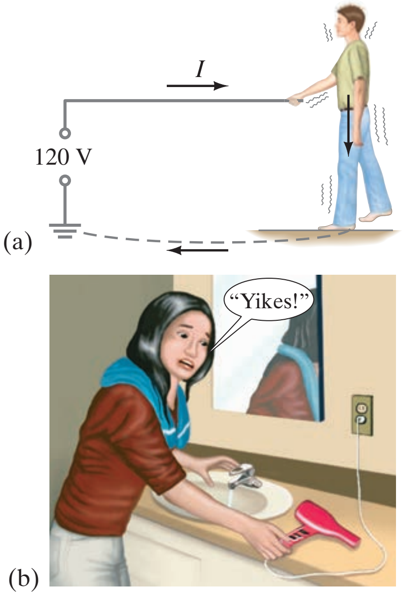


FIGURE 19–25 You can receive a shock when the circuit is completed.

CAUTION

Keep one hand in your pocket when other touches electricity

PHYSICS APPLIED

Grounding and shocks

You can get a shock by becoming part of a complete circuit. Figure 19–25 shows two ways the circuit might be completed when you accidentally touch a “hot” electric wire—“hot” meaning a high potential relative to ground such as 120 V (normal U.S. household voltage) or 240 V (many other countries). The other wire of building wiring is connected to ground—either by a wire connected to a buried conductor, or via a metal water pipe into the ground. The current in Fig. 19–25a passes from the high-voltage wire through you to ground through your bare feet, and back along the ground (a fair conductor) to the ground terminal of the source. If you stand on a good insulator—thick rubber-soled shoes or a dry wood floor—there will be much more resistance in the circuit and much less current through you. If you stand with bare feet on the ground, or in a bathtub, there is lethal danger because the resistance is much less and the current greater. In a bathtub (or swimming pool), not only are you wet, which reduces your resistance, but the water is in contact with the drain pipe (typically metal) that leads to the ground. It is strongly recommended that you not touch anything electrical when wet or in bare feet. The use of non-metal pipes would be protective.

In Fig. 19–25b, a person touches a faulty “hot” wire with one hand, and the other hand touches a sink faucet (connected to ground via the pipe or even by water in a non-metal pipe). The current is particularly dangerous because it passes across the chest, through the heart and lungs. A useful rule: if one hand is touching something electrical, keep your other hand in your back pocket (don’t use it!), and wear thick rubber-soled shoes. Also remove metal jewelry, especially rings (your finger is usually moist under a ring).

You can come into contact with a hot wire by touching a bare wire whose insulation has worn off, or from a bare wire inside an appliance when you’re tinkering with it. (Always unplug an electrical device before investigating its insides!)† Also, a wire inside a device may break or lose its insulation and come in contact with the case. If the case is metal, it will conduct electricity. A person could then suffer a severe shock merely by touching the case, as shown in Fig. 19–26b. To prevent an accident, metal cases are supposed to be connected directly to ground by a separate ground wire. Then if a “hot” wire touches the grounded case, a short circuit to ground immediately occurs internally, as shown in Fig. 19–26c, and most of the current passes through the low-resistance ground wire rather than through the person. Furthermore, the high current should open a fuse or circuit breaker. Grounding a metal case is done by a separate ground wire connected to the third (round) prong of a 3-prong plug. Never cut off the third prong of a plug—it could save your life. A three-prong plug, and an adapter, are shown in Figs. 19–27a and b.

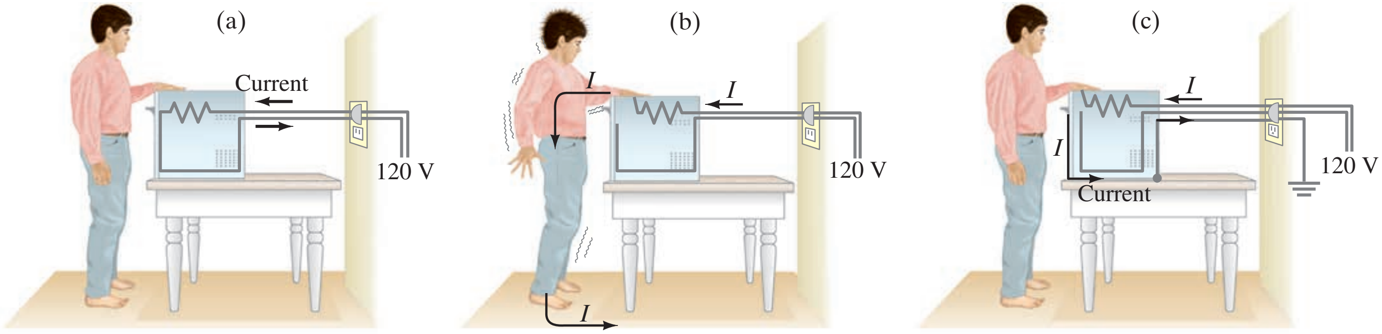
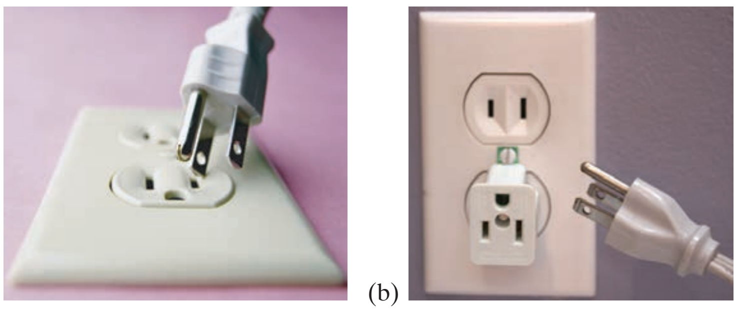


FIGURE 19–26 (a) An electric oven operating normally with a 2-prong plug. (b) A short to a metal case which is ungrounded, causing a shock. (c) A short to the case which is grounded by a 3-prong plug; almost no current goes through the person.

†Even then you can get a bad shock from a capacitor that hasn’t been discharged until you touch it.



(a) (b)

FIGURE 19–27 (a) A 3-prong plug, and (b) an adapter (white) for old-fashioned 2-prong outlets—be sure to screw down the ground tab (green color in photo).

Safe Wiring

Why is a third wire needed? The 120 V is carried by the other two wires—one **hot** (120 V ac), the other **neutral**, which is itself grounded. The third "dedicated" ground wire with the round prong may seem redundant. But it is protection for two reasons: (1) It protects against internal wiring that may have been done incorrectly or is faulty as discussed above, Fig. 19–26. (2) The *neutral* wire carries the full normal current ("return" current from the hot 120 V) and it does have resistance—so there can be a voltage drop along the neutral wire, normally small; but if connections are poor or corroded, or the plug is loose, the resistance could be large enough that you might feel that voltage if you touched the neutral wire some distance from its grounding point.

CAUTION
Necessity of third (ground) wire

Some electrical devices come with only two wires, and the plug's two prongs are of different widths; the plug can be inserted only one way into the outlet so that the intended neutral (wider prong) in the device is connected to neutral in the wiring (Fig. 19–28). For example, the screw threads of a lightbulb are meant to be connected to neutral (and the base contact to hot), to avoid shocks when changing a bulb in a possibly protruding socket. Devices with 2-prong plugs do *not* have their cases grounded; they are supposed to have double electric insulation (or have a nonmetal case). Take extra care anyway.

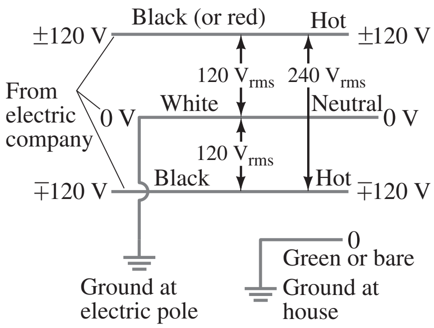
FIGURE 19–28 A polarized 2-prong plug.

The insulation on a wire may be color coded. Hand-held meters (Section 19–8) may have red (hot) and black (ground) lead wires. But in a U.S. house, the hot wire is often black (though it may be red), whereas white is neutral and green (or bare) is the dedicated ground, Fig. 19–29. But beware: these color codes cannot always be trusted.

CAUTION
Black wire may be either ground or hot. Beware!

[In the U.S., three wires normally enter a house: two *hot* wires at 120 V each (which add together to 240 V for appliances or devices that run on 240 V) plus the grounded *neutral* (carrying return current for the two hot wires). See Fig. 19–29. The "dedicated" *ground* wire (non-current carrying) is a fourth wire that does not come from the electric company but enters the house from a nearby heavy stake in the ground or a buried metal pipe. The two hot wires can feed separate 120-V circuits in the house, so each 120-V circuit inside the house has only three wires, including the dedicated ground.]

FIGURE 19–29 Four wires entering a typical house. The color codes for wires are not always as shown here—be careful!



Normal circuit breakers (Sections 18–6 and 20–7) protect equipment and buildings from overload and fires. They protect humans only in some circumstances, such as the very high currents that result from a short, if they respond quickly enough. *Ground fault circuit interrupters* (GFCI or GFI), described in Section 21–9, are designed to protect people from the much lower currents (10 mA to 100 mA) that are lethal but would not throw a 15-A circuit breaker or blow a 20-A fuse.

Another danger is **leakage current**, by which we mean a current along an unintended path. Leakage currents are often "capacitively coupled." For example, a wire in a lamp forms a capacitor with the metal case; charges moving in one conductor attract or repel charge in the other, so there is a current. Typical electrical codes limit leakage currents to 1 mA for any device, which is usually harmless. It could be dangerous, however, to a hospital patient with implanted electrodes, due to the absence of the protective skin layer and because the current can pass directly through the heart. Although 100 mA may be needed to cause heart fibrillation when entering through the hands and spreading out through the body (very little of it actually passing through the heart), but as little as 0.02 mA can cause fibrillation when passing directly to the heart. Thus, a "wired" patient is in considerable danger from leakage current even from as simple an act as touching a lamp.

Finally, don't touch a downed power line (lethal!) or even get near it. A hot power line is at thousands of volts. A huge current can flow along the ground from the point where the high-voltage wire touches the ground. This current is great enough that the voltage between your two feet could be large and dangerous. Tip: stand on one foot, or run so only one foot touches the ground at a time.