

NOTE - WE HAVEN'T YET  
DISCUSSED ALTERNATING  
CURRENT, BUT WILL SHORTLY

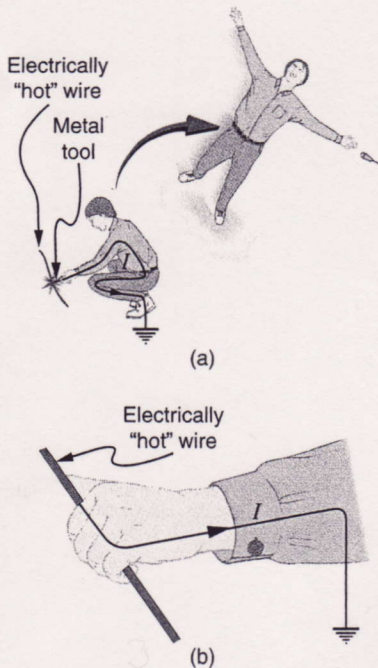
### Shock Hazards

Electrical currents through people produce tremendously varied effects. An electrical current can be used to block back pain. The possibility of using electrical current to stimulate muscle action in paralyzed limbs, perhaps allowing paraplegics to walk, is under study. TV dramatizations in which electrical shocks are used to bring a heart attack victim out of ventricular fibrillation (a massively irregular, often fatal, beating of the heart) are more than common. Yet most electrical shock fatalities occur because a current put the heart *into* fibrillation. A pacemaker uses electrical shocks to stimulate the heart to beat properly. Some fatal shocks do not produce burns, but warts can be safely burned off with electric current. Of course, there are consistent explanations for these disparate effects. The major factors upon which the effects of electrical shock depend are

1. The amount of current  $I$
2. The path taken by the current
3. The duration of the shock
4. The frequency  $f$  of the current ( $f = 0$  for DC)

Table 19.3 gives the effects of electrical shocks as a function of current for a typical accidental shock. The effects are for a shock that passes through the trunk of the body, has a duration of 1 s, and is caused by 60 Hz power.

Very small currents pass harmlessly and unfelt through the body. This happens to you regularly without your knowledge. The threshold of sensation is only 1 mA and, although unpleasant, shocks are apparently harmless for currents less than 5 mA. A great number of safety rules take the 5 mA value for the maximum allowed shock. At 10 to 20 mA and above, the current can stimulate sustained muscular contractions much as regular nerve impulses do. People sometimes say they were knocked across the room by a shock, but what really happened was that certain muscles contracted, propelling them in a manner not of their own choosing. (See Figure 19.20(a).) More frightening, and potentially more dangerous, is the "can't let go" effect illustrated in Figure 19.20(b). The muscles that close the fingers are stronger than those that open them, so that the hand closes involuntarily on the wire shocking it. This can prolong the shock indefinitely. It can also be a danger to a person trying to rescue the victim, because the rescuer's hand may close about the victim's wrist. Modern electric fences, used in animal enclosures, are now pulsed on and off to allow people who touch them to get free, rendering them less lethal than in the past.



**Figure 19.20** An electric current can cause muscular contractions with varying effects. (a) The victim is "thrown" backward by involuntary muscle contractions that extend the legs and torso. (b) The victim can't let go of the wire that is stimulating all the muscles in the hand. Those that close the fingers are stronger than those that open them.

**TABLE 19.3**

#### EFFECTS OF ELECTRICAL SHOCK AS A FUNCTION OF CURRENT\*

Current (mA)	Effect
1	Threshold of sensation
5	Maximum harmless current
10–20	Onset of sustained muscular contraction; cannot let go for duration of shock; contraction of chest muscles may stop breathing during shock
50	Onset of pain
100–300+	Ventricular fibrillation possible; often fatal
300	Onset of burns depending on concentration of current
6000 (6 A)	Onset of sustained ventricular contraction and respiratory paralysis; both cease when shock ends; heartbeat may return to normal; used to defibrillate the heart

\*For an average male shocked through trunk of body for 1 s by 60 Hz AC. Values for females are 60–80% of those listed.



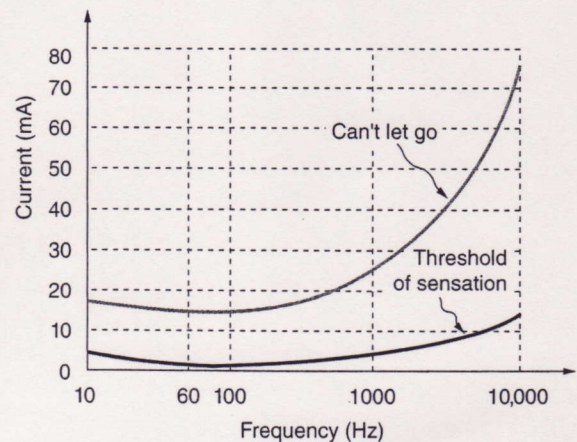
Greater currents may affect the heart. Its electrical patterns can be disrupted, so that it beats irregularly and ineffectively in a condition called *ventricular fibrillation*. This condition often lingers after the shock and is fatal due to a lack of blood circulation. The threshold for ventricular fibrillation is between 100 and 300 mA. At about 300 mA and above, the shock can cause burns, depending on the concentration of current—the more concentrated, the greater the likelihood of burns.

Very large currents cause the heart and diaphragm to contract for the duration of the shock. Both the heart and breathing stop. Interestingly, both often return to normal following the shock. The electrical patterns on the heart are completely erased in a manner that the heart can start afresh with normal beating, as opposed to the permanent disruption caused by smaller currents than can put the heart into ventricular fibrillation. The latter is something like scribbling on a blackboard, whereas the former completely erases it. TV dramatizations of electric shock used to bring a heart attack victim out of ventricular fibrillation also show large paddles. These are used to spread out current passed through the victim to reduce the likelihood of burns.

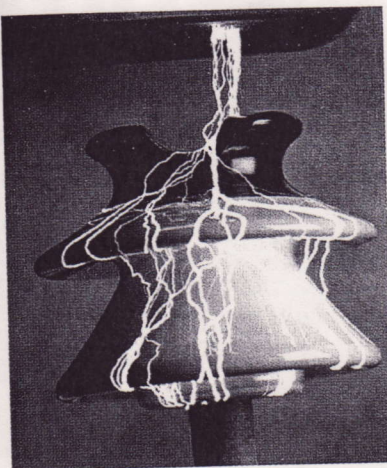
Current is the major factor determining shock severity (given other conditions such as path, duration, and frequency are fixed, such as in the table and preceding discussion). A larger voltage is more hazardous, but since  $I = V/R$ , the severity of the shock depends on the combination of voltage and resistance. For example, a person with dry skin has a resistance of about 100 k $\Omega$ . If he comes into contact with 120 V AC, a current  $I = (120 \text{ V})/(100 \text{ k}\Omega) = 1.2 \text{ mA}$  passes harmlessly through him. The same person soaking wet may have a resistance of 5000  $\Omega$  and the same 120 V will produce a current of 24 mA—above the “can’t let go” threshold and potentially dangerous.

Most of the body’s resistance is in its dry skin. When wet, salts go into ion form, lowering the resistance significantly. The interior of the body has a much lower resistance than dry skin because of all the ionic solutions and fluids it contains. If skin resistance is bypassed, such as by an intravenous infusion, a catheter, or exposed pacemaker leads, a person is rendered **microshock sensitive**. In this condition, currents about 1/1000 those listed in Table 19.3 produce similar effects. During open heart surgery, currents as small as 20  $\mu\text{A}$  can be used to still the heart. Stringent electrical safety requirements in hospitals, particularly in surgery and intensive care, are related to the doubly disadvantaged microshock sensitive patient. The break in the skin has reduced his resistance, and so the same voltage causes a greater current, and a much smaller current has a greater effect.

Factors other than current that affect the severity of a shock are its path, duration, and AC frequency. Path has obvious consequences. For example, the heart is unaffected by an electric shock through the brain, such as may be used to treat manic depression. And it is a general truth that the longer the duration of a shock, the greater its effects. Figure 19.21 presents a graph that illustrates the effects of frequency on a shock. The curves show the



**Figure 19.21** Graph of average values for the threshold of sensation and the “can’t let go” current as a function of frequency. The lower the value, the more sensitive the body is at that frequency.



**Figure 19.22** Are these dangerous? The answer depends on AC frequency and the power involved.

minimum current for two different effects, as a function of frequency. The lower the current needed, the more sensitive the body is at that frequency. Ironically, the body is most sensitive to frequencies near the 60 Hz frequency in common use. The body is slightly less sensitive for DC ( $f = 0$ ), mildly confirming Edison’s claims that AC presents a greater hazard. At higher and higher frequencies, the body becomes progressively less sensitive to any effects that involve nerves. This is related to the maximum rates at which nerves can fire or be stimulated. At very high frequencies, electrical current travels only on the surface of a person. Thus a wart can be burned off with very high frequency current without causing the heart to stop. (Do not try this at home with 60 Hz AC!) Some of the spectacular demonstrations of electricity, in which high voltage arcs are passed through the air and over people’s bodies, employ high frequencies and low currents. (See Figure 19.22.) Electrical safety devices and techniques are discussed in detail in Section 22.8\*.