Electrical Safety in the Operating Room

2011 Edition

D. John Doyle MD PhD
Department of General Anesthesiology
Cleveland Clinic Foundation
9500 Euclid Avenue E31
Cleveland, Ohio, USA 44195
Email doylej@ccf.org
Tel 216-444-1927
Fax 216-444-9247

OUTLINE

- PRINCIPLES OF ELECTRICITY
- ELECTRICAL SHOCK HAZARDS
- GROUNDING
- THE LINE ISOLATION MONITOR
- GROUND FAULT CIRCUIT INTERRUPTER
- ELECTROMAGNETIC INTERFERENCE (EMI)
- IMPLANTED DEFIBRILLATORS
- ELECTROCAUTERY

GOALS AND OBJECTIVES

The principal goals and objective of this presentation are as follows:

[1] Understand the following basic concepts pertaining to electricity:

- Voltage
- Current
- Resistance
- Ohm’s law
- Capacitance
- Direct current
- Power
- Alternating current
- Alternating current frequency

[2] Understand the following basic concepts pertaining to electrical safety

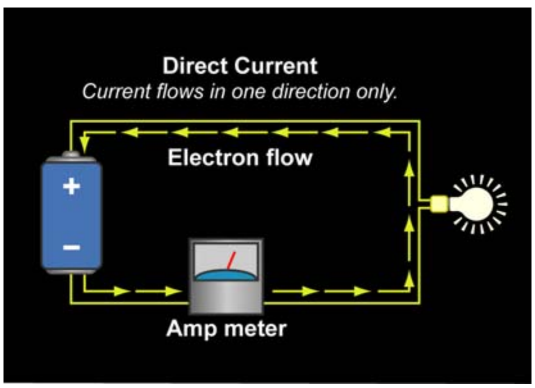
- Macroshock
- Microshock
- “Let go” current
- Grounding
- Circuit isolation
- Ground fault interrupter
- Line isolation monitor
- Leakage current
- Electromagnetic interference

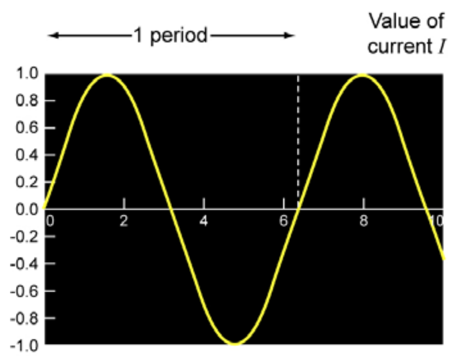
Remember: Electricity can be dangerous!!

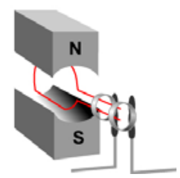
PART I: PRINCIPLES OF ELECTRICITY

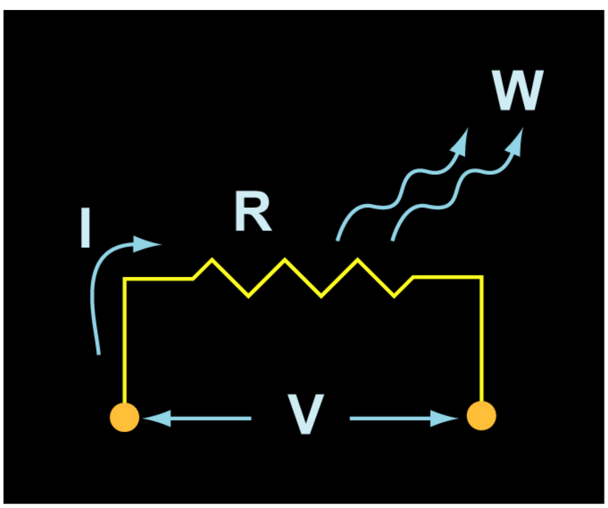
Conductors and Insulators: A conductor is any substance that permits the flow of electrons (or electric current). Copper and silver are examples of excellent conductors of electricity. Glass cannot conduct electricity, and is called an *insulator*.

Direct and Alternating Currents: If the electron flow or current flow is always in the same direction, it is referred to as *direct current* (DC) [see left panel, below]. However, if the electron flow reverses direction at a regular interval, it is termed *alternating current* (AC) [see right panel, below]. Alternating current usually takes on a sinusoidal form. The alternating current from the wall that we use everyday in North America completes 60 cycles per second (60 Hz); in Europe the frequency is 50 Hz. The voltage supplied is usually 120 volts (but often 220 volts in Europe).









***Ohm's law*:**

E (or V) = I x R

where

E (or V) is electromotive force (in volts)

I is current (in amperes)

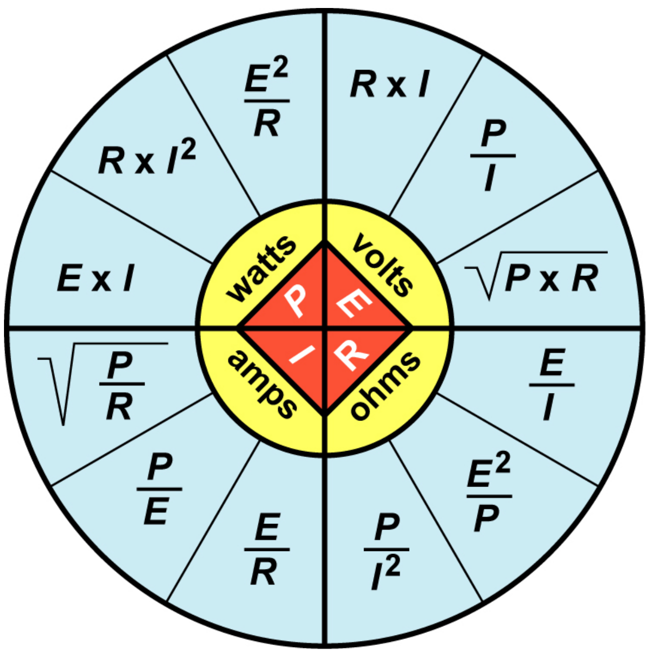
R is resistance (in ohms)

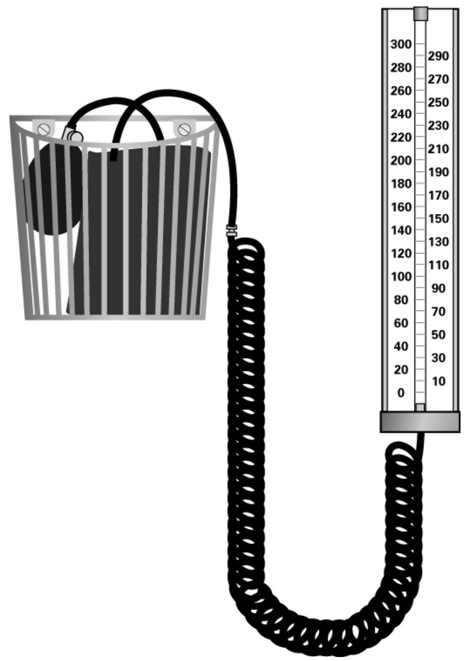
EXAMPLE 1
What resistance across a 100 volt source would produce a current of 100 ma (=0.1 amp)?

ANSWER
From Ohm's law, R= E / I = 100 volts / 0.1 amp = 1000 ohms

EXAMPLE 2
If a 200 volt pulse from a nerve stimulator results in a current flow of 50 ma, what is the skin resistance?

ANSWER
From Ohm's law, R= E / I = 200 volts / 0.05 amp = 4000 ohms





Blood Pressure Analogy

Note that Ohm's law (E = I x R) is analogous to the physiologic equation:

BP = CO × SVR

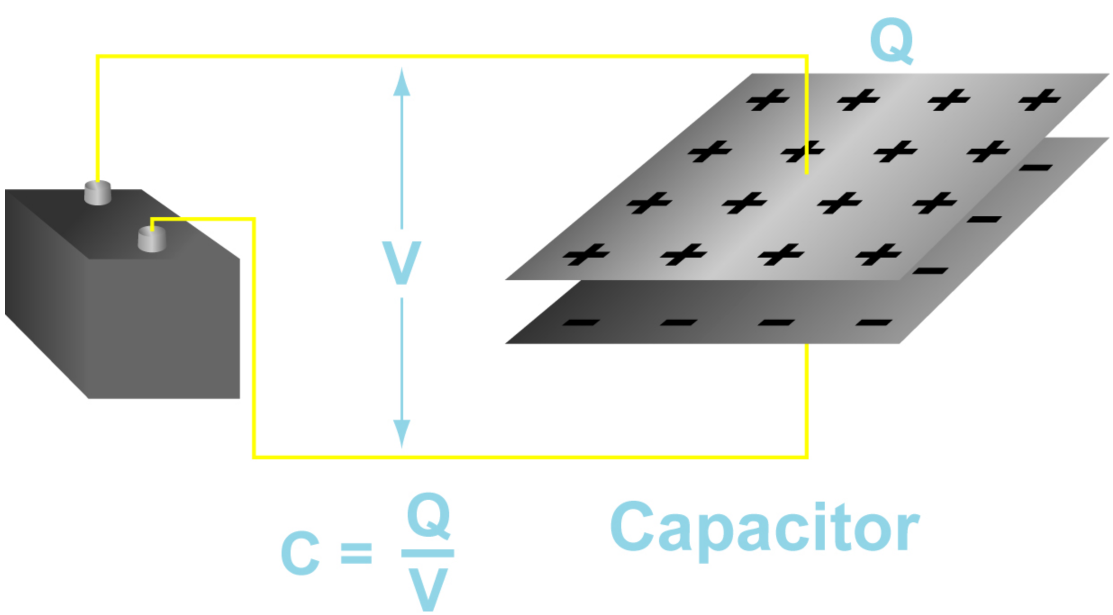
That is, blood pressure (BP) is equal to the cardiac output (CO) times the systemic vascular resistance (SVR).

Electrical power:
Electrical power (P or W) is measured in watts.

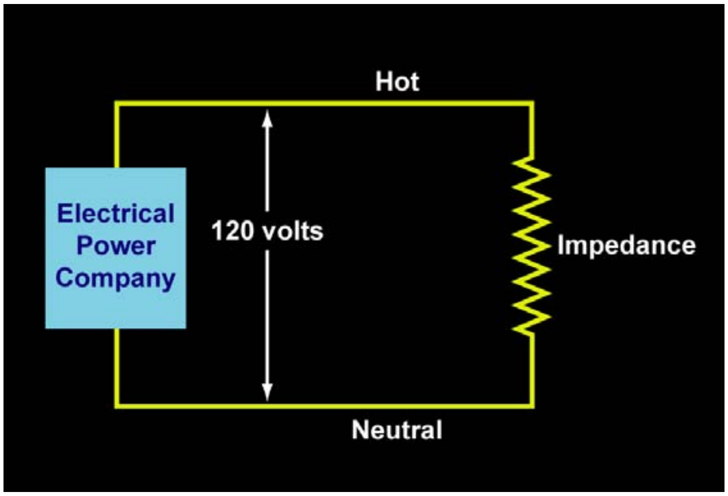
W = E x I (or P = E x I)

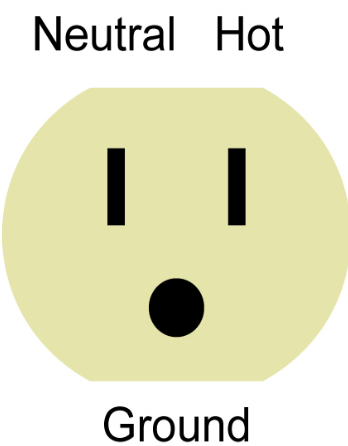
Electrical energy:
The watt-second (or joule, J) is commonly used to denote electrical energy expended in doing work. The energy produced by a cardiac defibrillator is measured in watt-seconds (or joules), while the kilowatt-hour is frequently used to measure larger quantities of electrical energy. As an example, electrical utility companies charge their customers on the basis of kilowatt-hours of electricity consumed.

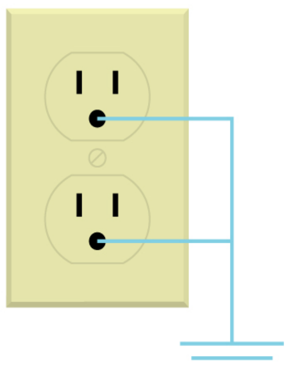
Capacitance:
A *capacitor* consists of any two conductors (such as parallel plates) that are separated by an insulator. A capacitor stores charge (electrons). In a DC circuit the capacitor plates are charged by a voltage source (*i.e.*, a battery) and there is only a momentary current flow as the capacitor charges. No further current can then flow unless a resistance is connected between the two plates and the capacitor is subsequently discharged. In contrast to DC circuits, a capacitor in an AC circuit permits current flow, depending on the *impedance* presented by the capacitor at a given frequency of alternating current.



PART II: ELECTRICAL SHOCK HAZARDS







Stimulation with electricity can cause muscle cells to contract, and can thus be used therapeutically in equipment such as pacemakers or defibrillators or diagnostically when a nerve stimulator is used to assess the degree of neuromuscular blockade. However, contact with a large electrical voltage (like a power line), whether AC or DC, can lead to injury or even death, often as a result of ventricular fibrillation. It takes approximately three times as much DC current as AC current to cause ventricular fibrillation.

A typical power cord consists of two conductors. One designated as “hot” carries the current to the load; the other is neutral, and it returns the current to the source. The potential difference between the two is 120 volts. To receive an electrical shock, one must be in contact the electrical circuit at two points, and there must be a voltage supply that causes current to flow through an individual.

When this occurs, damage can occur in one of two ways. In the **first mechanism**, the electrical current can disrupt the normal electrical function of cells. Depending on its magnitude and path, the current can contract muscles, paralyze respiration, or lead to cardiac arrest via ventricular fibrillation. The **second mechanism** involves the dissipation of electrical energy throughout the body's tissues: an electrical current passing through any resistance raises the temperature of that substance, sometimes sufficiently to produce a burn.

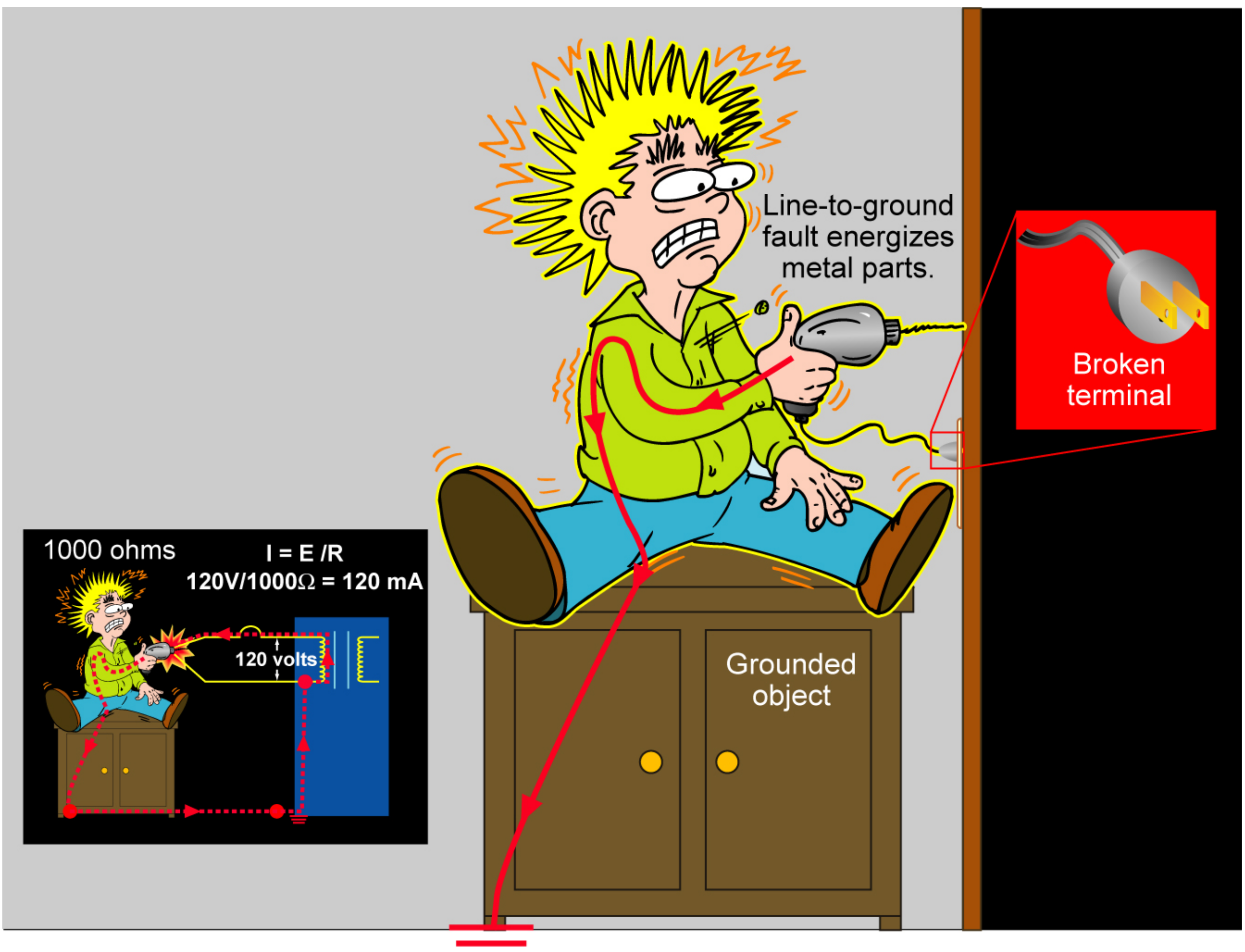
Electric Current (1 second contact)	Physiological Effect
20 microamperes	Can possibly cause ventricular fibrillation in a “microshock” setting
1 – 5 mA	Threshold of feeling, tingling sensation.
10-20 mA	"Can't let go!" current - onset of sustained muscular contraction.
100-300 mA	Ventricular fibrillation in “macroshock” setting

The severity of an electrical shock is determined by the amount of current (amperes), its path through the body, and the duration of the current flow. For the purposes of this discussion, it is helpful to divide electrical shocks into two categories.

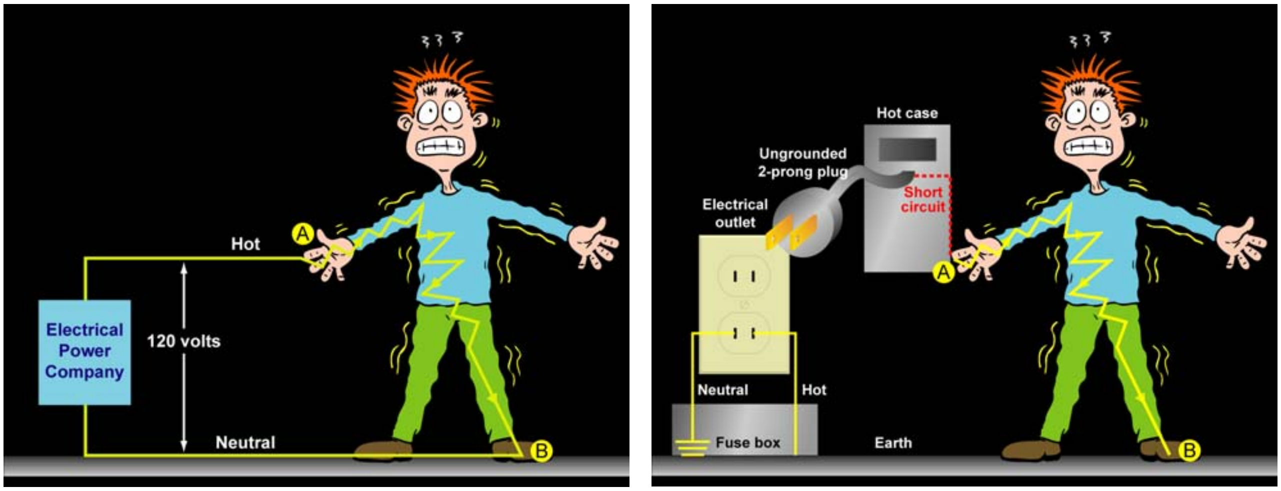
Macroshock refers to large amounts of current flowing through a person, which can cause harm or death. **Microshock** refers to very small amounts of current (in the microampere and milliampere range) and applies only to the electrically susceptible patient, such as an individual who has an external conduit that is in direct contact with the heart. This can be a pacing wire or a saline-filled catheter such as a central venous or pulmonary artery catheter. In the case of an electrically susceptible patient, even minute amounts of current (microshock) may cause ventricular fibrillation.

In the electrically susceptible patient ventricular fibrillation can be produced by a current that is below the threshold of human perception. The exact amount of current necessary to cause ventricular fibrillation in this type of patient is unknown but may be as little as 20 microamperes.

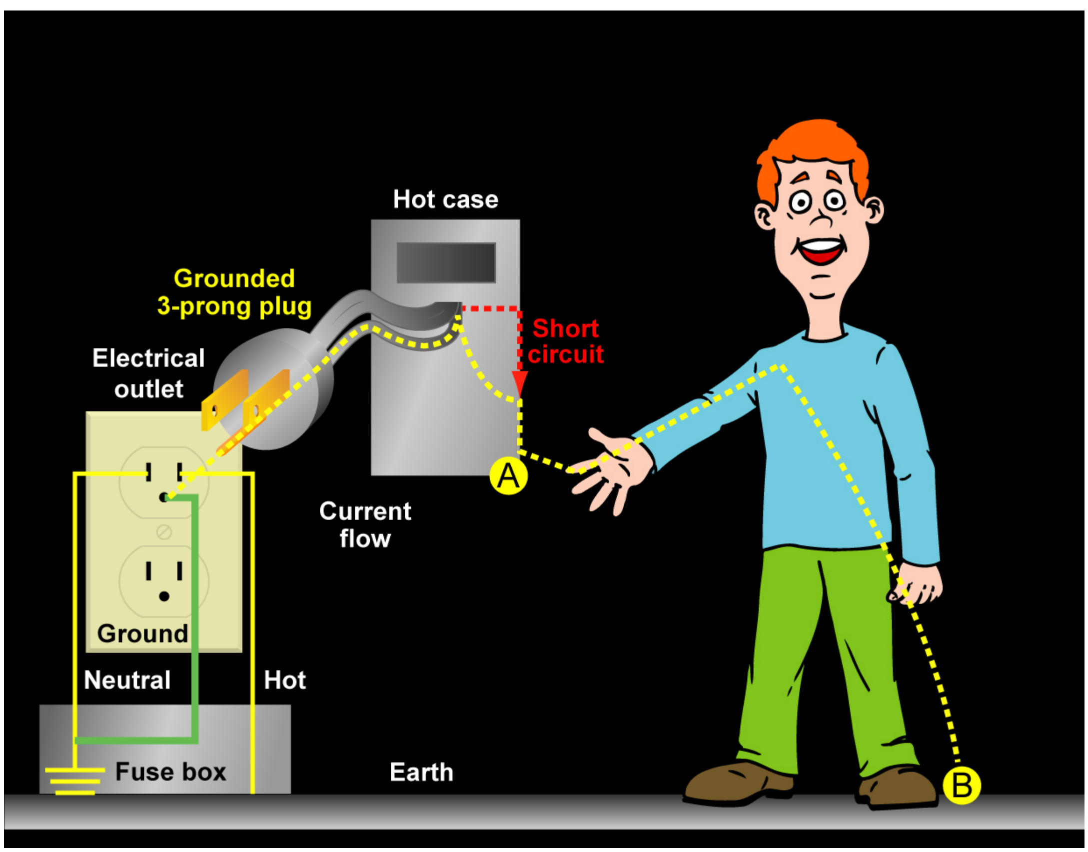
PART III: GROUNDING



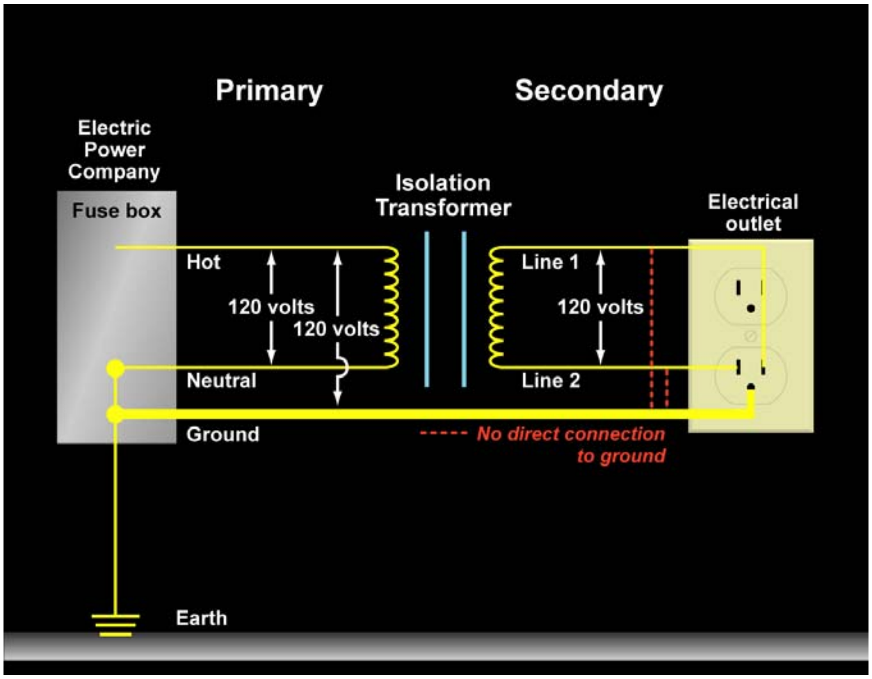
Ground connections on electrical plugs are used to help prevent electric shocks. An electrical shock may occur when an individual gets connected between the hot and neutral connectsions in a circuit, either directly as shown on the panel below on the left, or via a frayed wire that has resulted in a short circuit producing a “hot case”, as in the panel below on the right.



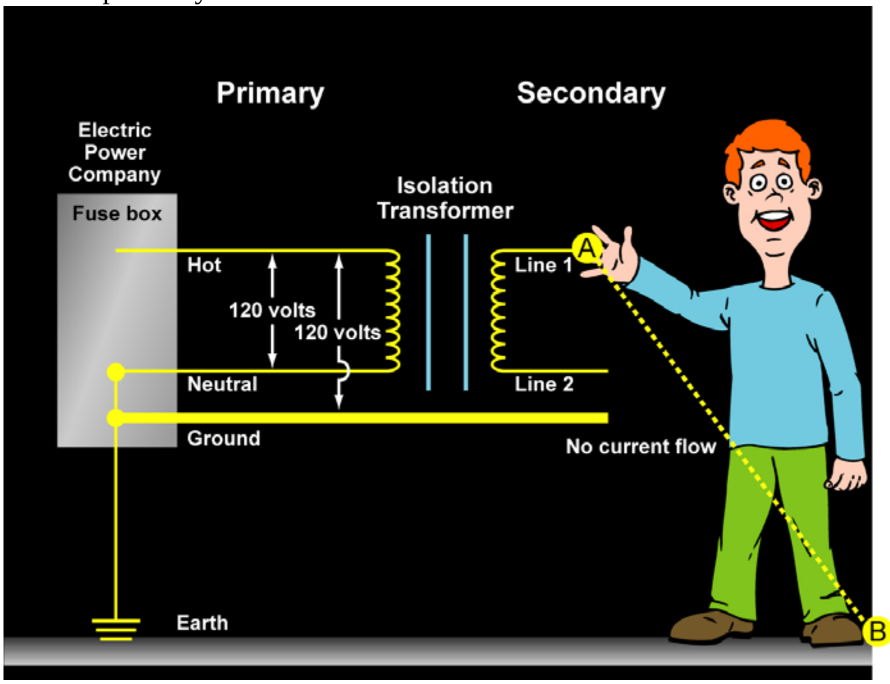
Note, however, that if a 3-pronged plug is employed so that the case is grounded, any short circuit current from a frayed wire or the like will safely return any current to the ground instead of travelling through the victim. This is illustrated below.



PART IV: THE LINE ISOLATION MONITOR



Isolated power systems are frequently used in operarting rooms. Such systems use an **isolation transformer** system so that neither of the two output lines powering the operarting room equipment offers any voltage with respect to ground. This helps eliminate the shock hazard associated with working in wet environments like the operarting room. However, this safety systems only works reliably if the isolation transformer and the things connected to it are working properly. To check that the isolation system is working OK, we use a line isolation monitor (LIM). The LIM monitors the isolated power system to ensure that it is fully isolated from ground, and has an indicator that indirectly displays the impedance to ground of each side of the isolated power system. The LIM meter will indicate the total amount of leakage current in the system



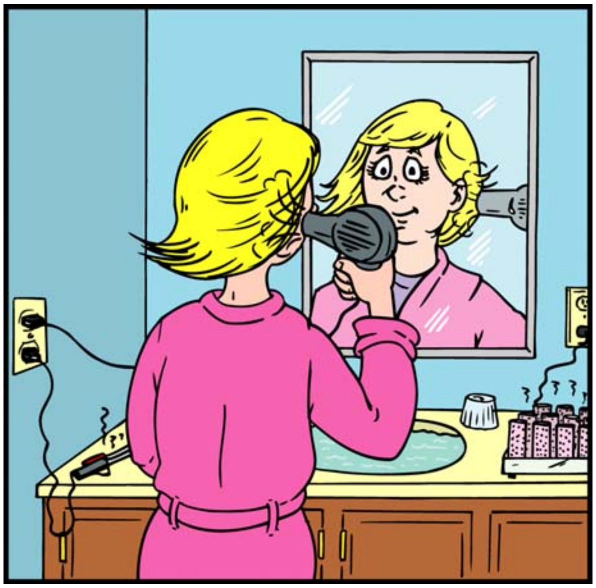
resulting from AC capacitance effects, and from any equipment plugged into the system. The reading on the LIM meter does not mean that an actual current is flowing; rather, it tells us how much current would flow in the event of a **first fault**. The LIM is usually set to alarm at 2 to 5 mA, depending on the system. Once this limit is reached, alarms are triggered. This does not necessarily mean that there is a hazardous situation, but only that the system is no longer totally isolated from ground. It would require a **second fault** to create a dangerous situation. For example, if the LIM were set to alarm at 2 mA, using Ohm's law, the lowest allable impedance for either side of the isolated power system would be 60,000 ohms, since by Ohm’s law R = 120 / 0.002 = 60, 000. Therefore, if either side of the isolated power system had less than 60,000 ohms impedance to ground, the LIM would trigger an alarm.

SAMPLE HOSPITAL POLICY

LINE ISOLATION MONITOR ALARM

INFORMATION: Line isolation monitor alarms play an important role in patient and user safety. Whenever these devices go into alarm, there is an unsafe electrical condition in some electrical piece of equipment.

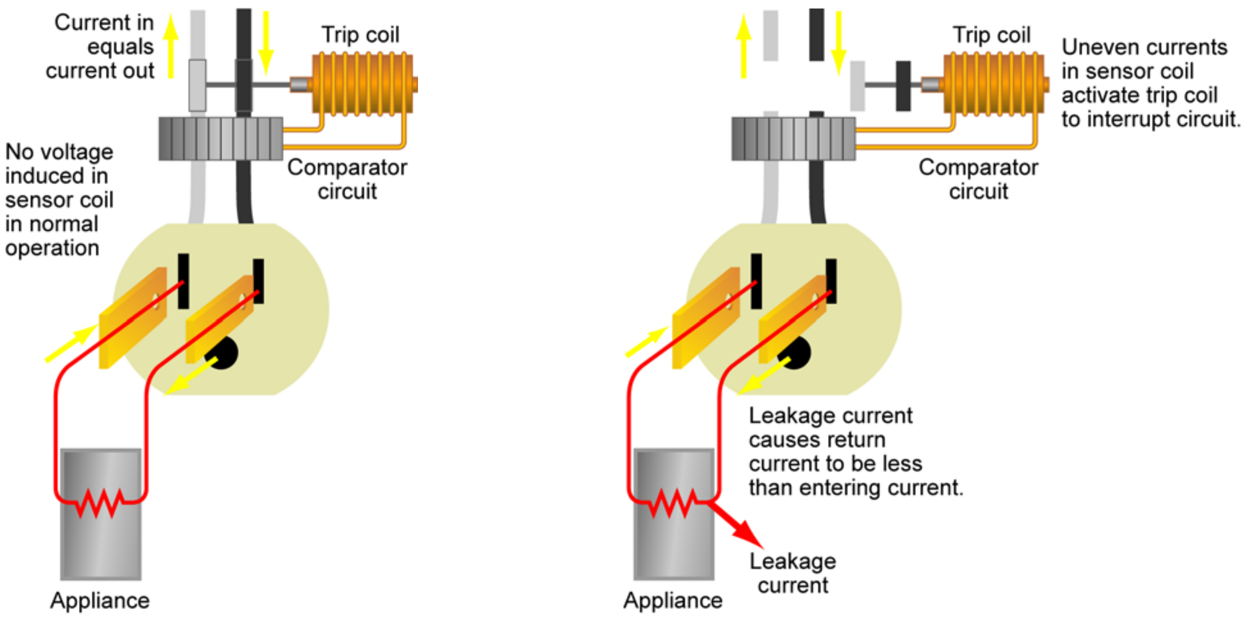
PROCEDURE: When an alarm sounds, the cause is usually due to a defective piece of electrical equipment. The user should silence the alarm and unplug the last piece of equipment plugged in before the alarm sounded. If the alarm clears after unplugging the last item connected, it is safe to proceed as long as the item is not plugged in. If the alarm continues to sound, call Clinical Engineering.



Activities carried using electrical equipment in wet areas are especially hazardous. The use of ground fault circuit interrupter (GFCI) devices or isolated power systems can be helpful in reducing the hazards involved.

PART V: GROUND FAULT CIRCUIT INTERRUPTERS

The ground fault circuit interrupter (GFCI) (illustrated below) is another device to help prevent individuals from receiving an electrical shock in a grounded power system. Electrical codes for most new construction require that a GFCI circuit be present in potentially hazardous (*e.g.*, wet) areas such as outdoor electrical outlets. Ordinarily, the current in both the hot and neutral wires in a power outlet is equal. The GFCI monitors both sides of the circuit for the equality of current flow; if a difference is detected, the power is immediately interrupted. If an individual should contact a faulty piece of equipment such that current flowed through the person, an imbalance between the two sides of the circuit would be created, which would be detected by the system. Because the GFCI can detect very small current differences (in the range of 5 mA), the GFCI will open the circuit in a few milliseconds, thereby interrupting the current flow before a significant shock occurs. Thus, the GFCI provides a high level of protection at a very modest cost. The disadvantage of using a GFCI in the operating room is that it interrupts the power without warning. A defective piece of equipment could no longer be used, which might be a problem if it were of a life-support nature, whereas if the same faulty piece of equipment were plugged into an isolated power system, the LIM would alarm, but the equipment could still be used.



PART VI: ELECTROMAGNETIC INTERFERENCE (EMI)

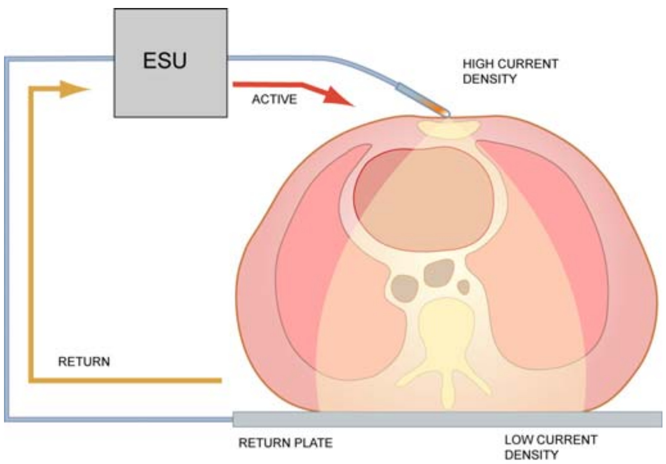
Rapid advances in technology have led to an explosion in wireless communication devices. These include cellular telephones, cordless telephones, walkie-talkies, and wireless Internet access devices. All of these have something in common: they emit electromagnetic interference (EMI). There has been concern that the EMI emitted by these devices may interfere with pacemakers or various types of monitoring devices in critical care areas. Studies have been done to find out if cellular telephones or walkie-talkies cause problems with cardiac pacemakers. Any time a cellular telephone is on, it is communicating with the cellular network, even though a call is not in progress. Therefore, the potential to interfere with devices exists. However, walkie-talkies are far more likely to cause problems with medical devices than cellular telephones. This is because they operate on a lower frequency than cellular telephones and have a higher power output. The ECRI recommends that cellular telephones be maintained at a distance of 1 meter from medical devices while walkie-talkies be kept at a distance of 6–8 meters.

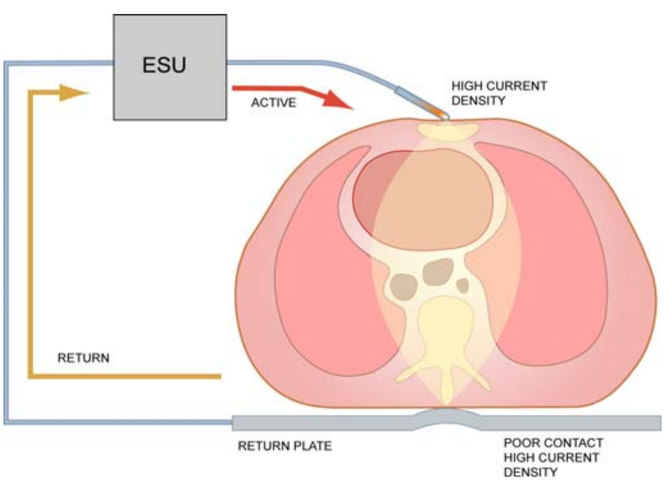
PART VII: IMPLANTED DEFIBRILLATORS

Automatic implantable cardioverter-defibrillators (AICDs) are capable of sensing ventricular tachycardia (VT) and ventricular fibrillation (VF) and then automatically defibrillating the patient using their internal energy source. It is important to be aware that the use of a unipolar cautery may cause electrical interference that could be interpreted by the AICD as VT or VF. This would trigger a defibrillation pulse that might itself cause an episode of VT or VF. Patients with an AICD is also at risk during electroconvulsive therapy. In both cases, the AICD should be disabled. Although most AICDs can be disabled with a magnet, some require a special programming device to turn it off. The device is later reactivated at the end of surgery It is always best to consult with the AICD / pacemaker service before starting surgery. Finally, an external defibrillator and a noninvasive pacemaker should be readily available whenever a patient with an AICD is anesthetized.

PART VIII: ELECTROCAUTERY

Electrocautery can be used to CUT or to COAGULATE tissue using radiofrequency electrical energy. This electrical energy does not produce shock effects (like VT or VF) because it is high in frequency, in the megahertz region. Special attention should be directed at placement of the electrocautery return pad (sometimes erroneously called a “ground plate”) to avoid electrical burns to the patient (see below).





NEED MORE INFORMATION? SOME SUGGESTED READINGS

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