APPENDIX D: Understanding Electrical Hazards

Electrical shock is a result of electrical current flowing through the body. In general, there are three contributing factors that determine the severity of the electrical shock:

1. ***The path and the amplitude of the current through the body,***
2. ***The amount of time that current flows through the body, and***
3. ***The frequency of the current that flows through the body.***

1.1 Current path and amplitude

The path that current takes through the subject's body determines the lethality of the electrical shock. It is more dangerous if the current flows through the heart muscle and lungs.

There are two ways that the electrical current can flow through human body:
- Resistive coupling in which the human body acts as a resistor.
- Capacitive coupling where the human body acts as a capacitor.

1.1.1 Resistive Coupling

In the case of resistive coupling, to close the current path a person will have to be in contact with at least two points in the live circuit. The second point of contact, however, could be the ground the subject is standing on, or any conductive element (such as a pole, or panel, etc.) which he or she is touching. *The path that current takes, and the resistance of that path, determines how much current would be generated*. Of course, the current always take the path of least resistance. The amplitude of this current is one of the main factors determining the severity of the electrical shock.

Floating power supplies (batteries or power supplies with an isolating transformer) provide current that does not seek to return current via ground, but some current may flow from stray capacitive coupling. However, the voltage sources in this lab are **not isolated**; therefore, even a single point of contact to any elements fed by these power supplies potentially completes a current path via ground.

It is estimated that a healthy, dry human body with no skin cuts can exhibit around 100,000 Ohms of resistance. This value drops rapidly if the skin is damaged or moist (down to 1,000 Ohms) or the voltage exceeds the skin puncture level of 25-50V. The resistance of the internal organs, however, is much lower at around 300-1000 Ohms. Figure 1, below, depicts the resistance model of the internal organs. As can be seen, the human body can be modelled as a resistive network with different terminals. The total resistance at low voltage is mainly present on the outer layer of the skin: the dead and dry layer of cells covering the body.

The current flowing through the human body follows Ohm's law and can be found as:

$$I = \frac{V}{R}$$

The electric shock hazard depends on the current, not the voltage. It is the amount of charge moved through the body, and the duration of charge displacement, which causes shock. Nevertheless, as Ohm's law suggests, this current is dependent on both the source voltage and the path (resistances) through the body. Therefore, a certain voltage can cause shocks with different levels of severity when applied across different parts of the body because the current that flows through the resistances of each path are different.

Body Part	Resistance
Dry Skin (no cuts or scabs)	Over 100,000 Ohms
Wet Skin	1,000 Ohms
Within the Body	500 Ohms
Ear to Ear	100 Ohms

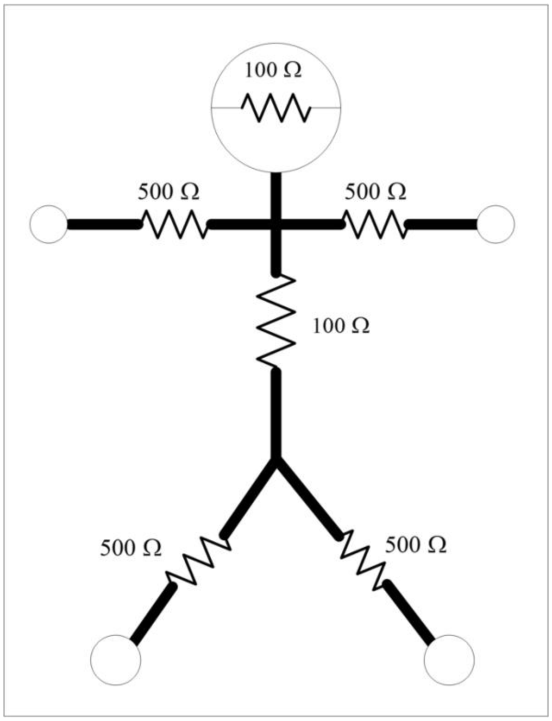

Figure 4. Human Body Resistance Model

Table 1 and Figure 5 show the harmful physiological effects of different amounts of electrical current on a human body for the duration of one second. As can be seen, the effects of electrical shock depend on the current amplitude. A certain amount of current, e.g., 5 mA, can be caused by a wide voltage range, from 5-500 V. This depends on the fact that the skin in the current path is dry and not damaged. **This is one of the reasons why liquids are prohibited to be brought to the lab**.

Humans can perceive currents as low as 1mA. A current of about 3 mA DC flows when testing a fresh 9V battery for a smoke detector across soft tissue, such as a tongue. The maximum harmless current is 5 mA. However, at current levels where a shock does no direct physiological harm, there are still possibilities of inflicting indirect injuries. The shocked individual may react voluntarily or involuntary by muscle contraction. In moving away, possibly very rapidly and by reflex action without thinking, he or she can fall over backwards, bang against a nearby chair or workbench, or just hurt their hand against the chassis of the item they are working on.

Current levels between 10 and 20 mA (depending on the body mass and gender), determine the "**let-go threshold**" current. Beyond that, the muscles are contracted, and the subject can't release the conductor. Above this limit, involuntary clasping of the conductor is present. This results in longer duration of electrical current flow through the subject's body. The severity of the electrical shock depends on the duration of the current flow. The fact that the subject can't disconnect from the live voltage increases the time that current flows through the body and therefore multiplies the severity of the shock. Moreover, as the grip tightens, resistance reduces and the increased current may burn through the subject's skin, leaving only the internal body resistance with dramatically increased current amplitude.

AC-line frequency currents larger than 30mA can cause ventricular fibrillation if it flows through the subject's upper body. The heart itself produces a dipole current of about 2.5 mA, as shown in Figure 6, and any external current of this magnitude can interfere with the normal heart rhythm. As can be seen from Table 1, ventricular fibrillation caused by a sustained 100 mA AC current can be fatal. For greater currents, besides the effects on the subject's heart and respiratory system, the tissues may burn because of the extensive heating of the tissues.

Table.1 Shock Physiological Effects ***(For 1 second contact of AC source 60Hz)***

Electric Current	Physiological Effect	Voltage required to produce the current with assumed body resistance: 100,000 Ohms Dry Skin	1000 Ohms Wet Skin
1 mA	Threshold of feeling, tingling sensation	100 V	1 V
5 mA	Accepted as maximum harmless current	500 V	5 V
10-20 mA	Beginning of sustained muscular contraction ("Can't let go" current)	1,000 V	10 V
100-300 mA	Ventricular fibrillation, fatal if continued. Respiratory function continues	10,000 V	100 V
6 A	Sustained ventricular contraction followed by normal heart rhythm (defibrillation). Temporary respiratory paralysis and possibly burns	600,000 V	6,000 V

Source: Georgia State University website