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Electricity and the Body

University Physics II
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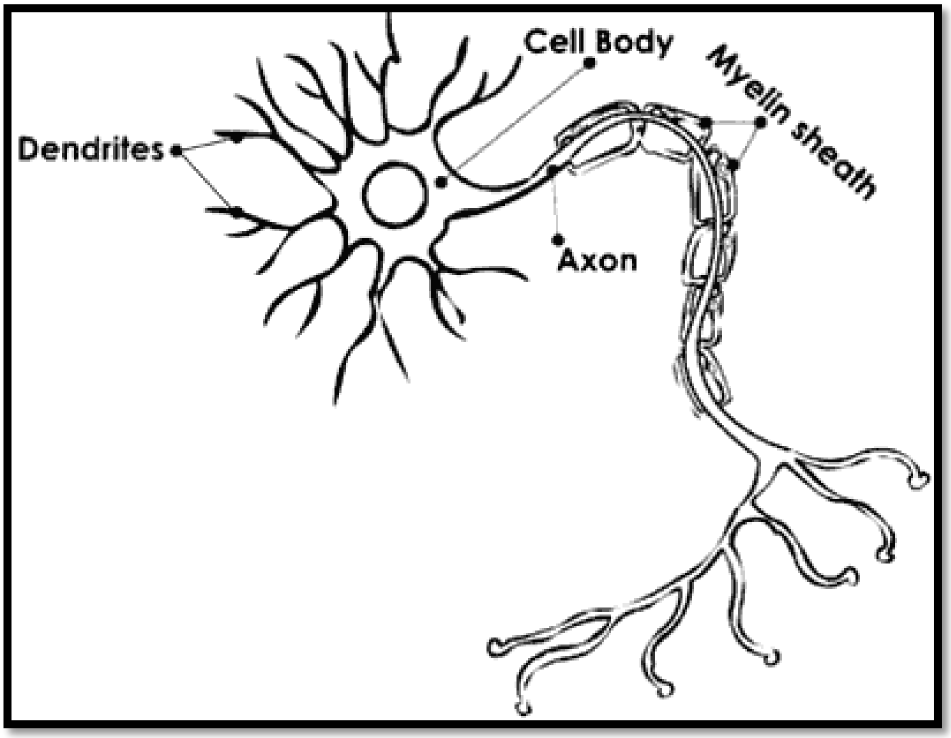
Electricity has some incredible qualities. The subject of Physics II is nearly entirely devoted to the study of magnetism and electricity, and yet large portions of the science of electricity are unexplored in the class. The study of electricity may range from spinning a coil of wire to powering supercomputers and is thus an immense topic. One of the concepts of electricity that is largely unexplored in Physics II is the effects and presence of electricity in and on the human body. Electricity is found in the nervous system where it serves to coordinate the body's motion and actions, but electricity introduced from outside of the body possesses the capability to control human motion without the decision of the human and even end life.

With such a wide array of interactions and uses of electricity related to the human body, it seems best to begin with the nervous system, the body's electrical system. The nervous system is simply based on small electrical pulses that initiate bodily motion. These pulses are quite small, even less than one-twentieth of a volt, but they direct everything within the body (Olesky 2000).

The nervous system is made up of two major parts: the Central Nervous System (abbreviated as the CNS, composed of the brain and spinal cord), and the Peripheral Nervous System (or the PNS, which connects the CNS to receptive parts of the body). These are made up of neurons (nerve cells) that are composed of axons, dendrites, and receptors. Axons supply the electrical signals. The axons are attached to a tree-like array of nerves called dendrites that transfer these pulses. The dendrites carry the pulses to the receptors where they create motion in the body. This is illustrated below in Figure 1. The brain contains a vast number of neurons, and these determine body actions by sending electrical pulses through the CNS and the PNS to the target locations within the body. The nervous system is able to send these pulses throughout the body due to the conductivity of the cell membranes that the current passes through and the small amount of conducting fluid in the nerves (Brodal 2010).



<u>Figure 1</u>: Axons and Dendrites as part of a neuron (Voytek 2011)

Due to the conducting state of the nervous system in the movement of electricity, the effects of current are present in the nerves, and a number of equations may be used to describe the nervous system and even find the electrical field of a section of the nervous system. To solve for the electric field, begin with Ohm's Law. Ohm's Law calculates electric current and is written as

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

where I is the current (in amps), V is the potential difference (in volts), and R is the resistance (in ohms) (Stewart et al. 2011). This equation can be used inside of another equation for current *density*, or the current-per-unit-area, which is defined to be

$$J = \frac{I}{A}$$

where J is the current density (in $\frac{mA}{m^2}$) and A is the area (Nave). Combined, these two equations can be written as

$$J = \frac{V}{RA}$$

where R is adjusted for conductors. Resistance (R) can be written in terms of resistivity for conductors, and so R may be written as

$$R = \frac{\rho L}{A}$$

where ρ is the resistivity of a conductor (because nerves conduct electricity), L is the length of the current, and A is the cross sectional area (Nave). Then, combining all three equations, they can be written as

$$J = \sigma E$$

where σ is the inverse of ρ. Thus, by rearranging the equation to solve for the electric field, the field for a nerve is

$$E = \frac{J}{\sigma}$$

recorded in units of V/m (He 2005). These and other equations are some of the foundations for neural engineering and some biomedical engineering, and they are based on many of the simple equations in Physics II.

In light of the nature of the nervous system and its ability to carry electricity and current well, scientists have studied how the nervous system might be stimulated and how the body responds to this stimulation. Because the nervous system is linked to pain receptors in the body, increased electrical current within the nervous system may lead to pain, and even at relatively low amounts of electrical current, an induced current in the body may cause death. In Stephen L. Herman's book titled *Delmar's Standard Book of Electricity*, Herman explains that the conductivity of the body varies only slightly due to the state of the body. For instance, if the subject has been sweating, the conductivity of the person will rise slightly due to the natural conductivity of sweat (specifically, the salt in the sweat). However, because variation in conductivity is small, a relative level of pain from electricity can be determined purely from how many amps of current are passed through a person. A person may experience a wide array of feelings with the change in current. At 0.002-0.003 amps, the body may experience a mild tingling sensation, though it is not likely to be one of pain. However, if the amplitude is increased by only roughly 0.007 amps to a range of around 0.010-0.020 amps, suddenly the pain becomes great. At 0.030-0.040 amps a person may experience muscular paralysis, and at 0.1-0.2 amps, the human heart may experience heart fibrillation, and the subject will die if uncared for (Herman 2003). A little bit of current can go a long way in the human nervous system.

Discoveries such as these over time led to the development of a new, terrifying instrument of capital punishment, the ever-famous electric chair. Designed by Thomas Edison and George Westinghouse, the chair was intended to instantly kill an individual who received the death penalty by introducing large voltages and currents to the victim, running the current from the head (which is shaved and covered by a wet sponge filled with brine) to the feet. These were supposed to override the victim's nervous system to stop their heart and brain. An image of the basic electric chair frame is shown below in Figure 2. Though Edison believed that a direct current would be the most effective way to deliver the electricity, Westinghouse proposed that the chair use an alternating current instead of a direct current, and this was generally agreed on by scientists to be the best type of current for a quick death (Parkinson et al. 2010).

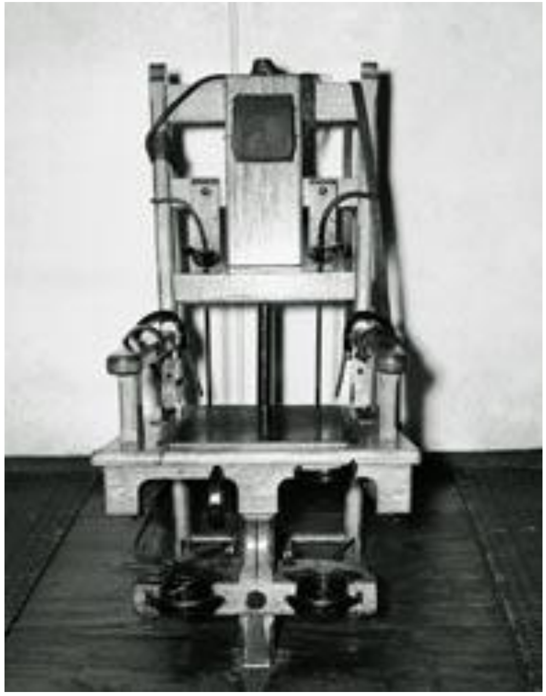


Figure 2: The Electric Chair (Amandolare 2011)

Despite how seemingly sound the theory was and how well it worked on other animals, even large animals like horses, the first use of the electric chair went horribly wrong. William Kimmler was sentenced the death penalty for hacking his mistress to death with a hatchet, and on August 6, 1890 in New York, he was the first man ever to experience death with the electric chair. After Kimmler was strapped to the chair, a high voltage ran for 17 seconds through Kimmler's body. Kimmler's breathing stopped during the shock, and he appeared dead. The executioner then ended the flow of electricity, but only shortly after the electricity stopped, Kimmler began breathing again. The executioner raced to restart the current, this time letting it run for roughly 70 seconds. The smell of burning flesh filled the air as Kimmler's head and legs were burned by the intense electrical current, and Kimmler was pronounced dead soon after the second shock, but not before proving the inefficiency of the electric chair. The killing took eight minutes when it was predicted to take only seconds (Parkinson et al. 2010).

New York, nonetheless, decided to keep the electric chair as a form of the death penalty in the place of hangings, where victims were often strangled to death or even decapitated. It did not believe the electric chair to be a form of cruel and unusual punishment. Over time, many more states adopted the electric chair as a form of capital punishment. Though the chair was fairly reliable, it was clear that the electric chair was not the most efficient method for the death penalty. On numerous occasions, issues arose regarding the conduction of electricity to the sponge and the person, and the result was often excruciating pain and severe burns to the unlucky victims.

One particularly gruesome shocking happened only around 20 years ago in the state of Florida. A man named Pedro Medina received the death sentence by the electric chair in 1997. During the shock, roughly 2000 volts of electricity were introduced to kill him, but the procedure went terribly wrong. The head covering on Medina caught on fire, and the electrical operator made the hasty decision to cut off the supply of electricity to Medina before the normal two minutes of shock had occurred. Medina was still very much alive as his head burned from the electrical fire, and he lived until shortly after the fire died out. These and other similar incidents have led many states to abandon the practice of killing with the electric chair, concluding that it is a form of cruel and unusual punishment, including Nebraska (which ended the practice recently, on February 8, 2008) ("US: Electric Chair Banned as Cruel, Unusual Punishment" 2008). Even so, 9 states still use the electric chair as a form of capital punishment. The most recent execution was of Paul Warren Powell on March 18, 2010 in the state of Virginia. He was shocked once for 30 seconds to stop his heart, and he was shocked again for another 60 seconds to ensure that his heart would not restart, though there appeared to be smoke coming from his legs ("The Electric Chair").

Despite how dangerous electricity is in large amounts on the human body, small doses of electricity have been shown to be incredibly helpful for a variety of different illnesses and injuries. There are a number of therapies that use small doses of electricity to stimulate, strengthen, and correct the body. One of these therapies is known as electroconvulsive therapy, or ECT. Electroconvulsive therapy is used for mental imbalances and illnesses and primarily serves to balance serotonin and dopamine levels in the brain. Electricity is run in a current across the brain, creating a seizure inside the brain (and if uncontrolled, the body). This seizure serves to regulate these imbalanced levels in patients. Though the reason why this works is still not entirely understood, it has been proven to be very effective. Over 100,000 procedures are now performed every year. Additionally, in viewing the effectiveness of the procedure when treating conditions like severe depression, electro-convulsive therapy has been shown to have an response rate of roughly 85% of the patients tested compared against the 35% response rate recorded from medical drugs (Mankad et al. 2010). A picture of this procedure is shown in Figure 3 below.

Figure 3: Electroconvulsive Therapy ("Brain Stimulation Therapies" 2009)

Before the 1930's, mental illnesses such as schizophrenia and mania were treated with a wide variety of different methods including hydrotherapy (which used cold packs on the head), water therapy (which used tub-type baths for very long periods of time), prolonged sleep therapy, insulin comas, and Scotch douches, but these were unsuccessful. Drugs were introduced with little success before Italian Neurophysicists Ugo Cerletti and Lucio Bini considered using electricity for therapy. In 1937, they ran electricity through the brain of a schizophrenic patient, inducing a full-body seizure. Though the procedure seemed violent, the result was that the patient's symptoms were significantly reduced following the procedure. However, due to the striking similarity to the electric chair, and due to the ideas of books such as *One Flew Over the Cookoo's* Nest, society rejected the idea of ECT as a medical practice for many, many years afterwards (Mankad et al. 2010).

After years of social rejection, electroconvulsive therapy began to make a comeback as the American Psychiatric Association noted the effectiveness of the procedures and began encouraging a greater use of them for patients in the 1970's. It noted that that electroconvulsive therapy is very effective for a host of mental illnesses including schizophrenia, hyperemotionality (which is severe depression), hypermotility (which is manic excitement or delirium), acute and severe psychosis, parkinsonism (which is paralysis from the nervous system), and even some life-threatening conditions (like severe catatonia, which is an extremely abnormal mental state). The safety of the procedure has also increased dramatically. With muscle relaxers, the only part of the body that experiences the seizure is the brain (which is not damaged because the level of current is low), and that effectively prevents damage to the body from the thrashing of a full-body seizure. It is even deemed safe during the first two trimesters of pregnancy. The limitations on performing the procedure today, however, primarily lie in the lack of trained doctors to give the procedure and in the relatively high cost of the procedure (Coffey 1993).

Another successful practice , more widely known than ECT, is called electrical muscle stimulation, or simply EMS. It is a procedure used to rehabilitate muscles in the body and is popular with athletes and athletics. The ideas for this electric muscle stimulation began with Luigi Galvani who proposed that the body could likely be stimulated by electricity.

Galvani is famous for his experimentation with a frog and electricity. While dissecting the lower half of a frog, the skin had been removed exposing the muscles and nerves of the frog. A nearby assistant had been at work on the frog with a scalpel when a nearby electrical machine sparked and the frog's legs kicked. Startled, Galvani began experimenting on the frogs legs. He attempted to repeat the accidental experiment by touching the crural nerve with a host of different materials while the machine created a spark. In one of the experiments, Galvani placed the frog on a sheet of glass and touched the nerve with a grounded conductor, and the frog's legs kicked. He additionally did experimentation with lightning, hanging the legs from a metal pole with brass hooks attached to the ribs, and again they kicked from the static electricity. Galvani was one of the first to study conductors, and he was additionally responsible for the first experimentations of EMS (Keithley 1999).

He was soon followed by the great Michael Faraday, father of Faraday's Laws (part of Maxwell's equations), and Michael's laws helped to make the ideas of Galvani seem more plausible to science and understandable. Surely enough, the procedure has proven to be fairly effective, and the electricity is used to simulate the nervous system at low frequencies to cause muscle contraction (McLaughlin 2009).

For the process, two pads are placed on the skin on both sides of a muscle, one on each side. A machine sends current between the pads to cause contraction, and the current alternates to cause the muscles to contract and relax at a steady rate for roughly ten to twenty minutes. A picture of the arrangement of the pads (with four pads instead of two) is shown in Figure 4 below. The therapeutic power of this procedure is largely based on the polarity of the current. This process is used to "reeducate" muscles that have been injured or impaired by causing the repeated contractions to stimulate the muscle that has rested or been impaired. Additionally, electrical muscle stimulation may increase muscle strength and has even been recorded to slow atrophy, the process of cells wasting away in the body (Clover 2007).

Figure 4: Electrical Muscle Stimulation (Griess)

In light of the electricity found within the human body and how the body interacts with outside electricity, the intricacy of the body and its fragility is more clearly displayed. However, the knowledge of the body's electrical system has also lead mankind to great discoveries regarding treatment for a host of illnesses and injuries, and it is likely that as more experiments and tests are performed, even more discoveries will be made that will push medicine and treatment to new heights. At the center of these discoveries is the simple science discussed in Physics II, and it is likely that the equations and sciences that physicists have been discussing for the past several decades will be the foundations of many of the discoveries soon to come.

Bibliography

1) Oleksy, Walter G. *The Nervous System*. New York: The Rosen Publishing Group, 2000.

2) Brodal, Per. *The Central Nervous System: Structure and Function*. Oxford: Oxford University Press, 2010.

3) Voytek, Bradley. Quora, "Neuroscience: What's the difference between an axon and a synapse?." Last modified May 10, 2011. Accessed April 26, 2012. http://www.quora.com/Neuroscience-1/Whats-the-difference-between-an-axon-and-a-synapse.

4) Stewart, John, and Gay Stewart. *UPII Spring 2012 Course Guide*. Fayetteville: The University of Arkansas, 2011.

5) Nave, Carl R. HyperPhysics, "Ohm's Law, Microscopic View." Accessed April 26, 2012. http://hyperphysics.phy-astr.gsu.edu/hbase/electric/ohmmic.html.

6) He, Bin. *Neural Engineering*. New York: Kluwer Academic Publishers, 2005.

7) Herman, Stephen L. *Delmar's Standard Book of Electricity*. Delmar Publishers; Cengage Learning, 2003.

8) Parkinson, Dave, and Tracie Lamourie. Canadian Coalition Against the Death Penalty, "The History of the Electric Chair." Last modified Decem 29, 2010. Accessed April 25, 2012. http://www.ccadp.org/electricchair.htm.

9) Amandolare, Sara. Finding Dulcinea, "On This Day: First Woman Executed by Electric Chair." Last modified March 20, 2011. Accessed April 26, 2012. http://www.findingdulcinea.com/news/on-this-day/March/First-Woman-is-Executed-by-Electric-Chair.html.

10) Human Rights Watch, "US: Electric Chair Banned as Cruel, Unusual Punishment." Last modified Febru 08, 2008. Accessed April 25, 2012. http://www.hrw.org/news/2008/02/07/us-electric-chair-banned-cruel-unusual-punishment.

11) Capital Punishment U.K., "The Electric Chair." Accessed April 25, 2012. http://www.capitalpunishmentuk.org/chair.html.

12) Mankad, Mehul V., John L. Beyer, and Richard D. Weiner. *Clinical Manual of Electroconvulsive Therapy*. Arlington: American Psychiatric Publishing, Inc., 2010.

13) National Institution of Mental Health, "Brain Stimulation Therapies." Last modified Novem 17, 2009. Accessed April 26, 2012. http://www.nimh.nih.gov/health/topics/brain-stimulation-therapies/brain-stimulation-therapies.shtml.

14) Coffey, E. Edward. *The Clinical Science of Electroconvulsive Therapy*. Washington, DC: American Psychiatric Press, Inc., 1993.

15) Keithley, Joseph F. *The Story of Electrical and Magnetic Measurements from 500 BC to the 1940's* . New York: John Wiley and Sons, 1999.

16) McLaughlin, Erin. suite101, "Electric Muscle Stimulation Therapy: Chiropractic Treatment and Pain Therapy." Last modified Decem 17, 2009. Accessed April 23, 2012. http://erin-mclaughlin.suite101.com/electric-muscle-stimulation-therapy-a180833.

17) Clover, Jim. *Sports Medicine Essentials: Core Concepts in Athletic Training & Fitness Instruction*. Independence: Cengage Learning, 2007.

18) Griess, Lukas. Midland Chiropractic and Rehab, "Electrical Muscle Stimulation." Accessed April 26, 2012. http://www.midlandchiroandrehab.com/electrical-muscle-stimulation/.