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Original Paper

Multidisciplinary Education—Bridging Physics to Life Sciences In Introductory College Labs

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Abstract

A simple circuit that produces a voltage pulse analogous to the pulse generated in the neuron was developed. This circuit is suitable for an introductory physics lab experiment to improve students understanding of applications to real life. By including a simple description of how neurons send electrical signals, a direct connection is made between physics and the human body. This is especially relevant to students pursuing careers in biology, medicine, and other pre-health areas, but also important to any student who is curious about the role physics plays outside of the lab.

Keywords

multidisciplinary education, introductory labs, lab experiment

1. Introduction

Introductory physics labs provide a unique chance for students to learn physics that they do not learn as effectively from lectures, reading assignments, and homework. Lab is also a stage for improving physical intuition, which is invaluable to the aspiring scientist and critical thinker. Unfortunately, the benefits of physics lab are often insufficient to hold the attention of students in introductory physics courses. Holmes and Wieman (2018) in their recent article in Physics Today emphasized the importance of introductory physics labs as they are the place to offer a unique opportunity to teach reasoning and critical thinking.

It is vital to develop physics labs that emphasize the role physics plays in other areas of study as well as in everyday life. A lab that teaches physics in the context of another field, such as biology, can help students make connections between subjects often overlooked in the traditional physics lab curriculum. Pre-health students for example do not see a connection to their field of study when they do the traditional lab experiments in the introductory physics lab. For that purpose, Meredith and Redish

(2013) highlighted the need to make introductory physics courses beneficial for life sciences students. Mylott, Kutschera, and Widenhorn (2014) presented a laboratory activity aimed at introductory physics students in life-science majors. The activity teaches principles of RC (resistance-capacitor) circuits by connecting alternating current (ac)—circuit concepts to bioelectrical impedance analysis.

It is important for these students to know that many biological phenomena can be understood in the context of electric circuits. Hodkin and Huxley (1963) modeled the neuron in the form of a circuit shown in Figure 1, which earned them a Nobel Prize in Physiology and Medicine. In their circuit, the cell membrane acts like a capacitor, $C_{mem,}$ with two parallel plates representing the inside and outside of the cell membrane. The resistors in Figure 1 represent the fact that ions pass through the membrane easily (low resistance) at some times but cannot pass through the membrane at other times (higher resistance).

Since it is difficult for students in the introductory college courses to understand the complex circuit developed by Hodkin and Huxley, we developed a simpler, but not as refined, circuit that can generate a voltage pulse similar to that generated by the neuron. We would like to emphasize that the circuit we developed can by no means compete with the circuit developed by Hodkin and Huxley.

2. Method

Before students use our "neuron circuit", they should understand the concepts of voltage and current. For that, we used the Arbor Scientific's Bulb Board shown in Figure 2 in which light bulbs act as resistors and can be arranged in so many different ways. In addition, we used the Genecon Hand Crank Generator instead of a battery to supply voltage to the light bulbs. This generator produces a DC voltage if the handle is turned by hand. The interesting thing about this generator is that the student can physically feel the electric resistance of the circuit. That is to say, the student will exert more effort to produce the same current through a higher resistance versus a lower resistance—making the concept of electric resistance more tangible should be very beneficial for the students.

Students then connect the light bulbs (resistors) in many arrangements such as in series, in parallel and in other combinations. They then measure the voltages across, and the currents through, each bulb for each of the arrangements.

3. Results

The simple circuit that we developed is shown in Figure 3. It serves as a simple physical model to produce the action potential of the neuron due to the permeation of ions across the axon membrane.

The action potential across the neuron membrane and the current in the neuronal membrane as functions of time are shown in Figure 4—similar figures can be found in many textbooks such as in Serway (2015). The membrane allows potassium ions to pass through easily, which creates a charge imbalance and thus a potential difference across the membrane—this is seen as the-70 mV potential at time t = 0. As the neuron is stimulated, sodium ions suddenly pass through the membrane into the axon which depolarize the membrane and takes on a positive potential that peaks at 30 mV with respect to the outside of the cell at t ~2 ms. Once this peak is reached, potassium ions flow quickly out of the cell restoring the resting potential to - 70 mV. In terms of currents, we see this as a large positive current as sodium ions flow into the cell to create the positive potential peak and a large negative current as the potassium ions flow out of the cell to restore the resting potential. The membrane responds to changing potentials by allowing different ions to flow in and out of the cell. This can be thought of as a membrane that changes its electrical resistance to a certain type of ions based on the potential.

The circuit we constructed shown in Figure 3 demonstrates how a certain type of resistor can respond to an external stimulus and changes its resistance, allowing a signal that is similar to the action potential to be produced. The membrane of the neuron allows ions to flow across it easily at times and restricts the flow of ions at other times—this is just like a resistor in an electrical circuit that can change its resistance. The resistor we used in our circuit, Figure 3, was a photocell. When there is light shining on the photocell, it has a low resistance, and when there is no light shining on it, the photocell has a high resistance. The ohmmeter that we used in our circuit, in addition to measuring the resistance of the photocell, provides a voltage source that drives a current through the photocell. This is evident when we connect the circuit, we see ~1.5V DC on the oscilloscope, so we can think of this as the resting potential. We measured the voltage across the photocell using an oscilloscope. The voltage changes according to Ohm's law, V = IR, so as the resistance of the photocell changes, the voltage across the photocell changes as well. The student will observe how the voltage changes on the oscilloscope as they turn the handle of the Genecon generator**.** The voltage signal on the oscilloscope that the student sees is shown in Figure 5. This signal mimics the typical voltage generated by a neuron when stimulated as shown in Figure 4 (a).

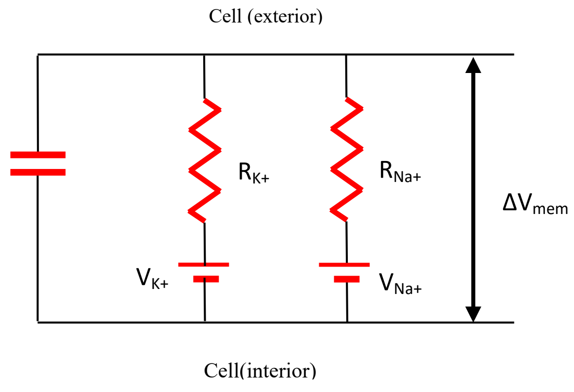

Figure 1. The Hodkin and Huxley Circuit Representing the Electric Activities of the Neuron

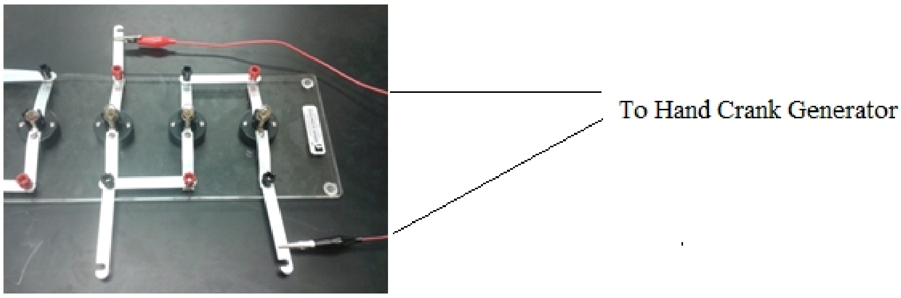

Figure 2. Series Combination of Light bulb Resistors. The Bulbs Were Also Arranged in Parallel and other Combinations

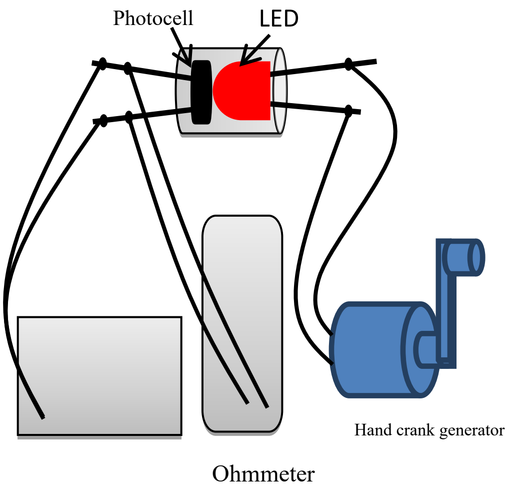

Figure 3. The Developed Circuit that Can Generate a Voltage Pulse Roughly Analogous to the Action Potential of the Neuron

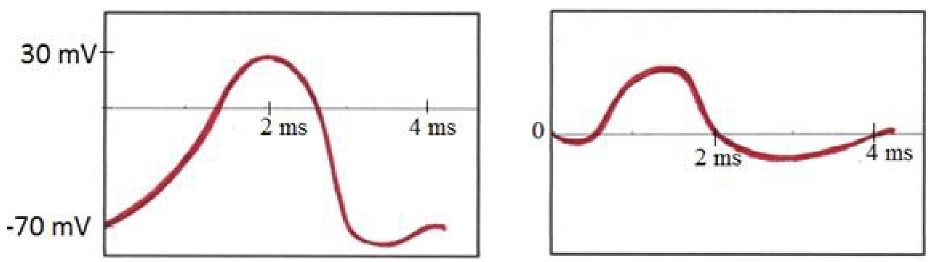

Figure 4 (a): A sketch of neuron voltage impulse, action potential versus time.

Figure 4 (b): Sketch of electric current in arbitrary unit in the axon membrane wall as a function of time

Figure 4. (a): A Sketch of Neuron Voltagre Impilse, Action Potential Versus Time, (b) Sketch of Electric Current in QArbitrary Unit in the Axon Membrane Wall As a Function of Time

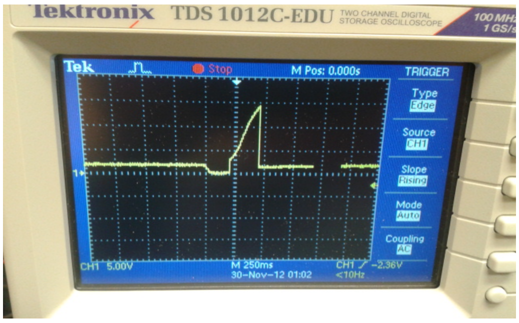

Figure 5. The Voltage Pulse Produced on the Screen of the Oscilloscope Used in Our Circuit Shown in Figure 3

4. Discussion

By using simple, inexpensive, readily available equipment (a photocell, an LED, a Genecon hand crank generator, an ohmmeter, and an oscilloscope), we were able to develop a circuit that produces a voltage signal which is qualitatively similar to the action potential that propagates along the axon of the neuron. The main thrust of this experiment is to give the message to the life sciences students taking introductory physics courses that electric circuits can model a biological system. This helps motivate students who are not going to be physicists to be more attentive about understanding physics. The excitement and the knowledge from this experiment should inspire students to work on multidisciplinary research in the future that links physics to biology and medicine.

Acknowledgment

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References

Eccles, J., Hodgkin, A., & Huxley, A. (1963). *The Nobel Prize in Physiology or Medicine*. Retrieved from http://www.nobleprize.org

Holmes, N., & Wieman, C. (2018). Introductory Physics Labs: We Can Do Better: *Physics Today*, *71*(1), 38-35. https://doi.org/10.1063/PT.3.3816

Meredith, D. C., & Redish, E. F. (2013). Reinventing physics for life sciences majors: *Phys. Today*, *66*(7), 38-43. https://doi.org/10.1063/PT.3.2046

Mylott, E., Kutschera, E., & Widenhorn, R. (2014). Bioelectrical impedance analysis as a laboratory activity: At the interface of physics and the body: *American Journal of Physics*, *82*, 521. https://doi.org/10.1119/1.4866276

Serway, R. A., & Vollie, C. (2015). *College Physics* (10th ed., pp. 647-649). CENGAGE Learning: USA.