Animal & Plant Electricity

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Overview

In his *Experiments and Observations Made at Philadelphia in America* (1769), Benjamin Franklin described how a turkey was “killed for dinner by the electric shock, and roasted by the electric jack, before a fire kindled by the electrified bottle; when the health of all the famous electricians of England, France, Holland, and Germany, [were] drunk in electrified bumpers, under the discharge of guns from the electrical battery.”

Beyond the salon of the gentrified elite, electricity began to undergo more serious investigation. Around 1790, Luigi Galvani discovered that he could induce the muscles of dead frog legs to twitch by static electricity and coined the term “animal electricity” to describe this phenomenon. Galvani believed that nerves and muscles of the frogs’ legs stored electricity.

Alessandro Volta later showed that the electricity was produced externally. The latter’s contribution became known as the battery. Galvani, however, was not entirely mistaken. Living organisms do in fact produce electricity.

The purpose of this unit is to demonstrate the electrical characteristics of cellular transmissions. Students will construct simple batteries and electrical circuits as well as study a device for amplifying an electrical signal in order to record the electrical activity produced in muscles and to discover that even plants are electrically excitable and can display electrical responses to environmental stimuli.

Rationale

My school, Swenson Arts & Technology High School, is a career-technical (i.e., vocational) high school located in northeast Philadelphia. We offer training in the construction, automotive, information technology, allied health, and culinary trades, but we also provide education in academic areas. I primarily teach chemistry, but for the past five years, I have also taught the anatomy and physiology course, which is for students in our allied health program. The program is co-ed, but the vast majority of the students are female.

As a topic in high school, electricity is usually covered in an Introduction to Physical Science or Physics courses and occasionally, in conjunction with electrochemistry, in Chemistry class but virtually never in Biology. Consequently, a discussion of the electrical characteristics of neurons is typically beyond the scope of a course in anatomy and physiology.

A goal of this unit is to provide an educational framework upon which students in a high school anatomy and physiology class will be able to understand the physical basis that underlies the operation of the nervous system using simple circuits as models. The objectives are aligned to the STEM standards prescribed by the School District of Philadelphia, the Next Generation Science Standards, and the Common Core.

Objectives

Students will be able to

- Describe how voltaic cells are used as batteries
- Relate voltage, current, resistance, and the movement of electrons
- Use schematic diagrams to analyze an electrical circuit
- Explain how sensory signals and motor commands are transmitted through nerves
- Study devices for amplifying electrical signals
- Record electrical signals produced by neurons and muscles
- Measure action potentials in plants and invertebrates
- Build and manipulate a neuron equivalent circuit

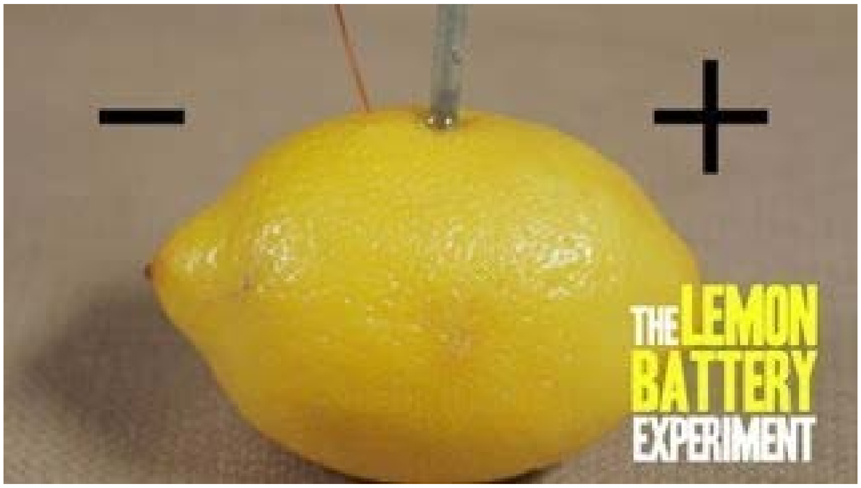
Strategies

This unit is a starting point for further activities that will be built upon in response to the outcomes. The overarching theme in this unit is to provide hands-on, inquiry based learning opportunities because as a Chinese proverb (frequently attributed to Confucius) states: *I hear and I forget. I see and I remember. I do and I understand*.

Most of the initial activities in this unit are based on or similar to lesson plans found elsewhere. The latter activities lend themselves well to a problem-based learning (rather than project-based learning) approach as articulated by Grant Wiggins and others (see *Understanding by Design*). It is anticipated that students will add their own concepts to further enrich the topic outcomes. This "backwards design" approach begins with engaging students to identify the desired results, proceeds with determining acceptable evidence, and then turns to planning the learning experiences and instruction. Students will be actively engaged in the task of designing solutions and it is likely that some of their ideas will be incorporated in further iterations of these lessons.

Classroom Activities/Lesson Plans

- **Fruit Power**



https://www.youtube.com/watch?v=GhbuhT1GdpI

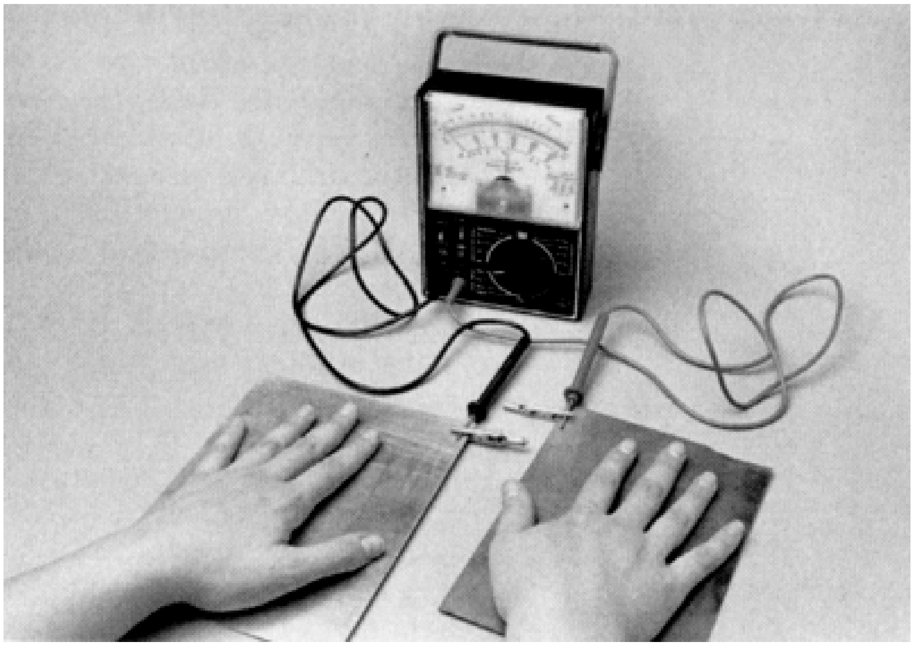
Overview
A battery is a device that converts chemical energy into electrical energy. The following activity demonstrates how a difference in metals can be used to generate electricity.

Materials (for each pair of students)
Lemon
Copper wire (or pennies)
Galvanized nail (or piece of zinc)
Digital multimeter (DMM) with alligator clip leads

Procedure
1. Gently roll a lemon on a table surface to soften it.
2. Insert the galvanized nail and a piece of a copper wire into the fruit a couple of inches apart.
3. Attach the leads and set the DMM to volts.

Discussion
Other fruits or vegetables should work (e.g., oranges, even potatoes). Students could try pairing with other pieces of metal (e.g., magnesium ribbon, aluminum nails, etc.) and comparing the voltages. More advanced students might use half reactions to calculate the theoretical voltages. If time permits, students can put their lemon batteries together in series to measure the combined voltage.

Human Salt Bridge



http://exploratorium.edu/snacks/hand_battery

Overview

Electrons travel from the copper plate to the zinc plate. The human body acts as a salt bridge.

Materials

Digital multimeter (capable of reading microamps) with alligator clip leads
Zinc plate
Copper plate

Procedure

1. Attach the leads as show below and then place one hand on metal each plate.
2. Set the DMM to microamps and read the current.

Discussion

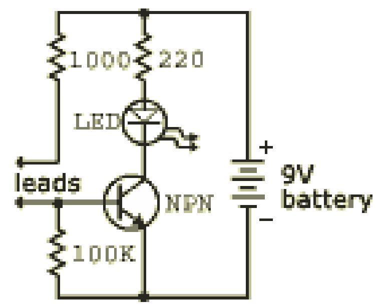
As the previous activity, other pairs of different metals will produce a current. A device, really a toy, which uses the human body as a conductor to light up LEDs and make noise, is available online (http://www.stevespanglerscience.com/energy-stick.html).

- **Simple Circuits**

Overview
This series of activities is not intended to be a unit on electrical circuits and is aimed at presenting the minimum background necessary for understanding the electrical characteristics of nerve cells. Therefore, the focus here is on a limited set of electrical components: a battery, some LEDs, resistors, capacitors, and NPN transistors.

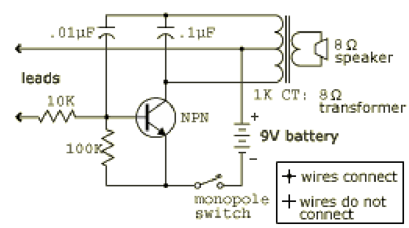
Materials (for each pair of students)

For Part 1:
9-V battery and clip with leads
breadboard
hook-up wire
LED
220-ohm resistor
100K-ohm resistor
transistor, e.g., 2N2222A
digital multimeter (capable of reading microamps)



http://www.pbs.org/transistor/teach/teacherguide_html/images/lesson4c.gif

For Part 2:
wire
10K-ohm resistor
100K-ohm resistor
switch
capacitors (0.1 microfarad and 0.01 microfarad)
8-ohm transformer (Radio Shack Cat # 273-1380)
8 ohm speaker



http://www.pbs.org/transistor/teach/teacherguide_html/images/lesson4d.gif

Procedure
See **Transistorized! Lesson 4**
http://www.pbs.org/transistor/teach/teacherguide_html/lesson4.html

Discussion
In this lesson, students build circuits and explore how transistors function. The lesson plan is one of several from PBS in conjunction with their excellent video, *Transistorized!* (1998), which is, unfortunately, difficult to find at this time.

- **Capturing Signals**

Overview
Neural signals are in the kHz range and can be detected using audio speakers or measured using digital audio recording software. This activity utilizes the sound recording capacity of a readily available, open-source software program called Audacity (http://sourceforge.net/projects/audacity). Audacity is capable of recording multiple-tracks as well as generating tones of various waveforms. Students will utilize the sound ports of two laptops to produce a waveform on one computer for input into the second laptop.

Materials
two laptop computers (1 for each student or pair of students)
Audacity software program
3.5mm M-M stereo cable (3-6 ft.)

Procedure
1. Locate and open the Audacity program.
2. From the Generate menu, select Tone and choose a waveform.
3. Click the Play button (▶).
4. Experiment with the frequency and the amplitude.
5. Pair up with another student (or pair of students).
6. Create a new project on one of the computers and connect the stereo cable between the sound output port of one computer and the sound input of the second computer. Note: on some laptops, this may be the same port.
7. Click Record on one computer and Play on the other.
8. Zoom in and compare the recordings.

Discussion

Students should be familiar with the terms *frequency, amplitude*, and *wavelength*. A slink or rope may be used to illustrate the wave equation:

velocity (m/s) = frequency (Hertz) x wavelength (m)

There are many tutorials online on using Audacity, but the program is rather easy to figure out by experimentation. Students will need to know how to locate and open the program, generate a waveform, record sounds, and zoom in or out.

Audacity has five built-in generators: Chirp, DTMF, Noise, Silence and Tone. The user may select the waveform (Sine, Square, Sawtooth, and Square with no alias), the frequency (in Hertz), the amplitude (0-1), and the duration of the sound. Chirp also allows setting of the start and end amplitude and frequency.

- **Amplifying Signals**

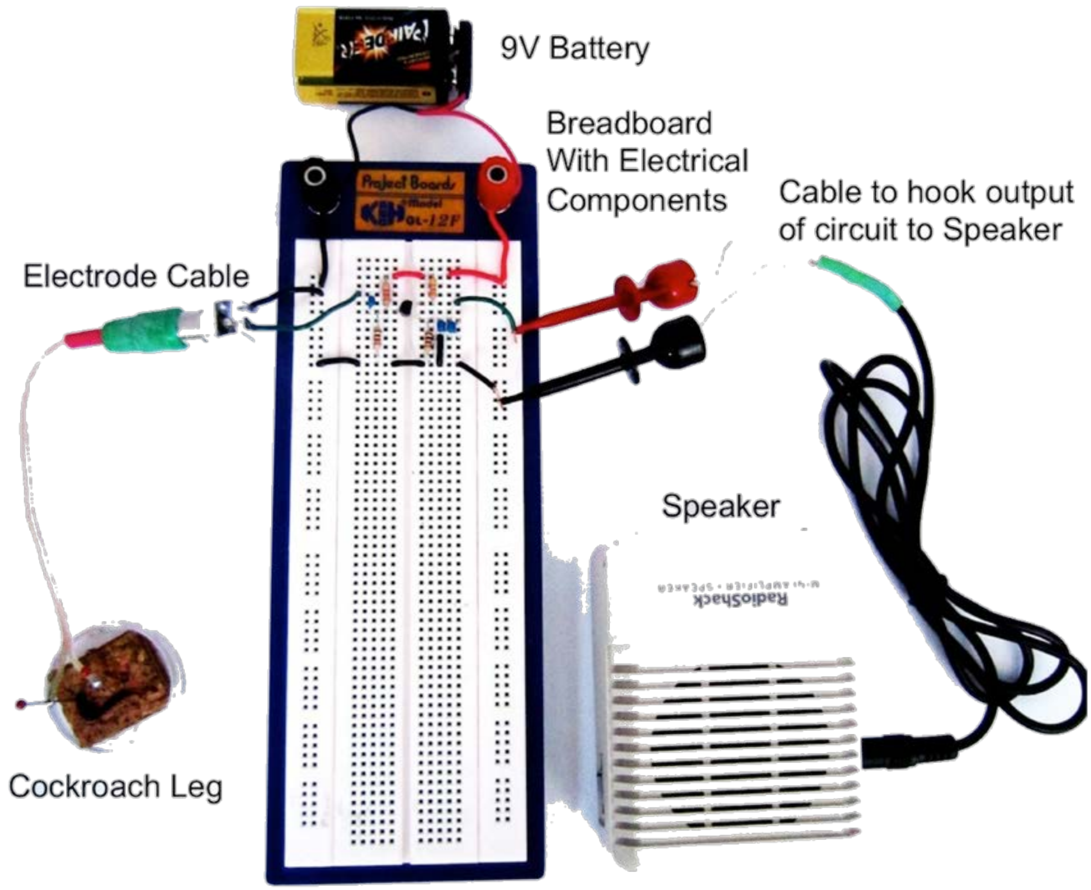
  Overview
  Students will learn about electrophysiology and record action potentials after building a simple amplifier circuit using a couple of transistors and some resistors and capacitors.

  Materials (for each pair of students)
  (2) NPN transistors (2N4401)
  (4) 4.7 kΩ Resistors -
  (4) 1 kΩ Resistors
  (4) 50 Ω Resistor
  (2) 1 µF capacitors
  (4) 10 µF capacitors
  some jumper wire
  a solderless breadboard
  a 9V battery connector
  a 9V battery
  small speaker with RCA cable, or
  laptop computer with Audacity program
  3.5mm stereo cable (cut in half)

  Procedure
  For detailed instructions on the construction of this circuit, refer to **Experiment: Transistor Circuit Design** https://backyardbrains.com/experiments/transistorDesign

  Discussion
  Ideally, this experiment uses a cockroach leg to generate the action potential spikes. The Backyard Brains web site includes other experiments that examine muscle action potentials (http://backyardbrains.com/experiments/muscleAP) and the action potentials in Venus Fly Trap plants (http://backyardbrains.com/ experiments/plants), but these experiments utilize the SpikerBox available from Backyard Brains company. It is unknown whether the circuit described here could be adapted for these purposes.

  Alternatively, SpikerBoxes can be purchased as bare boards or as kits (or even assembled). One of my students, who had no prior experience with soldering, built one for her senior project. She bought a cockroach at a local insect museum for her presentation. It blew the judges away.



https://backyardbrains.com/experiments/img/1StageBig.jpg

http://backyardbrains.com/products/img/Spikerbox.jpg

A Model Neuron

Overview
Students will build and manipulate a circuit that uses electrical circuit components in order to simulate different neuron properties while altering the structure of the circuit. The objective is a better understanding of the electrical characteristics of a neuron.

Materials (for each pair of students)
a 6V (or 9V?) battery
Digital multimeter (DMM) with alligator clips
100 μF 100-volt non-polarized capacitor (1)
100 kΩ resistors (2)
alligator clips to connect the components (9) or
    a solderless breadboard

Procedure
See Dabrowski et al. (2013), pp. A50-A52

Discussion
It has been widely stated that the membrane of a neuron is like a capacitor, and many equivalent models utilize a RC circuit to represent it. Most treatments, however, are beyond the capacity of high school students. The activity outlined by Dabrowski et al. (2013) appears to be simple enough and allows students to model ion channels and to manipulate the model by altering resistance and capacitance. It does not require any sophisticated software programs.

Annotated Bibliography/Resources

Print and Web:

2-minute neuroscience videos. Neuroscientifically Challenged. Web. http://www.neuroscientificallychallenged.com/2-minute-neuroscience-videos. Accessed 16 Feb. 2015.

More than a dozen short video clips that cover the basics of neuroscience. Topics include the neuron, synaptic transmission, membrane and action potentials, and divisions of the nervous system.

Dabrowski, K.M., Castaño, D.J. and Tartar, J.L. (2013, Fall). Basic Neuron Model Electrical Equivalent Circuit: An Undergraduate Laboratory Exercise. *Journal of Undergraduate Neuroscience Education*, 12(1): A49-A52.

The authors describe a hands-on laboratory exercise that uses a battery, a capacitor, and a couple of resistors to build and manipulate a neuron equivalent circuit.

Gage, G. (2012, Sep. 9). Experiment: Transistor design. Backyard Brains. Web. http://wiki.backyardbrains.com/Experiment:_Transistor_Design! Accessed 25 Feb. 2015.

Instructions on building an amplifier using “a transistor, a power source, some resistors, and some capacitors. “

Gage, G. (2014, Nov. 14). Data analysis. Backyard Brains. Web. http://wiki.backyardbrains.com/Data_Analysis. Accessed 25 Feb. 2015.

Instructions on how to record and analyze electrical signals (spikes) using an iPhone or iPad, an Android phone or tablet, or a laptop computer (a desktop computer is not recommended due to interference from line noise).

Huguenard, J., and McCormick, D. (1993). *Electrophysiology of the neuron: An interactive tutorial*. New York: Oxford University Press.

A companion to G.M. Shepherd’s textbook, *Neurobiology*, this lab manual includes experiments that investigate areas such as action potentials and the physiological properties of nerve cells.

Mims, F.M. (1983). Getting started in electronics. Fort Worth, TX: Radio Shack.

There have been at least two subsequent editions of this classic, which is apparently out-of-print at this time. The book does an excellent job of explaining how analog and digital components work and includes quite a few circuits one can build and test.

Piccolino, M. (1998, July 15). Animal electricity and the birth of electrophysiology: The legacy of Luigi Galvani. *Brain Research Bulletin*, 46(5): 381–407.

From the Abstract:
The matter of the scientific controversy between Galvani and Volta is examined here in the light of two centuries of electrophysiological studies leading to the modern understanding of electrical excitability in nerve and muscle…In addition, a revolutionary phase of the 18th century science that opened the way for the development of modern neurosciences is reevaluated.

Saftari, F. (2013, May 26). Use your laptop as oscilloscope. Instructables. Web. http://www.instructables.com/id/Use-Your-Laptop-as-Oscilloscope. Accessed 20 March 2015.

Instructions on constructing an interface for protection when connecting to the sound input of a computer.

Sayood, K. (2006). *Understanding circuits: Learning problem solving using circuit analysis.* San Rafael, CA: Morgan & Claypool.

This “textbook” was made available to TIP participants on Penn Libraries web site. It can also be downloaded from the publisher for a fee ($30). This resource is a good introduction to theory and includes a number of problem-solving exercises.

Silverman, L.P., and Bunn, B.B. (1992, April). The world’s longest human salt bridge. *Journal of Chemical Education*, 69(4), 309-310.

The record for the longest human bridge was set at Virginia Tech when 1500 people joined hands. The authors conducted an experiment and determined the average resistance of the human body to be 1 MΩ.

Wiggins, G., and McTighe, J. (2005). *Understanding by design*, 2nd ed. Alexandria, VA: Association for Supervision & Curriculum Development.

A good introduction to the concepts of curriculum by unit development and problem-based learning, this book includes a useful template.

Appendix/Content Standards

PA Common Core Standards for Reading in Science and Technical Subjects, 11-12

CC.3.5.11-12.A.
Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
CC.3.5.11-12.B.
Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
CC.3.5.11-12.C.
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.
CC.3.5.11-12.D.
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context.
CC.3.5.11-12.E.
Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas.
CC.3.5.11-12.F.
Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.
CC.3.5.11-12.G.
Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.
CC.3.5.11-12.H.
Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
C.3.5.11-12.I.
Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.
CC.3.5.11-12.J.
By the end of grade 12, read and comprehend science/technical texts in the grades 11–12 text complexity band independently and proficiently.

PA Common Core Standards for Writing in Science and Technical Subjects, 11-12

CC.3.6.11-12.A.
Write arguments focused on discipline-specific content.
CC.3.6.11-12.B.
Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
CC.3.6.11-12.C.
Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
CC.3.6.11-12.D.
Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
CC.3.6.11-12.E.
Use technology, including the Internet, to produce, publish, and update individual or shared writing products in response to ongoing feedback, including new arguments or information.
CC.3.6.11-12.F.
Conduct short as well as more sustained research projects to answer a question (including a self- generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
CC.3.6.11-12.G.
Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.
C.3.6.11-12.H.
Draw evidence from informational texts to support analysis, reflection, and research.
CC.3.6.11-12.I.
Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

PA Academic Standards for Science and Technology

3.1.12.A5.
Analyze how structure is related to function at all levels of biological organization from molecules to organisms.
3.1.12.A6.
Analyze how cells in different tissues/organs are specialized to perform specific functions.
3.2.12.A4.
Apply oxidation/reduction principles to electrochemical reactions.
3.2.12.B4.
Develop qualitative and quantitative understanding of current, voltage, resistance, and the connections among them.
3.4.12.C3.
Apply the concept that many technological problems require a multi-disciplinary approach.

Next Generation Science Standards
HS-LS1-2.
Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.
HS-LS1-3.
Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.
HS-PS4-1.
Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.