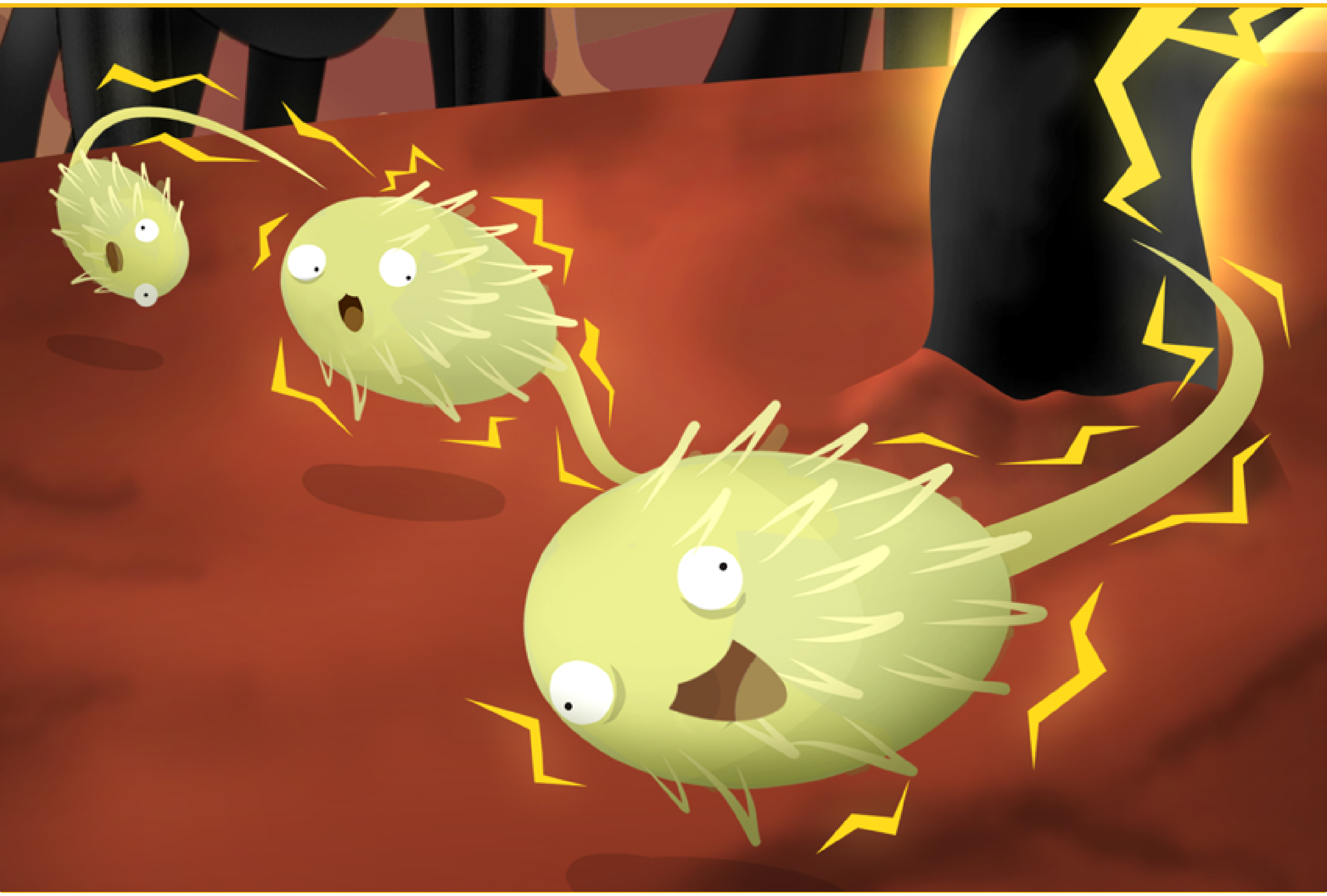
SUB-MODULE 2

MudWatt

NGSS TEACHER'S GUIDE

Electricity and Circuits



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INTRODUCTION

Learning Objectives

In this module, students are introduced to the fundamental concepts of electricity and how to measure the amount of electricity and power being produced in a microbial fuel cell. In addition to determining maximum power output using the MudWatt microbial fuel cell, students determine maximum power output using potentiometry (measuring power at various resistances). Finally, students attempt to increase the amount of power produced by their MudWatt microbial fuel cell by changing one variable in their MudWatt microbial fuel cell.

Essential Questions

1. **What is electricity?**
2. **How are electrical current, resistance, voltage and power related?**
3. **How can we determine the amount of power being generated in a Microbial Fuel Cell?**
4. **What changes can be made to a Microbial Fuel cell to maximize power output?**

By The End of This Lesson...

Students will be able to:

- Define electricity, current, resistance, voltage and power
- Recognize when electricity is flowing through a circuit
- Measure the voltage and resistance in a circuit
- Apply Ohm's Law to calculate current and power in an electrical circuit

NGSS Alignment

CORE IDEAS

Core Idea PS1: Matter and Its Interactions

PS1.A: Structure and Properties of Matter

Core Idea PS3: Energy

PS3.A: Definitions of Energy

CROSS CUTTING CONCEPTS

- ☐ Patterns
- ☐ Cause and effect: Mechanism and explanation
- ☐ Scale, proportion, and quantity
- ☐ Systems and system models
- ☑ **Energy and matter: Flows, cycles, and conservation**
- ☐ Structure and function
- ☐ Stability and change

PRACTICES

- ☑ **Asking questions (for science) and defining problems (for engineering)**
- ☐ Developing and using models
- ☑ **Planning and carrying out investigations**
- ☑ **Analyzing and interpreting data**
- ☑ **Using mathematics, information and computer technology, and computational thinking**
- ☑ **Constructing explanations (for science) and designing solutions (for engineering)**
- ☑ **Engaging in argument from evidence**
- ☑ **Obtaining, evaluating, and communicating information**

Vocabulary

Atom	Electromotive force (EMF)	Neutrons
Conductors	Electrons	Power
Current	Insulators	Protons
Electricity	Nucleus	Resistance
		Voltage

Glossary

Atom the basic unit of a chemical element

Conductors materials through which electricity flows easily

Current amount of electricity that is flowing through the wires

Electricity the movement of electrons from one atom to another

Electromotive force or EMF the force that moves electrons in a certain direction

Electrons subatomic particles that move around the nucleus of an atom and carry a negative electrical charge

Insulators materials through which electricity does not flow easily

Nucleus the dense, central region of an atom consisting of protons and neutrons

Neutrons subatomic particles in the nucleus that carry no electrical charge

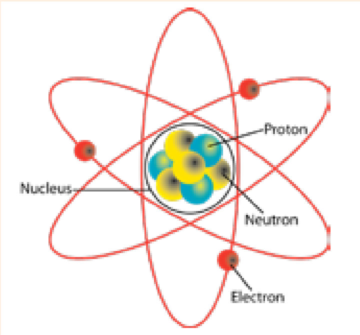
Power the amount of energy used per unit of time

Protons subatomic particles in the nucleus that carry a positive electrical charge

Resistance A measurement of how much opposition a material has to current flow, measured in Ohms (Ω)

Voltage a measure of the electric potential, or EMF, that exists between two points, measured in volts

Part A: The Building Blocks of the Universe



http://www.ck12.org/book/CK-12-Earth-Science-Concepts-For-High-School/section/3.1/

Figure 1. An Atom

Atoms are the basic unit of a chemical element. They are the smallest unit of matter (that still retains its characteristics) and are made of smaller, subatomic particles called protons, neutrons and electrons. **Protons** are positively charged particles, **neutrons** are particles that have no electrical charge and **electrons** are negatively charged particles. If we could see an atom it would look approximately like the image in ***Figure 1***.

Protons and neutrons are concentrated in the center of the atom, in the nucleus, while the electrons are zipping around the nucleus. Even though the electrons are relatively far away from the nucleus and there seems to be a lot of empty space in an atom, the electrons are zipping around SO fast that, just like the blades of a fan when they are spinning, the atom behaves as if there were no empty space.

There are over 118 different types of atoms that have been identified and each one is made of identical subatomic particles: protons, neutrons and electrons.

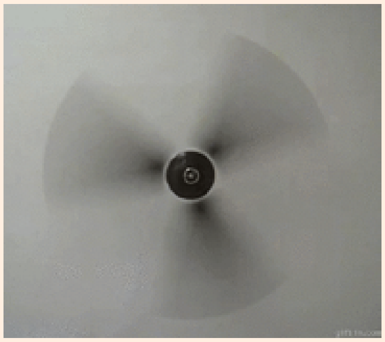


Figure 2. Fan blades spinning like electrons around an atom

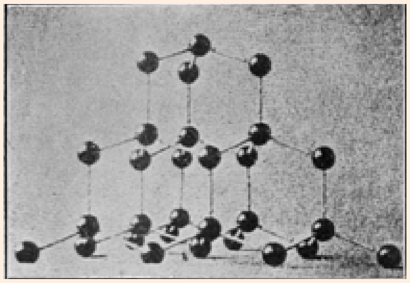
If all protons, neutrons, and electrons are identical, then what makes atoms different from each other?

The **number of protons** in the nucleus is what distinguishes one atom from another. Each atom has a unique number of protons in its nucleus, which makes that atom behave differently from any other atom.

The subatomic particles in atoms are held together by **attractive forces**. Particles having opposite charges attract strongly. The electrons closest to the nucleus experience a stronger attraction to the protons in the nucleus than electrons that are orbiting farther away from the nucleus. Electrons can be lost to another atom if the attractive force to the other atoms is stronger than the attractive force within the atom. How easily or not an atom's electrons are lost to other atoms determines how electrically conductive a material is, or how easily electricity can flow through that material.

Atoms sometimes gain or lose electrons to other atoms. When electrons move from atom to atom a **current** is produced. Electricity is the movement of electrons from one atom to another. Some atoms hold onto their electrons very tightly. Materials composed of such atoms tend not to let electricity move through them very easily and are called insulators. Other materials, particularly metals like copper and gold, don't hold onto electrons quite as strongly; thus, electrons can move more easily from one atom to the next. We call these types of materials that can carry electricity **conductors**.

For some atoms, such as Carbon atoms, the form in which the atoms are connected will change whether or not it is a conductor. For example, when Carbon molecules are connected together as sheets in a **hexagonal** pattern (creating graphite), it is a strong **conductor**, but when the Carbon molecules are connected in a **pyramid** pattern (creating diamond), it is a strong **insulator**.



https://commons.wikimedia.org/wiki/File:PSM_V87_D114_Arrangement_of_carbon_atoms_in_a_diamond.png#/media/File:PSM_V87_D114_Arrangement_of_carbon_atoms_in_a_diamond.png

Figure 3. Arrangement of carbon atoms in a diamond

Part B: Electric Potential and Current

How do electrons start to move?

Electrons need to get energized to be able to move just like you need energy to move. Where does that energy come from? For an object to move from rest, a **force** must be applied to that object. Newton cleverly has called this his **first law of motion** – an object at rest will stay at rest unless acted upon by an unbalanced force. No force, or equal forces all around, means a resting object will not move.

The force that moves electrons in a certain direction in a wire is called the **Electromotive Force** or **EMF**. Sometimes EMF is thought of as electrical "**pressure**." When there are more electrons in one place than another, the resulting imbalance in electrical charge moves the electrons to balance the charges between the two places.

The secret to electricity is creating a situation where one location has more electrons than another and connecting those two places by a wire so that electrons can move to try to balance the charges.

How does this EMF get created?

An EMF can be made in many ways. We can use the MudWatt as an example of a living battery in which an EMF is created.

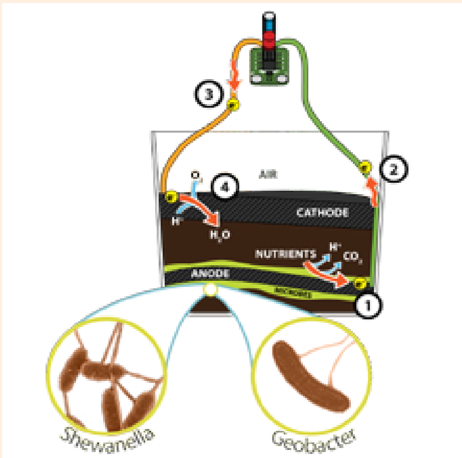


Figure 4. Diagram of a MudWatt

In a MudWatt, electrons are given off by the electrogenic bacteria surrounding the anode (the electrode that is buried in the mud). This creates a **higher concentration of electrons** at the anode than at the cathode so the electrons move through the wire towards the cathode.

In a chemical battery, such as the ones we use for our flashlights, a chemical reaction happens inside the battery. Electrons are given off during these reactions. Batteries consist of two electrodes (the anode and the cathode), just like the MudWatt. However, in chemical batteries, the anode is made of material that **concentrates electrons**, while the cathode is not. Thus, an imbalance of electrons is created between the two electrodes. When the two electrodes are connected by a wire, the electrons flow through the wire from the anode to the cathode.

EMF is measured as **voltage**, measured in units of volts. A volt is a measure of the electric potential, or EMF, that exists between two points.

Measuring Voltage

We learned earlier that voltage is a measure of the electric potential, or force that is set up to drive the flow of electrons. Another way to think of voltage is to think about water in a hose with a hand operated nozzle on the end. Even when the water is not flowing, there is still **pressure** in the hose. The amount of pressure in the hose is analogous to level of **voltage** in an electrical circuit. Like the water in the hose, the electrons will not flow until a **conductor** enables them to move from an area with higher negative charge to an area with lower negative charge.

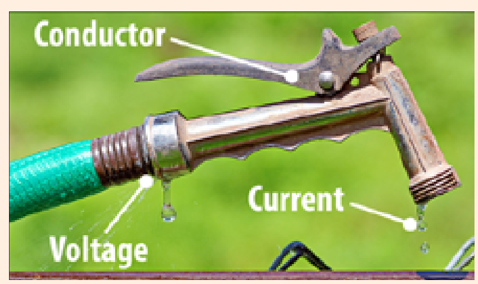


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Figure 4. Diagram of Voltage and Current in a Water Hose

Measuring Current

Another measurement we would like to know is how much electricity is flowing through the wires in a circuit. The amount of electricity that is flowing through the the wires is called the **electrical current**. In the water hose analogy, current is like the rate of flow of the water in the hose. The amount of electrical current flowing in a wire is measured in Amps (short for Amperes).

Part C: Electric Potential and Current

Every electrical circuit has a certain amount of **resistance** to the flow of current through it. Many factors affect the resistance of a particular material. The resistance in a wire can change with the **thickness** of the wire and with the type of **material** the wire is made of. The amount of resistance in a circuit is measured in Ohms (Ω).

Resistance in a wire or other conductive material creates friction, which produces **heat**. If you send to much current through a wire that is not designed to handle that much current, then the friction causes so much heat that fires can start! In some cases where the EMF or voltage is too high for the wires used, components called **Resistors**, can be added to the circuit to protect against excessive heating. Resistors restrict the flow of electricity in a controlled way.

How are voltage, current and resistance related?

In 1827, George Ohm published an equation that relates voltage, current and resistance. This equation, known as Ohm's Law:

Equation 1: Ohm's Law

$$I = V/R$$

I = current (A), V = voltage (V), and R = resistance (Ω)

Understanding Ohm's law

As shown in **equation 1**, the electrical current in a circuit can be calculated by dividing the voltage by the resistance. If the resistance is held constant, and you increase your voltage (say by adding another battery to your circuit), then the current will also increase. In our hose analogy, this would be the equivalent of keeping your nozzle at the end of the hose slightly open, while opening up the faucet (leading to more pressure and therefore more water flow).

Ohm's Law can be rearranged if you are trying to solve for voltage or resistance. These equations are mathematically identical.

Equation 2: $$V = I \times R$$

Equation 3: $R = V/I$

In **equation 2**, voltage can be calculated if the current and the resistance in a circuit are known. From the equation, we can see that if either the current or the resistance in a circuit is increased (while the other is unchanged), the voltage will also increase.

In **equation 3**, resistance in a circuit can be calculated if the voltage and current are known. If the current is held constant, an increase in voltage will result in an increase in resistance. If the current is increased while the voltage is held constant, the resistance will decrease.

Note: For a wide variety of materials (such as metals) the resistance is fixed and does not depend on the amount of current or the amount of voltage.

Part D: Power, Glorious Power!

When talking about energy production, the term power is frequently used. **Power** is the amount of energy used per unit of time. The unit of power is the Watt, which is a rate of the amount of Joules (a discrete unit of energy) per second.

The amount of power can be calculated, if the voltage and current are known, using the following equation:

Equation 4: $P = V \times I$

The **Power** (P) in Watts is equal to the **voltage** (V) in Volts multiplied by the **current** (I) in Amps, so increasing the voltage or current in a circuit will increase the amount of power produced.

Equation 5: $P = V^2/R$

Power is also related to the resistance in a circuit by the following equation:
Here the **Power** (P) in **Watts** (W) is equal to the **voltage** in volts (V) squared divided by the **resistance** (R) in Ohms.

Activity 1: Insulators and Conductors

Objective: In this activity students will test different object to see which ones are effective conductors of electricity and which ones are insulators.

Time

15 minutes

Materials

- 3-alligator clips and circuit wire
- 2.5 volt bulb and socket
- 1 "D" cell battery

Procedure

1. Connect the wires, light bulb and battery to complete a circuit. The light bulb should illuminate.
2. Disconnect two wires and connect them to various object to determine whether electricity flows through them (conductor) or not (insulator).
3. Make a data table in your science notebook to record which objects are conductors and which ones are insulators like the one shown below.

Conductors	Insulators

Questions:

1. What do the objects that conducted electricity have in common?
2. What do the object that were insulators have in common?
3. Why do electrical wires have a coating of plastic on them?

Activity 2: Measuring Voltage and Current of a MudWatt

In this experiment you will be measuring the voltage of the MudWatt when no electrons are flowing. This is called the "Open Circuit Voltage" and it represents the maximum EMF that your MudWatt can build up (think of the water in the hose analogy building up pressure with no water able to escape).

However, when you are measuring current in this experiment, you are measuring the electron flow when there are no restrictions blocking it anymore (in our hose analogy, think of the nozzle just being opened completely, allowing water to flow freely).

Time

15 minutes

Materials

- MudWatt Science Kits
- Soil
- Multimeter

Procedure

Measuring voltage

1. Set the multimeter to the millivolts setting (For most multimeters, this is the "2000m" within the "V" section on the face of the multimeter).
2. Connect the positive (red) wire of the multimeter directly to the cathode wire (orange) of the MudWatt.
3. Connect the negative (black) wire of the multimeter directly to the anode wire (green) of the MudWatt.
4. Record the voltage of the MudWatt in the data table.
5. Make recordings of the voltage over time

Measuring current

1. Connect the wires, light bulb and battery to complete a circuit. The light bulb should illuminate.
2. Disconnect two wires and connect them to various object to determine whether electricity flows through them (conductor) or not (insulator).
3. Make a data table in your science notebook to record which objects are conductors and which ones are insulators like the one shown below.

Activity 2: Measuring Voltage and Current of a MudWatt

Date and Time	Voltage (microVolts)	Current (microAmps)

Questions:

1. Did the voltage change over time? If so, in what way did it change?

2. Did the current change over time? If so, in what way did it change?

3. Did the values change during the time that you were taking the measurement? If so, why? (Think of the hose analogy).

4. If you added any special ingredients to your MudWatt, how did that affect the voltage and current over time? Explain.

Activity 3: Finding a MudWatt's Maximum Power

Microbial Fuel Cells have a "Maximum Power Point" that is achieved when you apply a certain external resistance (i.e. a resistor) to it.

In this lab, you will be building a microbial fuel cell using the MudWatt kit. Once constructed, you will be able to measure voltage of your MudWatt while it is being subjected to different resistors, and calculate current and power from these measurements.

Note: A MudWatt's max power will change over time as your microbe community develops, so track your MudWatt's growth by performing Sweeps throughout its lifetime.

Time: 45 minutes

Materials:

- MudWatt Science Kits
- Soil
- MudWatt MaxTracker (multimeter + resistors)

Preparation

Assemble your MudWatt(s) according to the instructions included in the kit. To compare different treatments to multiple MudWatts, add a special ingredient to the soil or change something about the configuration of each MudWatt. More instructions on this can be found in Module 4.

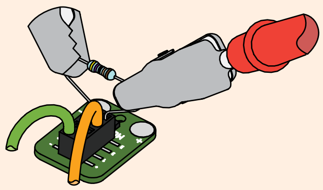
It may take up to 10 days before the red LED on the hacker board starts blinking, but you will start taking measurements before that.

Procedure

Each day examine the MudWatts to see if the red LED light is blinking. If the LED is blinking, measure the amount of power produced using the MudWatt Explorer App. This app converts the number of blinks per minute into microWatts of power. If the light is not blinking, record the value as 0.

Once the number of blinks per minute has stopped increasing or decreasing, measure the voltage by doing the following:

1. Remove all components from the Hacker Board, except the anode wire (green), and plug the cathode wire (orange) into Pin 3.
2. Switch the multimeter setting to "2000 m," and plug the red probe (+) into the "VΩmA" port and the black probe (-) into the "COM" port. Attach the alligator clips to the tips of the probes.
3. Plug a resistor into Pin 5 and Pin 6 (orientation does not matter). Identify and record its value using the color chart on the next page.



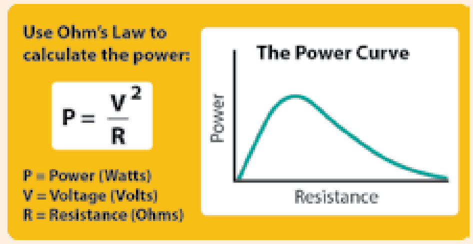
4. After 15 minutes, check the voltage by clipping the multimeter's red probe (+) to the resistor's wire in Pin 5, and the multimeter's black probe (-) to the resistor's wire in Pin 6 as shown below. Record the measured voltage.

Activity 3: Finding a MudWatt's Maximum Power

Procedure (cont.)

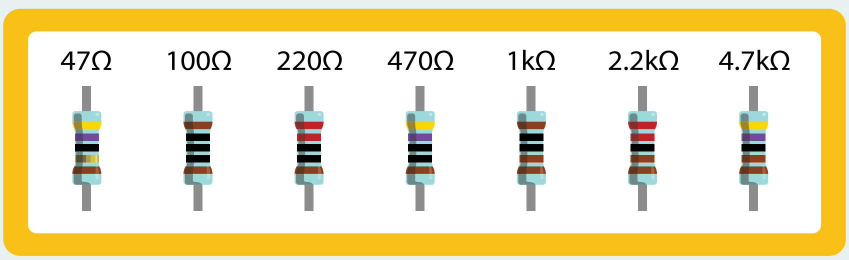
5. Repeat Steps 3 and 4 for all resistors provided, noting the measured voltage as it corresponds to each resistor. Don't forget to turn off the multimeter when you're done!

6. Calculate current and power (in microwatts, or μW)for each measurement, using the Ohm's Law equation and Power equation. Record values in a data table like the one shown in the Data Table below.



Resistor Data Chart

Resistors can be so small that you can't print numbers on them. Instead, resistors using a series of color bands to determine their resistance value. To make things easier, you can match the colors of your resistors below to identify their resistance value. (Ω = Ohms, k = x1000)



Resistance (Ohms)	Voltage (Volts)	Power (Watts)
4700		
2200		
1000		
470		
220		
100		
47		

Questions:

1. **What was the maximum power output for your MudWatt?**

2. **At which resistance was the most power generated?**

3. **What was the highest and lowest amount of Power produced?**

4. **Why did the power change with the different resistors?**

5. **Which manipulated variable produced the highest maximum power in the MudWatt™?**

6. **Try to explain why this change caused the power output to increase.**

Activity 4: Connecting Multiple MudWatts Together

What happens when you connect multiple MudWatts together? More Power! But, depending on how you connect them, you will either get more voltage or more current. We encourage you to experiment with connecting multiple mudwatts together and seeing the effects for yourself!

Time: 30 minutes

Materials:

- Multiple MudWatt Science Kits
- Jumper wire
- Alligator Clips
- MudWatt MaxTracker (multimeter + resistors)

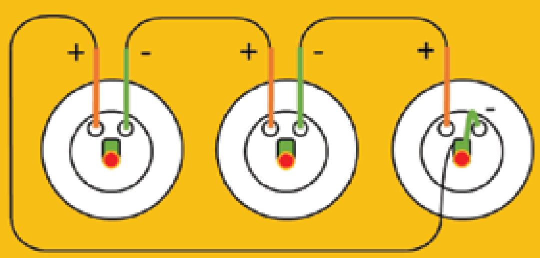
Procedure

Assemble MudWatt™ according to the instructions included in the kit. To compare different treatments, add a special ingredient to the soil or change something about the configuration of the MudWatt. More instrustions on this can be found in Module 4.

It may take up to 10 days before the red LED on the hacker board starts blinking, but you will start taking measurements before that.

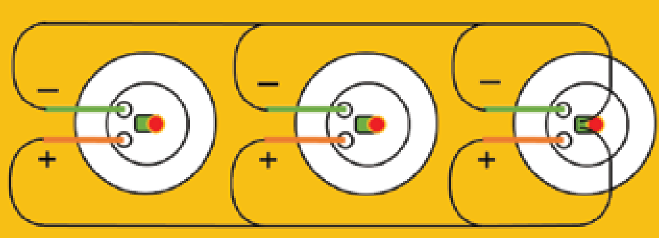
Connecting MudWatts in Series

In circuits, when components are connected in **series**, it means that the (-) end of one component is connected to the (+) end of another. In his configuration, an electron has to through all the components in order to complete the circuit. When MudWatts (or standard batteries) are connected in series, their voltage is added, but their current stays the same.



Connecting MudWatts in Parallel

In circuits, when components are connected in **parallel**, it means that he (+) end of one component are connected to the (+) end of another and the same is true for the (-) ends. When MudWatts (or standard batteries) are connected in parallel, their current is added, but their voltage stays the same.



We encourage you to experiment with different configurations to see the effect. For example, you could put some MudWatts in series, and others in parallel and measure the circuits overall voltage and current values to see if they are what you would expect.

Apart from measuring the voltage and current of your multi-MudWatt circuit, try to measure the impact on the power, as measured by the blinking LED and the MudWatt Explorer App. Do two MudWatts double the blink rate of the LED, or the buzz rate of the buzzer?

REFERENCES

Resources:
https://www.nde-ed.org/EducationResources/HighSchool/Electricity/voltage.htm

Implementation of the MudWatt™ Microbial Fuel Cell. Shannon Root Cheney High School Cheney, WA Keri West Pre-service Lewis-Clark State College Lewiston, ID Andrea Dale Clarkston High School Clarkston, WA Washington State University Mentors Dr. Haluk Beyenal. Chemical and Bioengineering & Jerome Babauta Graduate Student July 2011http://serc.carleton.edu/microbelife/extreme/environments.html

http://www.physics.uc.edu/~hanson/ASTRO/LECTURENOTES/ET/S04/Life/ExtremophilesChart.html

http://www.sciencebuddies.org/science-fair-projects/project_ideas/Elec_p071.shtml

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