Implementation of the MudWatt™ Microbial Fuel Cell

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TABLE OF CONTENTS

PROJECT SUMMARY:

Overview of Project

In this teaching module students will assemble a MudWatt ™ sediment microbial fuel cell and learn how power is generated by electrochemical reactions. They will measure the electrical potential of the fuel cell when various resistances are applied to the system and calculate the current and power generated by the fuel cell. Also, students will learn how manipulating experimental variables affects the power generated by the fuel cell. Students will analyze and interpret the data they collected by making graphs and completing a laboratory report.

Throughout this module students will practice what engineers do by trying their hand at maximizing the efficiency of a system because it is already constructed. This will allow them to learn a basic tenant of engineering-maximizing efficiency. By giving students the goal of maximizing power in the microbial fuel cell they built, students will also learn about electricity, Ohm's Law, conservation, transformation of energy, chemical reactions, atomic structure, reduction/oxidation chemistry, and renewable energy sources.

Intended Audience

This module is intended for a 9th grade physical science class. However, it could be easily modified for use in a biology, chemistry, physics, or environmental science classes. Students should have background knowledge in solving algebraic equations, atomic structure, cellular respiration, the scientific method, and reduction/oxidation chemistry.

Estimated Duration

This module will take 3 weeks to complete (See Appendix A). It includes approximately four, 55-minute class periods for an introductory PowerPoint, vocabulary activity and interactive circuit-building activity. The laboratory introduction and set-up will take one 55-minute class period. After construction the MudWatts™ will need time to produce electrochemical activity. Therefore the students should spend the next 7-10 school days observing the flashing LED and recording blinks per minute. The final laboratory exploration and analysis will take 2-3 55-minute class periods with a summative assessment taking 30 minutes of the last class period.

INTRODUCTION

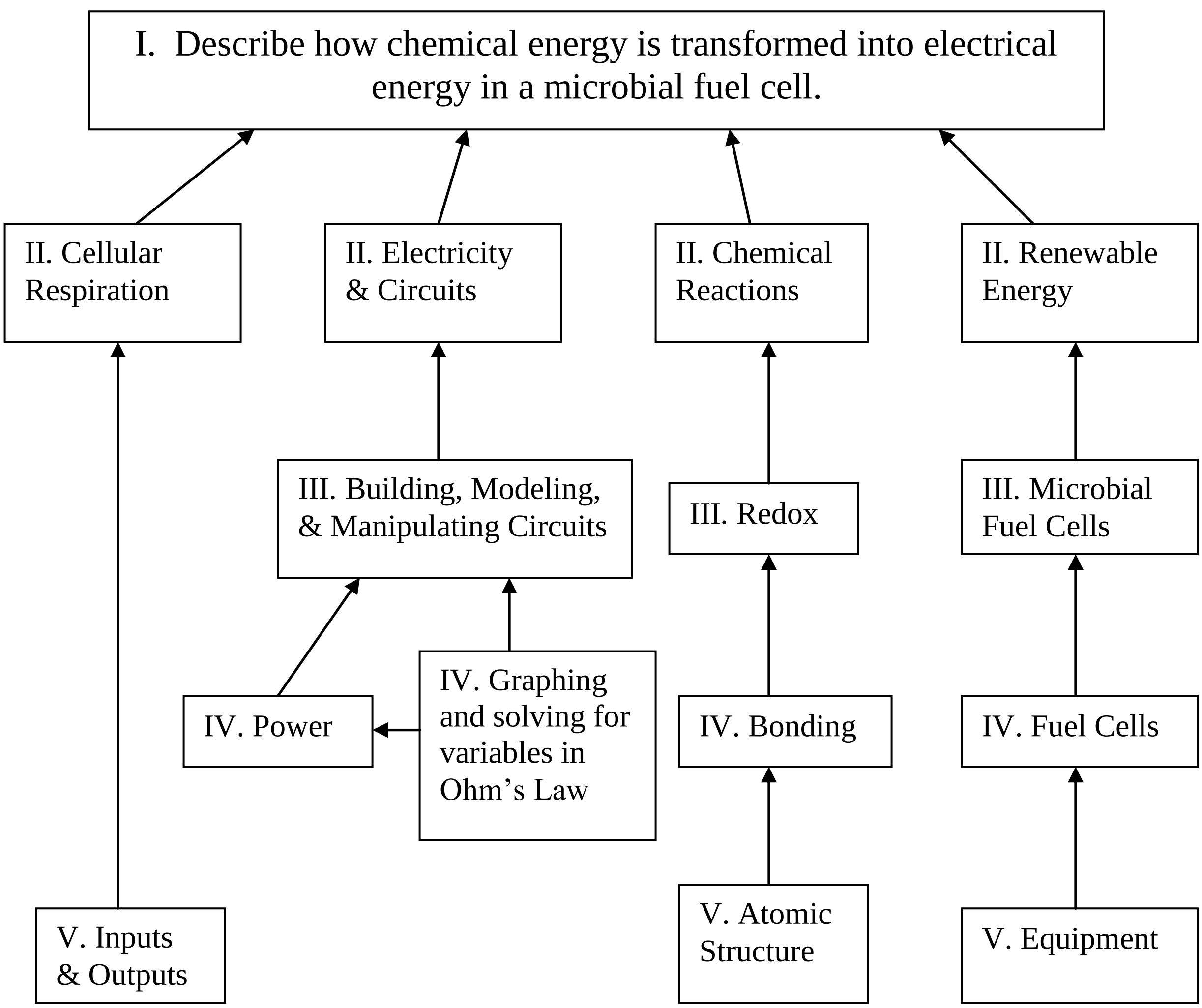
In this module, students will build a MudWatt™ microbial fuel cell from a kit that can be purchased online. Students will learn about engineering through their experience assembling, manipulating, and researching microbial fuel cells. The problem-solving approach to the module will strengthen their understanding of the scientific process and promote inquiry through a scientific lens when approaching a concrete problem.

The module will teach students about atomic structure and its relation to electricity, electrical circuits, and Ohm's Law. Students will learn to grasp how energy can be transformed from the chemical energy we obtain from food, into electrical energy we use in our everyday lives. Furthermore, students will start to think about alternative energy sources that are being developed in order to meet the world's energy needs. By understanding the conversion of energy stored in the chemical bonds of molecules to a flow of electrons, students will comprehend a practical application of both reduction-oxidation chemistry and cellular respiration.

Four activities were developed for this module which include: 1) an introductory PowerPoint lecture, 2) a vocabulary worksheet, 3) an online interactive circuit-building lab activity, and 4) a multi-day lab in which students work in groups to build a MudWatt™. Each group will select and research a different experimental variable to manipulate when they construct and monitor their MudWatt™. Data from each group will be combined for the whole class to analyze and interpret the results. Students will turn in a report once the lab is finished, which will include a power density graph and conclusion questions answered in complete paragraphs.

RATIONALE FOR MODULE

The 2010 pass rate for the Washington state high school science assessment was a mere 44.8% (OSPI, 2011). Clearly, high school science students have a great deal of room to improve their understanding of fundamental science concepts. In response to this problem, this module was developed to bring cutting-edge collegiate research to students to give them an authentic experience with solving a problem by applying math, science, and engineering principles. Our goals are to increase interest and preparedness of high school science students, increase the number of students who pursue higher education science and engineering degrees, and to increase the pool of candidates for jobs in these fields. The module is also aligned to Washington state science and math standards so that this selection of the standards can be taught in a more interactive, hands-on approach that fosters student enthusiasm in the fields of science, math, and engineering.



SCIENCE

This module utilizes and teaches concepts from physics, chemistry, biology, and mathematics to students in a ninth grade physical science class. Some topics that reach across all disciplines that students will use and learn about include energy transformation, renewable and alternative energy sources, and graphing.

Activity 1-- PowerPoint Introduction to MFC Mini-Unit
Activity 2 – Vocabulary Four-Square and Ohm's Law Worksheet
Activity 3 – Interactive Circuit Activity
Activity 4 – Inquiry Based MudWatt™ Lab
Activity 5 – Summative Assessment

Core Content	Concepts	Module Activity
Math	• Direct Variation • Inverse Variation	• 3 • 3
Physics	• Ohm's law • Energy Conservation • Power	• All • 1, 4 • All
Chemistry	• Reduction/Oxidation Reactions • Chemical Bonding	• 1, 4 • 1
Biology	• Cellular Respiration • Microbiology	• 1, 4 • 1
Engineering	• Efficiency • Sustainable Energy Sources	• 1, 3, 4 • 1, 4

MATHEMATICS

Students in Algebra I study a variety of functions and learn to work fluently with equations. As students learn about Microbial Fuel Cells, it will be necessary for them to apply Ohm's Law to make calculations of current, resistance, and voltage. This gives students real world examples of both inverse and direct variation, as each set of variables in Ohm's law are related in one of these two ways. Students are also given opportunities to solve for a given variable in terms of the other variables when making repeated Ohm's Law calculations.

ENGINEERING

This module is designed to teach students about what engineers do and understand that the goal of an engineer's work is to create a product that solves a specific problem. Engineers apply theoretical scientific knowledge to create these products. Students will learn about how engineers designed a new energy source, the microbial fuel cell, using the MudWatt™ as a model. They will practice engineering as they use the scientific method to maximize the power generated by the microbial fuel cell. The introductory PowerPoint will discuss the science background necessary to understand microbial fuel cells and the need for development of alternative energy sources. The interactive circuit building lab gives students the chance to use their engineering skills to build a circuit to specifications. Lastly, the MudWatt™ lab gives students the opportunity to utilize a cutting-edge product and determine how to optimize the conditions of operation to maximize energy.

GOALS

This module addresses the following Washington State Grade Level Standards:

Content Area	Standard
Mathematics	A.1.3.B- Represent a function with a symbolic expression, as a graph, in a table, and using words, and make connections among these representations (includes inverse variation)
	A.1.4.E- Describe how changes in the parameters of linear functions and functions containing an absolute value of a linear expression affect their graphs and the relationships they represent (includes direct variation)
	A.1.7.D- Solve an equation involving several variables by expressing one variable in terms of the others
Biology	LS1B- The gradual combustion of carbon-containing compounds within cells, called cellular respiration, provides the primary energy source of living organisms; the combustion of carbon by burning of fossil fuels provides the primary energy source for most of modern society.
Chemistry	PS2A- Atoms are composed of protons, neutrons, and electrons. The nucleus of an atom takes up very little of the atom's volume but makes up almost all of the mass. The nucleus contains protons and neutrons, which are much more massive than the electrons surrounding the nucleus. Protons have a positive charge, electrons are negative in charge, and neutrons have no net charge.
	PS2E- Molecular compounds are composed of two or more elements bonded together in a fixed proportion by sharing electrons between atoms, forming covalent bonds. Such compounds consist of well-defined molecules. Formulas of covalent compounds represent the types and number of atoms of each element in each molecule.
	PS2G- Chemical reactions change the arrangement of atoms in the molecules of substances. Chemical reactions release or acquire energy from their surroundings and result in the formation of new substances.
Physics	PS1G- Electrical force is a force of nature independent of gravity that exists between charged objects. Opposite charges attract while like charges repel.
	PS1H- Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces.
	PS3A- Although energy can be transferred from one object to another and can be transformed from one form of energy to another form, the total energy in a closed system remains the same. The concept of conservation of energy, applies to all physical and chemical changes.

ACTIVITIES:

Activity 1- PowerPoint Introduction to MFC Mini-Unit

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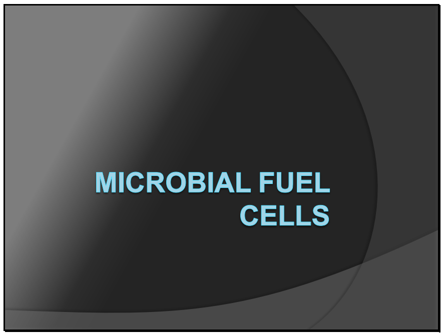

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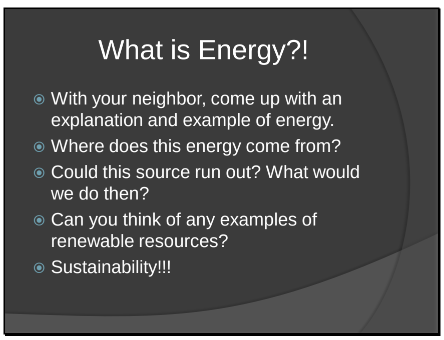

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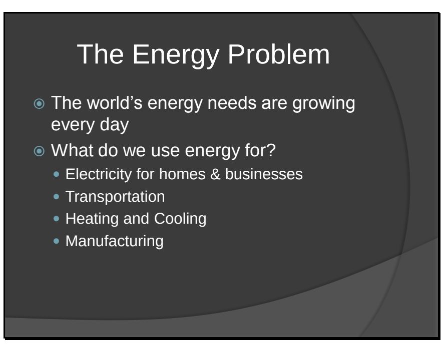

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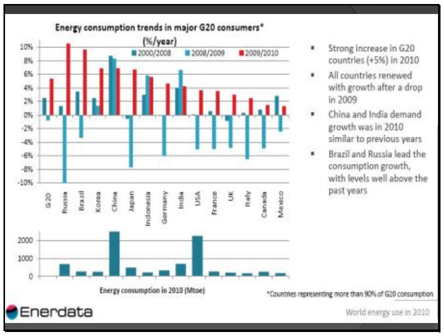

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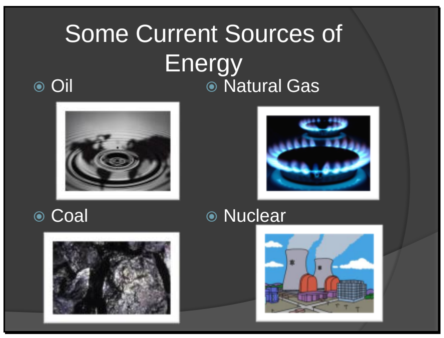

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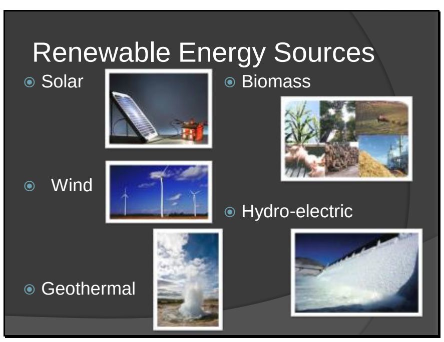

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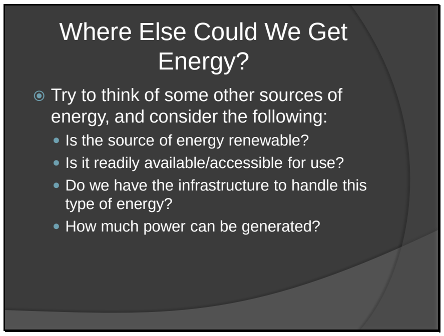

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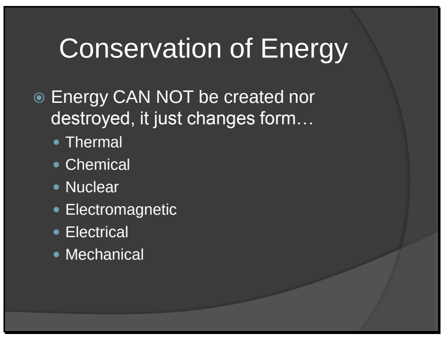
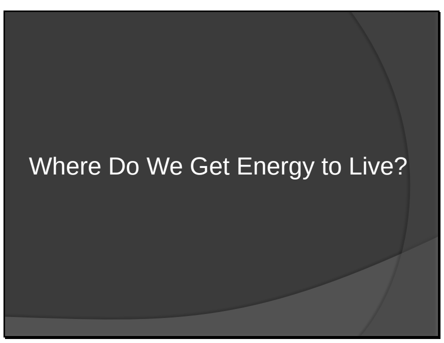


These are the 6 main forms of energy. All six main forms are found in either kinetic or potential states.

Slide 9



Students Brainstorm.

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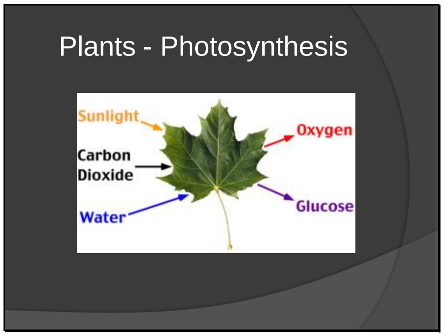
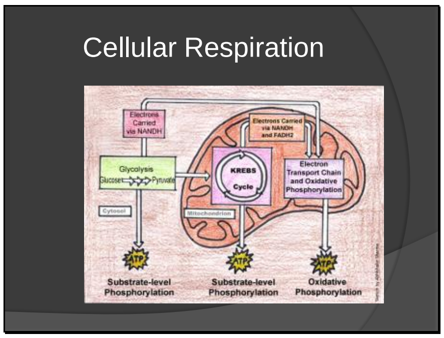


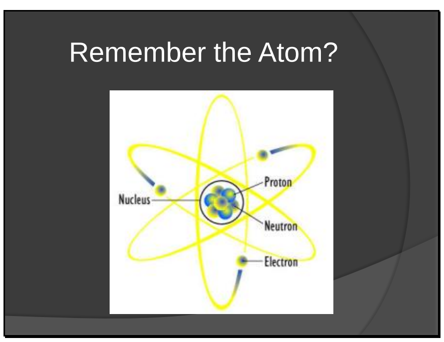
Energy + Carbon dioxide + Water = Glucose(or similar sugar compound) + Oxygen

Slide 11



Humans eat plants(or animals who have eaten plants) and this gives us the sugar we need to break down thus deriving energy. Can get up to 36 ATP from this process. The Anode of the MFC wants to collect the electrons as they are going through the electron transport chain.

Slide 12



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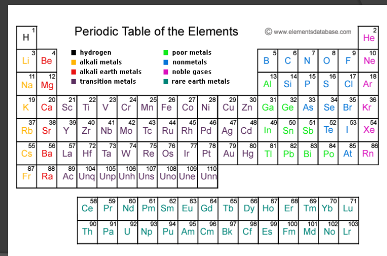
Periodic Table



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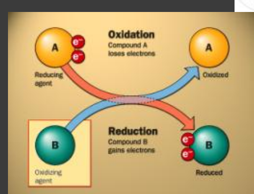
Reduction/Oxidation Reactions

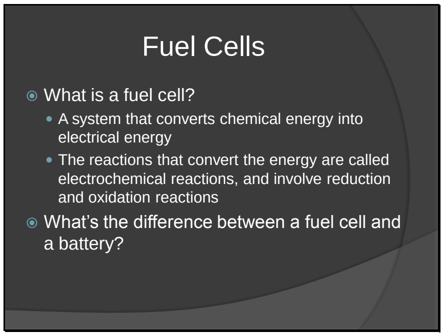


Slide 15

A Creative Solution for an Alternative Energy Source

- There are bacteria all over the world, which are producing energy just by living & eating
- What if we could convert the energy they produce by consuming food into an electrical energy source?
- This is how the idea of a microbial fuel cell (MFC) was born

Slide 16



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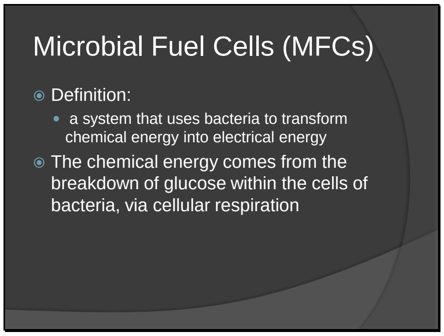

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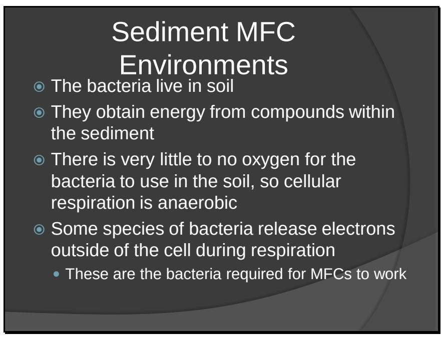

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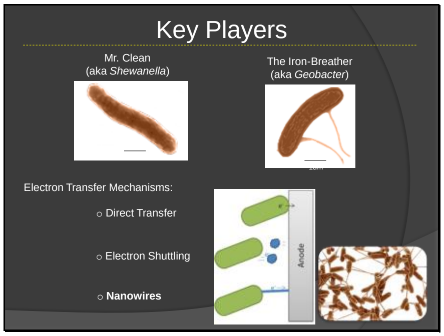

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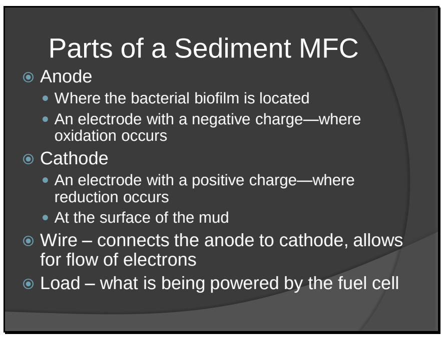

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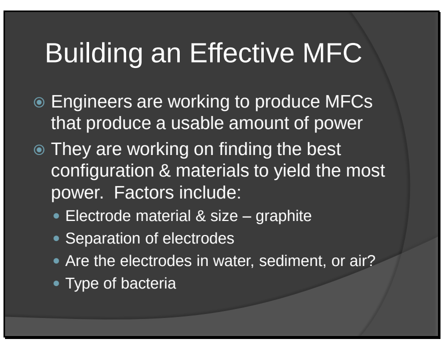

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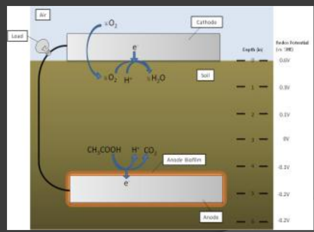
Soil-based MFCs



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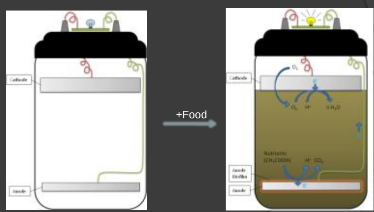
The MudWatt

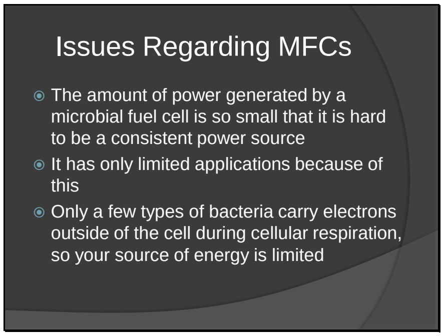


Slide 24

Application of MFC Technology

- Wastewater treatment plants could produce power using a by-product they already have
- Currently, MFCs are used by the Navy to power sensors that periodically take readings in remote locations in the ocean, so batteries don't have to be replaced – this saves a great deal of time & labor

Slide 25



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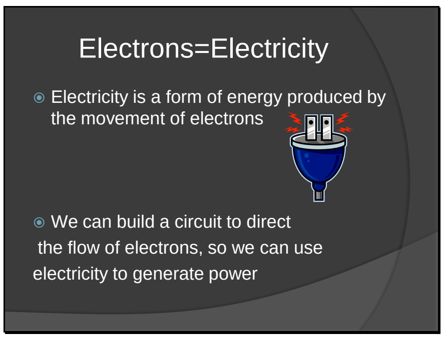

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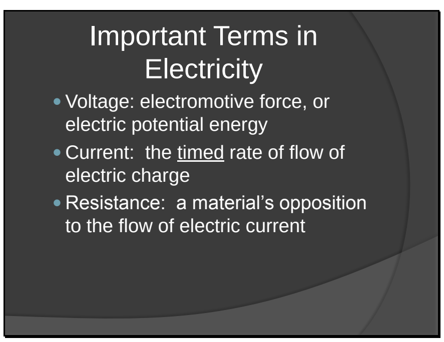

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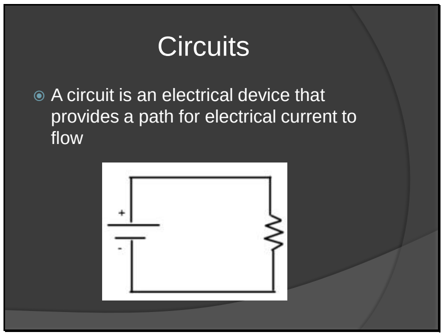

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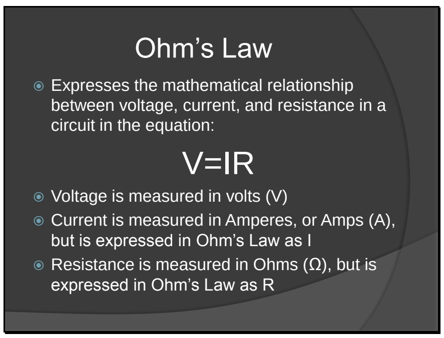

An analogy used to describe Ohm's law uses hydraulics. Voltage is the analog of water pressure, current = water flow rate, and flow restrictors placed in pipes between points where the water pressure is measured, is the analog of resistors.

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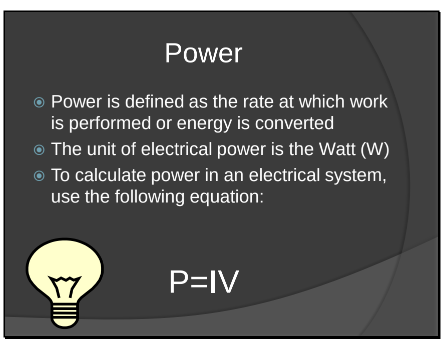

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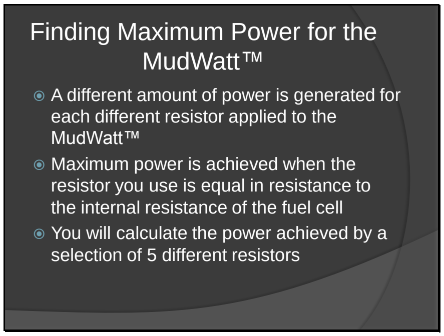
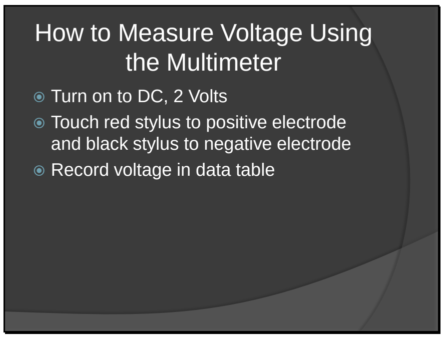


Internal resistance is the resistance due to the composition of the soil.

Slide 32



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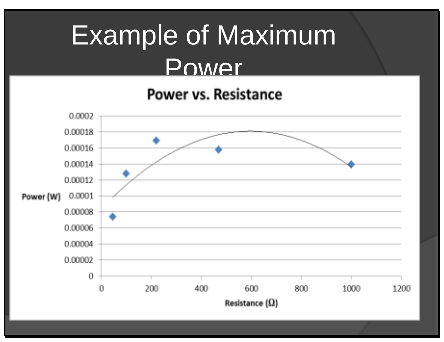


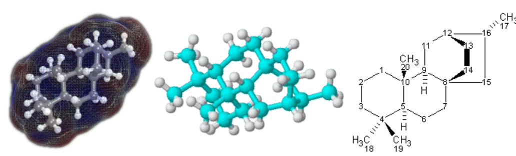
Activity 2 – Vocabulary Four-Square and Ohm's Law Worksheet

Four-Square Vocabulary

Directions:
For each word in the vocabulary list, create a four-square organizer that clearly explains the meaning of the word. For each word, use at least 3 website resources to help you create your four-square. Please complete this assignment on a separate sheet of paper or in your science notebook.

Word List:
Current, Voltage, Resistance, Power, Capacitor, Anode, Cathode, Fuel Cell, Oxidation, Reduction

Example Four-Square:

<table>
<tr><td>Definition
Tiny particles that make up all living and non-living things, and are made up of atoms</td><td>Picture
</td></tr>
<tr><td colspan="2">Molecule</td></tr>
<tr><td>Real-Life Example

Acetaminophen
Sold as Tylenol^{TM}, this has a similar shape to another pain-killer, aspirin. They both act in a similar way to reduce pain and fever. It is comprised of:
$C_8H_9O_2N$
8 carbon atoms
9 hydrogen atoms
2 oxygen atoms
1 nitrogen atom</td><td>Metaphor

If you compare atomic units to language, atoms are the letters of the alphabet. The letters combine to form words, which are similar to molecules. A string of words form a sentence, which could be many molecules combining in a solution.</td></tr>
<tr><td colspan="2">Sources: http://en.wikipedia.org/wiki/Molecule</td></tr>
<tr><td colspan="2">http://www.nyhallsci.org/marvelousmolecules/marveloussub.html</td></tr>
<tr><td colspan="2">http://www.merriam-webster.com/dictionary/molecule</td></tr>
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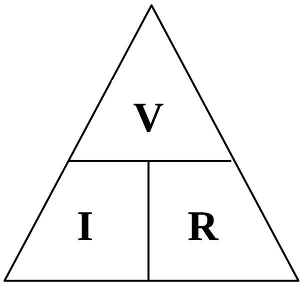
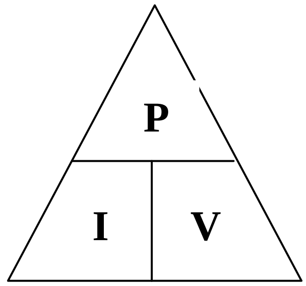
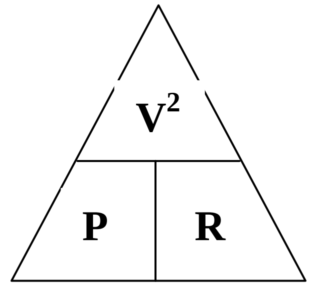
Ohm's Law Worksheet







$V = IR$ $\quad$ $P = IV$ $\quad$ $P = (V^2)/R$

Please practice the Ohm's law equations by filling in the two tables below:

Voltage (V)	*Current (I)*	*Resistance (R)*
9V		*20Ω*
9V		*5Ω*
	0.25A	*150Ω*
6V	*2A*	

Work:

Voltage (V)	*Current (I)*	*Resistance (R)*	*Power (P)*
2V		*25Ω*	
12V			*32W*
	0.5A	*47Ω*	
	1.75A		*19W*

Work:

Activity 3 – Interactive Circuit Activity

Circuit Lab

I. Introduction

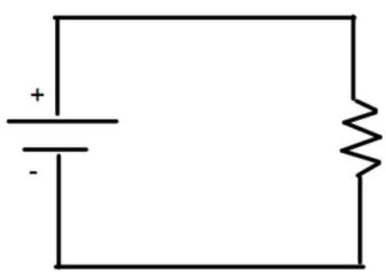
Remember that _____________ is electric potential energy, or the ability to cause electrons to flow. _____________ is the friction that affects the flow of electrons. While ___________ is flow rate of electrons.

In a simple circuit, we should be able to understand the relationship between voltage, resistance, and current. Remember that ____________ Law explains the relationship between these 3 variables. Given any two of the variables, the third can be calculated from them. Ohm's law is given by the equation ____________________, where V is _______________, I is _______________, and R is _______________.

In a ________________ drawing of a circuit the following symbols represent the given parts of the circuit:

Circuit Component	Symbol
Wire	
Resistor	
Battery	

An example of a schematic drawing of a circuit with these 3 components could look like this:



Fill in the units of measure for the following variables in a circuit:

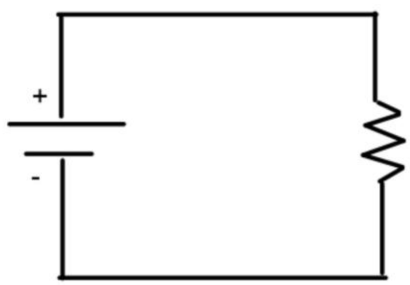
Variable	**Unit of Measure**	**Symbol**
Voltage		
Current		
Resistance		
Power		

You may at this point be wondering how power is related to the other 3 more familiar variables. Remember that power is an amount of energy per unit of time. Power can be determined by the equation ____________.

II. Circuit Construction Lab

In this part of the lab you will use the website PhET Interactive Simulations "Circuit Construction Kit (DC only), Virtual Lab" under the physics tab at http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc-virtual-lab.

1. a. In the virtual lab, construct the following circuit using wires, a battery and a resistor.



   b. What is the resistance of the resistor (right-click on the resistor)?

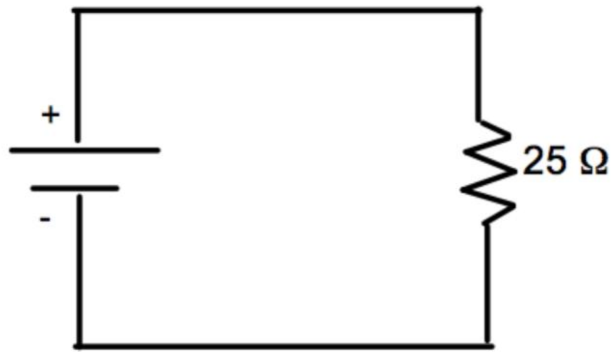
   c. What is the voltage of the battery (right-click on the resistor)?

   d. Use Ohm's Law to determine the current. Show your calculation.

   e. Using the equation P=IV, determine the power generated. Show your calculation.

2. a. Predict what will happen to the current and the voltage if the resistance is increased. Explain your reasoning.

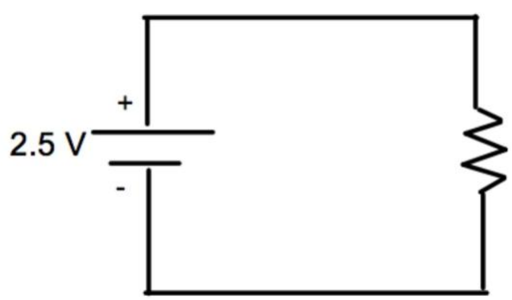
   b. Using the website, construct the following circuit (use the default settings unless otherwise specified):



c. What is the voltage? What is the current? What is the power?

3. a. Predict what will happen to the current and resistance if the voltage is decreased. Explain your reasoning.

b. Using the website, construct the following circuit (use default setting unless otherwise specified):



c. What is the current? What is the resistance? What is the power?

III. Direct and Inverse Variation

1. Consider a circuit where the voltage remains constant, such as a battery that always delivers 9 volts of potential.
a. If the battery is 9V, and current is 0.5A, what is the resistance?

b. If the battery remains 9V, and the current is increased to 0.75A, what is the resistance?

c. Fill in the blank: If the voltage is constant, as the current increases, the resistance _________________.

d. If the battery is always delivering 9V, what type of relationship (direct or inverse) describes how the current and resistance are related?

2. Consider a circuit where the resistance remains constant (this will be the case of the MudWatt fuel cell). Assume a 20 Ω resistor is used in a circuit.
a. If the resistance is 20 Ω, what is the current when the voltage is 5V?

b. If the resistance remains 20 Ω, what is the current when the voltage increases to 10V?

c. Fill in the blank: If the resistance is constant, as the voltage increases, the current _______________.

d. If the resistance in the circuit remains constant, what type of relationship (direct or inverse) describes how the current and voltage are related?

3. What type of relationship exists between voltage and resistance when the current remains constant? Give 2 example calculations that support your conclusion.

IV. Engineering a Circuit

1. Using the Virtual Lab, create and then draw and label a circuit that uses wire, one light bulb, one battery, and has a current of 2.25A.

2. a. Create a circuit with one resistor, one battery and some wire (do not use the default settings). Draw and label the circuit, and determine the current.

b. Without changing the voltage on the battery, make your circuit have ½ the current. Draw and label this circuit, and determine the current.

3. a. Create a circuit with one light bulb, one battery, and some wire (do not use default settings). Draw and label the circuit, and determine the current.

b. Without changing the voltage on the battery, make your light bulb shine brighter. Draw and label the circuit, and determine the current.

4. Summarize at least 3 important ideas you learned about current, resistance, voltage, batteries, light bulbs, and resistors.

Activity 4 – Inquiry Based MudWatt™ Lab

Name____________________________ Per._____ Date______________________

MudWatt Lab

In this lab, you will be building a microbial fuel cell using the MudWatt™ kit. Once constructed, you will be able to measure voltage with different resistors added to the system, and calculate current and power from these measurements. The goal of the lab is to determine how manipulation of experimental factors will change the power generated by the MudWatt™. You will be working in groups of 2-4 with each group setting up their own MudWatt™ with a unique experimental variable. It will be your responsibility to research environmental variables that impact the rate of cellular respiration and electrical conduction. Once you have determined the variable your group would like to manipulate, inform your instructor the quantities needed to perform the experiment.

Which variable will your group be manipulating? ____
Why? (Be as specific and scientific as possible)

____

____

____

____

____

____

Review your vocabulary terms.

Read through the procedure. Then fill in your hypotheses below.

Question #1: In your individual MudWatt™, at which resistance is the most power generated?

Hypothesis #1: ____

____

Question #2: Which manipulated variable produces the highest maximum power in the MudWatt™?

Hypothesis #2: ____

____

Equipment:

MudWatt™ kit	Gloves
Multimeter	Stopwatch
Balance	Beaker
Scoopula	Mud

(*Other equipment dependent on individual group manipulations*)

Set-up Procedure:

1. Class divided into groups of 2-4, and each group selects a variable to manipulate.
2. Gather MudWatt™ kit, mud, gloves, and a beaker from the front table (1 per group).
3. Acquire materials needed for manipulated variables.
4. Add appropriate amount of manipulated variable to the mud in a beaker and mix thoroughly.
5. Assemble MudWatt™ according to the instructions included in the kit.
6. Clean lab station and rinse beakers.

Data Acquisition Procedure:

1. Starting the day following set-up, count the number of blinks per minute the LED light produces. If the light is not blinking, record the value as 0.
2. When you notice that the blinks per minute rate has stopped increasing or decreasing, measure the voltage by doing the following (this could take anywhere from 1-2 weeks):
    a. Obtain a multimeter , turn it onto the 2 V, DC setting.
    b. Take the jumper, capacitor, and LED light off of the hacker board of the MudWatt™.
    c. Connect the 1000-Ohm resistor found in the MudWatt™ kit (see the color code on the MudWatt™ instructions to find the correct resistor). Connect the resistor into ports 1 and 4 on the hacker board.
    d. Once the resistor is plugged into the hacker board, set a timer and wait 2 minutes before obtaining the voltage.
    e. To read the voltage using the multimeter, touch the tip of the red point to the round metal circle that is positive (+) on the hacker board, and the tip of the black point to the round metal circle that is negative (-).
    f. Record the voltage in the table labeled "Power for Manipulated Variable (Group Data)".
    g. Disconnect the 1000-Ohm resistor.
    h. Repeat steps c-g, going from the next highest resistor to the lowest resistor (470-Ohms to 47-Ohms).
3. Calculate current and power for each measurement, using the Ohm's Law equation, and Power equation. Insert values into data table #1.
4. Share your data with the instructor, and fill in maximum power from the class data into Data Table #2.

Results:

Open Circuit Potential: ______________________

Data Table #1: Power for Manipulated Variable (Group Data)

Resistance (Ohms)	**Voltage (Volts)**	**Current (Amperes)**	**Power (Watts)**
1000			
470			
220			
100			
47			

Data Table #2: **Maximum** Power for all Variables (Class Data)

Variable	**Resistance (Ohms)**	**Voltage (Volts)**	**Current (Amperes)**	**Power (Watts)**

Conclusion:

For Hypothesis #1:

1. Make a graph using Microsoft Excel comparing power (y-axis) and resistance (x-axis), and attach to your lab. Include a TAIL (Title, Axis, Intervals, & Labels/Legend). Describe below what is happening in the graph.

2. In your fuel cell, at which resistance was the most power generated? Give high and low data, the difference between the two, refer to your hypothesis, and give a scientific explanation for the results.

3. List one way a fuel cell differs from a battery, and one way a fuel cell is the same as a battery?

4. Where is the energy coming from in a fuel cell?

For Hypothesis #2:

5. Which manipulated variable produced the highest maximum power in the MudWatt™? Give high and low data, the difference, refer to your hypothesis, and give a scientific explanation for the results.

6. If you could use two variables to produce maximum power in the MudWatt™, which two would you use and why?

7. Why is a product like the MudWatt™ useful?

8. Describe a way YOU would develop and implement a sustainable energy source. Include people it would help, location, and materials needed.

Activity 5 – Summative Assessment

Assessment

1. You have a circuit with a 9V battery, and a 100Ω resistor. Calculate the current.

2. If the voltage is set at 1.5V, and the resistance increases, how will the current respond?

3. In a microbial fuel cell, __________ energy is transformed into ______________ energy.

4. In a circuit, the flow of which subatomic particle is considered electricity?

5. In a microbial fuel cell, does oxidation or reduction occur at the anode?

6. Give one similarity and one difference between a fuel cell and a battery.

7. When using the multimeter, _______ is the color of the probe you touch to the positive side of a battery, and _______ is the color of the probe you touch to the negative side of a battery.

8. What units are used for the following parts of a circuit:

   Voltage –

   Current –

   Resistance –

9. How does engineering differ from science?

10. Summarize how you can determine the maximum power produced by a microbial fuel cell.

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Appendix A: Calendar

Day 1 – All Period	Day 2 – All Period	Day 3 – All Period	Day 4 – All Period	Day 5 – All Period
Power Point-Activity 1	Vocab-Activity 2	Circuit Lab-Activity 3	Circuit Lab-Activity 3	MudWatt Set-up-Begin Activity 4

Day 6 – 5 Min	Day 7 – 5 Min	Day 8 – 5 Min	Day 9 – 5 min	Day 10 – 5 Min
Record Blinks in Table	Record Blinks in Table	Record Blinks in Table	Record Blinks in Table	Record Blinks in Table

Day 11 – 5 Min	Day 12 – 5 Min	Day 13 – All Period	Day 14 – All Period	Day 15 – Flex
Record Blinks in Table	Record Blinks in Table	MudWatt Lab	MudWatt Lab	Finish MudWatt Lab if necessary

Appendix B: MudWatt™ Expenses

MUDWATT™ MFC KIT

Explore the power of microbes with the MudWatt™ Microbial Fuel Cell (MFC) Kit. Simply fill this kit with soil from your backyard (or someone else's backyard), along with anything you find in your refrigerator. Within days the attached LED light will start to blink using only the power produced by the electricity-generating microbes in your soil!

The MudWatt™ is the perfect educational kit for classrooms and hobbyists since it incorporates a wide range of scientific topics. It's easy to incorporate the MudWatt™ into a class discussion on microbiology, soil chemistry, electrochemistry, or electrical engineering. Visit our **Community Page** to share ideas and data and take part in the development of MFC technology!

$44.95

Kit Includes:

- 1 Complete MudWatt™ MFC:

- MudWatt™ **ANODE**
- MudWatt™ **CATHODE**
- MudWatt™ **VESSEL**
- MudWatt™ **HACKER**

- 1 Educational Booklet
- 1 Instructional Booklet
- 1 Pair of Nitrile Gloves

Appendix C: Phet Troubleshooting

PhET Tips for Teachers Circuit Construction Kit (All versions) Written by Trish Loeblein, Sam Reid, Kathy Perkins, last updated July 19, 2010 Authors: Loeblein, Reid, Perkins

Tips for controls:

Components are dragged from the toolbox to make circuits with the exception of the voltmeter and stopwatch.

Use the **Save** button to save a configuration for lecture or homework.

In order to open a saved circuit, download the file. To open a file, Circuit Construction Kit simulation must be running, press the **LOAD** button, if the file was not saved with the .cck extension, then in the **FILE TYPES** box, select **ALL FILES**.

Right Click helps explore many situations. For example, you can break a junction, remove a component, or change values like resistance.

The current charts have a movable sensor that can be dragged to different locations, If you want more than one chart, click again on the button . The voltage charts work similarly, but requires that both sensors are connected across a component

You can **Pause** the sim and then use **Step** to incrementally analyze.

If you are doing a lecture demonstration, set your screen resolution to 1024x768 so the simulation will fill the screen and be seen easily.

The “Reset Dynamics” will discharge any capacitors or inductors

Under **Options,** you can change the colors if it is helpful for viewing.

Important modeling notes / simplifications:

The model is computed with Modified Nodal Analysis. Capacitors and inductors are linearized at each time step, and dynamic timestep subdivisions are used to trade off accuracy and speed.

There are 4 versions of **Circuit Construction Kit**. The DC version is the simplest and is a good spot to start students. The AC version includes AC voltage sources, capacitors, and inductors.

The “Virtual Lab” versions do not have the ammeter that can be moved onto components to determine the current. This was a request of teachers who use ammeters that must be incorporated into the circuit.

Fire denotes a short circuit or very high current

If the current is high and the blue dots for the electrons cannot be drawn fast enough, the sim changes speed and this displays :.

When you change the Wire Resistivity, the amount of resistance will vary with the length of the wire. So to find the resistance value for any wire, read both the current and voltage and use Ohm’s Law R=V/I

Insights into student use / thinking:

Students sometimes have difficulty recognizing if a switch is completely closed or not.

Our studies show that complex concepts and lab skills about circuits may be made easier for students who use this simulation. To read more, see these articles (names have been shortened for simplification).
“Assessing..Environments” “Assessing..Tutorials”

Suggestions for sim use:

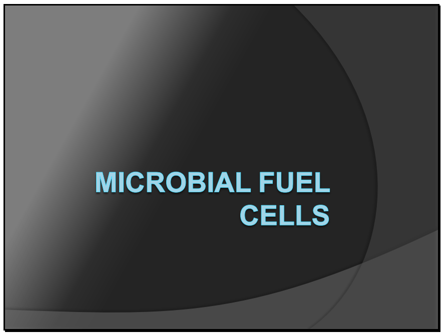
For tips on using PhET sims with your students see: **Guidelines for Inquiry Contributions** and **Using PhET Sims**

The simulations have been used successfully with homework, lectures, in-class activities, or lab activities. Use them for introduction to concepts, learning new concepts, reinforcement of concepts, as visual aids for interactive demonstrations, or with in-class clicker questions. To read more, see **Teaching Physics using PhET Simulations**

For activities and lesson plans written by the PhET team and other teachers, see: **Teacher Ideas & Activities**

Appendix D: Student Copy of PowerPoint Introduction

Slide 1



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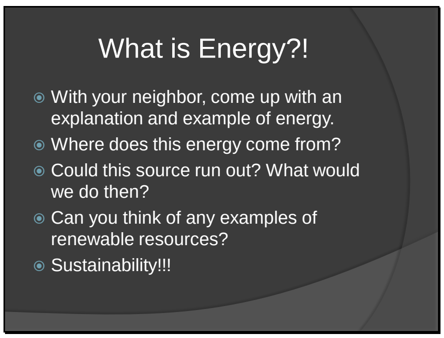

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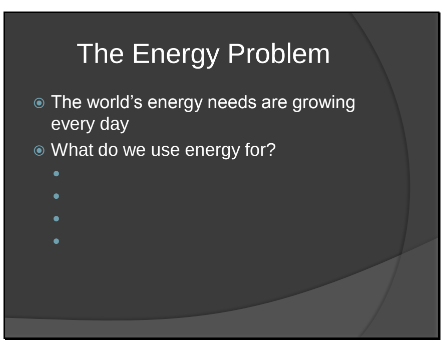

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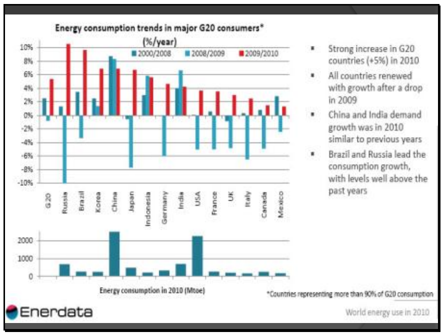

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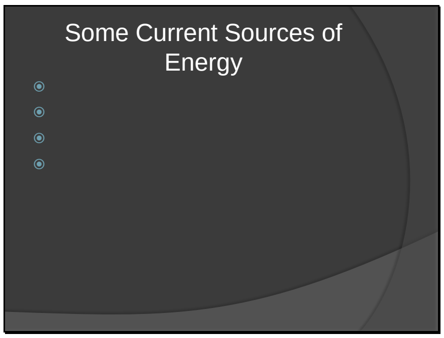

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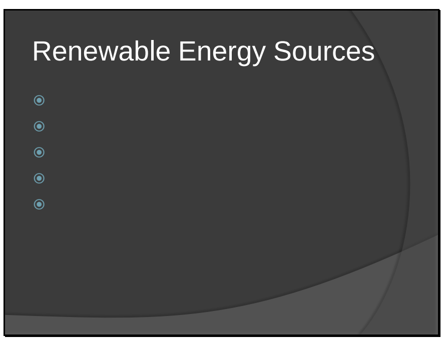

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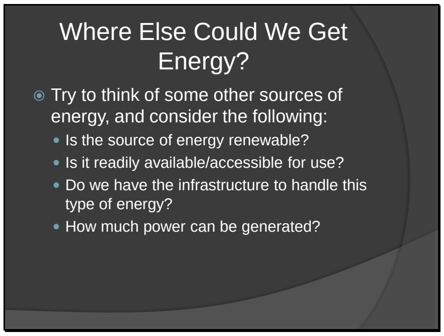

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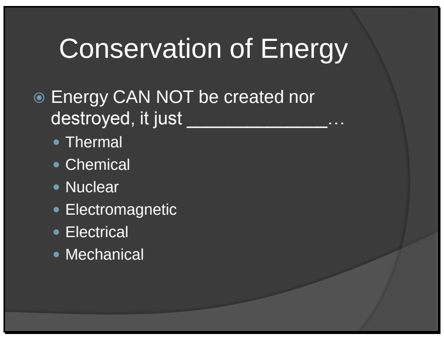
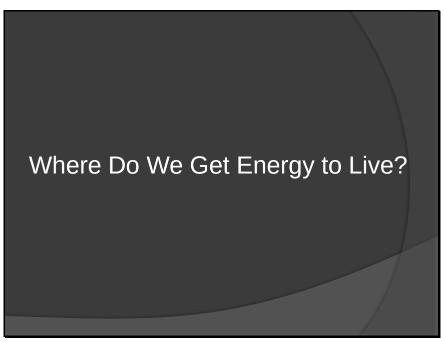


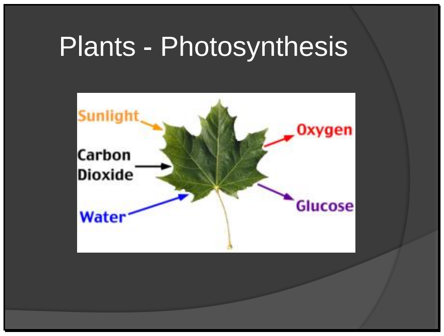
These are the 6 main forms of energy. All six main forms are found in either kinetic or potential states.

Slide 9



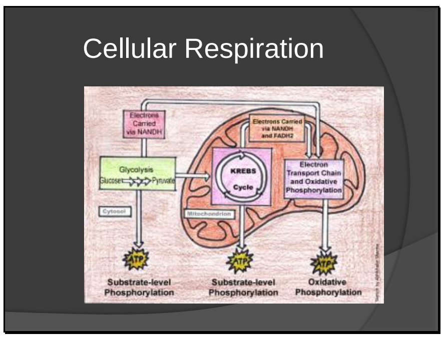
Students Brainstorm.

Slide 10



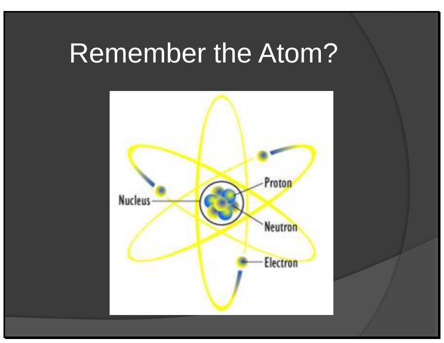
Energy + Carbon dioxide + Water = Glucose(or similar sugar compound) + Oxygen

Slide 11



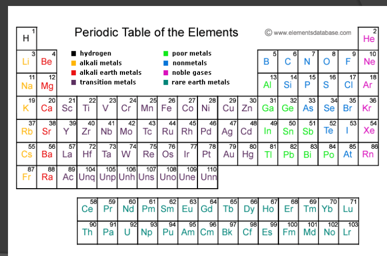
Humans eat plants(or animals who have eaten plants) and this gives us the sugar we need to break down thus deriving energy. Can get up to 36 ATP from this process. The Anode of the MFC wants to collect the electrons as they are going through the electron transport chain.

Slide 12



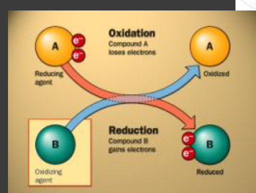
Slide 13

Periodic Table



Slide 14

Reduction/Oxidation Reactions

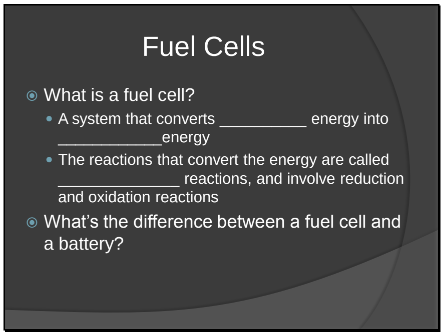


Slide 15

A Creative Solution for an Alternative Energy Source

- There are bacteria all over the world, which are producing energy just by living & eating
- What if we could convert the energy they produce by consuming food into an _________ energy source?
- This is how the idea of a ____________ _____ (MFC) was born

Slide 16



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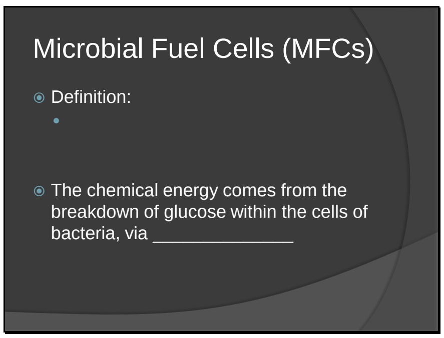

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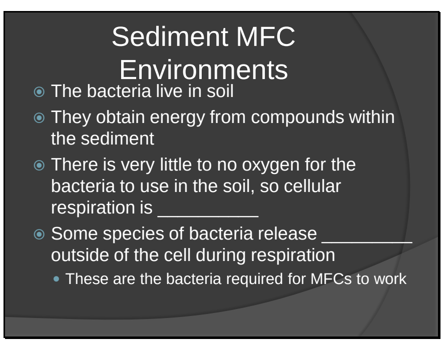

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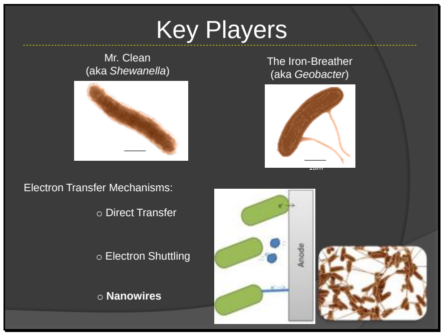

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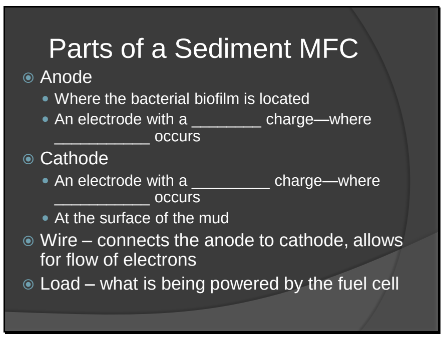

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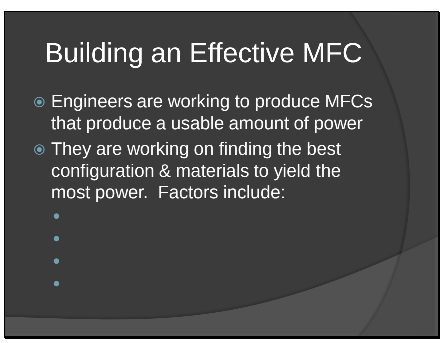

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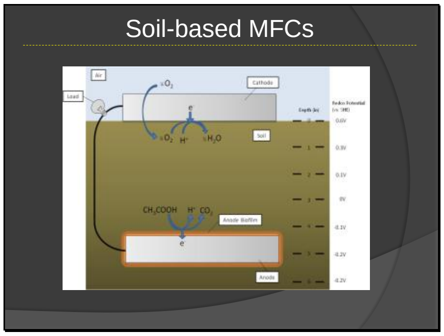

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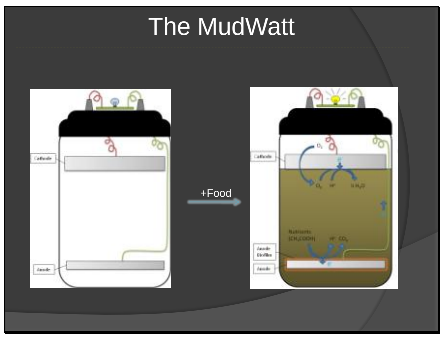

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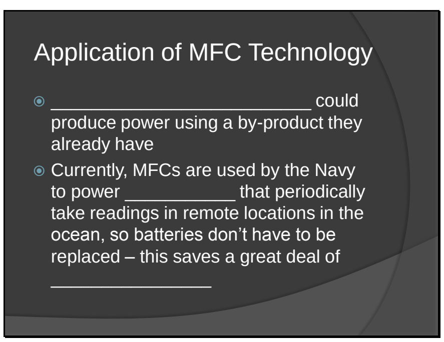


Slide 25

Issues Regarding MFCs

- The amount of power generated by a microbial fuel cell is so __________ that it is hard to be a consistent power source for many appliances we use in our everyday life
- It has only limited applications because of this
- Only a few types of bacteria carry electrons ______________ during cellular respiration, so your source of energy is limited

Slide 26

Electrons=Electricity

- Electricity is a form of energy produced by ______________________

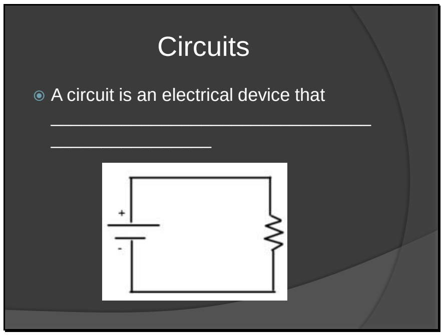
- We can build a circuit to direct the flow of electrons, so we can use electricity to generate _________

Slide 27

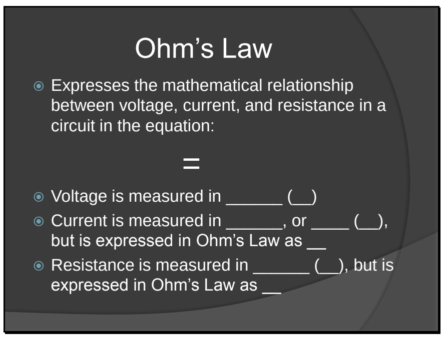
Important Terms in Electricity

- _______: electromotive force, or electric potential energy
- _______: the timed rate of flow of electric charge
- _______: a material's opposition to the flow of electric current

Slide 28

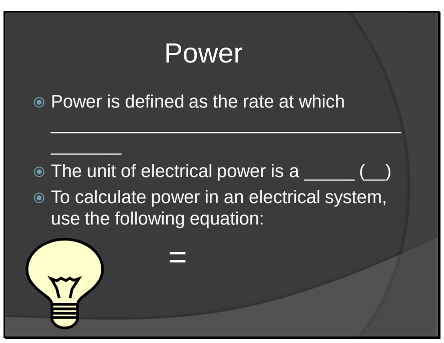


Slide 29



An analogy used to describe Ohm's law uses hydraulics. Voltage is the analog of water pressure, current = water flow rate, and flow restrictors placed in pipes between points where the water pressure is measured, is the analog of resistors.

Slide 30



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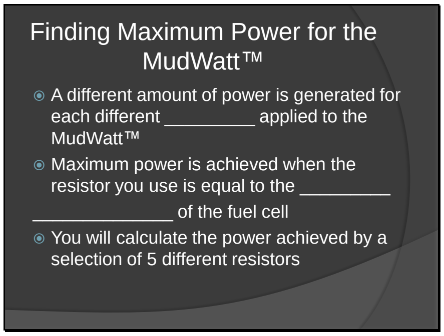
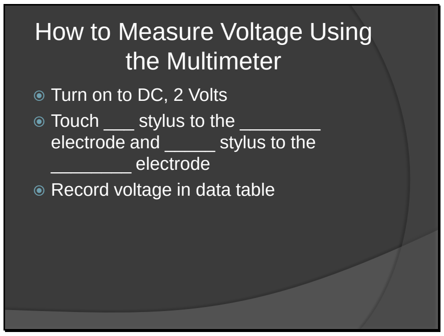


Internal resistance is the resistance due to the composition of the soil.

Slide 32



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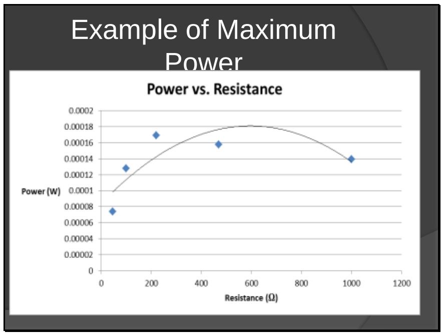
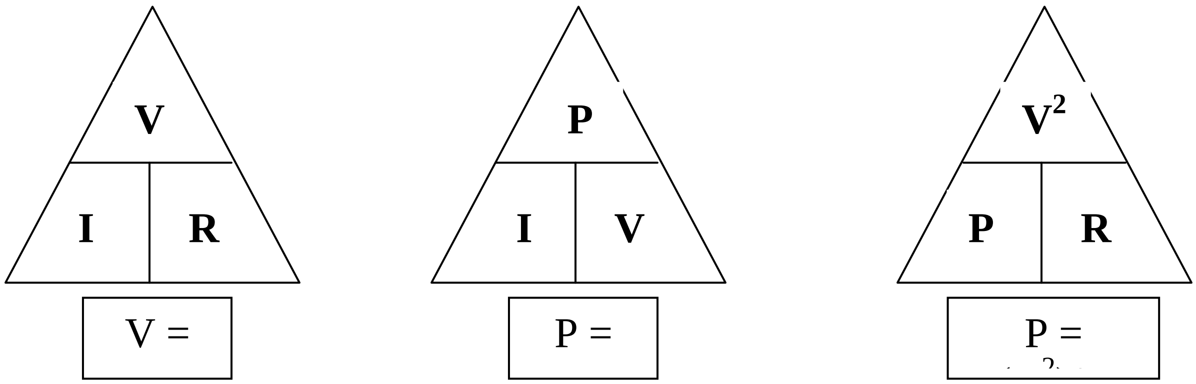


Appendix E: Ohm's Law Worksheet Key

Ohm's Law Worksheet



KEY

Please practice the Ohm's law equations by filling in the two tables below:

Voltage (V)	*Current (I)*	*Resistance (R)*
9V	***0.45A***	*20Ω*
9V	***1.8A***	*5Ω*
37.5V	*0.25A*	*150Ω*
6V	*2A*	***3Ω***

Work:

Voltage (V)	*Current (I)*	*Resistance (R)*	*Power (P)*
2V	***0.08A***	*25Ω*	***0.16W***
12V	***2.67A***	***4.5Ω***	*32W*
23.5V	*0.5A*	*47Ω*	***11.75W***
10.86V	*1.75A*	***6.21Ω***	*19W*

Work:

Appendix F: Interactive Circuit Lab Key

Activity 3 – Interactive Circuit Activity

Sample Answers

Circuit Lab

1. Introduction

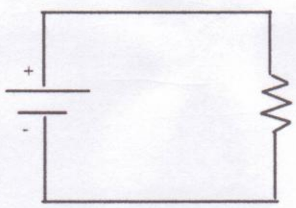
Remember that voltage is electric potential energy, or the ability to cause electrons to flow. Resistance is the friction that affects the flow of electrons. While Current is flow rate of electrons.

In a simple circuit, we should be able to understand the relationship between voltage, resistance, and current. Remember that Ohm's Law explains the relationship between these 3 variables. Given any two of the variables, the third can be calculated from them. Ohm's law is given by the equation $V = IR$, where V is voltage, I is current, and R is resistance.

In a schematic drawing of a circuit the following symbols represent the given parts of the circuit:

Circuit Component	Symbol
Wire	—
Resistor	
Battery	-||+

An example of a schematic drawing of a circuit with these 3 components could look like this:



Fill in the units of measure for the following variables in a circuit:

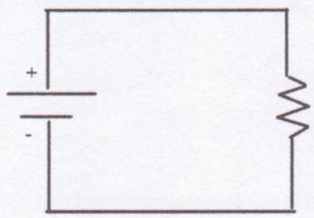
Variable	Unit of Measure	Symbol
Voltage	Volts	V
Current	Amperes	A
Resistance	Ohms	Ω
Power	Watts	W

You may at this point be wondering how power is related to the other 3 more familiar variables. Remember that power is an amount of energy per unit of time. Power can be determined by the equation $P = IV$.

II. Circuit Construction Lab

In this part of the lab you will use the website PhET Interactive Simulations "Circuit Construction Kit (DC only), Virtual Lab" under the physics tab at http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc-virtual-lab.

1. a. In the virtual lab, construct the following circuit using wires, a battery and a resistor.



b. What is the resistance of the resistor (right-click on the resistor)? $10\,\Omega$

c. What is the voltage of the battery (right-click on the ~~resistor)?~~ battery) 9V

d. Use Ohm's Law to determine the current. Show your calculation.

$V = IR$

$\frac{9}{10} = \frac{I(\cancel{10})}{\cancel{10}}$ $\quad I = 0.9A$

e. Using the equation P=IV, determine the power generated. Show your calculation.

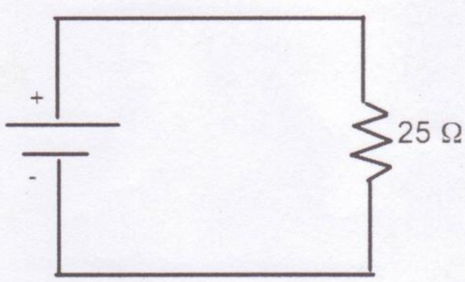
$P = (0.9)(9)$

$P = 8.1W$

2. a. Predict what will happen to the current and the voltage if the resistance is increased. Explain your reasoning.

The voltage will remain the same because it is determined by the battery's construction. The current will decrease because the resistance will decrease the ability of the electrons to flow.

b. Using the website, construct the following circuit (use the default settings unless otherwise specified):



c. What is the voltage? What is the current? What is the power?

$V = 9v$

$V = IR$

$\frac{9}{25} = \frac{I(\cancel{25})}{\cancel{25}}$

$I = 0.36A$

$P = IV$

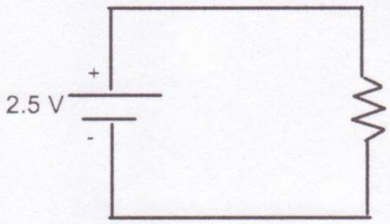
$P = (0.36)(9)$

$P = 3.24W$

3. a. Predict what will happen to the current and resistance if the voltage is decreased. Explain your reasoning.

The resistance will stay the same because it is due to the construction of the resistor. The current will decrease because with a lower voltage, electrons are less motivated to move, or flow.

b. Using the website, construct the following circuit (use default setting unless otherwise specified):



c. What is the current? What is the resistance? What is the power?

$R = 10\Omega$

$V = IR$

$\frac{2.5}{10} = \frac{I(\cancel{10})}{\cancel{10}}$

$I = 0.25A$

$P = IV$

$P = (0.25)(2.5)$

$P = 0.625W$

III. Direct and Inverse Variation

1. Consider a circuit where the voltage remains constant, such as a battery that always delivers 9 volts of potential.

a. If the battery is 9V, and current is 0.5A, what is the resistance? $\frac{9}{0.5} = \frac{(\cancel{0.5})R}{\cancel{0.5}}$ $R = 18\Omega$

b. If the battery remains 9V, and the current is increased to 0.75A, what is the resistance? $\frac{9}{0.75} = \frac{(\cancel{0.75})R}{\cancel{0.75}}$ $R = 12\Omega$

c. Fill in the blank: If the voltage is constant, as the current increases, the resistance __decreases__.

d. If the battery is always delivering 9V, what type of relationship (direct or inverse) describes how the current and resistance are related? They are inversely related because as one variable increases the other decreases.

2. Consider a circuit where the resistance remains constant (this will be the case of the MudWatt fuel cell). Assume a 20 Ω resistor is used in a circuit.

a. If the resistance is 20 Ω, what is the current when the voltage is 5V? $\frac{5}{20} = \frac{I(\cancel{20})}{\cancel{20}}$ $I = 0.25A$

b. If the resistance remains 20 Ω, what is the current when the voltage increases to 10V? $\frac{10}{20} = \frac{I(\cancel{20})}{\cancel{20}}$ $I = 0.5A$

c. Fill in the blank: If the resistance is constant, as the voltage increases, the current __increases__.

d. If the resistance in the circuit remains constant, what type of relationship (direct or inverse) describes how the current and voltage are related? There is a direct relationship because as one variable increases the other also increases.

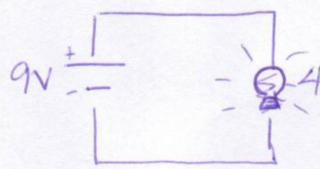
3. What type of relationship exists between voltage and resistance when the current remains constant? Give 2 example calculations that support your conclusion.

There is a direct relationship between voltage and resistance when current is constant. Examples:

$\frac{10}{2} = \frac{2(R)}{2}$ $R = 5\Omega$ $\quad \frac{20}{2} = \frac{\cancel{2}(R)}{\cancel{2}}$ $R = 10\Omega$ As the voltage was increased, the resistance increased.

IV. Engineering a Circuit

1. Using the Virtual Lab, create and then draw and label a circuit that uses wire, one light bulb, one battery, and has a current of 2.25A.



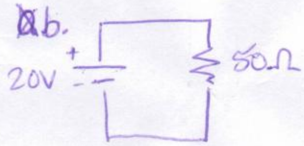
$I = \frac{V}{R}$

$I = \frac{9}{4} = 2.25A$

2. a. Create a circuit with one resistor, one battery and some wire (do not use the default settings). Draw and label the circuit, and determine the current.

b. Without changing the voltage on the battery, make your circuit have ½ the current. Draw and label this circuit, and determine the current.

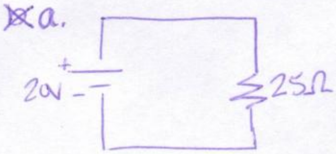
~~A~~b.



$I = \frac{20}{50}$

$I = 0.4A$

~~B~~a.



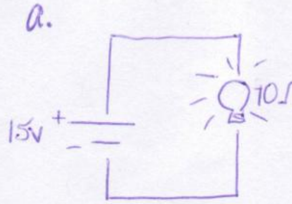
$I = \frac{20}{25}$

$I = 0.8A$

3. a. Create a circuit with one light bulb, one battery, and some wire (do not use default settings). Draw and label the circuit, and determine the current.

b. Without changing the voltage on the battery, make your light bulb shine brighter. Draw and label the circuit, and determine the current.

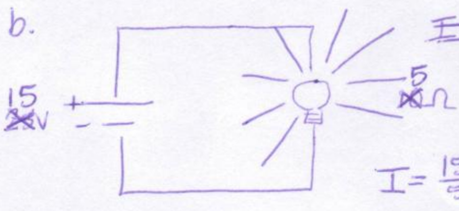
a.



$I = \frac{15}{10}$

$I = 1.5A$

b.



~~$I = \frac{25}{10} = 2.5A$~~

$I = \frac{15}{5} = 3A$

4. Summarize at least 3 important ideas you learned about current, resistance, voltage, batteries, light bulbs, and resistors.

- a light bulb acts as a resistor in a circuit
- holding voltage constant, to decrease current, increase resistence
- current is always determined by voltage divided by resistance