Grass Roots GK-12 Laboratory Activity

Title:	**Energy from Waves (Shake Light Pre-Lab Version)**
Initial Version: **Revision:**	Rev. 1 – August 4, 2014 Rev. 2 – December 21, 2014
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Course & **Appropriate Level:**	Physics, STEM – Renewable Energy, Physical Science (?) 8 – 12
Abstract:	In this activity students will build a device to harness electrical energy from waves. The purpose of this activity is to demonstrate the working principles of one type of renewable energy: tidal or wave energy. After building their devices, students will be able to observe, measure, and record the power output through DataStudio®, determine the electrical energy produced and calculate the efficiency of their device.
Time Required:	80 minutes
NY Standards Met:	*Highlights: Standards 1, 4, 6, and 7* *See appendix for full description*
Special Notes:	None

Student Learning Outcomes:

Upon completion of this lab activity, students should be able to:

- Perform an energy efficiency analysis of their wave-energy harvesting device
- Measure and analyze fundamental variables from the experiment: voltage, current, power output
- Predict the way in which material and wave properties affect the obtainable power output
- Connect their engineering analysis to a financial analysis by calculating a pay-back-period for their device
- Understand the concept of conservation of energy
- Understand the basic principles of magnet-induced electric current
- Discuss under what conditions would the efficiency of the wave-energy generator improve

Class Time Required:

- 10 minute discussion/intro
- 30 minute lab – build magnet-bobber device
- 20 minute – data collection
- 20 minutes – analysis, calculation, and discussion of results

Teacher Preparation Time:

- 10 – 15 minutes of lab set up: distributing lab materials, etc.

Tips for the Teacher:

- This lab involves splashing water – keep laptops elevated and as far from wave tank as possible.
- For a typical device the voltage outputs are very low, O(mV)
- The data acquisition device that you use should have high time-resolution in order to capture the electricity generation dynamics of the system
- You need software that allows you to post-process the data (we used Pasco PasPort equipment and DataStudio® to record and analyze the data.)

Assumed Prior Knowledge of Students:

- Kinetic energy concepts
- Magnetic induction (From the Shake Light Lab)
- Basic equations of circuits relating power, Ohm’s law, and energy.
- Manipulate and plot data

Background Information for Teacher:

For this version of the lab, students should have completed the shake light lab, in which they would have constructed a shake light coil, necessary for the pre-lab activity. The pre-lab activity serves two purposes; to instruct students how to setup and use the voltage/current sensor to properly collect and analyze power data from the wave generator and to help expose them to an engineering application in which the mechanical energy used to produce relative motion between a magnet and a coil of wire is harnessed from a renewable natural resource rather than one's hand.

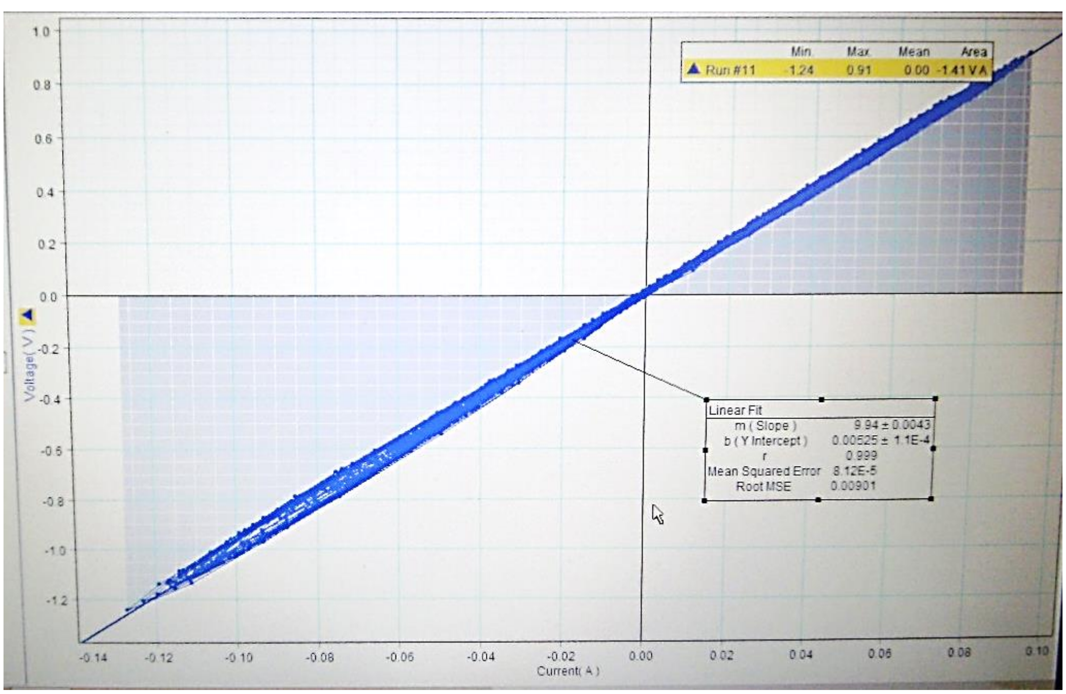
Discrepant Event:

Unlike most experiments performed at this level, the energy generation efficiency of this device is extremely low relative the theoretical maximum. This low efficiency requires further discussion about the losses in the system and how the wave behavior would be changed if the device were more efficient.

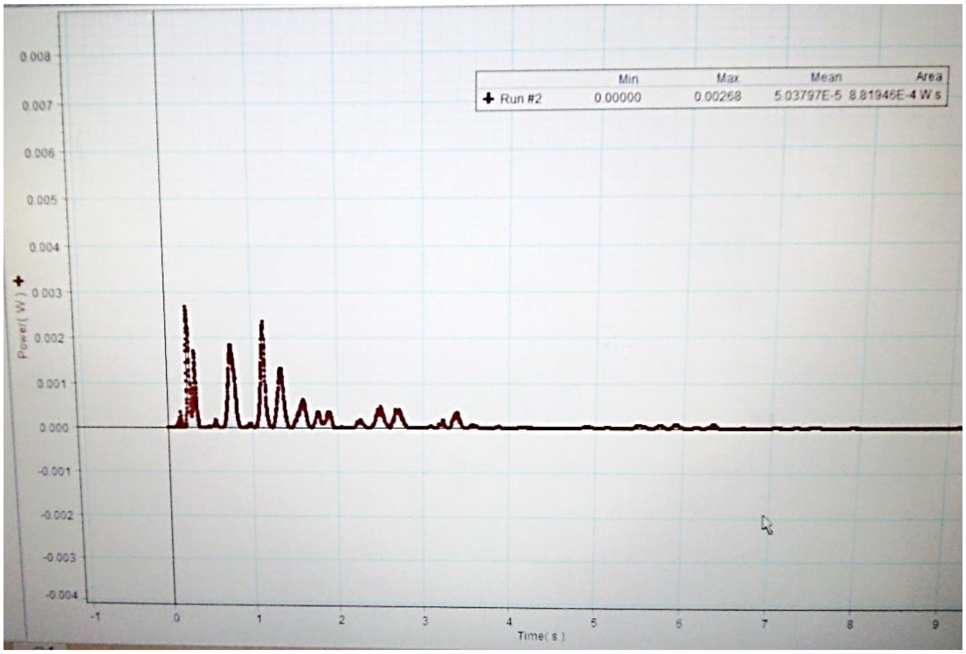
Experimental Data:

The picture below is of a typical voltage-current graph from the shake light Pre-Lab. Students will be tempted to think that the area is power, since units of area are V·A = J/s = W. It is the instructor's duty to make sure that notion is dispelled. A good question to ask is whether the shake light produced the maximum value of voltage and current the entire time. They should realize that wasn't the case. The area of this graph, then, represents the maximum power possible, if the shake light had produced a constant maximum voltage and current in the circuit.

Also note that the slope of the line is about 10 V/A, which does represent the constant value of resistor used for the circuit. Make sure students see this. Even though voltage and current varied, the constant through the entire trial (the slope) was the resistance of the resistor. This is a really nice representation of Ohm's Law, R = V/I.



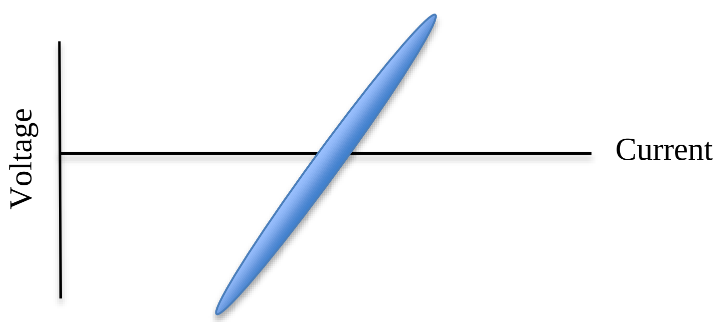
The next picture is representative of the power-time graphs from part 7 of the Wave Generator Investigation. The area of this graph is the total energy produced in W·s (J). The students should see that these generators produce much less energy than the shake light generators, as the waves dampen quickly over time.



NOTE: Make sure that when students collect their first set of data for this type of graph in the pre-lab that they double click on the data set under “Summary” select the “numeric” tab and set “fixed decimals” to 5 digits to the right of the decimal. Also, especially for the wave investigation, it will be difficult to see the power peaks. Remind students to use the “scale to fit” button in the upper left hand corner of the graph.

Answers to questions during the Pre-lab:

1) [Generate a graph of voltage versus current for the shake light...Sketch what the graph looks like on the axis below.]



2) [Record the slope below. What is the significance of the slope and how do you know?]

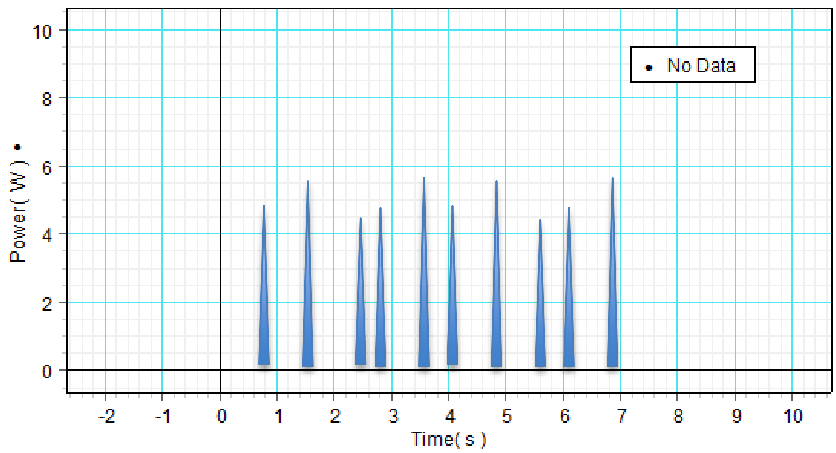
slope = 10.0 V/A

The slope is the constant value of the resistor, Ohm's Law states that voltage divided by current (the slope, in this case) is resistance.

3) [What do you think the area of the graph represents?]

Power.

4) [Sketch the shape of your trial on it.]



5) [Compare the area from the voltage-current graph with the power-time graph. Explain why the area of the voltage-current graph is not the true power produced by the shake light coil.]

The total power is far less than the area of the voltage-current graph might suggest. The true power produced is shown on the power-time graph. Students should realize that the maximum values of voltage and current were not kept constant (as the first graph area would suggest, since the area corresponds with the maximum values during the shaking).

6) [Determine the area of the power-time graph, and note the units. What does this area represent?]

Areas will vary, based on how the students shook the shake light apparatus during the trial. The area represents the total electrical energy produced during the shaking period.

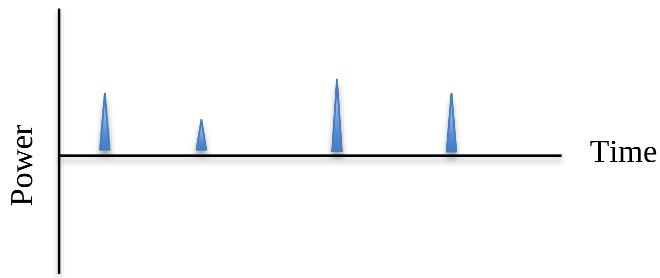
Answers to questions during the Wave Generator Investigation:

1) [Determine the total energy produced in the circuit and record below.]

   The total energy will vary, depending on how the students generated the waves. The students should know to find the area under the curve to determine the total electrical energy produced in the circuit.

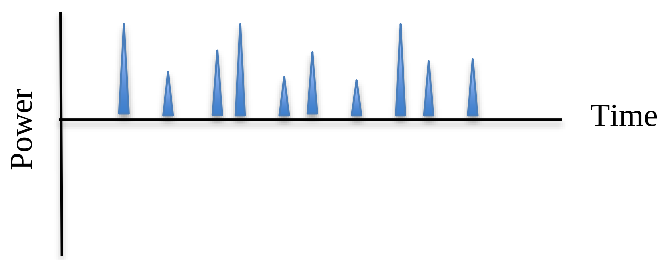
2) [Sketch the power vs. time graph, and explain how you found the total energy in the circuit:]

   Found total energy by finding graph area under the curve.



3) [Increase the frequency of the waves. How does this impact the power versus time graph and the total energy produced?]

   More peaks, closer together, greater total energy.



4) [Explain why the change in energy that occurred at higher frequency happened.]

   More peaks means greater area, which is the total energy.

5) & 6) [Increase the amplitude of the waves. Does this impact the power-time graph and energy? Explain this result:]

When amplitude is increased starting from a small wave, the power output will increase, but if the waves were larger to begin with, increasing the amplitude will produce little to no effect on the power output. This is because current is only generated when the magnet travels through the wire coil, which would set physical limits to the stroke length which produces power. If the maximum stroke length is not exceeded, power will increase. After the wave amplitude exceeds this stroke distance, however, no additional power is generated.

7) [Measure the height of the water level in the tank and record:]

Eighteen to twenty-two centimeters.

[Calculate the gravitational potential energy that the block would possess if it were held at the tank's water level]

PE = mgh = (10.9 kg)(9.81m/s^2)(.200 m) = 21.4 J

[Determine the total energy produced during this sampling window as before and record.]

Total energy will vary, but will be quite small (on the order of 10^{-3} to10^{-5} joules)

[Calculate the energy conversion efficiency of your device.]

$$\eta = \frac{E_{out}}{E_{in}} * 100 = \frac{3.8765 \times 10^{-4}}{21.4} * 100 = 0.00181\%$$

Answers to post-lab questions:

1. [How does the power generated and efficiency of the wave apparatus compare to that of the shake light? Explain why you think so.]

   The power developed in the shake light over 20 seconds is greater than that of the wave generator. The area of the power-time graph is greater for the shake light. Be sure students do not confuse this with efficiency. They may tend to think the shake light is more efficient due to the greater power, but without having established the input energy, determining the efficiency of the shake light is not possible.

2. [If your device were 100% efficient, how would the waves behave?]

   If the device were 100% efficient it would remove all of the kinetic energy from the wave and the wave would completely stop as soon as it made contact with the bobber.

3. [Is this feasible? Explain why you think so.]

   No. The operation of the wave generator requires that the ocean wave completely pass the generator. Therefore, no wave generator can truly be 100% efficient.

4. [Your device cost $20 to produce. If you were to drop the brick every ten seconds to generate electricity from your device, how long will it take you to make back your $20? [Assume electricity is valued at 12 cents/Kilowatt-hr]]

   Drops per hour = 3600 s / 10 s per drop = 360 drops per hour
   Energy harvested per hour = 3.8765×10^{-4} J/drop * 360 drops/hr = 0.1396 J/hr
   $ generated per hour = (0.12 $/(1000W * 3600s)*(0.1396 J/hr) = 4.6533×10^{-9} $/hr
   Payback time = 20 $ / (4.6533×10^{-9} $/hr) = 4.298×10^{9} hr = 490,640 yea

I. Materials List (alternative)

1. Patio stone or rock (we used a 10.9-kilogram red retaining wall block)
2. PasPort® voltage/current sensor with USB Link

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3. Fishing line
4. Magnet wire
5. Suction cup with eyelet hole on top
6. Section of pool noodle with hollow center
7. 15 mL centrifuge tube
8. Magnets
9. Bobbers
10. Plastic bin (66 Qt.)

II. Assembly Instructions (refer to Assembly Diagram next page)

1) Wind magnet wire around the center of the centrifuge tube (approximately 50 meters) to make the wave coil assembly. Leave a half-meter of wire hanging on either end to connect to the voltage probe. Be sure to remove approximately 1 centimeter of coating on the magnet wire with sand paper at each loose end of the wire for good electrical contact.

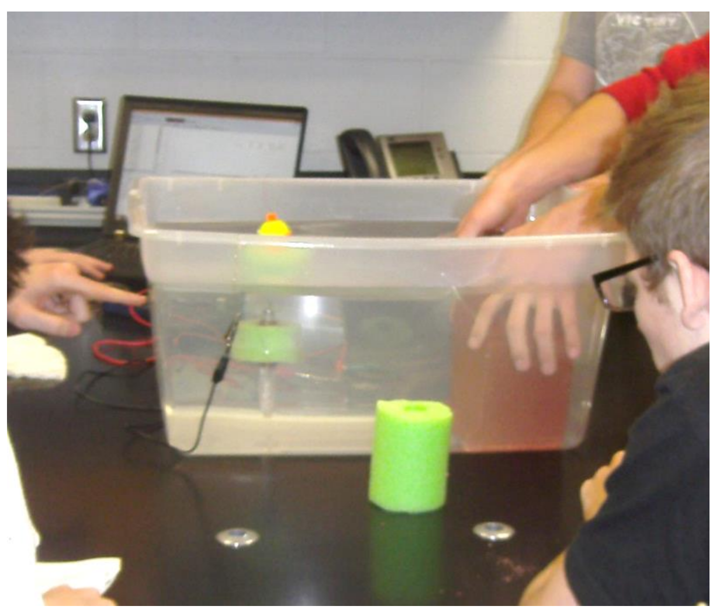
2) Slice open one of the pool noodle sections and insert the centrifuge tube. Reseal the noodle with the tape provided, ensuring both wire leads come out of the top of the noodle.

3) Fill the plastic bin with water until the water level is about 15 centimeters from the top. This will help to minimize spill.

4) Tape a loop of fishing wire to the bottom of the centrifuge tube (pointy end) then tie it to the suction cup. The centrifuge tube should be about 5 centimeters from the suction cup.

5) Attach the suction cup to the bottom of the tank. Place the suction cup approximately 15 centimeters from one end of the container to allow free movement of the wave coil assembly.

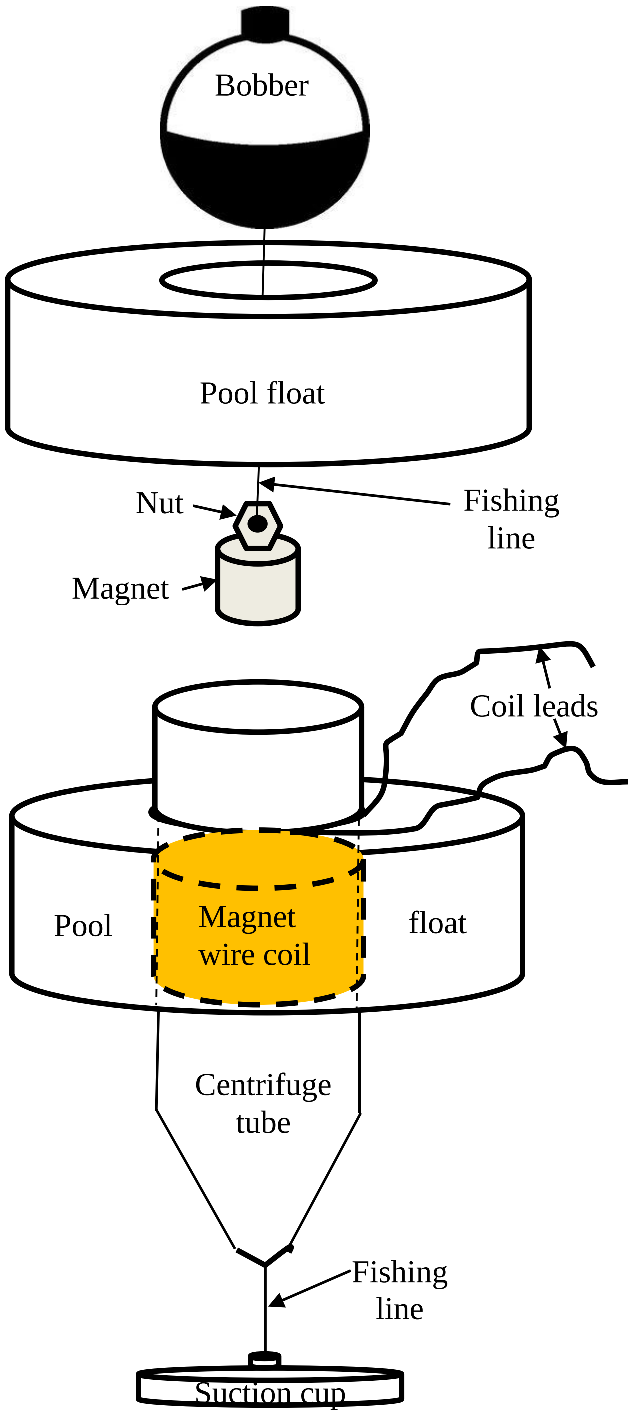
6) Attach the small nut provided to a flat side of the magnet (they will attract magnetically) and tie a loop of fishing line to the nut, run the line through the other section of pool noodle, then secure the loop to the fishing bobber. Make the fishing wire loop is long enough so that the magnet will hang in the center of the wire coil when suspended in water above the centrifuge tube.



7) Lower the magnet into the centrifuge tube until the bobber assembly floats on the surface of the water. Adjust length of the fishing line if necessary. Make some waves to ensure the magnet assembly does not lift off from the wave coil assembly.

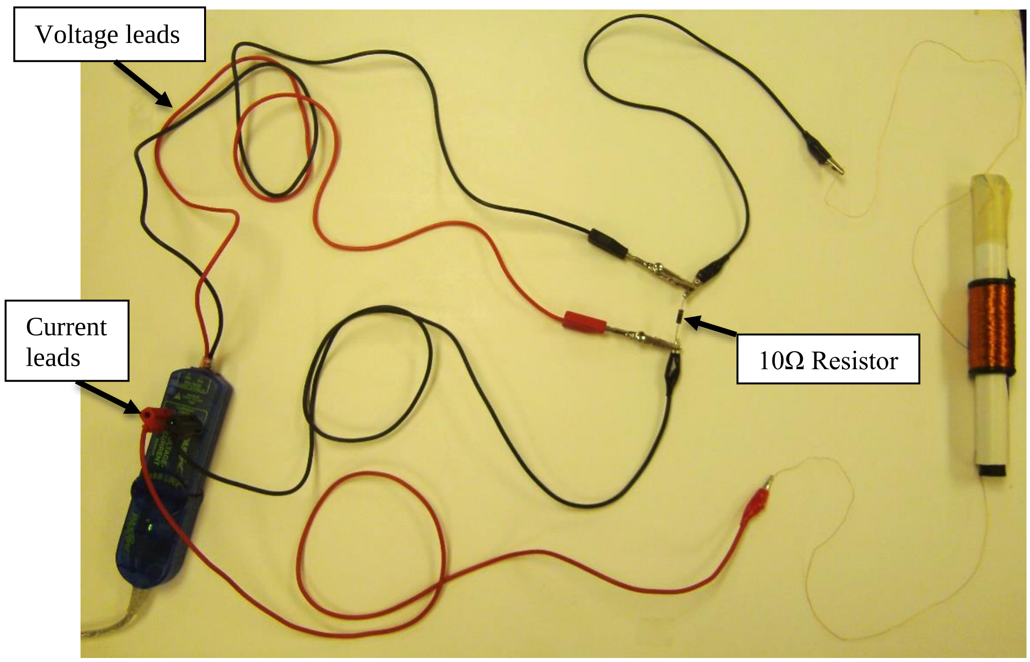
8) You are now ready to begin. Proceed with the Pre-Lab Activity, Determining Power of the Shake Light.

Assembly Diagram

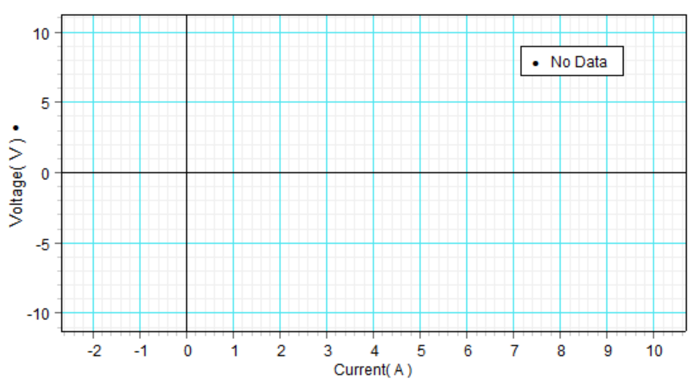


III. Pre-lab Activity: Determining Power of the Shake Light

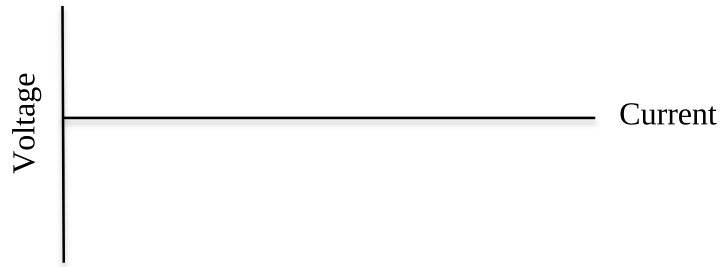
1) Find the 10-ohm resistor (Band colors: brown, black, black, gold) at your station. Connect it to your shake light coil apparatus and the voltage/current probe as shown in the picture below. Note that the voltage probe leads are connected parallel to the resistor, and the current leads are in series between one of the shake light's leads and the resistor.



2) Plug the USB link into the laptop and launch DataStudio® when the prompt screen appears. There will be a digital display of voltage and current. Close this display and click "ok." To set up the experiment, click "Setup" and when the experiment setup window appears you will see that voltage and current are selected. Select power as well and set the sample rate to 1000 Hz. Close the experiment setup window and double click "Graph" under "Displays" in the bottom left-hand corner of your screen. Select a voltage-time graph. When the graph appears, left-click on the x-axis title, time, and select "current" from the menu that appears. You should now have a graph of voltage versus current that looks like this:



3) Generate a graph of voltage versus current for the shake light. Press "Start" to begin data collection and then shake the flashlight for 20 seconds. Then press stop. Sketch what the graph looks like on the axis below.

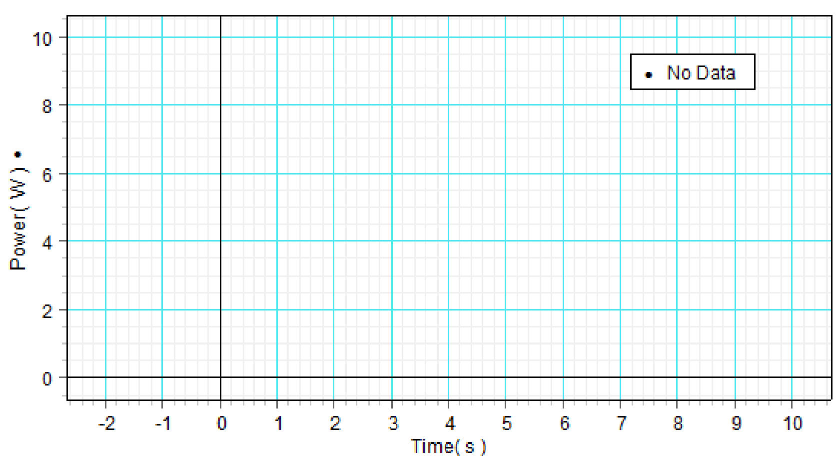


4) If the circuit is properly connected, your graph should be linear. If not, check the circuit and try again. Once your graph is linear, do a linear fit to get the slope of the line. Record the slope below. What is the significance of the slope and how do you know?

slope = ____________

5) Click the drop down tab next to the Greek letter sigma (Σ) and select "area" to determine the area of the graph. What do you think the area of the graph represents?

6) Now look at a graph of power versus time for the trial. Display a graph of power versus time by selecting "Graph" under "Displays" and selecting a power vs. time graph. A graph similar to the one shown below should appear. Click the "scale to fit" button on the top left hand corner of the graph as needed to properly view the graph. Sketch the shape of your trial on it.



7) Compare the area from the voltage-current graph with the power-time graph. The value may be quite small, even reading zero. To correct, click on the colored data set under “Summaries” and select the “numeric” tab, and set “fixed decimals” to 5 digits to the right of the decimal. Now you should have a value for area. Explain why the area of the voltage-current graph is not the true power produced by the shake light coil.

8) Determine the area of the power-time graph, and note the units. What does this area represent? [NOTE: Check your answer with the instructor before proceeding to the next step.]

9) Disconnect the alligator clip leads that are attached to the shake light coil magnet wire leads and connect them to the wave generator coil magnet wire leads (we will use the same circuit with 10-ohm resistor for the Wave Generator Investigation).

10) Proceed to Part IV – Wave Generator Investigation and Analysis.

IV. Wave Generator Investigation and Analysis

1) Move the bobber assembly up and down slowly for 15 seconds, and observe the power time graph produced. Determine the total energy produced in the circuit and record below.

Energy _______J

2) Sketch the power vs. time graph, and explain how you found the total energy in the circuit:

3) Increase the frequency of the waves (move the bobber up and down faster). Sketch the graph. How does this impact the power versus time graph and the total energy produced?

4) Explain why the change in energy that occurred at higher frequency happened.

5) Increase the amplitude of the waves (same frequency, but larger disturbances). How does this impact the power-time graph and energy?

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6) Explain this result:

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7) This next investigation can be messy. Place several layers of paper towels around your wave tank. You will be creating the next disturbance in the tank with the 10.9-kilogram red stone retaining block. Follow the procedure below:

   b. Measure the height of the water level in the tank and record:

      h =________ m

   c. Using the given mass of the block and the height of the water in the tank, calculate the gravitational potential energy that the block would possess if it were held at the tank's water level [show calculation below].

      PE = _________ J

   d. Simultaneously start recording data from your wave coil apparatus and drop the block into the tank. [NOTE: For best results, hold the block vertically and slightly lower the block until it breaks the surface tension of the water and then let go of the block. This will also reduce the amount of splash over.

   e. Record data until the water is calm or you no longer see power peaks on the graph of power vs. time. Determine the total energy produced during this sampling window as before and record. This is the amount of electrical energy successfully converted from the mechanical energy of the waves.

      Total Energy = _________ J

   f. Calculate the energy conversion efficiency of your device [show calculation below] and then answer the Post-Lab Analysis Questions on the next page:

V. Post-Lab Analysis Questions

1. How does the power generated and efficiency of the wave apparatus compare to that of the shake light? Explain why you think so.

2. If your device were 100% efficient, how would the waves behave?

3. Is this feasible? Explain why you think so.

4. Your device cost $20 to produce. If you were to drop the brick every ten seconds to generate electricity from your device, how long will it take you to make back your $20? [Assume electricity is valued at 12 cents/Kilowatt-hr]