Cornell University Grass Roots GK-12 Program

Advancing Research in Renewable Energy and Cleaner Fuels

The Shake Light STEM Unit Overview

How to have Students derive Faraday's Law of Electromagnetic Induction and learn a lot about AC power generation by building, exploring, designing circuits for, and analyzing the output of, a simple shake flashlight.

(...A Modeler's Approach)

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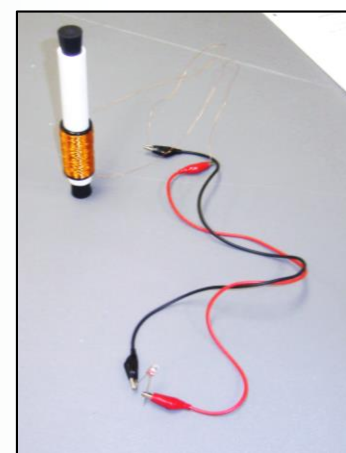


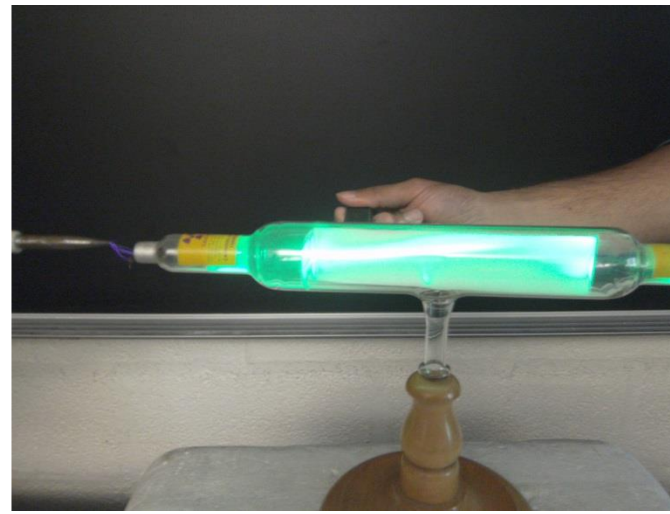
The Model:

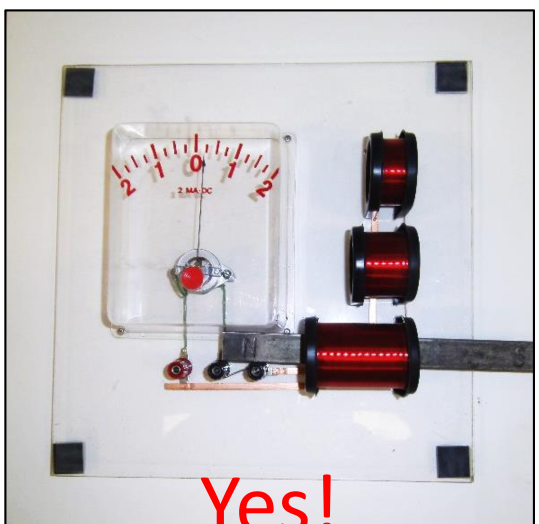
Relative motion between a magnetic field and a conductor causes magnetic force to be exerted on the charges within the conductor, which can cause charge separation, thereby inducing a voltage (an electromotive force) in the conductor, which can then be harnessed to produce electrical power. This phenomenon is referred to as **Electromagnetic Induction**.

Note: the idea of this unit is for students to develop their own models of electromagnetic induction and AC power generation. For best results, teachers should take on the role of facilitator rather than instructor, by carefully laying out the learning experiences in a logical manner, but allowing students to discover with minimal guidance.

Step 1 – Introduce Electromagnetic Induction.

Show that moving charges experience magnetic force when there is relative motion between them and a magnetic field.

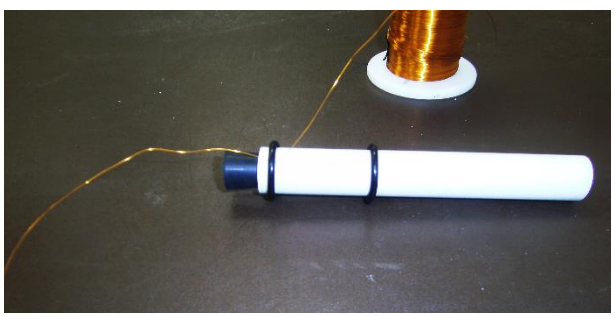




<u>Question</u>: Can we exert magnetic forces on charges within a wire to cause them to flow as current?

Step 2 – Construct the Apparatus 1 Shake Light

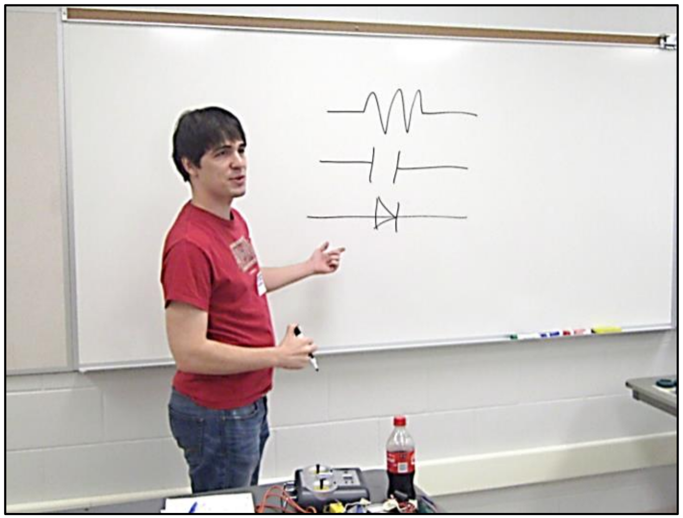
- PVC body tubes
- Magnet wire
- #15 O-rings
- #1 rubber stoppers



- Electric drill
- Patience!

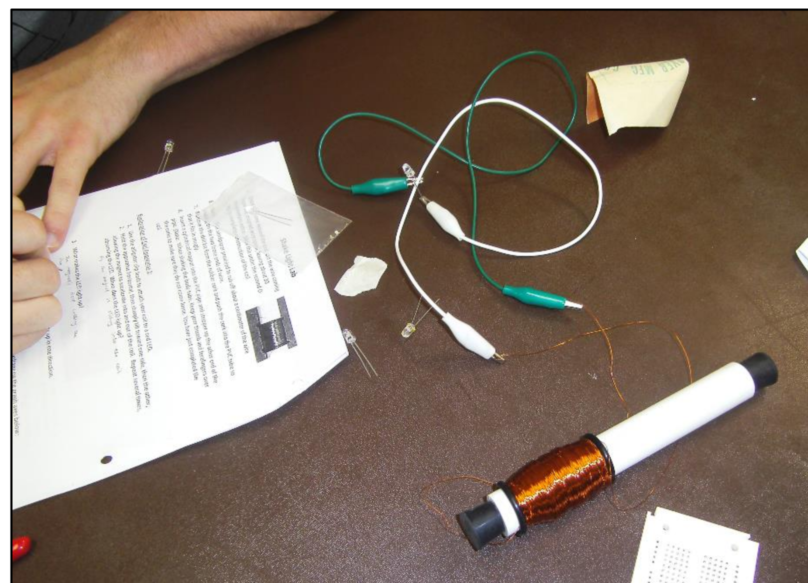
Students spool 100m of magnet wire onto the body tubes, so that a magnet can go in & out of the coil, not all the way through. This way students only generate either a positive or negative pulse each transition in or out of the coil.

Step 3 – Conduct the LED Pre-lab Activity



Introduce the LED and explain it acts like a one-way path for current. Students will only see their red LED light up when the magnet moves in one direction in the coil (not both). This sets up the circuit design challenges and helps develop the concept of AC versus DC voltage as well as that of rectification.

- Students make hypotheses about what's going on in the coil to make the LED light up when it does (magnet transitions in or out of the coil).
- Students test and refine hypotheses by trying to figure out how to get the LED to light up on the opposite transition.



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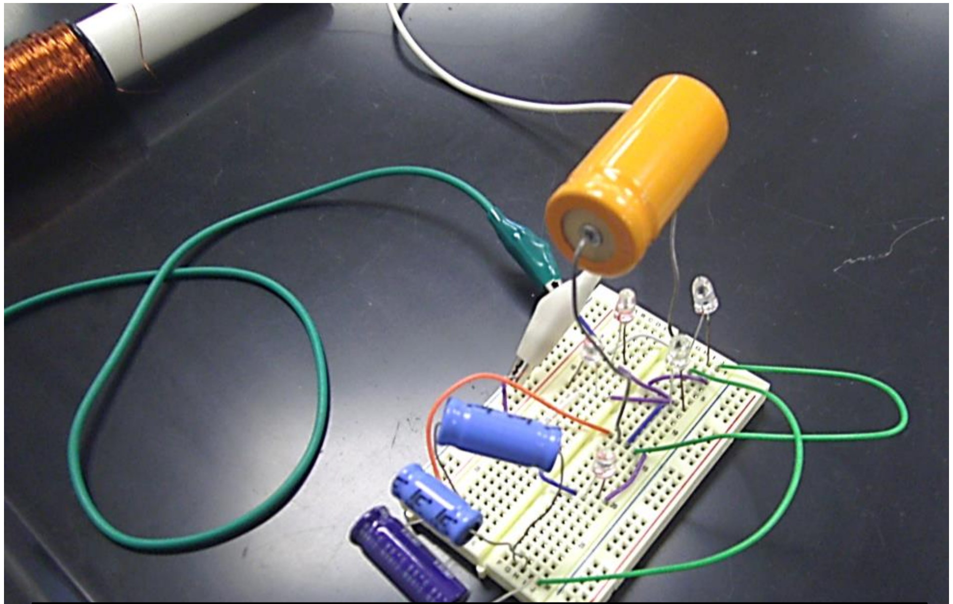
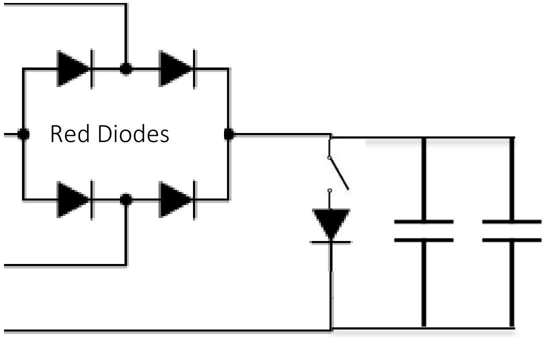
Step 4 – Circuit Design Challenge!

- Students are challenged to build a circuit that will allow the red LED to light every time the magnet transitions in and out of the coil.
- Students are then challenged to add capacitors to the circuit to see who can get their LED to stay lit the longest.
- Students are also tasked with designing a switch they can use to turn the light on and off with.

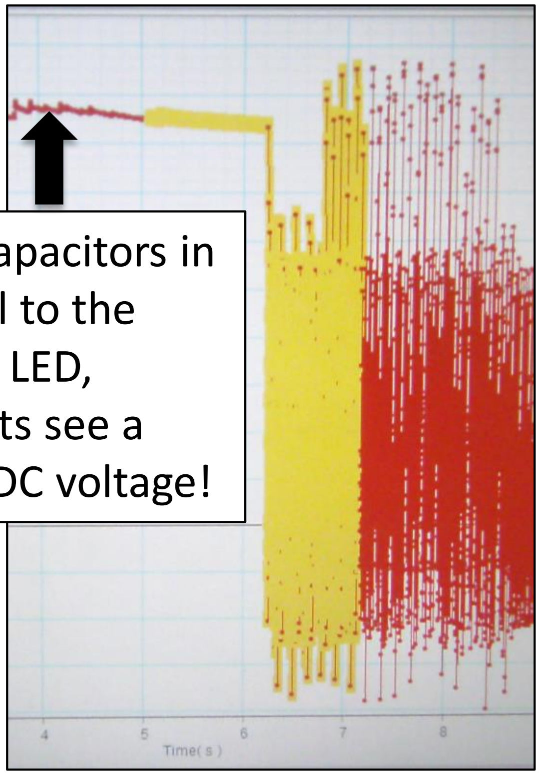
- Students end up making full-wave, four diode rectifier circuits.



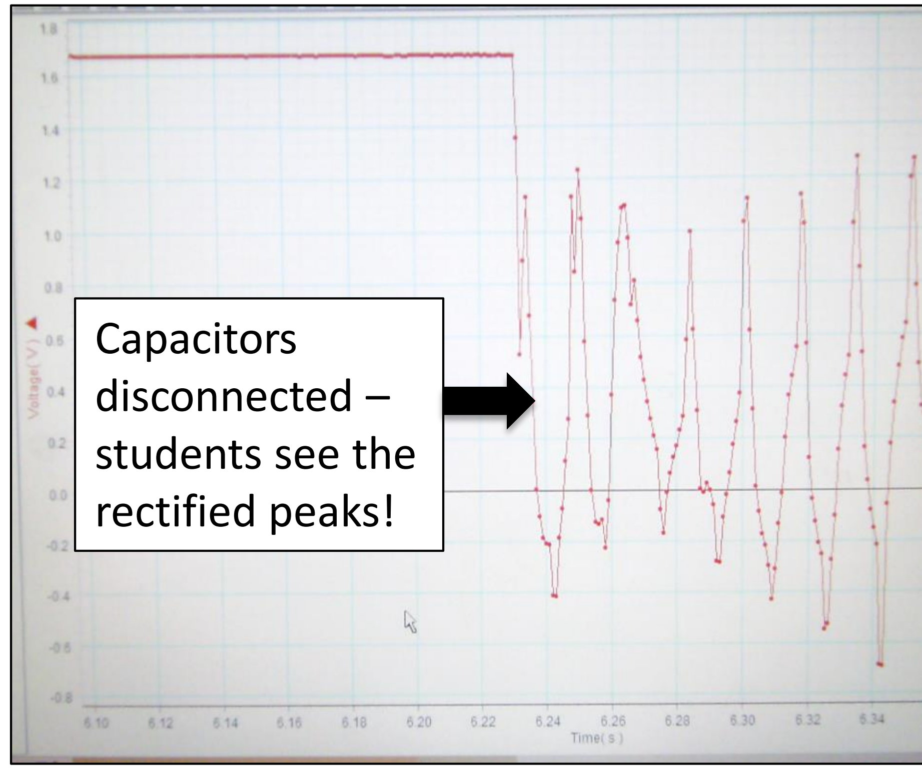
Circuit diagram 3 – example of switch properly added (in series with yellow LED).



Voltage time graphs illustrate how their circuits work!



With capacitors in parallel to the output LED, students see a ripple DC voltage!

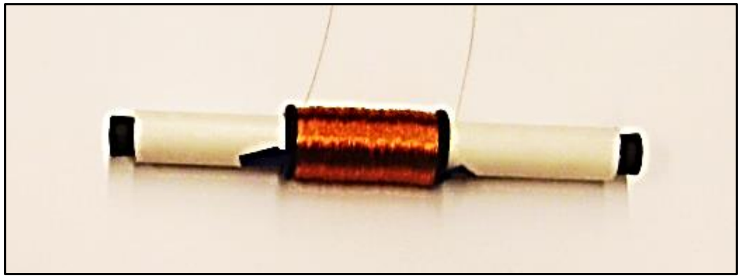


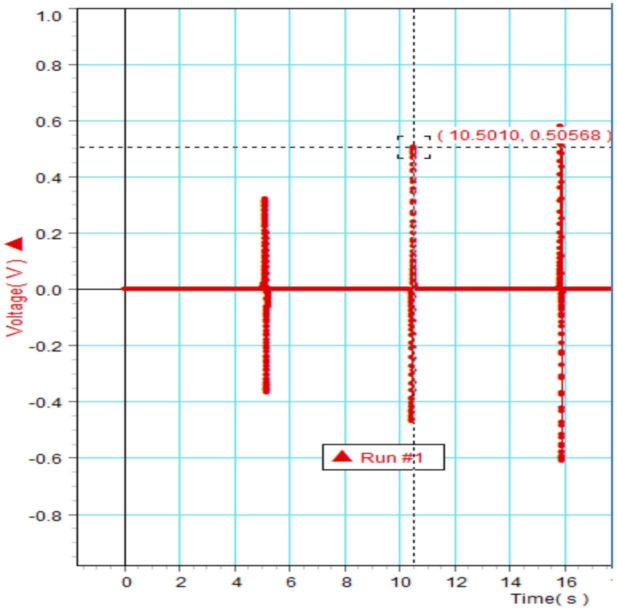
Capacitors disconnected – students see the rectified peaks!

Question: How might the output of the LED change if the magnet were allowed to travel all the way through the coil?

Step 5 – Construct the Apparatus 2 Shake Light

Students spool 100m of magnet wire onto longer body tubes, so that a magnet can go all the way through the coil. Now students generate a positive and negative pulse every time the magnet passes through the coil.

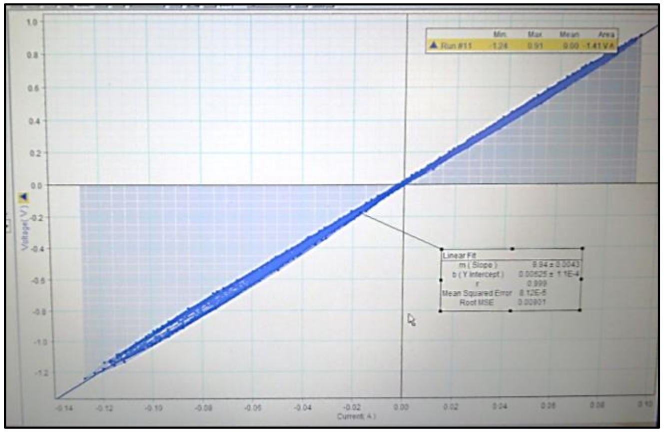


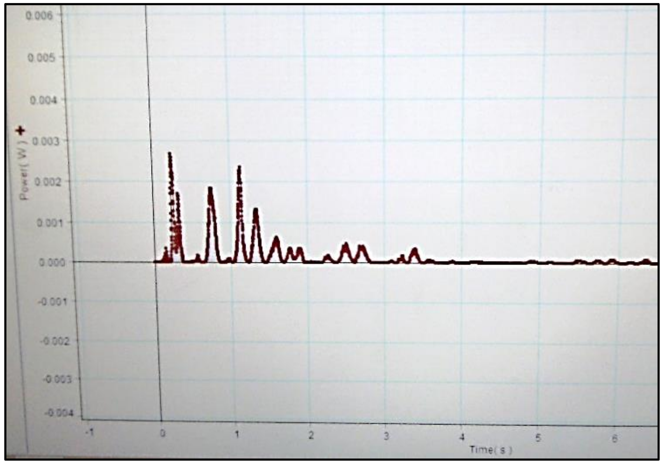


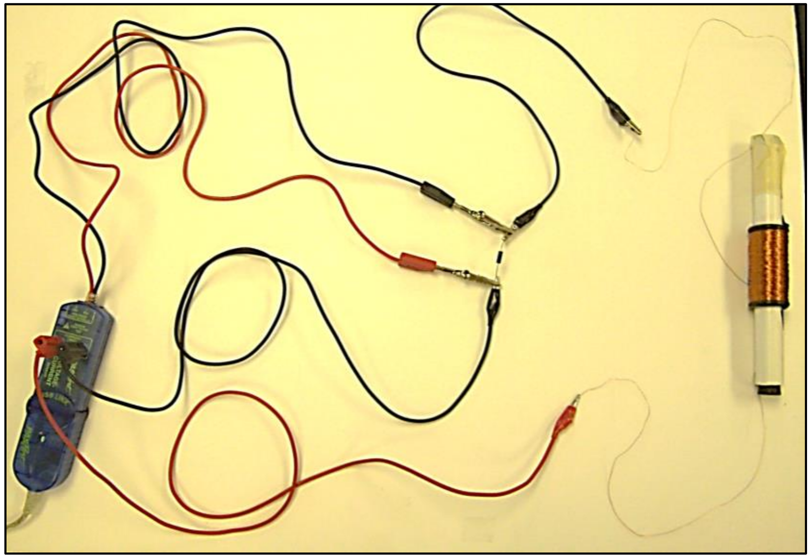
<u>Question</u>: Does apparatus 2 generate more or less power than apparatus 1? How can you tell?

Step 6 – The Shake Light Pre-lab (for the Wave Power Lab)!

Introducing the Wave Power lab in this way directly ties AC voltage concepts developed in the Shake Light project to an important application of Electromagnetic Induction in a developing renewable energy field. Students also learn how to determine the total energy produced in apparatus 2 by analyzing voltage vs. current and power vs. time graphs.





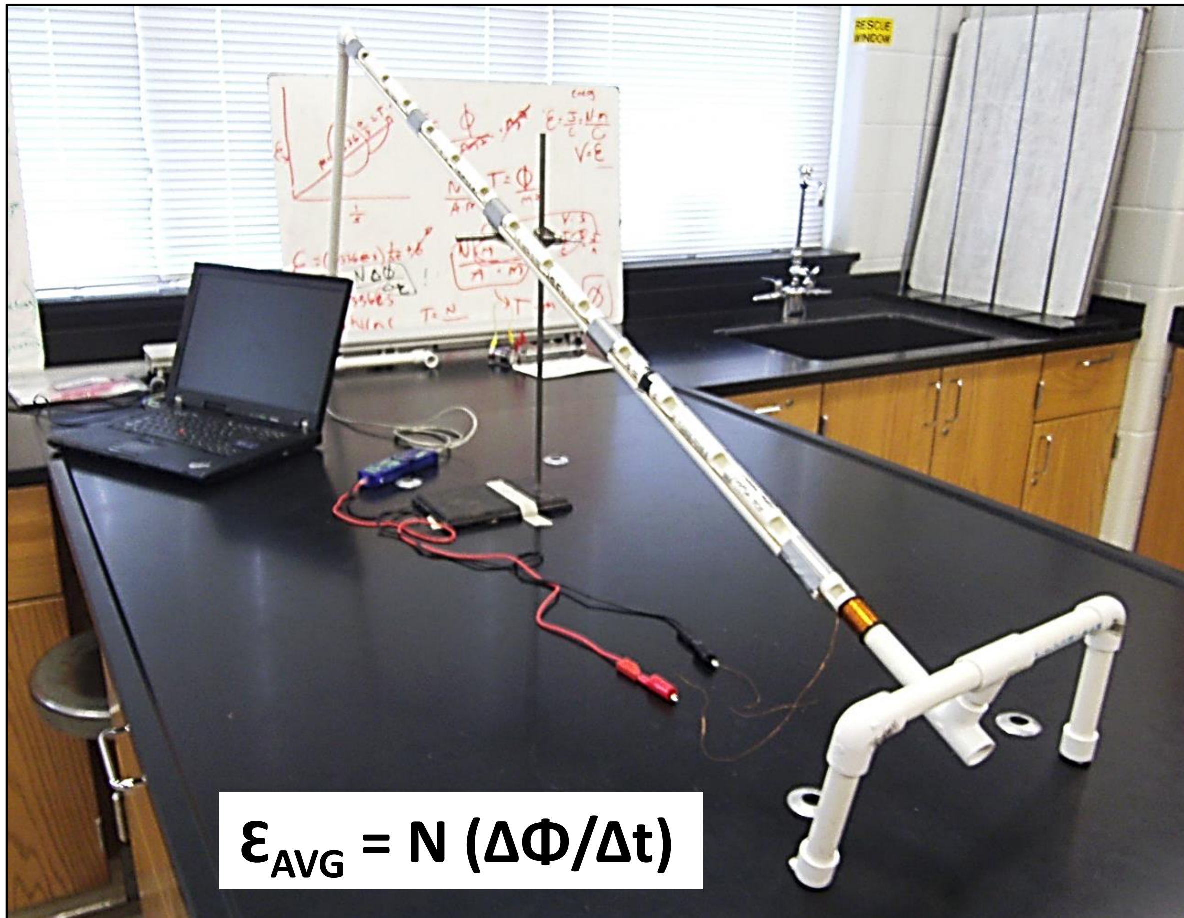


Step 7 – The Wave Lab!

Students construct an induction coil similar to their shake light coils within a pool float buoy assembly and analyze the power produced in a wave tank. From graphs of power versus time, students extract the total energy produced in the device and compute the efficiency of the device by comparing the harvested energy with the energy used to produce the waves.

The LinMAc (Linear Magnet Accelerator) Investigation!

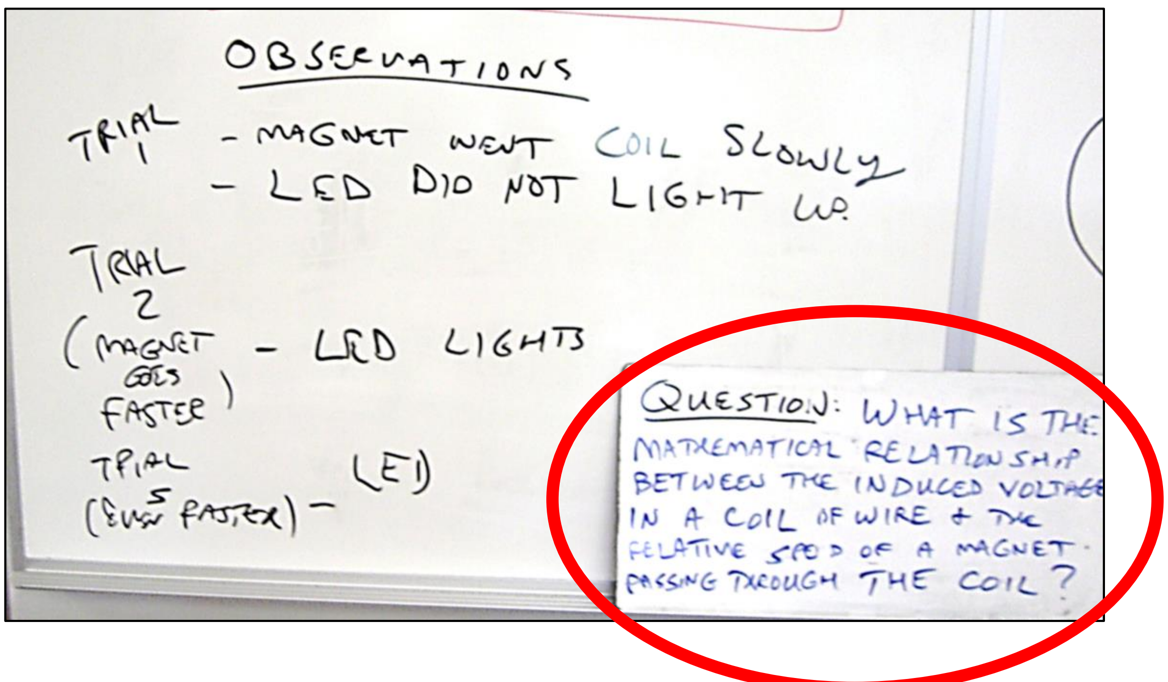
The LinMAc investigation is the culminating experience of the unit. Students actually derive Faraday's Law of Electromagnetic Induction, using a coil similar to that of the shake light lab, except that this coil is wound onto an inclined, elongated body tube. Ultimately, they will use the relationship to predict the average induced voltage in their coil for a given Δt and the known total change in flux.

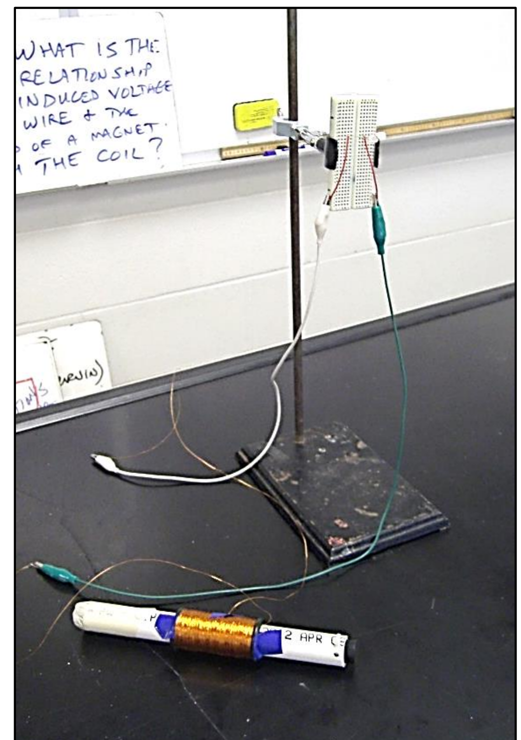


$$\varepsilon_{AVG} = N\,(\Delta\Phi/\Delta t)$$

Step 8 – Revisit the Shake Light (demonstration)

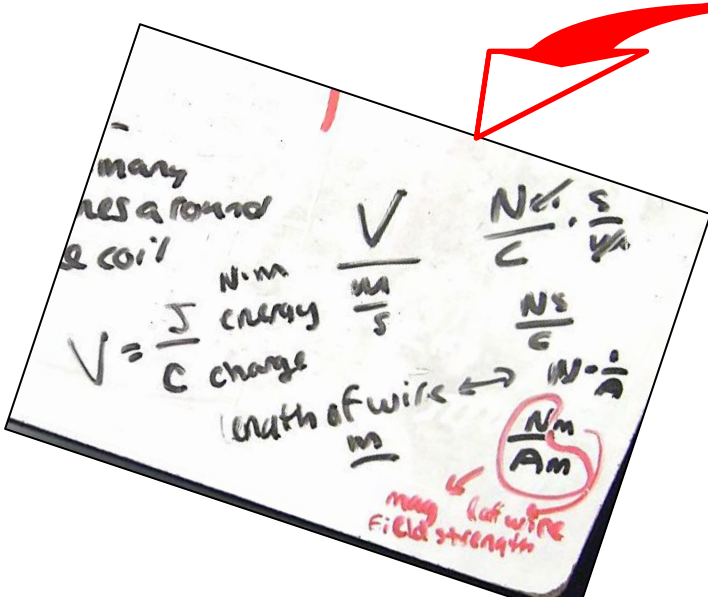
Now it's time for the students to develop graphical and mathematical models of electromagnetic induction. To introduce the LinMAc, students made observations of an LED attached to apparatus 2. The speed of the magnet through the coil was varied, and students were asked to determine the mathematical relationship between maximum induced voltage and speed of the magnet entering the coil.

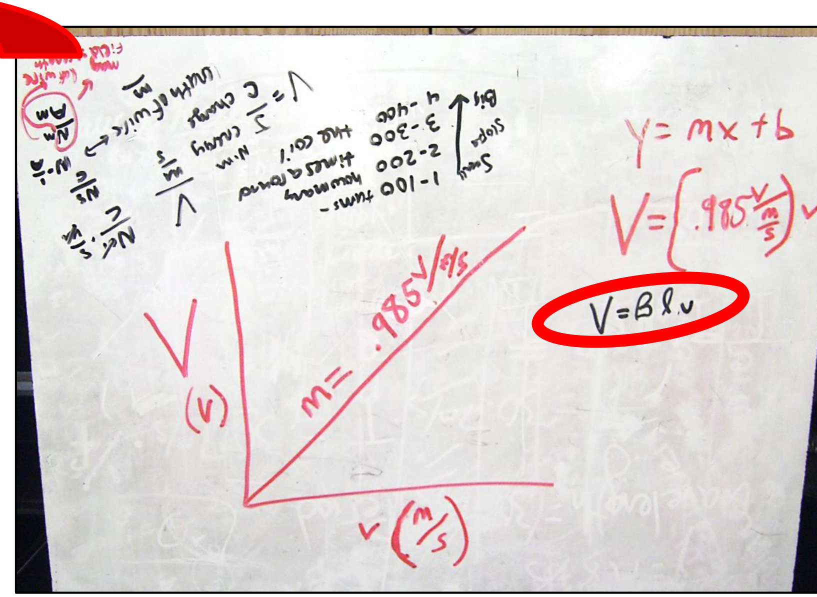




Step 9 – The LinMAc! (Linear Magnet Accelerator)

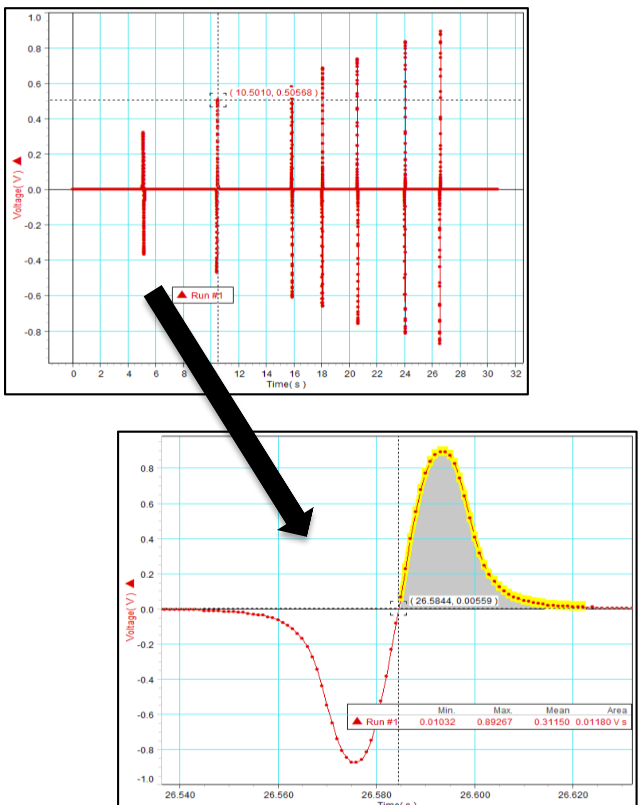
The initial question of the lab leads students to find the relationship shown below (V = Blv). Analysis of units leads most students to the assumption that the slope of their graph represents the product of the Magnet's field strength and the length of wire in the coil. This is not correct, however, since the magnet moves with respect to the coil. The realization that their equation is not quite complete provides the impetus for more detailed examination of the data and provides an excellent opportunity to learn about motional EMF.

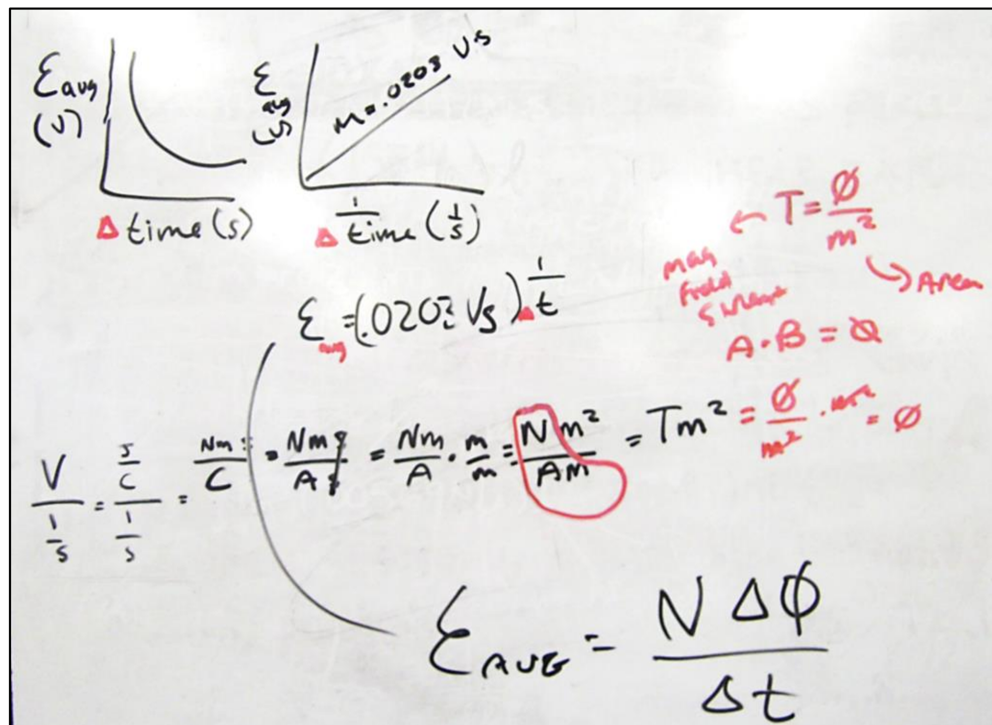




Step 10 – Final Analysis of the LinMAc data

Once guided to the idea that the time of the flux change is the important variable, rather than the speed of the magnet, students go back to their initial graphs and collect time and average induced voltages and derive the complete (and correct) mathematical relationship.





The Next Step: Wind Power Unit

Currently under construction

Students will learn about another important renewable energy resource, wind power, build and analyze wind turbines to learn how Electromagnetic Induction is applied in this field to convert mechanical wind energy to electrical energy.

Cornell Grass Roots GK-12 Program

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