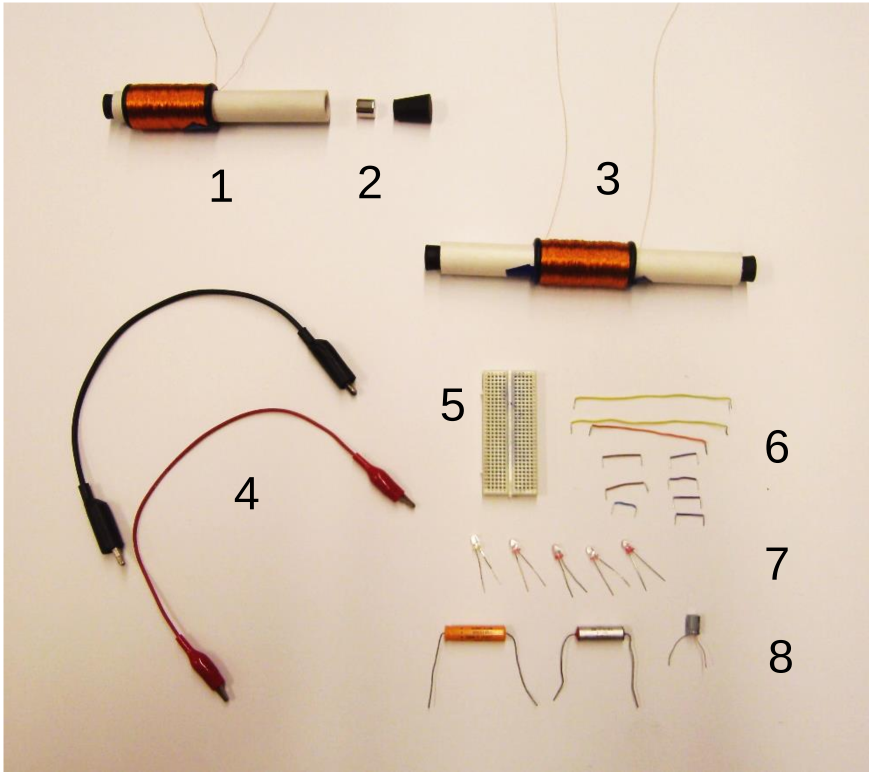
Shake Light – A Model of Electromagnetic Induction

I. Introduction

In this investigation, you will construct a basic "shake light" flashlight and use the apparatus to learn how voltages are produced by relative motion between magnets and wires. This method, called electromagnetic induction, is the most common method for producing power.



II. Materials List

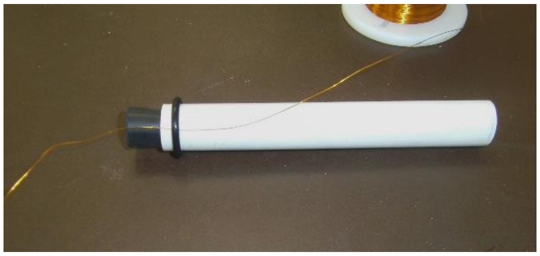
1. Coil Apparatus 1 (Short body tube – 100m magnet wire coil, wound near one end, with #1 rubber stoppers at each end)
2. slug magnet (3/8" x1/2")
3. Coil Apparatus 2 (Long body tube – similar coil, but center-wound magnet wire)
4. alligator to alligator clip cables
5. small bread board
6. set of small bread board wires
7. LEDs (3mm – one yellow, 4 red)
8. various capacitors

III. Shake Light Assembly Instructions

Purpose: To construct a basic "shake light" flashlight and use the apparatus to learn how voltages are produced by relative motion between magnets and wires. This method, called electromagnetic induction, is the most common method for producing power.

Instructions for Coil Apparatus 1:

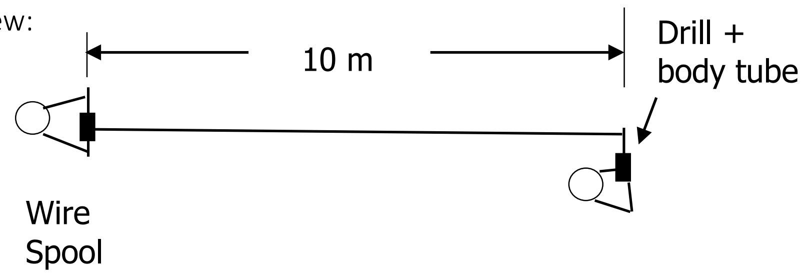
1. Obtain the short length of PVC pipe. Slip one of the #15 O-rings onto the end and thread the loose end of the magnet wire under it, as shown in the diagram below. Make sure to pull about 30 centimeters of wire through.



2. Slide the other O-ring onto the other end, so that it is roughly 4 centimeters away from the first O-ring. The space between the O-rings is where you will wind your coil.

3. Insert the rubber tube stopper into the end of the PVC pipe and insert the drill bit embedded in the stopper into the chuck of the drill and hand tighten the chuck.
4. Have the person holding the spool move to a position ten meters away. SLOWLY spool 100 meters of magnet wire onto the PVC pipe, between the O-rings. IT MUST BE ALL WOUND IN THE SAME DIRECTION. Carefully spool wire onto coil so that the wire is evenly distributed along its length. [Note: It is helpful to use a small piece of masking tape to mark 10-meter increments as you go, so you will know when you have wound 100 meters onto the coil.

Top View:



Additionally, students found it helpful to use a folded piece of masking tape to guide the wire carefully onto the body tube. They used it to lift up slightly on the wire as it went onto the tube and then slowly rastered it back and forth between the O-rings.

5. Once you have wound the coil, cut the wire coming from the magnet wire spool, leaving about 30 centimeters extra. Slide this under the second O-ring to complete construction of the coil.

6. Use the fine sandpaper provided to rub off about a centimeter of the wire coating on the two loose ends of wire.
7. Remove the drill bit from the rubber cork and push the cork into the PVC tube so that it fits in snugly.
8. Insert a cylindrical magnet into the PVC pipe and stopper up the other end of the pipe. [Note: When shaking the body tube. Keep your thumb and forefingers over the corks to make sure they do not come loose. You have just completed the coil.

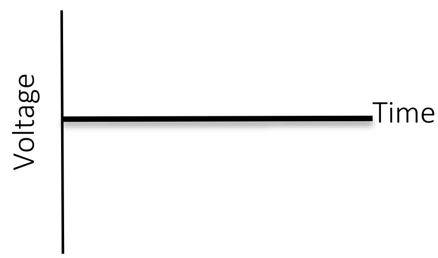
<u>Instructions for Coil Apparatus 2</u>: Construction is similar to that of Coil 1. When you are ready to make coil apparatus 2, simply wind the magnet wire from your first apparatus onto the middle of the long length of PVC pipe, using the previous method.

IV. Shake Light Pre-Lab – Exploration of Coil Apparatus 1

1. Use the alligator clip leads to attach your coil to a red LED.
2. Hold the apparatus horizontal, then tilt toward one side, then the other, allowing the magnet to slide into and out of the coil. Repeat several times, observing the LED. When does the LED light up?
3. What makes the LED light up?
4. Hypothesize why the LED only lights up in one direction.
5. Sketch what you think is happening with voltage on the graph axes below:

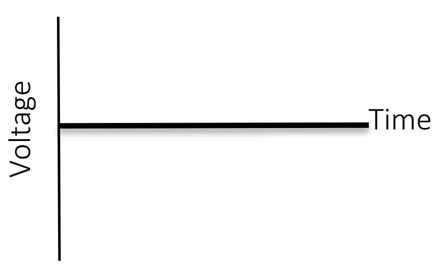
Magnet going into coil

Magnet coming out of coil

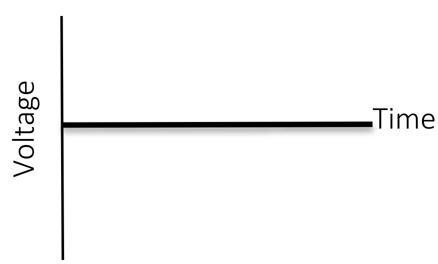


6. Disconnect the alligator clip leads from the coil. Hook the coil wire to the voltage probe provided at your station. Hold the apparatus with the magnet away from the coil and start collecting data. Then tilt the apparatus so that the magnet goes into the coil. Sketch what is happening with voltage on the corresponding graph below. Then tilt the apparatus in the opposite direction so that the magnet comes out. Sketch what is happening with voltage on the corresponding graph below. (you may need to experiment with how sharply you tilt – check with the instructor to make sure you have good graphs)

Magnet going into coil



Magnet coming out of coil



7. Is your hypothesis from question 4 supported by the graphs? [Explain why or why not.]

8. What could you do to make the LED light up in the other direction?

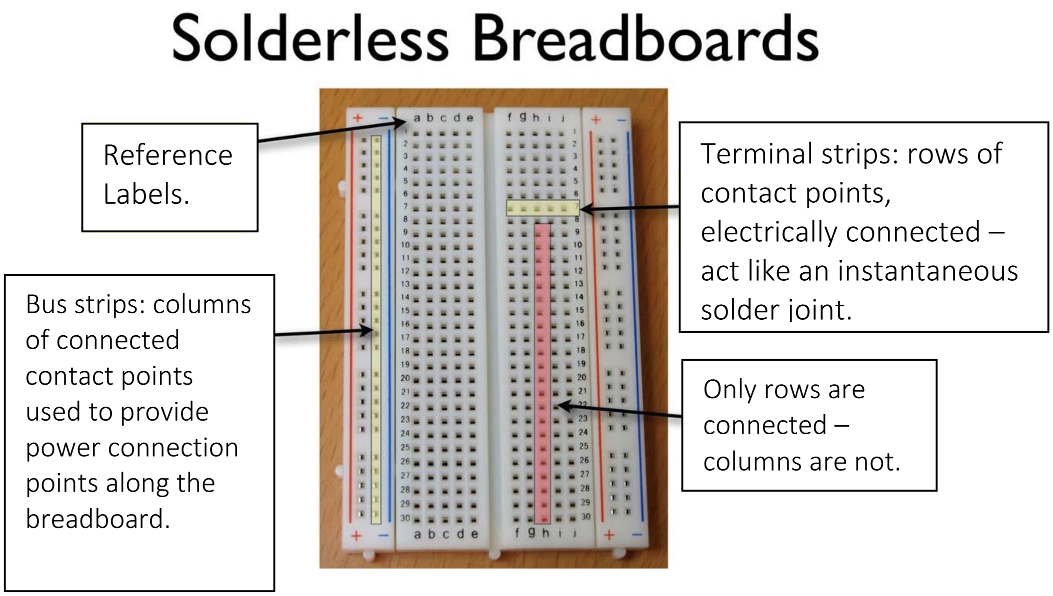
9. Test your ideas and record results below (Check procedures with instructor before attempting).

10. Challenge. Once you have recorded your results and verified them with the instructor, you are ready to proceed to the Shake Light Circuit Design Challenge on the next page.

V. Shake Light Circuit Design Challenge

Given a breadboard, a yellow LED, and 3 more red LEDs, construct a circuit that makes the yellow LED light up when the magnet moves in both directions (in and out of the coil).

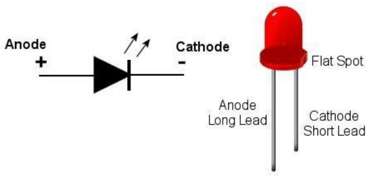
1. You will be using solderless breadboards to design your circuits. Use the diagram below to familiarize yourself with their characteristics (if necessary).



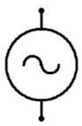
2. Design your circuit with the materials provided. Remember that a diode is like a one way street for current to flow. How would you design a traffic pattern (circuit) that allows traffic going in opposite directions (current) to flow in the same direction at a specific point (yellow LED)?

3. Once you have a circuit that lights up the yellow LED when you shake the magnet out of and into the coil, show your instructor to verify your solution and then draw a schematic diagram of it in the space provided on the next page:

Circuit Symbols needed:
Diode (LED)



Power supply (your shake light)



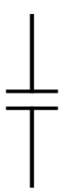
Circuit diagram 1

4. Note that the yellow Led lights up very briefly when you shake the body tube. Use the capacitors at your station to try to figure out a way to connect them into your circuit to dissipate the electrical energy over time, so that the yellow LED stays lit longer. <u>**Note**</u>**: 5 Bonus points will be awarded to the group who can get their LED to stay lit longest.**

Longest time lit: __________

5. Sketch the circuit diagram of your best circuit arrangement with the capacitor(s) to keep the yellow LED lit longest.

Circuit Symbol needed:
Capacitor



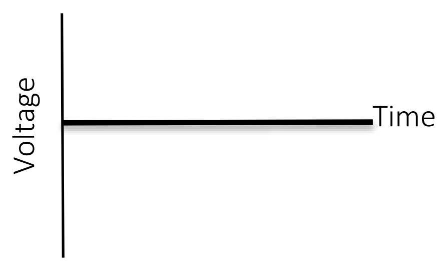
Circuit diagram 2

6. Observe the voltage output across the terminals of the yellow LED with the voltage sensor. Sketch the pattern you see on the graph below:

7. Your shake magnet outputs an AC voltage, i.e. +voltage peaks when the magnet moves into the coil and –voltage peaks when the magnet moves out of the coil. How do the voltages on this graph compare to the shake light coil output?

8. Explain what you think your circuit is doing to produce this waveform.

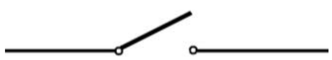
9. Start the voltage probe again and after a few seconds, disconnect the capacitor(s). Sketch the pattern you see on the graph below:



10. Hypothesize why this pattern is different.

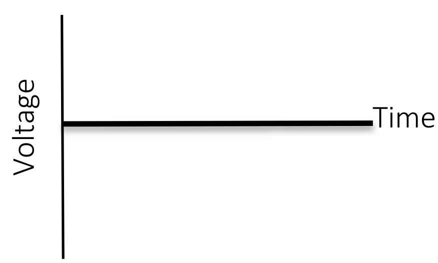
11. Now design a switch using the connecting wires at your station that could be used to store energy in the capacitor(s) for later use. You must be able to demonstrate to the instructor that you can turn your light on and off with the switch. Once you have finished, sketch a diagram of your circuit including the switch.

Circuit Symbol needed:
Switch



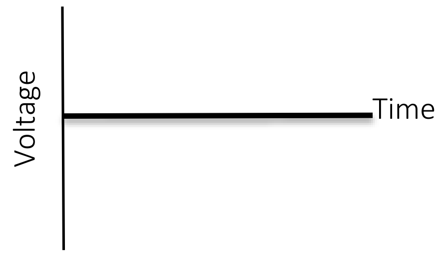
Circuit diagram 3

12. Hypothesize what would happen if the magnet was allowed to pass completely through the coil, instead of going in and coming out. Sketch what you think the output voltage signal would look like on the graph below:

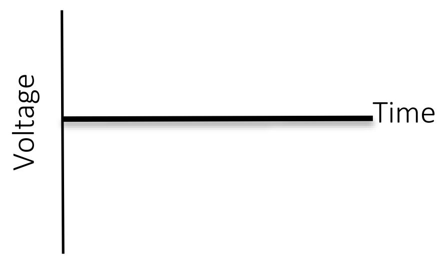


13. <u>Construct coil apparatus 2</u>, using same instructions as your first apparatus, but this time wind the wire off from the first apparatus onto the middle of the second body tube so the magnet will be able to pass through completely with each shake.

14. Hook up apparatus 2 to the voltage sensor. Tilt the apparatus so the magnet passes through the coil and then back one time and sketch the actual signal on the graph:



15. Now repeatedly shake the body tube back and forth. Sketch what the signal looks like on the graph below:



16. Based on your observations of the voltage output from apparatus 2, predict what would happen if you were to connect a single LED to it. When would the LED light?

17. Test your prediction by hooking up one of the red LEDs to apparatus 2 and shake at a low frequency, to see when the LED lights up. Record what you see below:

18. Is the LED circuit you designed for apparatus one still necessary to get the LED to light up with each shake? Explain why you think so.

19. Question: Is the LED circuit still useful if connected to apparatus 2? Follow procedures A and B below to find out.

    A. Obtain apparatus 1 from your instructor. Disconnect the capacitors in the LED circuit, and hook up apparatus 1 to the circuit. Shake apparatus 1 to light the red and yellow LEDs. Take note of the brightness of the LEDs and how hard you must shake to light them.

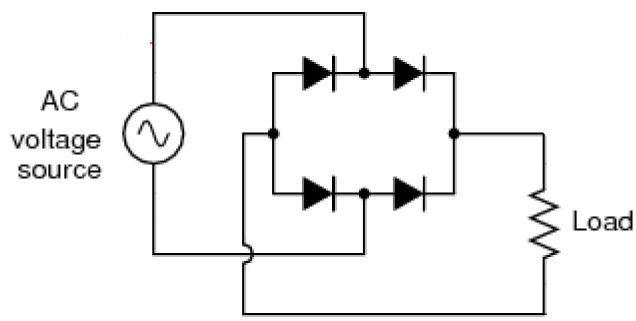
    B. Disconnect apparatus 1 and hook up your apparatus 2 to the LED circuit. Shake the apparatus and note how the brightness of the LEDs compares to that given off when apparatus 1 was attached to the circuit. Also note whether the amount of effort in shaking is more, less or the same.

    C. Answer the question from #19, and explain why you chose your answer.

VI. Shake Light Post-Lab Analysis

1. The process of converting an AC voltage to a DC voltage is called "Rectification." You have built a circuit that converts (rectifies) the AC signal coming from your shake light into a DC input to the LED, so that current always flows in the same direction and thus lights with each transition of the magnet (either in and out of the coil for apparatus 1 or through the coil and back for apparatus 2). Which apparatus produced greater power in conjunction with your LED circuit? [Explain why.]

2. The circuit you designed is called a four-diode full wave bridge rectifier (see diagram below). The AC voltage source represents the apparatus, and the load represents the yellow LED. Since current can only flow in complete loops, use two different colors pens/pencils to illustrate the current loops for both positive and negative voltage inputs from the AC source.



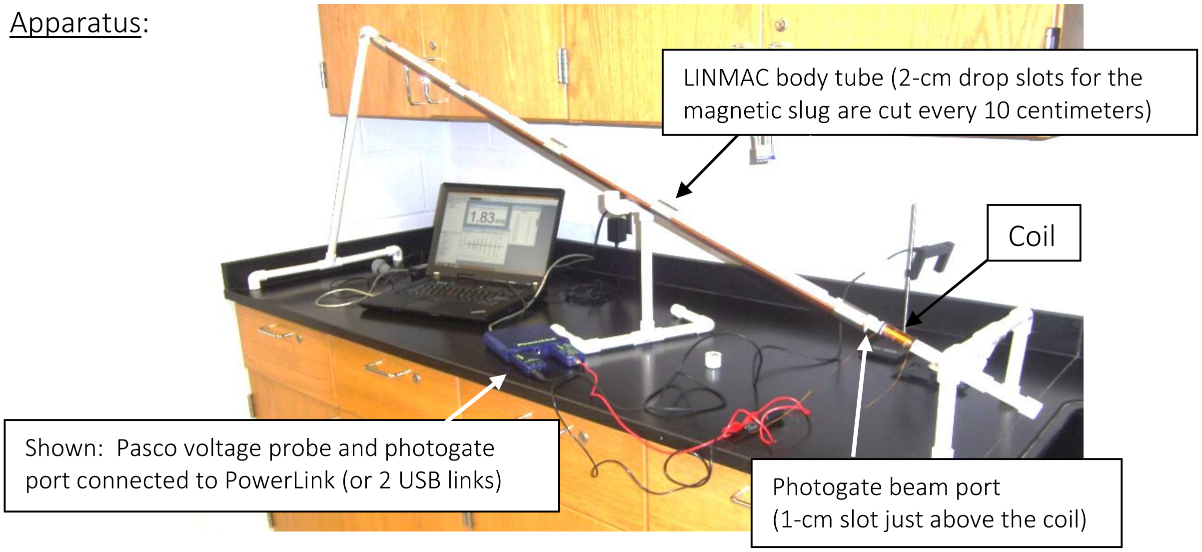
3. Why do you think this is this called a "full-wave" rectifier? The single LED you used initially also rectified your output from apparatus 1. What might be a good name for the apparatus 1 "rectifier?" [Explain why.]

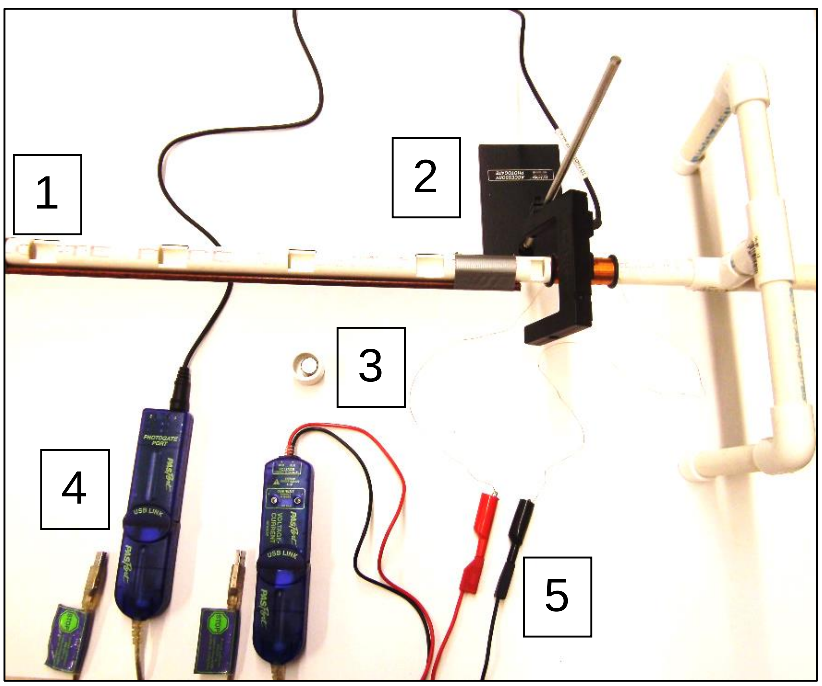
4. What circuit element, besides capacitors, could we introduce to this circuit to help us store more charge and increase the duration the LED lights? Sketch how that circuit element would need to be attached in the circuit diagram above, using an appropriate schematic symbol.

VII. The LINMAC – (LINear Magnet ACcelerator) Investigation

Purpose: To have students determine the mathematical relationship between the maximum induced potential in a coil of wire and the speed of a magnet passing through the coil.

Apparatus:

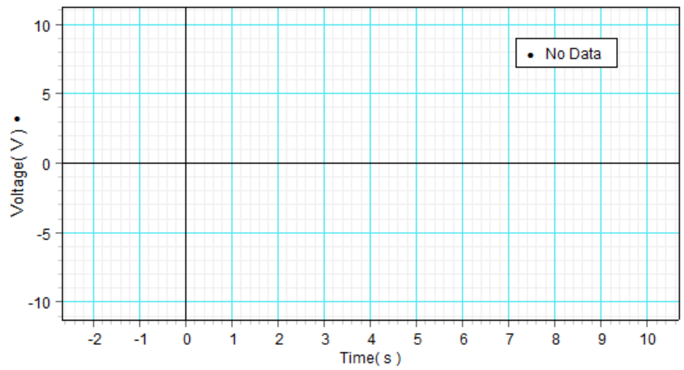




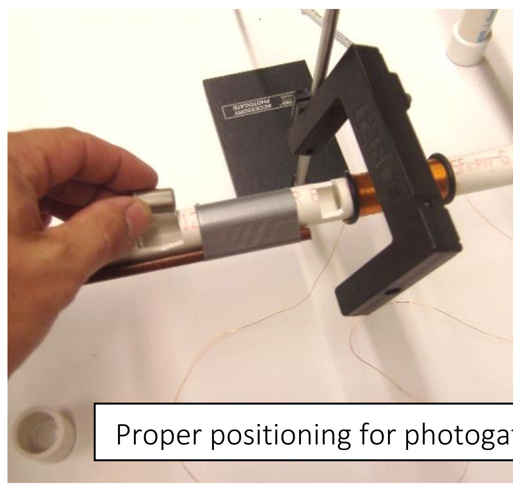
1. LINMAC body tube with coil
2. photogate
3. 2-cm slug magnet
4. photogate port with USB link (Pasco)
5. voltage/current sensor with USB link (Pasco)

Setup for data collection:

1) Insert the voltage/current sensor into a USB link and 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. Deselect current 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. You should now have a graph of voltage versus time as shown below.



2) You are now set up to measure the induced voltage in the coil. To measure the speed of the magnet through the coil, attach the photogate port to another USB link and insert the digital jack of the photogate head into port 1. Set the photogate up so that the infrared beam of the photogate goes through the narrow groove just above the coil on the LINMAC body tube as shown in the diagram. Then insert the USB link into the laptop.



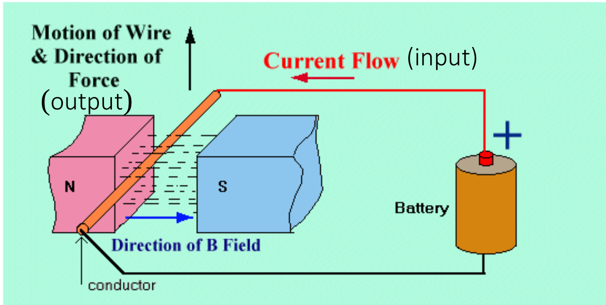
Proper positioning for photogate

Select "photogate timing" on the pop-up menu, and then go to setup and select "velocity in gate" and de-select "time in gate" and "time between gates." The cylindrical magnets are each 2 centimeters long, so click on the "constants" tab and enter "0.20 m" for "flag length." Double click "Digits" under displays in the bottom left hand corner of your screen and select "velocity in gate." You should now have a digital display of magnet speed going into the coil. When you are all set up to collect data, simply press "Start," and use the drop slots cut into the body tube to release the magnet at different heights. The magnet will go into the coil faster as you release it from higher positions. On the voltage time graph, you will see an AC voltage pattern similar to that of apparatus 2 in the shake light lab. Use the smart cursor to measure the maximum induced voltages on the second peaks of each waveform on the graph.

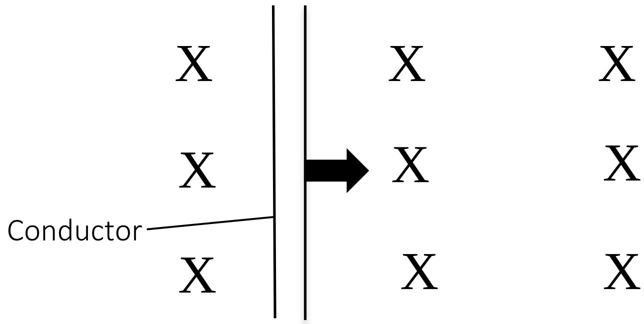
Electromagnetic Induction

Pre-lab Activity (AP Physics)

1. The right hand rule for magnetic force on a current carrying conductor is reversible, and is called the Universal Right Hand Rule. In your previous experience, the input was the direction of conventional current and the output was the direction of the force on the conductor, as shown in the diagram.



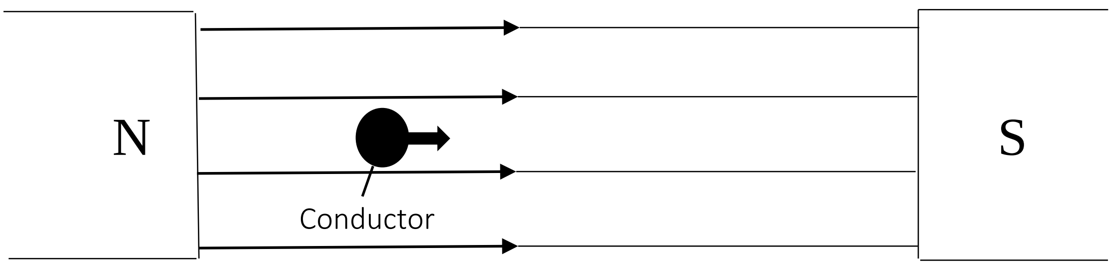
   a. Use the right hand rule to determine which direction current would flow in the wire moving in the magnetic field shown below (assuming that it is part of a complete circuit), using the conductor motion as the input (The arrow on the conductor represents the direction of motion of the conductor). Draw an arrow on the wire to show the direction of conventional current (output).



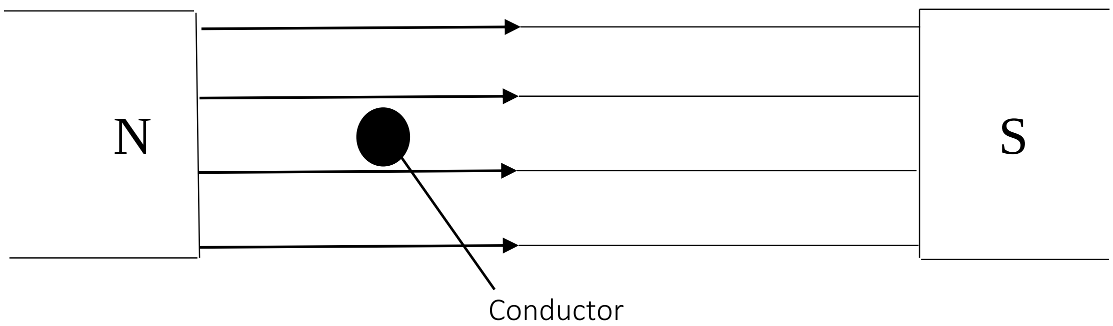
   b. The relative motion between the conductor and the field induces a voltage across the conductor in the field (which is responsible for the current). Draw a "+" and a "-"on the wire in the diagram to show how charge must have been redistributed to produce the current direction you indicated in a.

   c. What would happen to the direction of current if the conductor was moved in the opposite direction, and why?

2. Determine the direction of current in the conductor moving as shown in the magnetic field below. Explain why you think so.



3. Sketch arrows, attached to the conductor, on the diagram below to show the direction you'd have to move the conductor to induce the maximum voltage across the wire. Explain why you think this.



4. The voltage induced (and the current generated as a result) is directly related to the strength of the magnetic field and the length of wire in the magnetic field. If the