

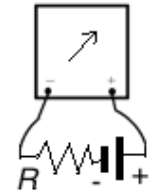
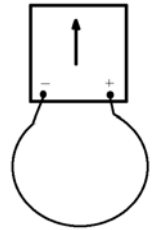
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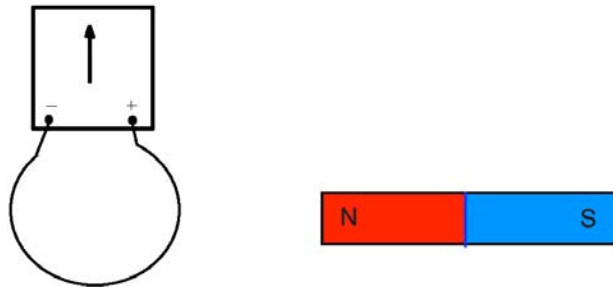
**Lab 5: Faraday's Law**

**Part I**

In this part you will run an actual experiment with a coil connected to a galvanometer and a magnet. In each experiment an actual coil is represented by a loop connected to a galvanometer as shown on the right. Make sure that while connecting the coil and the galvanometer you attach the windings correctly. **When looking as shown, a *counterclockwise* current deflects the arm of the galvanometer to *the right*!** (if there is a 1.5 V battery *and* a decade resistor you could connect the battery to a 100 Ohm resistor and then briefly touch the terminals of the galvanometer by the leads attached to the battery and the resistor and to see the deflection; **DO NOT** connect any battery directly to a galvanometer because that will destroy it!)



1. The picture below shows your first experiment.



Use BAO pictures and predict how the arm/needle of the galvanometer will deflect when the magnet slowly approaching the coil (note: you can always sketch a graph for a flux as a function of time, but for the graph you need to set the area vector, and usually the most convenient choice is out of the screen, because for a proper galvanometer CCW current deflects the arm of a galvanometer to the right).

2. Run an experiment and check your prediction.

You have to do three more experiments by changing the polarity of the magnet, and/or the moving object (the magnet or the coil), and/or the direction of the motion. Clearly describe below your experiments and your observations. Draw “before-after-to oppose” diagrams for each experiment.

3.

4.

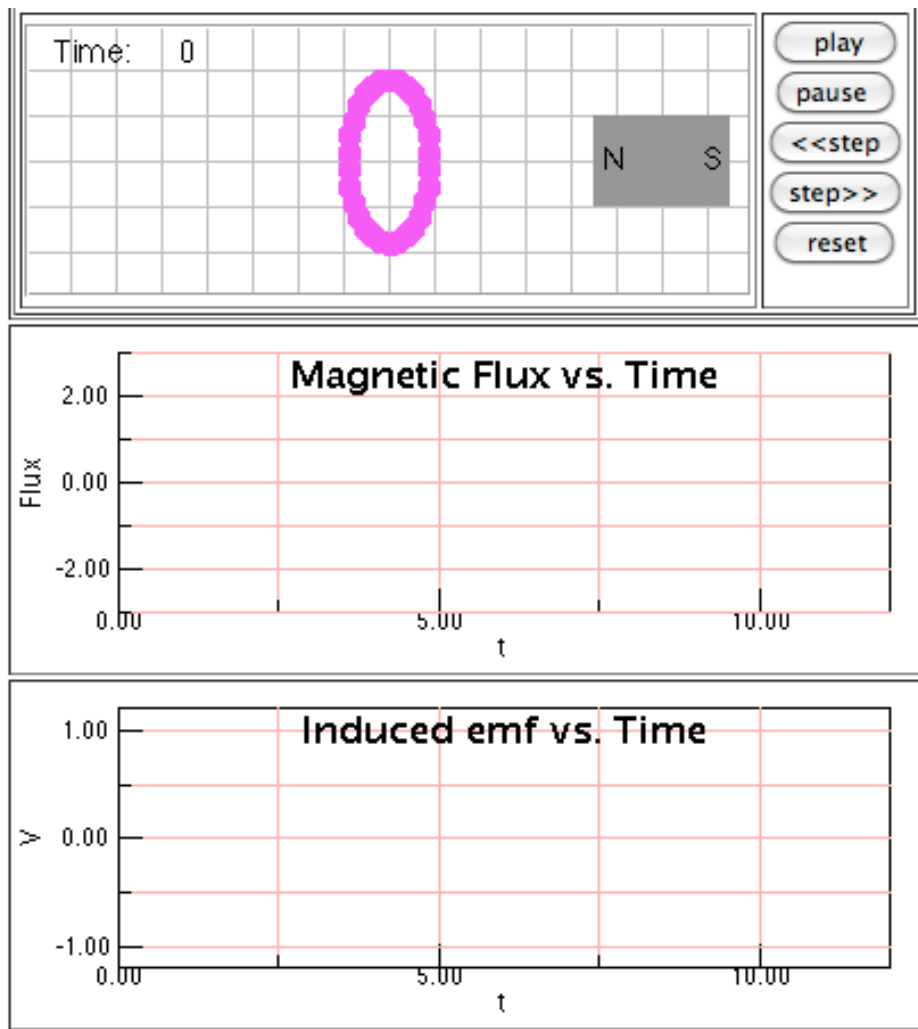
5.

Imagine that in the picture below a magnet passing through a coil traveling at a *constant* velocity.

6. When the magnet is at its initial position, what is the direction of the magnetic field *through the loop* (i.e. at the location of the loop)?

to the left     to the right     up     down     into the page     out of the page

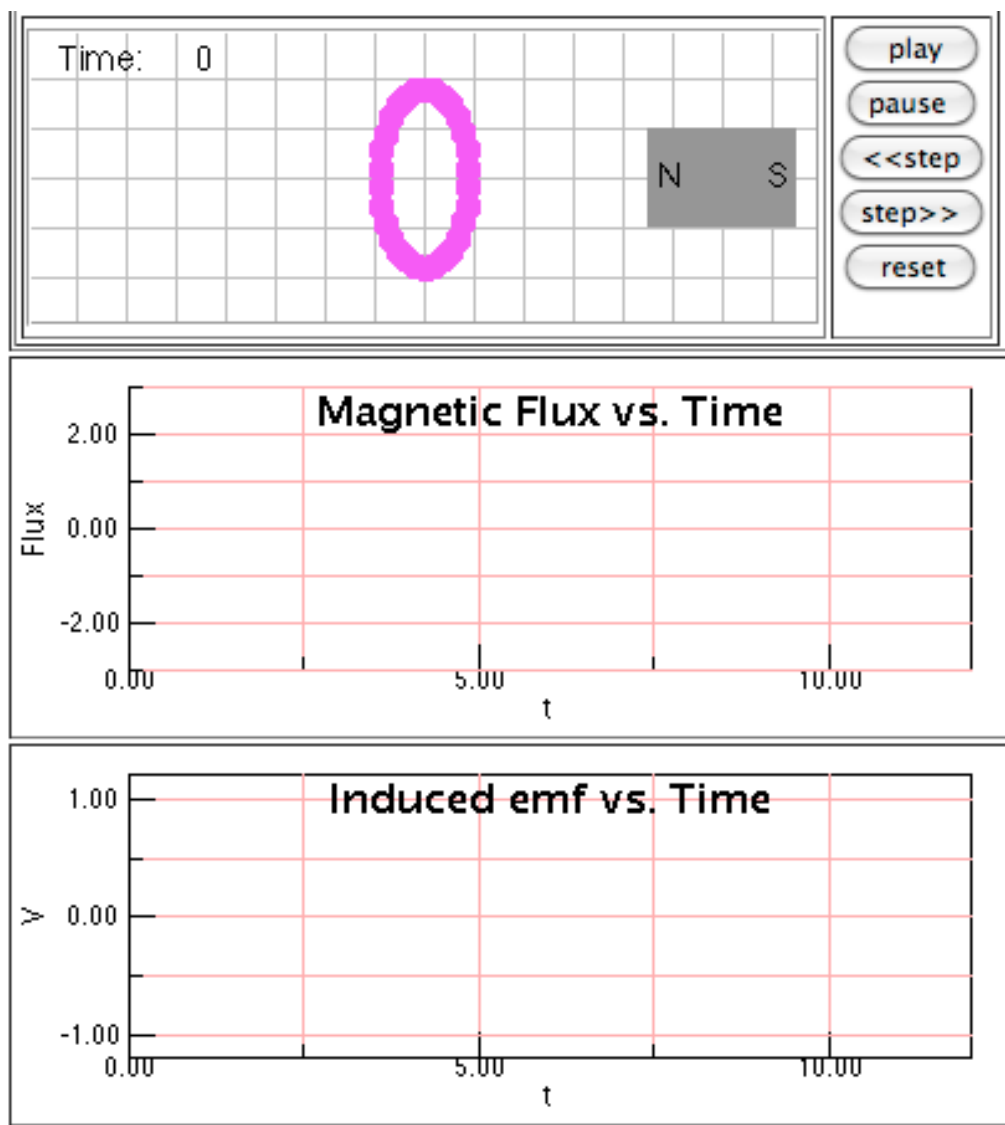
7. In the pictures below set and draw the area vector of the loop, draw it (*for **this** part of the lab the direction of the area vector is **up to you***), and sketch the two graphs for a case when the magnet is moving toward the observer on the left from the perspective of the observer (hint: imagine it is you watching the magnet).



8. Explain your reasoning for your answer to question 2 (why does each graph look like it is?).

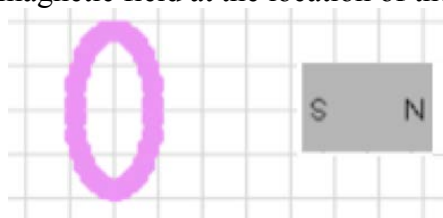
9. What is the direction of the current induced in the loop from the point of view of an observer looking at the approaching magnet (a hint: use BAO pictures).

10. Sketch the graphs for the case in which the magnet moves *twice as fast* as the magnet in question 7.

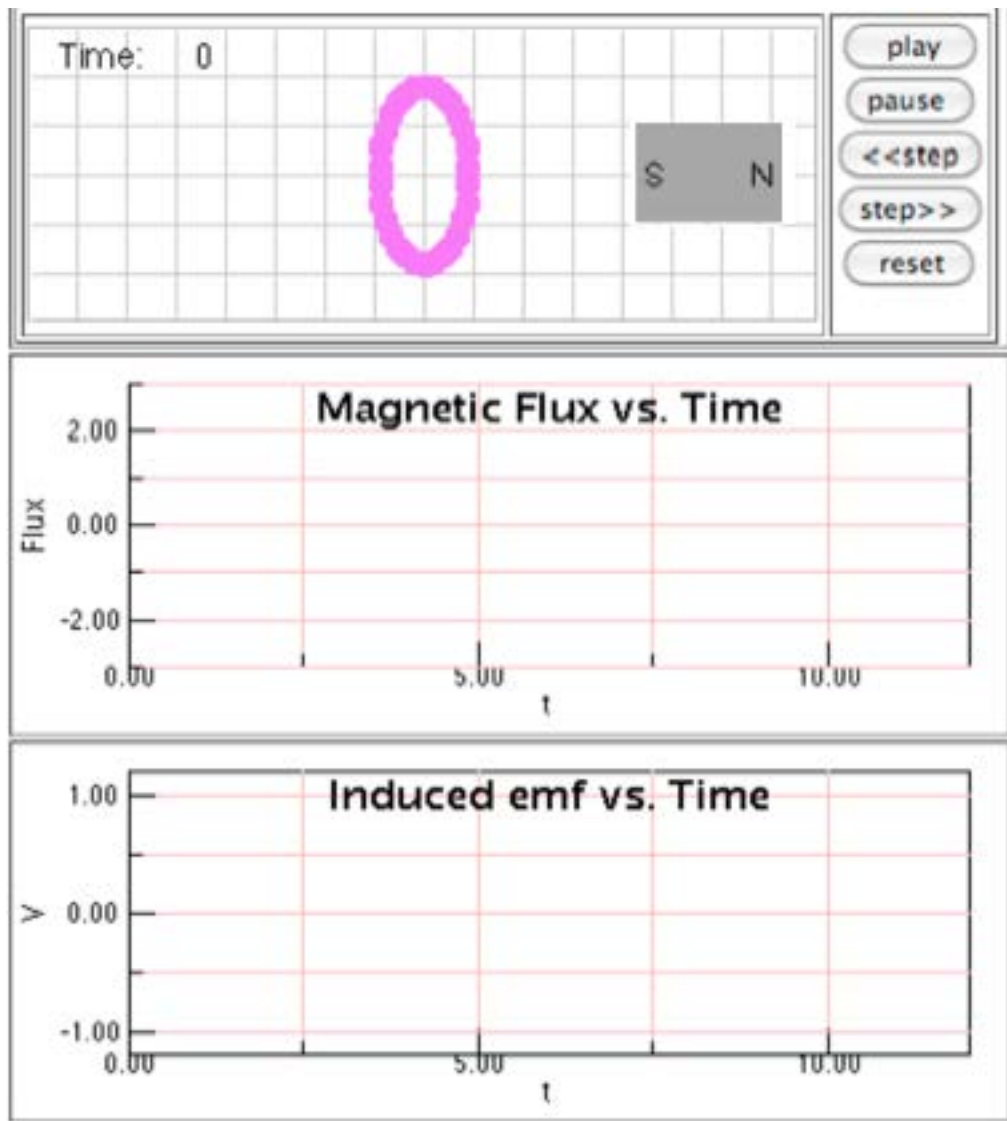


11. Explain how the slope of the line tangential to the flux vs. time graph is related to the induced EMF.

12. Suppose that the initial position of the magnet is such that its south pole faces the loop (see the picture). What is the direction of the external magnetic field at the location of the loop?



Sketch the graphs for this case (keep your choice of the area vector, assume the magnet travels with a constant velocity).



13. Now open the following link: [http://physics.bu.edu/ulab/prelabs/prelab\\_faraday\\_1.html](http://physics.bu.edu/ulab/prelabs/prelab_faraday_1.html).

Run the simulation.

14. Do your graphs look similar to the graphs provided by the applet? If not, explain why.

15. What is the direction of the area vector for the loop *in the applet*?

to the left     to the right     up     down     into the page     out of the page

16. Explain how you come up with your answer to question 15.

17. What is the location of the magnet when the magnetic flux is at *its maximum*? If the area of the loop is  $2 \text{ cm}^2$ , and the cross-sectional area of the magnet is  $0.5 \text{ cm}^2$ , and assuming all the data provided by the graphs use SI units, find the average value of the magnetic field inside the magnet (choose wisely which area to use!).

18. What is the value of induced emf at the moment when the magnetic flux is at its maximum? Explain why is the emf has this value at that instant.

Explain why does the graph for induced emf is have two peaks?

19. Compare the two colored areas shown in the applet when the magnet stops. What is the meaning of each area?

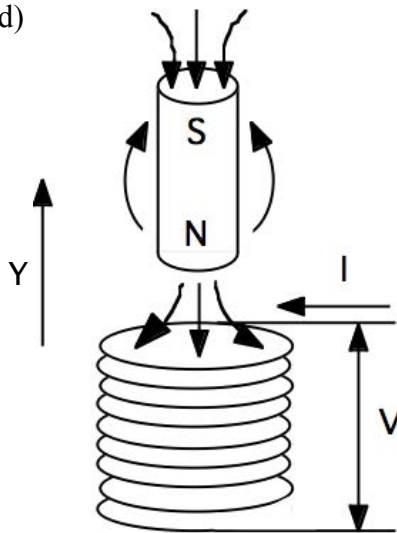
## Part II: Faraday's Law of Induction Experiment

In this experiment you will make measurements to verify important aspects of Faraday's Law of Induction.

1. Write the general expression for a magnetic flux through a loop (assume that the magnetic field is uniform). Draw a picture to illustrate the definition. Explain the meaning of each variable.

### APPARATUS

- o Computer and interface
- o Coil set (200, 400, and 800 turns)
- o Cylindrical magnet 1 x 1/4" (marked)
- o Drop tube set-up



While falling down through a tube, the magnet is always perpendicular to the loops of the coil. In this case, the magnetic flux through a single loop of the coil can be written in terms of the magnitude of the average value of the vertical component of the magnetic field,  $B_y$ , at the *center* of the loop which is in the *middle* of the coil, and the area of the loop  $A$ :

$$\Phi_{\text{loop}} = B_y A \cos(\theta) \quad (1).$$

2. Explain, why in your experiments  $\theta$  is either  $0^\circ$  or  $180^\circ$ ?

The EMF induced in a *single loop* is given by Faraday's Law of Induction

$$\varepsilon = -\frac{\Delta\Phi}{\Delta t} \quad (\Delta t \rightarrow 0) \quad (2).$$

3. Write an expression for the EMF induced in a coil with  $N$  turns.

(3)

## THE EXPERIMENT

The experiment consists of dropping a bar magnet through one of the coils of equal cross-sectional area but with different number  $N$  of total turns (as labeled on the coils).

4. Set the area vector of the coil **UP**, assume that the north pole of a magnet is *facing* a coil when it is above the coil, and sketch the graph for the magnetic flux as a function of time when the magnet is dropped through a tube (BTW: what is the *name* of such motion?).

5. The average rate of change of  $B_y$  with time can be written in terms of the magnet's speed relative to the coil,  $v_y$ , and the change of  $B_y$  with the magnet's position,  $y$ :

$$\left| \frac{\Delta B_y}{\Delta t} \right| = \left| \frac{\Delta B_y}{\Delta y} \cdot \frac{\Delta y}{\Delta t} \right| = \left| \frac{\Delta B_y}{\Delta y} \right| \cdot \left| \frac{\Delta y}{\Delta t} \right| = \left| \frac{\Delta B_y}{\Delta y} \right| \cdot v_y \quad (4).$$

where  $y$  is the  $Y$ -coordinate of the magnet's position (i.e. its vertical coordinate, i.e. its height) and  $v_y$  is the instantaneous speed of the magnet while it is falling (note: when using a plastic tube the falling magnet is *no* different from a falling tennis ball).

6. Combine all expressions from above to derive an expression for the magnitude of the EMF induced in a coil with  $N$  turns as a function of the number of turns  $N$ , the area of the coil  $A$ , the change in the average perpendicular component of the magnetic field  $\Delta B_y$ , and the change in time  $\Delta t$ , and eventually, as a function of the speed of the magnet  $v_y$  (and other variables).

Note that the area under the curve of the graph EMF vs. Time is also related to the change of the magnetic flux as

$$\text{Area}(\text{EMF from } t_1 \text{ to } t_2) = -N(\Phi_{2loop} - \Phi_{1loop}) = N(\Phi_{1loop} - \Phi_{2loop})$$

where,  $\Phi_{1loop}$  is the initial value of the magnetic flux through a *single* loop of a coil ( $\Phi_{2loop}$  is the final value).



## PROCEDURE

7. In your experiments you can vary the initial height of the magnet, the number of turns in the coil, and the orientation of the magnet. You should start FaradaysLaw.cmbl file (in PY106 folder).

The emf (a.k.a voltage  $V$ ) induced by the magnet in the coil will last for no more than 0.25 s, so to study it quantitatively, you will need a fast device to gather and store the voltage and time data. The data collection will be done by a computer which will automatically start recording data when the voltage reaches some trigger value. The digitized data are then stored on the computer for your further analysis.

Familiarize yourself with the method. **Read the instructions in full until question 8.**

**Before recording any data, always zero the voltage sensor.** Use the top clamp to hold a tube, use the bottom clamp to hold a coil (**note: do NOT squeeze the coil when tightening the clamp!**). Make sure, when the tube is inside a coil, the tube is *as vertical as possible*.


A computer is configured to start collecting data once the voltage exceeds a certain threshold and to collect data for 0.25 seconds (you can change these settings if you wish by going to Data Collection in the Setup menu, you can modify the threshold voltage in Triggering, and the data rate and sampling time in Sampling, **but do NOT save you setting**).

**ATTENTION! Please, leave the lab station in the same condition you received it from the previous section! Do not save the file with your data! Do not lose a magnet! Thank you!**



When readjusting or changing the coil, please, **do not squish the coil**, i.e. do not tight the clamp **too** tight.



After taking the data, a computer will display two graphs, one showing the magnetic flux through the coil as a function of time, and the other showing the induced voltage in the coil as a function of time.

Start the collection of data by hitting  button, wait a second or two, and drop a magnet through a coil **with the north pole of the magnet facing down**. You should see both, a graph and a table of the data on the computer screen. **NOTE:** *Make sure that for the magnet with the north pole down the flux shown in the graph is negative!* (if that is not the case just switch the wires connected to the coil).

There are several parameters which you should read and record from the graph of EMF as a function of time:

- \* The peak voltage of the first peak  $V_1$
- \* The peak voltage of the second peak  $V_2$
- \* The area under the curve for the first peak  $A_1$  (measured from the initial time to the instant when EMF = 0 V)

The area under the curve for the second peak  $A_2$  (measured from the instant when EMF = 0 V to the final time of the experiment)

Peak values can be found easily by clicking-and-dragging to select a region of the graph, and then hitting the STAT button, , and reading the provided data. Areas can be found in a similar way by selecting a particular area and hitting  button. **Note: the best way to select the region on the graph is to select data in the table.** This way you can be sure that the analyzed region covers the entire peak and does **not** include any part of the other peak.

Two more parameters are also important; number of turns  $N$ , and initial “height”  $H$  – which equals the distance from the top end of a tube to the middle of the coil (**note**: you can change  $H$  by *moving a coil along a tube*, or moving the tube along the coil, and releasing the magnet at the top end of a tube).

8. For your first coil use the one with **200 turns**. Set up the apparatus. Make sure the north pole of the magnet faces the coil. Run an experiment. Sketch the picture of the experiment (make sure the flux is **negative!**), indicate the area vector for the coil which is assumed in the experiment (in this experiment *selecting the direction of the area vector is NOT up to you*). Sketch the graphs. Write the values into the table below (also use this table for questions 9 to 12).

Q #	$N$	$H$	$V_1$	$V_2$	$A_1$	$A_2$
Q8						
Q9						
Q10						
Q11						
Q12						

Graph of B-flux as a function of time.

Graph of induced EMF as a function of time.

9, 10. Run the experiment two more times, dropping the magnet from *a different height* (i.e. readjust the location of a coil relative to a tube). Enter the data in the table on page 10.

**In all your experiments the north pole of the magnet should be down; the flux should be negative.**

Q9. Graph of B-flux as a function of time.

Q9. Graph of induced EMF as a function of time.

Q10. Graph of B-flux as a function of time.

Q10. Graph of induced EMF as a function of time.

11, 12. Run the experiment *two more* times, using the same initial height as in one of the previous experiments but using coils with a *different number of turns* (**when replacing coils, please, do not squish them!**). Write the values for each experiment. In all your experiments the north pole of the magnet should be down; the flux should be negative.

Q11. Graph of B-flux as a function of time.

Q11. Graph of induced EMF as a function of time.

Q12. Graph of B-flux as a function of time.

Q12. Graph of induced EMF as a function of time.

**For questions below use the data from the table for 8 – 12.**

13. Compare the two peak voltages for each of the runs you have done. What do you observe? Does one always have the magnitude larger than the other one? If so, which is larger, and why (hint: when a plastic tube is used the falling magnet is no different from a falling tennis ball)?

14. Compare the areas under each peak for each of the runs you have done. Should these areas be the same or should one be larger than the other one? Explain (hint: when a magnet is far from a coil there is almost no B-flux through the coil).

15. Compare the data from experiments in which you used different coils, but **the same initial height** of the magnet. What differences do you observe and why are they happening?

16. Compare the data from experiments in which you dropped the magnet from different heights, but through the same coil. What differences do you observe and why are they happening?

17. Using one of your data set of your choice, develop a strategy and estimate the magnetic field strength *inside* the magnet. Show your work (note: you have solved already a similar problem; note: when a magnet is far from a coil there is practically no flux through the coil; think of the flux when the magnet is **in the middle** of the coil, you also can use a ruler to measure the dimensions of the magnet).

18. Predict and sketch the graphs for the case in which you drop the magnet through the coil with the **north** pole of the magnet facing **up**.

19. Run an experiment in which you drop the magnet through the coil with the **north** pole of the magnet facing **up**. Compare your graphs (question 18) and the actual graphs.

20. Take a copper pipe and drop a small weight through it (not a magnet, some chalk, a paper clip, etc.). Now predict, what difference will you observe if you drop a magnet? Check your prediction. Explain the phenomenon. Replace a plastic tube with a copper tube, drop a magnet and observe the graphs.

**Lab 5 (12 tables): Computers, a Faraday's law experiment setup, a galvanometer, a bar magnet, a coil.**

**Unit layout**

**L5: 140 min**

**PI: 70 min**

**PII: 70 min**

**PE5: 60 min**

**Breaks when needed**

### Practice Exercise 5

The picture below shows a 10 m by 10 m region with a *uniform* magnetic field pointing *out* of the page; the magnitude of the magnetic field strength is 0.5 T. A rectangular loop (3 m by 2 m) is traveling to the right at speed of 0.5 m/s. At  $t = 0$  the right side of the loop is 2 m away from the region. Your goal is to plot the graph for the EMF induced in the loop as a function of time for time interval  $t = [0, 34]$  s. Set the area vector of the loop in such a direction so *the counterclockwise induced current is positive*. You do not have to draw the graph for the flux, but it might help.

