# Lab Sim 10: Faraday's Law and Magnetic Induction

## INTRODUCTION

Faraday's Law is the key to the castle—if the castle you are trying to unlock happens to be Maxwell's equations.  Ok, we are not going to immerse ourselves in Maxwell's vector calculus. Still, Faraday's Law is perfect for proving to ourselves that you cannot separate the electro– from the –magnetic.

According to Faraday's Law, a changing magnetic flux will create a voltage across a wire loop.  Or, changing the voltage across (or the current through) one loop of wire will induce a voltage across (or a current through) another loop, which draws us inexorably toward alternating current, motors, generators, and the twentieth (21ˢᵗ!) century in general.

## OBJECTIVES

- Demonstrate the connection between electricity and magnetism
- Define magnetic flux, and develop a method to measure it
- Apply Faraday's Law to a square coil of wire moving through a magnetic field and calculate the unknown $B$ field
- Observe the force on a current-carrying wire, and use it to predict the strength of an unknown magnetic field

## PIVOT INTERACTIVES

This exercise requires the online simulation (Lab 10: Faraday's Law).  You should sign in to your Pivot account and choose the correct Interactive from the PHYS 1420 selection.

## UNDERSTANDING MAGNETIC FLUX

Magnetic flux? It's a little bit abstract, but nothing you can't handle.  You probably already know that 'flux' means 'change,' but it's a bit different in the context of physics.  The term flux is used to indicate 'passing through.' In this case, we are thinking about how much magnetic field *passes through* a loop of wire.

Here's another thing: in physics, flux can be constant!  But when the magnetic flux *changes,* that's when things get interesting.
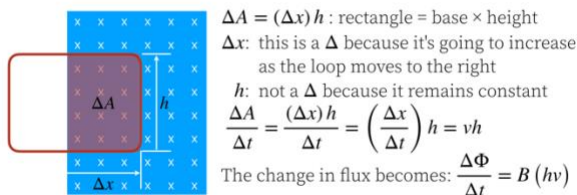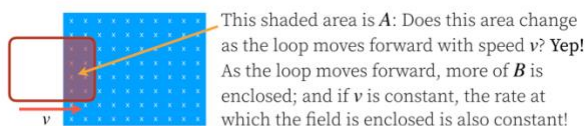
### Magnetic Flux



Think about using a loop of wire to "trap" magnetic field lines. The greater the area enclosed by the loop, the more field lines you can "lasso." The stronger the magnetic field, the more field lines there are, and the more lines

can be lassoed.  The rate of change means that, over time, the amount of trapped lines changes.  You can change the number of trapped lines in several ways:

1. Make the loop larger (or smaller);
2. Move the loop into (to trap more) or out of (to trap fewer) field lines;
3. Change the orientation of the loop (rotate it to lasso more or fewer lines);
4. Increase or decrease the magnetic field strength.

According to Faraday's Law, changing magnetic flux impresses a voltage across a wire loop.  If you make a coil having $n$ loops, the voltage increases by a factor of $n$:

$$V = -n\frac{\Delta\Phi}{\Delta t}$$

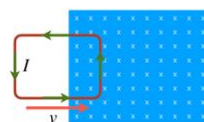We just figured out the flux change, so let's put the pieces together:
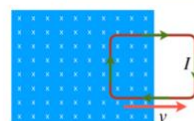
### Faraday's Law



The first video shows an apparatus to demonstrate electromagnetic induction.  Watch without making any

measurements, just paying attention to what happens, when it happens, and what changes.

1) (3 points) Given the video you just viewed, what are you going to measure? What will you be calculating with the measurements you make? Hint: Maybe take a look at the second video and see what measuring tools are available to you. Also, the number of loops in the coil is $n = 8$.

2) (2 points) When you present your results graphically:
   - What are your independent ($y$–axis) and dependent ($x$–axis) variables?
   - What is your slope?
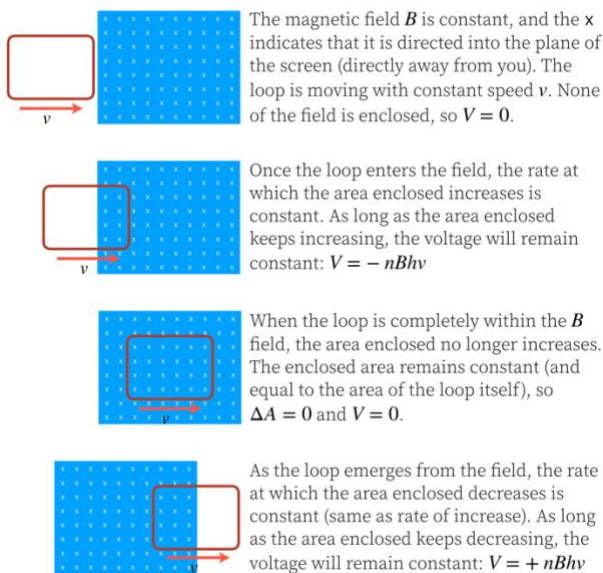   - What do you predict for your intercept? Hint: Transform $V = -nBhv$ into the form $y = mx$.

## APPLYING FARADAY'S LAW

Next, watch the second video. This interactive video allows you to measure the glider's speed and the *emf* generated by the coil passing through the magnetic gap.
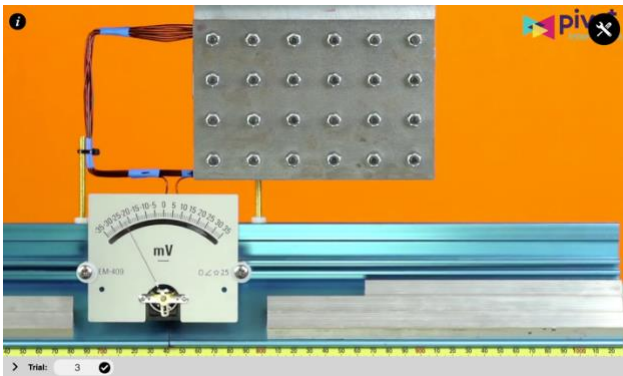


Spend a few minutes thinking about how you will make the required measurements as accurately as possible.

3) (1 point) Use the vertical ruler to measure the height $h$ of the loop carefully. Record your measurement in meters.



The magnetic field $B$ is constant, and the x indicates that it is directed into the plane of the screen (directly away from you). The loop is moving with constant speed $v$. None of the field is enclosed, so $V = 0$.

Once the loop enters the field, the rate at which the area enclosed increases is constant. As long as the area enclosed keeps increasing, the voltage will remain constant: $V = -nBhv$

When the loop is completely within the $B$ field, the area enclosed no longer increases. The enclosed area remains constant (and equal to the area of the loop itself), so $\Delta A = 0$ and $V = 0$.

As the loop emerges from the field, the rate at which the area enclosed decreases is constant (same as rate of increase). As long as the area enclosed keeps decreasing, the voltage will remain constant: $V = +nBhv$

Measuring the impressed voltage is a little more subtle than it seems. Watch the video and notice that the

voltmeter reading is not constant during the entire trip through the magnetic field!

You need to catch the voltage at either end but not in the middle. Also, when you record voltage values, don't include the sign; use the absolute value.

We need a sizable number of measurements to get a reliable average. Notice that we are taking data as the loop enters and again as it leaves the magnetic field. Use the same method for each video trial:

1. Align the joint where the carts meet with the tape measure attached to the track. Use the values already in the data table.

2. Record the absolute value of the voltmeter reading (no negatives).

4) (8 points) For each of the five trials, record the voltage when the cart is at each of the positions listed.

| POSITION (M) | TRIAL 1 VOLTAGE (V) | TRIAL 2 VOLTAGE (V) | TRIAL 3 VOLTAGE (V) | TRIAL 4 VOLTAGE (V) | TRIAL 5 VOLTAGE (V) |
|---|---|---|---|---|---|
| 0.74 | | | | | |
| 0.75 | | | | | |
| 0.76 | | | | | |
| 0.77 | | | | | |
| 0.89 | | | | | |
| 0.90 | | | | | |
| 0.91 | | | | | |
| 0.92 | | | | | |

Hint: Mind your units! Be sure to record volts, not millivolts!

5) (1 point) Verify that when the loop is entirely within the magnetic field, zero flux change means zero voltage. For Trial 1, over what frame range is $V = 0$?
   A. Frames 200–400
   B. Frames 450–490
   C. Frames 570–610
   D. Frames 630–660

We are assuming that the velocity $v$ of the cart is constant. However, in each trial, the cart experiences a slight but measurable, positive acceleration.

6) (2 points) How will you measure the velocity to minimize the impact of this experimental error? Hint: The joint where the two gliders meet can be easily aligned with the measuring tape on the air track. Also, if you do it right, a single measurement can be as accurate as an average of eight separate measurements—I know because I checked it for each of the four trials!

7) (5 points) Construct the data table you need to create the graph that verifies our expression for Faraday's Law ($V = -nBhv$). Make sure you label your columns and include the correct units. Prepare the appropriate graph and perform the linear regression. Hint: Use the absolute value of $V$ to make all values positive (basically,

ignore the negative)! Also, be sure to calculate and record the average voltage for each trial.

8) (1 point) Calculate the magnetic field strength, $B$, in the magnetic gap. The units are Teslas! Hint: Don't forget that $n = 8$ loops in the coil.

## MEASURING THE MAGNETIC FIELD USING THE LORENTZ FORCE

We can compare the measurement of the magnetic field strength using the concept of Lorentz Force. In the video below, the same magnetic gap assembly from the previous video is placed on a scale to measure the force caused by current flowing through a conductor immersed in the gap.



Watch the video once without trying to measure anything. Notice a few important details, like which reading on the power supply is the current and which is the voltage. Also, notice that the scale on which the magnetic gap assembly rests is measuring mass in grams (mass is not force!). Finally, notice that the scale reading is not zero when there is no applied current.

9) (1 point) When the current is zero, the scale reads **4294 grams**. What does this number mean?
   A. The plate and magnet assembly has a mass $m = 4294g$.
   B. The magnetic field is $B = 4294T$ before the current is switched on.
   C. Nothing; it's an arbitrary value that occurs because the person in the video did not correctly zero the scale before beginning the experiment.

10) (1 point) How do you convert a scale reading ($m$) in grams to a force ($F$) in Newtons? Hint: How much does the assembly weigh? Mass≠ weight!
   A. $F = \frac{m}{1000}$
   B. $F = mg$
   C. $F = \left(\frac{m}{1000}\right)g$

11) (1 point) How much of that scale force ($F$) is actually the *magnetic* force ($F_{mag}$)? Hint: Does the weight of the assembly ever change?
   A. All of it: $F_{mag} = F$
   B. Some of it: $F_{mag} = F - W$, where $W = mg$ is the weight of the assembly, measured before the current is switched on.
   C. None of it: $F_{mag} = 0$, and the changes in the scale reading result from the fluctuating mass of the assembly.

12) (1 point) Do you really need to calculate $F_{mag}$, or can you simply go ahead and graph the total force $F$ as a function of current?
   A. Don't bother to calculate $F_{mag}$! Subtracting the same value from each force is systematic and won't affect your slope! Just graph $F$ as a function of $I$.
   B. If you don't calculate $F_{mag}$, you are not going to get a valid slope. Subtracting the same value from each force removes any random error that might have occurred.

13) (5 points) Construct the data table you need to create the graph that illustrates our expression for the Lorentz Force ($F = ILB$). Make sure you label your columns and include the correct units. Prepare the appropriate graph and perform the linear regression.

14) (2 points) Use the slope of your graph to calculate the magnetic field $B$. Hint: You'll need to measure the length of the wire using the ruler tool if you have not already!

15) (1 point) Compare the values for the magnetic field strength from the two methods by calculating the percent difference. How confident are you in your values?

When you have completed this lab exercise in Pivot, please be sure to submit your responses. This lab is due no later than Thursday, 11 August 2022, at 11:59 PM CDT.