Faraday's Law

In this lab you will observe the effects of the "curly" electric fields associated with time-varying magnetic fields. You will use Faraday's Law to predict the emf in a coil exposed to a time-varying magnetic field, and then you will test your predictions experimentally. Faraday's law can be found in Sections 22.1 - 22.2 of the textbook.

Part I: Direction of the curly electric field

Recall if there is a time-varying magnetic field in a region of space, then there is an associated "curly" electric field (that is, a "curly" pattern of electric field in space) that can be detected in nearby regions. The direction of that electric field is determined by the following rule:

If you point your thumb in the direction of $-\frac{d\vec{B}}{dt}$, then your fingers curl around in the direction of the non-Coulomb ("curly") electric field.

Since this non-Coulomb electric field (that is, an electric field not due to stationary point charges) has exactly the same effect on charged particles as does any other electric field, we can observe its effects by placing a coil of wire in the region where we expect an electric field, and determining whether or not the mobile charges in the wire are affected by the electric field—that is, if a current flows in the coil of wire.

For the experiment you need:

coil of wire wrapped around plastic spool (with many turns) bar magnet compass connecting wires with alligator clips sensitive "galvanometer" (ammeter) multimeter stopwatch

(a) Consider a situation in which the North end of a bar magnet is moving toward a coil, as shown. The magnet is moving in the -z direction; the coil is in the x-y plane.

On the diagram draw arrows representing the following quantities:

(a.1) At the origin (inside the coil), draw an

arrow representing $-\frac{d\vec{B}}{dt}$ (the opposite

direction to the rate of change of the magnetic field due to the bar magnet).



(a.2) Four locations inside the wire of the coil are marked by dots. At each of these locations draw an arrow representing the non-Coulomb electric field at that location. Label these arrows "E".

(a.3) On the connecting wires leading away from the coil, draw arrows indicating the direction of conventional current that will flow as a result of the non-Coulomb electric field in the coil. Label these arrows "I".

Check with your partners and with an instructor to make sure your analysis is correct before going on.

(b) Use a compass to determine which is the North pole of the magnet. Label the North end of the magnet (if it is not already) with a piece of tape.

(c) Connect the coil directly to the galvanometer, using two connecting wires. The galvanometer will read positive if conventional current flows into the positive terminal, and negative if conventional current flows out of the positive terminal.

Move the North end of the magnet toward the coil.

(c.1) What are the magnitude and sign of the galvanometer reading while the magnet is moving?

If necessary, fix the connections so the galvanometer gives a positive reading when the magnet is moving toward the coil.

(c.2) What are the magnitude and sign of the galvanometer reading when the magnet stops moving? Explain.

(c.3) Observe and record the reading of the galvanometer in the other 3 possible situations. On each diagram label the ends of the magnet, show the direction of motion of the magnet, and draw arrows representing \vec{r}

 $-\frac{dB}{dt}$ inside the coil, the non-Coulomb electric field inside the wires, and the direction of conventional

current. For each situation, record the magnitude and sign of the galvanometer reading.



Checkpoint 1: Make sure your answer is correct before going on.

Part II: emf induced in a coil by a time-varying magnetic field

The quantitative, mathematical statement of Faraday's Law relates the round-trip integral of the non-Coulomb electric field to the rate of change of magnetic flux in the area surrounded by your round-trip path:

$$emf\Big|_{one\ loop} = \left|-\frac{d\Phi_{mag}}{dt}\right|$$

The emf is the round-trip integral of the non-Coulomb "curly" electric field along a path of interest: $emf = \oint \vec{E}_{NC} \cdot d\vec{l}$ and the magnetic flux is the product of the perpendicular component of magnetic field times the area inside the path:

$$\Phi_{mag} = \int \vec{B} \cdot \hat{n} \, dA \approx \sum \vec{B} \cdot \hat{n} \, \Delta A = \sum B \cos \theta \, \Delta A$$

Part II.a. Prediction

To predict the emf induced in the coil when you move the magnet, you will need to calculate the change in the magnetic flux through the coil, and you will need to know the time required to move the magnet away from the coil. If you hold the magnet near the coil, then quickly move it very far away, it is not a bad approximation to say that the magnetic flux changes from a nonzero value to a value that is nearly zero. So,

$$\Delta \Phi_{mag} = \Phi_f - \Phi_i$$
 where $\Phi_i \approx B_{mag} A_{one turn}$ and Φ_f is approximately zero

(a) Hold the bar magnet so the North pole is almost at the surface of the coil. Calculate the approximate magnetic flux through the entire coil when the magnet is in this position. In order to do this you will need to measure various distances, and make certain approximations or assumptions. You will also need to know the magnetic dipole moment of the bar magnet, which you can determine quickly using the procedure in your text book (find the center-to-center distance at which the bar magnet produces a 70 degree compass deflection; treat the bar magnet as a magnetic dipole located at the center of the magnet.)

Distance at which your magnet produces a 70 degree compass deflection Calculate magnetic dipole moment for your bar magnet Calculation Distance from the center of the coil to the center of your bar magnet when you hold the end of the magnet nearly even with the front surface of the coil Magnetic field inside one turn of the coil due to your Calculation bar magnet in the same position Average radius of one turn of the coil Area inside one turn of the coil Calculation Calculation Approximate magnetic flux inside one turn of the coil, using values calculated from above

Show calculations as well as results in the table below:

Number of turns of wire in the coil	
Approximate magnetic flux for all turns of the coil	Calculation

(b) Use a stopwatch to time how long it takes you to move the magnet rapidly away from the coil. (This motion takes significantly less than one second.) To get a reasonable measurement, time how long it takes you to move the magnet rapidly ten times away from the coil and back again, then divide by 20. (If the galvanometer goes off scale, you will need to move slower.)

Time for 10 round trips

Time to move magnet away from coil ______

Using your results above, calculate the approximate emf you should observe when you move the magnet rapidly

CHECKPOINT 1: Make sure your analysis is correct before going on.

Part II.b. Measurement of emf

Let's compare this emf to what you determined from the current you read using the galvanometer.

What is the maximum current reading?

Connect the coil and the galvanometer in series. Use a multimeter to measure the resistance of the combination.

What is the total resistance of the coil and galvanometer?

What is your experimentally determined emf?

How do your measurements compare to your predicted values? What factors could account for the difference?