

## Lab 2: Electromagnetic Induction

### Goal

The investigation of how changing magnetic fields can give rise to electric currents (**the Faraday's law**).

### Objectives

1. Explain what conditions are necessary for a magnetic field to produce an electric current.
2. Use Faraday's law to determine the magnitude of a potential difference across a coil produced by changing magnetic flux.

### Expectations

1. You are expected to take detailed notes during each step outlined in the procedure that can be used during the lab report write-up.
2. You are expected to provide a neat table of the data that you measured where you clearly label what each data set is and include units for all measured quantities.
3. You are expected to clearly record the measured values of any components that you use.
4. You are expected to clearly record the detail related to images captured by the oscilloscope.
5. You are expected to make your final plots in a program such as Excel. Make sure that your data points appear clearly on the plots, that all axes are clearly labeled and have units.
6. If it is possible to compare your measurements with an expectation or a prediction, you are expected to do so in your lab report
7. You are expected to answer the questions encountered in this manual as well as discuss exercises given during the lectures in your lab write up.

### Introduction to Concepts

The phenomenon of producing an induced electromotive force (emf) with the of a magnetic field is called electromagnetic induction (see Figure 1). The Faraday's law describes how changing magnetic fields can give rise to electric currents. The induced emf across the coil,

$$V_{emf} = -N \frac{\Delta\Phi}{\Delta t} \quad (1)$$

Where  $V_{emf}$  is the induced emf across the coil,  $\frac{\Delta\Phi}{\Delta t}$  is the rate of change of magnetic field across the coil, and  $N$  is no.of turns in the coil.

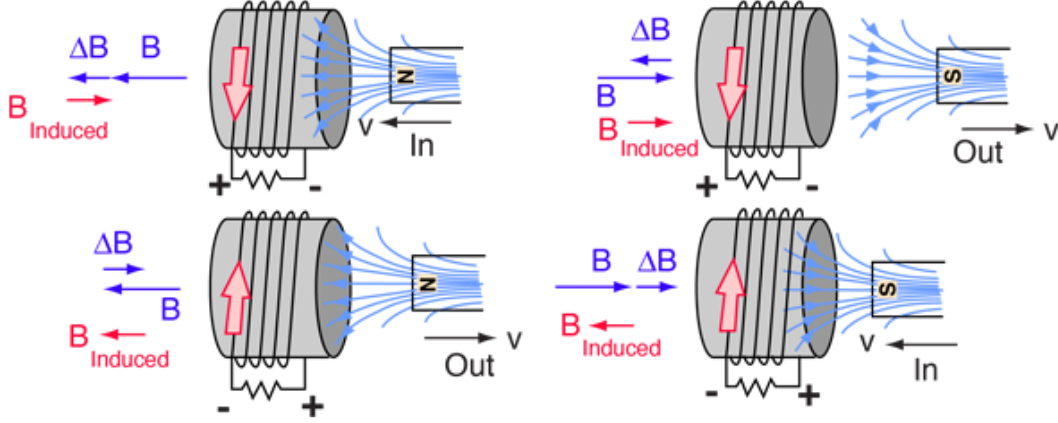


Figure 1: The change in magnetic flux creates potential difference across the coil generating an electric current through the resistor. The Lenz's law predicts the direction of the current in the coil.

### Electromagnetic Induction due to Current Carrying Coil

The axial magnetic field ( $B_z$ ) at the center of current carrying coil similar to the one shown in Figure 2 is given by,

$$B_z = N \cdot \frac{\mu_o I}{2R} \quad (2)$$

Now a time varying current such that,  $I(t) = I_{amp} \sin(\omega t)$  is applied to the current carrying coil where  $I_{amp}$  is the amplitude. It will produce a magnetic field such that,  $B(t) = B_{amp} \sin(\omega t)$  and,

$$B_{amp} = N_1 \frac{\mu_o I_{amp}}{2R} \quad (3)$$

and

$$B(t) = N_1 \frac{\mu_o I_{amp}}{2R} \sin(\omega t) \quad (4)$$

Where  $B(t)$  is the time varying magnetic field produced in the coil,  $\omega = 2\pi f$  is the frequency of the field,  $N_1$  is no. of turns in the coil and  $I_{amp}$  is the amplitude of the time varying current applied to the coil.

If a small coil is placed at the center of the coil shown in Figure 2 the magnetic field at the center will generate a potential difference across the small coil as predicted by the Faraday's law. The potential difference per unit length in the small coil at the center,

$$\frac{dV(t)}{dl} = -N_2 \frac{d\Phi}{dt} \quad (5)$$

Where  $\Phi$  is the magnetic flux across the small coil and  $N_2$  is no. of turns in the small coil. The total potential difference across the coil is,

$$V(t) = -N_2 \frac{d}{dt} \int_{coil \ length} (B(t) \cdot dl) \quad (6)$$

Where the integral is over the area of the coil and  $B(t)$  is given in the equation 4. After the integral, the total potential difference across the coil is,

$$V(t) = -N_2 \frac{d}{dt} B(t) \cdot A \quad (7)$$

Where  $A$  is the cross sectional area of the small coil normal to the direction of the magnetic field. Therefore using equations 7 and 4, the potential difference across the coil can be predicted.

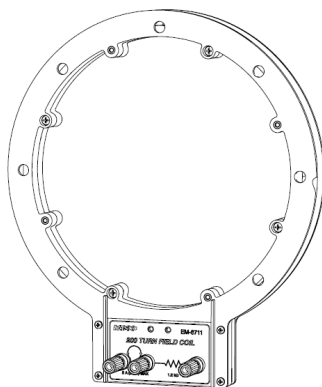


Figure 2: A current carrying coil of radius  $R$ . If a smaller coil is placed at the center of this coil, a changing magnetic field can be detected according to the Faraday's law

## Preliminary Lab Questions

1. Predict the direction of electric current for the movement of the the permanent magnet back and forth for four configurations shown in Figure 1
2. Predict the amplitude of the emf,  $V_{emf}$  when the magnet is moved “fast” and “slow”
3. What is the magnitude of magnetic field at the center of a current carrying coil?
4. If a coil with  $N$  no.of turns paced at the center of the current carrying coil, find an equation for the potential difference across the first coil? hint: solve equation 7 using the equation 4

## Equipment and Parts

1. Multimeter
2. Magnetic field sensor (Hall probe) to measure magnetic field
3. A stand and clap to hold the magnet and magnetic field sensor
4. A 200 turns current coil (small size) to detect electromagnetic induction

5. A 200 turns current coil (radius of  $10.5\text{ cm}$ ) (maximum allowed current of  $2\text{ A}$  to generate the magnetic field).
6. Power amplifier II as a power source (do not exceed the specified limiting current of  $1\text{ A}$ ).
7. PASCO voltage probe
8. Science workshop interface
9. A Laptop.

## Procedure

### Setup PASCO Software Suite

- Connect the **voltage probe** to Science workshop interface
- Connect the USB cable from Science workshop interface to the laptop
- Open the PASCO software suite in the laptop
- Add the voltage probe to current work environment
- Add a measurement tab to PASCO software suite work environment to record voltage reading in to a table and a graph
- Use “scientific notation” to record numbers by clicking the “Settings” button in the data table.
- Set the sampling rate to  $50\text{ Hz}$
- Click “Record” button in the PASCO software suite

### Induction using a Current Carrying Coil

- Measure the resistance of the current carrying coil (Coil1) using a multimeter  $F$
- Measure the average diameter of the Coil1 ( $R_1$ )  $F$
- Measure the length and height of the Coil2 to calculate the normal surface area  $F$
- Connect the **Power Amplifier II** to Science workshop interface
- in the PASCO suit, Add the Power Amplifier II to current work environment
- Click on the “Signal Generator” button at the left
- Set “AC” sinusoidal signal with value of  $5\text{ V}$  and frequency to  $50\text{ Hz}$ .
- Turn “On” the signal generator

- Using the multimeter measure the RMS output voltage at the “Red” and “Black” terminals of the Power amplifier II to verify output is approximately what you set in the PASCO suit
- Connect the two terminals of the voltage probe into the “Red” and “Black” terminals of the Power amplifier II
- Record the voltage and save the dataset
- Verify that Power Amplifier II is generating a 5 V and frequency to 50 Hz sinusoidal signal.
- Unplug the two terminals of the voltage probe from the Power amplifier II
- Connect the Power amplifier II to the current carrying coil (Coil1)
- Place the small coil (Coil2) at the center of the Coil1 (see Figure 3)
- Connect the two terminals of the voltage probe into the Coil2
- Set the sampling rate to 1 kHz
- Record the current in the Coil1 and induced voltage in the Coil2 into a dataset and to graphs to show time variation. You can select current and voltage output for the Power amplifier.
- Tabulate your results (current on Coil1 and induce voltage on Coil2) to show data at least for 1-2 seconds F
- Using measured value for the resistance of the coil and RMS value of voltage, calculate the RMS current in the coil
- Vary PASCO readings are correct for the current in the Coil1. F
- Measure the amplitude of the current in the Coil1 and amplitude of the induced voltage in the Coil2 using the dataset
- **Complete this during the lab** Calculate the induced voltage across the Coil2 using equations 7 and 4
- Compare calculated and measured values of induced voltage across the Coil2 F
- Remove the Coil2 from the center of the Coil1
- Remove the voltage probe from the PASCO Science workshop interface
- Connect the magnetic sensor into the PASCO Science workshop interface
- Using the settings icon, make sure sampling rate is set to 1 kHz and gain is set to 1×
- Set the sensor to measure “axial” magnetic field by using selector switch on the sensor

