# Induced EMF

## INTRODUCTION

The magnetic flux through a small element of surface with area $\Delta A$ is

$$\Delta\Phi_B = B\cos\phi\ \Delta A. \tag{1}$$

For a flat surface with area $A$ in a uniform magnetic field $\mathbf{B}$,

$$\Phi_B = BA\cos\phi. \tag{2}$$

Flux is a measure of the number of magnetic field lines that pass through the surface.

A changing magnetic flux through a circuit (due to some external field) induces an emf in the circuit. The quantitative relation is

$$|\boldsymbol{\varepsilon}| = \left|\frac{\Delta\Phi_B}{\Delta t}\right|. \tag{3}$$

If the circuit is a coil with $N$ turns and $\Phi_B$ is the flux through one turn, then

$$|\boldsymbol{\varepsilon}| = N\left|\frac{\Delta\Phi_B}{\Delta t}\right|. \tag{4}$$

If the circuit is a complete conducting loop with resistance, $R$, then the induced emf produces an induced current. The direction of the induced emf is the direction of the current that it produces. The direction of the induced emf is given by Lenz's law: the induced emf is in a direction that opposes the change that produced it. That is, the flux of the induced current opposes the change in flux due to the external field. If the flux of the external field is increasing, the magnetic field of the induced current is opposite to the direction of the external field. If the flux is decreasing, the magnetic field of the induced current is in the same direction as the external field. Lenz's law is a consequence of conservation of energy.

To prepare for this lab, review Magnetic Fields and Forces.

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# OBJECTIVE

In this lab, we will measure the direction of the induced emf in a coil when an electromagnet is inserted into the coil and when it is removed. We will compare our measured results with the direction predicted by Lenz's law.

# APPARATUS

Electromagnet (long rod with wire windings on it)

DC power supply

200-turn pick-up coil

Galvanometer

Two sets of a pair of connecting wires with banana plugs

# PROCEDURE

Please print the worksheet for this lab. You will need this sheet to record your data.

### Preparing the Power Supply

**1** Locate the DC power supply on your lab table but do not connect it to the circuit yet. Press the **On/Off** power button to the **On** position. Next, press the **RANGE** button to the "in" position (this sets the power supply to the 0-35 V/0-0.85 A range). Rotate the **Voltage** and **Current ADJUST** knobs fully counterclockwise. Then set the maximum output current for this experiment by pressing the **CC Set** button, and while holding it down, rotate the **Current ADJUST** knob clockwise until the AMP display reads 0.80. Release the **CC Set** button. Do not move the **Current** setting knob after this adjustment is done. The **Voltage ADJUST** knob will be used to set the output voltage but at this point leave the output at zero volts.

### Calibrating the Galvanometer

**2** We will first determine the relation between the direction of the current through the galvanometer and the direction the needle of the galvanometer deflects.

> **CAUTION:**
>
> The galvanometer is easily damaged if connected incorrectly.

Make sure the **Voltage ADJUST** knob on the power supply is fully counterclockwise. Turn on the power supply and turn up the voltage to **no more than 0.5 volts**. Connect a black connecting wire (lead) between the – jack on the power supply and the black jack on the galvanometer. Connect a red lead to the + jack on the power supply. **Do not** connect the red lead to the galvanometer. Just tap it very briefly on the red jack on the galvanometer and note the direction the galvanometer needle deflects. Recall that current flows out of the + terminal of the power supply. When current flows into the red jack on the galvanometer, the needle deflects in which direction?

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**3** Move the black lead that comes from the – jack on the power supply to the red jack on the galvanometer. Using the red lead that comes from the + jack on the power supply, tap the black jack on the galvanometer. Note the direction the needle deflects. When current flows into the black jack on the galvanometer, the needle deflects in which direction?

## Set Up the Electromagnet

**4** Connect the electromagnet to the DC power supply so that the end of the electromagnet opposite the plastic holder will be a south pole and have field lines directed toward it. Turn up the voltage on the power supply until the current is 0.80 A. Use the compass to verify that the magnetic field at the end of the electromagnet opposite the plastic holder is indeed directed toward this end of the rod. Adjust the connections to the electromagnet if necessary.

## Induced EMF

**5** Connect each jack of the pick-up coil to a jack on the galvanometer. Note the direction of the windings on the pick-up coil, as indicated by the black markings on the red tape at the ends of the coil. Use the right-hand rule and Lenz's law to predict the direction of the induced current in the pick-up coil if the south pole of the electromagnet is inserted rapidly into the pick-up coil. And then combine this predicted induced current direction with the calibration of the galvanometer to predict the direction the needle will deflect as the south pole is inserted into the coil, and record your prediction.

Rapidly insert the south pole of the electromagnet into the coil. Note the direction the needle of the galvanometer deflects, and record your experimental results.

**6** Predict the needle deflection if the south pole of the electromagnet is held at rest inside the pick-up coil. Record your prediction.

Insert the south pole of the electromagnet into the coil and hold it stationary. Note the needle deflection when the electromagnet isn't moving, and record your experimental results.

**7** Predict the needle deflection if the south pole of the electromagnet is pulled rapidly out of the coil, and record your prediction.

Pull the south pole of the electromagnet rapidly out of the coil. Note the direction the needle of the galvanometer deflects, and record your experimental results.

**8** Change the connection of the electromagnet to the DC power supply so that the end of the electromagnet opposite to plastic holder is a north pole. Use a compass needle to verify that the magnetic field at this end of the electromagnet is indeed directed away from the end of the rod.

**9** Repeat steps 5, 6 and 7 using the north pole of the electromagnet in place of the south pole.

When you have completed all parts of the lab, turn off the power supply and disconnect all the leads.

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