**INDUCED ELECTROMOTIVE FORCE – PH102**

**Short description:**
The purpose of this experiment is to study how currents can be induced in conductors by the presence of magnetic fields that change with time.

**Equipment:**
- Pair of coaxial cylindrical coils (solenoids)
- Two jack-banana cables (and two banana-alligator clips)
- Two banana cables
- Galvanometer
- PC software based oscilloscope and signal generator

**Theory:**
According to Faraday’s Law of Induction, a changing magnetic field induces an electric field. For an electrical circuit consisting of $N$ identical turns of wire, the magnitude of the induced emf is proportional to the number of turns and to the rate at which the magnetic flux is changing, so Faraday’s Law can be written in the form

$$\Delta V = -N \frac{\Delta \Phi_B}{\Delta t},$$

where $V$ is the emf induced around the circuit and $\Phi_B = \sum BA \cos\theta$ is the flux. $B$ is the magnetic field strength, $A$ is the area of the coil, and $\theta$ is the angle between $B$ and the normal to the coil area. The minus sign indicates that the current in the circuit due to the emf produces a magnetic field that acts to oppose the change in flux (this is known as Lenz’s Law).

The flux can be varied by changing $B$, $A$, or the angle $\theta$ between $B$ and $A$. If the magnetic field oscillates sinusoidally with frequency $f$ and the geometry of the circuit is fixed, the magnetic flux has time dependence

$$\Phi_B(t) = \Phi_{B,\text{max}} \cos(\omega t)$$

where $\omega = 2\pi f$. From Eqs. (1) and (2), it can be shown that the resulting induced emf is given by

$$V = N\omega \Phi_{B,\text{max}} \sin(\omega t) = N2\pi f \Phi_{B,\text{max}} \sin(2\pi f t)$$

So, the induced emf also varies sinusoidally with amplitude proportional to $N$ and $f$.

A transformer consists of two closely coupled coils. In this experiment we will have one cylindrical coil inside another coil of larger radius. An oscillating current in the inner coil (the primary) will produce an oscillating magnetic flux that will be seen in the outer coil (the secondary), which will
induce an oscillating voltage in the secondary coil. If the flux linkage is complete, then from Eq. (1) we find that

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

(4)

**Preliminary questions:**

1. Refer to Fig. 1 below. The coil is connected to a galvanometer (a sensitive current meter).

   ![Fig. 1](image)

   If the magnet is moved to the left, what is the direction of the current through the galvanometer (G)?

   (a) left  (b) right  (c) no current

2. Now assume the magnet is replaced with another coil connected to a battery, as shown below.

   ![Fig. 2](image)

   What will be the direction of the current through the galvanometer immediately after the switch connecting the battery is closed?

   (a) left  (b) right  (c) no current
Procedure:

Part 1 - Induced current due to the relative motion of a coil and a permanent magnet.

1. Connect the cylindrical coil (solenoid) to the galvanometer as shown in Fig. 1. Thrust the N-pole of the bar magnet into and then out of one end of the coil. Describe the effect that the direction of motion of the magnet has on the direction of the induced current. What effect does the speed of the magnet have on the magnitude of the induced current?

2. Repeat step 1, holding the magnet stationary while moving the coil. Describe your observations.

3. What is the effect of holding the magnet stationary inside the stationary coil?

4. Repeat steps 1-3 using the S-pole of the bar magnet. Describe your observations.

Part 2 - Transformers and alternating currents

1. Test your instruments and software:
   a. Check the cables. You should have two of them: one has 2-plugs (red and black), the other has 3-plugs (red, black and blue). Connect, or make sure, the 2-plugs cable is connected with its jack to the microphone input on the PC and the 3-plugs cable is connected to the speakers or headset output on the PC.
   b. On your PC, open the program Soundcard Oscilloscope by clicking the icon Scope on the desktop. This software provides an oscilloscope (OS) for displaying and measuring time varying voltages, through the microphone input, and it also provides a signal generator (SG) via the speaker output. Make sure the volume of the PC soundcard is not set on mute. If the window saying “No recording device found!” appears is because the microphone connection is not working properly. Do and click “continue”. Instead exit the program, check the cable and then re-open the program.
   c. Click the tab Signalgenerator and select Signalgenerator in separate window, so you can have both the Oscilloscope (OS) and the signal generator (SG) on your screen.
   d. Connect the red plugs from each cables together and connect the black plugs together as well. The blue plug is not used in this experiment.
   e. Start the SG by clicking on the icon next to Channel 1 (leave channel 2 off).
   f. Click Run/Stop on the OS and you should see a sine wave on the screen of the OS. You can vary the amplitude and frequency on the SG and regulate the reading on the OS by varying the amplitude [1/Div] and time [sec]. You can change the output voltage from the SG also by adjusting the volume level of the PC. The maximum peak to peak voltage (Vpp) that the OS can read is 2 Volts. If you provide a higher voltage, the OS will cut off the signal.
g. On the OS you can take measurements of the signal (frequency, voltage, time intervals) by clicking *measure* on the bottom left corner of the screen. Experiment by generating signals of different amplitude and frequency from the SG and check the reading on the OS.

2. **Analyze the induced emf:**
   Now we examine how the induced voltage $V$ depends on the frequency and number of turns.
   
   a. Connect now the output cable (SG three plugs: red and black - not the blue) to the inner coil and connect the input cable (OS two plugs: red and black) to the outer coil of the solenoid. Place the inner coil inside the outer coil.
   
   b. How the amplitude of the induced voltage changes as you vary the frequency of the signal generator?

   c. How does the amplitude of the induced voltage change as you move the inner coil in and out of the outer coil?

   d. Now place the inner coil completely inside the outer coil. For different SG frequencies, record in Table 1 below the corresponding $V_{pp}$ on the OS. Start at 200 Hz and increase the frequency by steps of 50 Hz.

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   Table 1

   e. Based on your observations, how does $V$ depend on $f$?

   f. Check you answer above by using Excel to plot $V_{pp}$ versus $f$. Does your plot agree with Eq. (3)?

3. Now set the frequency to a fixed value – say 1000 Hz. Measure the voltage of the outer coil $V_2$. Then measure the voltage of the inner coil $V_1$ (keep the output cables connected to the inner coil and connect the input cables to the inner coil). Examine the small coil (primary) and estimate the number of turns, $N_1$ by counting them. (You will probably have either one layer or two layers of turns). Use Eq. (4) to calculate the number of turns, $N_2$, on the large coil (secondary).

   $N_1 = _____$
   
   $N_2 = _____$

   EXIT the Scope program.