

Course and Section \_\_\_\_\_

Names \_\_\_\_\_

Date \_\_\_\_\_

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## ***INDUCED EMF PH 106 EXPERIMENT***

### **Introduction**

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** Galvanometer, one bar magnet, two banana cables. Pair of coaxial cylindrical coils (solenoids), a pair of jack-banana cables, USB audio adapter.

### **Theory**

According to Faraday's Law of induction a changing magnetic field induces an electric field. For a solenoid of  $N$  loops the induced emf  $\Delta V$  is proportional to the number of turns  $N$  and to the rate at which the magnetic flux is changing

$$\Delta V = -N \frac{d\Phi_B}{dt} \quad (1)$$

where  $\Phi_B = \int \vec{B} d\vec{A}$  is the total flux:  $B$  is the magnetic field and  $A$  is the area of the coil. The minus sign (Lenz's Law) indicates that the induced current produces an induced magnetic field (because of Ampere Law) which opposes the change of the flux.

A *transformer* consists of two closely coupled coils. In this experiment (second part) the smaller cylindrical coil is placed inside the larger coil. When an AC current of frequency  $f$  is passed through in the inner coil (the primary) it will produce an oscillating magnetic flux of frequency  $f$  in the outer coils (the secondary). This flux will induce an oscillating voltage in the outer coil

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

The induced emf  $V$  also varies sinusoidally with amplitude proportional to  $N$  and  $f$ .

If the flux linkage is complete, then it can be shown that.

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} \quad (3)$$

Where  $V_1$  and  $V_2$  are the peak to peak voltages of the inner/outer coils respectively and  $N_1$  and  $N_2$  the relative number of turns.

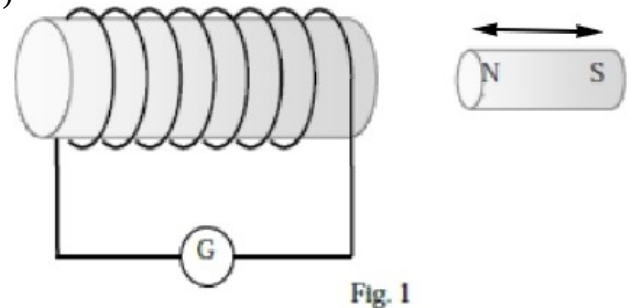
## PART 1 – Solenoid and Bar Magnet

The galvanometer is device very sensible in the measuring of currents.

### Procedure

*Step 1.* Connect the solenoid to the galvanometer (G) as shown in Fig. 1.

*Step 2.* Thrust the *N*-pole of the bar magnet in and out of one end of the solenoid.

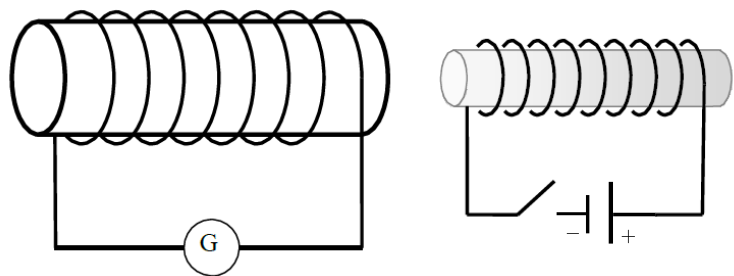


3. Does the galvanometer read a current when the magnet is moving?
4. Does the galvanometer read a current when the magnet stay at rest inside the solenoid?
5. How does the intensity of the current depend on the speed of the magnet?
6. How does the direction of the the current depend on the direction in/out of the magnet?
7. Reverse the magnet, *S*-pole to enter the solenoid. How are the directions of the current when compared to the previous question?

## PART 2 – Mutual Inductance

### Preliminary questions

The figure shows a solenoid connected to a galvanometer (G) and on its right another solenoid connected to a battery.



8. Which end of the coil with the battery becomes the North pole if the switch is closed?
9. Which end of the coil with the galvanometer becomes the North pole if the switch is closed?
10. What will be the direction of the current through the galvanometer (G) immediately after the switch connecting the battery is closed?

## Procedure

The PC sound-card is used as a signal generator (SG) and as an oscilloscope (OS). The SG is the speaker output and the OS is the microphone input.

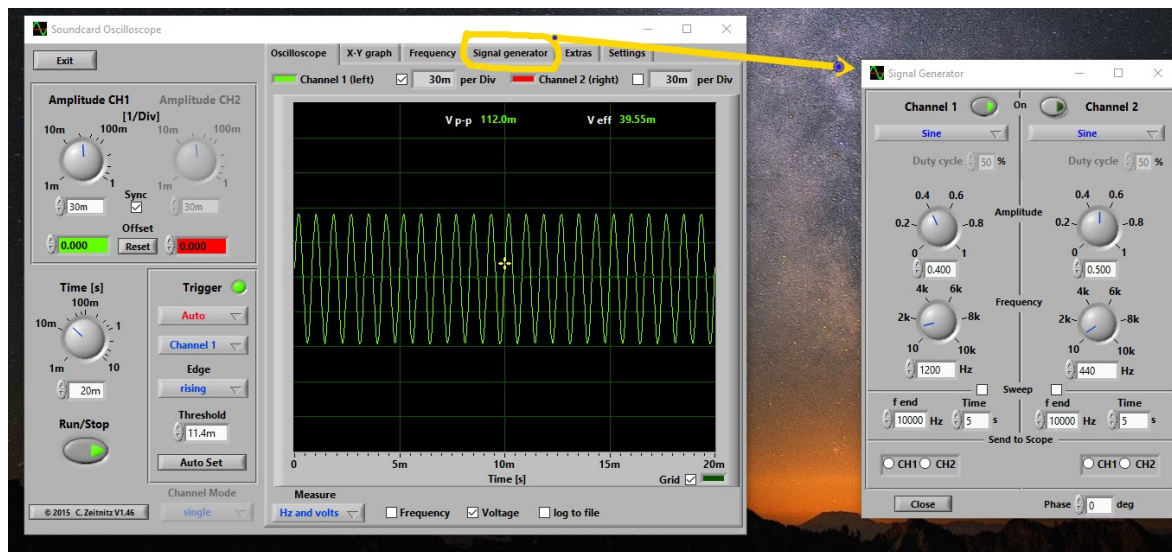
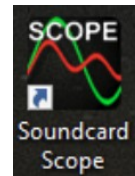
*Step 1.* Check that the USB audio adapter is connected into the front panel of the PC via the USB port. The green connector is the speaker output (SG), the pink connector is the microphone (OS).



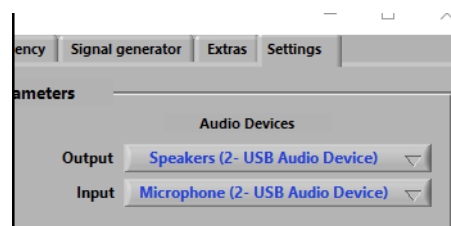
*Step 2.* Connect the jack of the jack-banana cable into the SG green connector and the other end of the cable (the red and black plugs) to the inner coil.

*Step 3.* Connect the jack of the other jack-banana cable into the OS pink connector and the other end of the cable (the red and black plugs) to the outer coil.

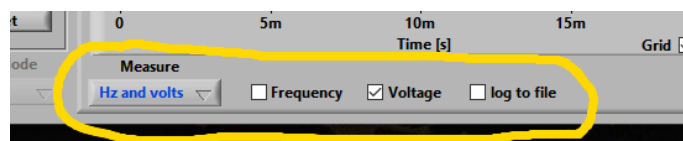
*Step 4.* Open the Soundcard Scope program by clicking the icon on the desktop. Then click the tab *Signal generator* and select to display the SG in a separate window, as show below:



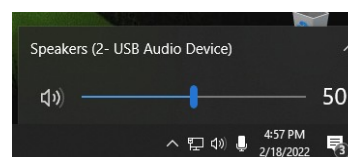
*Step 5.* Click on the *Setting* tab and select for the Output and Input the 2 - USB Audio Device.



*Step 6.* Click on the tab at the bottom left of the oscilloscope to display *Hz and volts* and select *Voltage*.



*Step 7.* Adjust the PC output volume to the value 25.



Step 8. On channel 1 of the SG set the amplitude to 0.300 and the initial frequency to 1000 Hz.

Step 9. Make sure the inner coil is completely inside the outer coil.

Step 10. Click on the SG to send a sinusoidal signal. Click on Run/Stop on the OS to see the relative image on the screen of the OS. You can regulate the reading on the OS by varying the amplitude [1/Div] and time [sec]. Check with the TA if you have any issue. Closing and re-start the Soundcard Scope program might solve the problem.



## Analysis

Step 11. Record the voltage peak to peak  $V_{pp}$  corresponding to 1000 Hz. You might have to wait two to five seconds for the signal to “settle down” to the correct voltage. Stop the SG and increase the frequency by 50 Hz, start again the SG and record the relative new  $V_{pp}$ . Take measurements of increasing frequency up to 700Hz.

11. Use the table below to collect your data.

f (Hz)	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
$V_{pp}$ (V)										

12. Based on your observations, how does the  $V_{pp}$  depend on the frequency? (Note: there is a off-set due to the sound-card's driver resulting in the non zero y-intercept).

13. Check you answer above by using Excel to plot  $V_{pp}$  versus  $f$ . Print a copy of the plot.

14. Does your plot agree with Eq. (2)?

Step 12. Set the frequency to a fixed value, say 1000 Hz. Measure  $V_2$  (the  $V_{pp}$  of the outer coil). Next measure  $V_1$ : simple unplug the black and red plugs from the outer coil and touch the others red and black plugs connected to the inner coil. The colors do not matter.

15. Record your results below.

$$V_1 = \text{_____ V}$$

$$V_2 = \text{_____ V}$$

16. The number of turns of the outer coil is  $N_2 = 2920$ . Use equation (3) to estimate  $N_1$

$$N_1 = \text{_____}$$

17. The actual value is  $N_1 = 235$  . Calculate the % error

$$\% \text{ error} = \frac{| \text{Estimated Value} - \text{Actual Value} |}{| \text{Actual value} |} = \text{_____} \%$$

18. Which are the source of errors, other than humans errors?