Experiment 1

Alternating Current with Coil and Ohmic Resistors

1- Objects of the experiment

- Determining the total impedance and the phase shift in a series connection of a coil and a resistor.
- Determining the inductance's value of the coil.

2- Principles

2-1- Inductors in an AC circuit:

If an alternating voltage

$$\Delta v = \Delta V_{max} \sin(\omega t) \text{ with } \omega = 2\pi f \qquad \text{(Equation 1)}$$

is applied to a coil with the inductance *L*, the current flowing through the coil is

$$i_L = \frac{\Delta V_{max}}{\omega L} \sin\left(\omega t - \frac{\pi}{2}\right) \qquad \text{(Equation 2)}$$

Therefore an inductive reactance

$$X_L = \omega L \qquad \text{(Equation 3)}$$

is assigned to the coil, and the voltage is said to be phase-shifted with respect to the current by 90° (see Figure 2). The phase shift is often represented in a vector diagram.

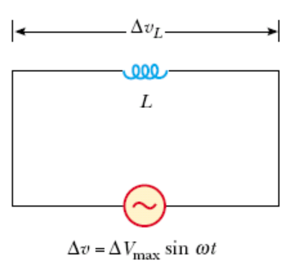


Figure 1. *A circuit consisting of an inductor of inductance L connected to an AC source.*

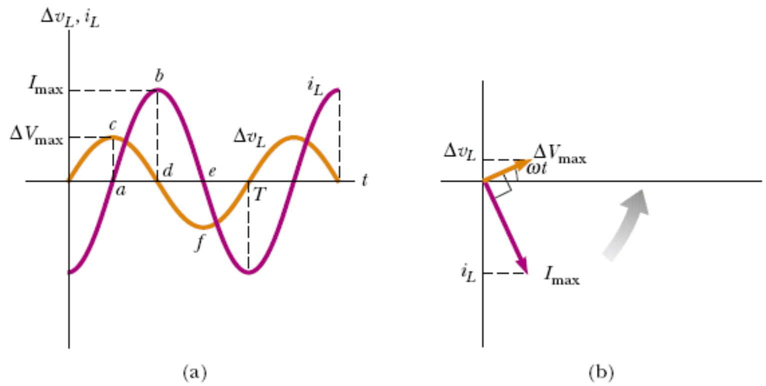
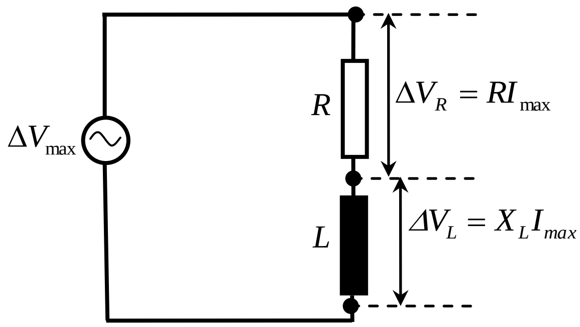


Figure 2. *(a) Plots of the instantaneous current and the instantaneous voltage across an inductor as functions of time. The current lags behind the voltage by 90°. (b) Phasor diagram for the inductive circuit, showing that the current lags behind the voltage by 90°.*

2-2- The RL series circuit



If the coil is connected in series with an ohmic resistor, the same current flows through both components. This current can be written in the form

$$i = I_{max} \sin(\omega t - \Phi) \qquad \text{(Equation 4)}$$

where Φ (phase angle) is unknown for the time being. Correspondingly, the voltage drops at the resistor and at the coil are, respectively,

$$\Delta v_R = I_{max} R \sin(\omega t) \qquad \text{(Equation 5)}$$

$$\Delta v_L = I_{max} X_L \sin\left(\omega t + \frac{\pi}{2}\right) \qquad \text{(Equation 6)}$$

The sum of these two voltages is

$$\Delta v = \Delta v_R + \Delta v_L \qquad \text{(Equation 7)}$$

It is simpler to obtain the sum by examining the phasor diagram

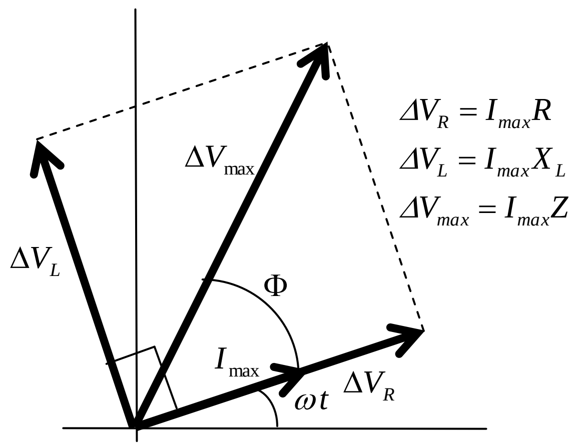


Figure 3. *Phasor diagram for the series RL circuits. The phasor ΔV_R is in phase with the current phasor I_{max}, the phasor ΔV_L leads I_{max} by 90°. The total voltage ΔV_{max} makes an angle Φ with I_{max}.*

The series connection of an ohmic resistor and a coil can be assigned the impedance

$$Z = \sqrt{R^2 + X_L^2} \qquad \text{(Equation 8)}$$

The voltage is phase-shifted with respect to the current by the angle

$$\Phi = \tan^{-1}\left(\frac{X_L}{R}\right) \qquad \text{(Equation 9)}$$

3- Apparatus

1 plug-in board A4; 1 resistor 1Ω; 1 resistor 100Ω; 1 coil 1000 turns; 1 function generator; 1 two-channel oscilloscope; 2 screened cables BNC/4 mm; connecting leads.

4- Setup

The experimental setup is illustrated in Figure 5.

- Connect the function generator as an AC voltage source.
- Connect the channel 1 of the oscilloscope to the output of the function generator, and feed the voltage drop at the measuring resistor 1Ω into the channel 2.
- Press the DUAL pushbutton at the oscilloscope, and select AC for the coupling and the trigger.

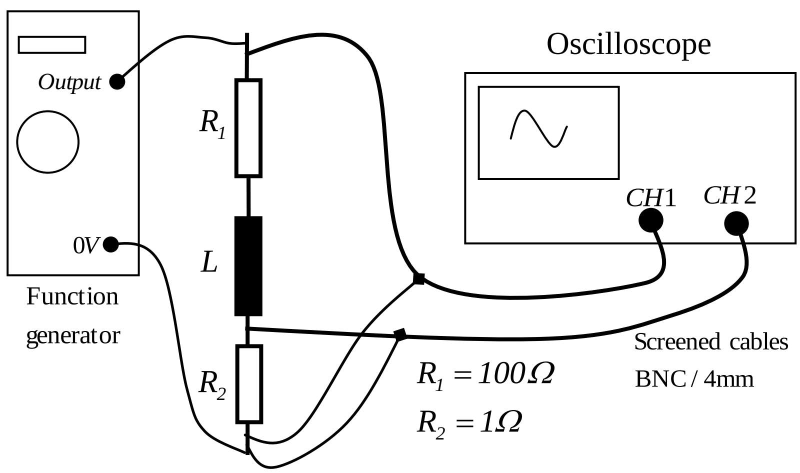
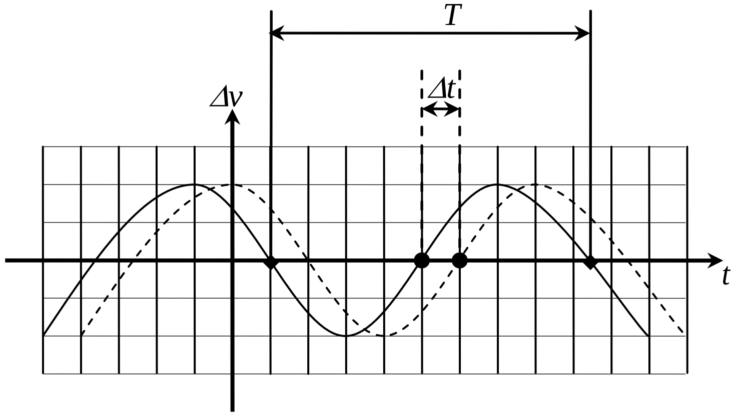


Figure 5. Experimental setup for determining the impedance and phase-shift in circuits with coil and ohmic resistors in series connection.

5- Carrying out the experiment

- Connect the coil as an inductance in series with the 100Ω resistor.
- Switch the function generator on by plugging in the plug-in power supply, and adjust a frequency of 1000Hz (T=0.1ms).
- Select an appropriate time-base sweep at the oscilloscope.
- Adjust an output signal ΔV_{max}=5V.
- Read the amplitude $\Delta V(R_2)$ of the signal in the channel 2 of the oscilloscope, and enter it in the table as current $I_{max} = \dfrac{\Delta V(R_2)}{1\Omega}$

- Read the time difference Δt between the zero passages of the two signals.



<u>Figure 4.</u> *Phase difference measurement.*

$$\Phi = 360\frac{\Delta t}{T} \quad (\text{ in degrees }) \qquad \text{(Equation 10)}$$

- Calculate the total impedance:

$$Z = \frac{\Delta V_{\max}}{I_{\max}} = \frac{5V}{I_{\max}} \qquad \text{(Equation 11)}$$

- Calculate the inductance of the coil as function of Φ:

$$L_1 = \frac{R_1}{\omega}\tan\Phi \, . \qquad \text{(Equation 12)}$$

- Calculate the inductance of the coil as function of the impedance Z:

$$L_2 = \sqrt{\frac{Z^2 - R^2}{\omega^2}} \qquad \text{(Equation 13)}$$

- Adjust other frequencies according to Table 1, and repeat the measurements.

Table 1. Measuring data for the oscillation period, current amplitude I_{max} and time difference Δt.

f (Hz)	ω (rad/s)	T (s)	I_{max} (A)	Δt (s)	Z (Ω)	Φ (Eq.10)	L_1 (H)	L_2 (H)
10000								
5000								
2000								
1000								
500								
200								
100								
50								

- Find average values of $\overline{L}_1$, and $\overline{L}_2$, and compare them.

- Fill the following table:

Table 2. Values of the inductive reactance and the impedance calculated from the measuring data from Table 1.

f (Hz)	ω (rad/s)	$X_L = \omega\left(\frac{\overline{L}_1 + \overline{L}_2}{2}\right)$ (Ω)	Z (Ω)
10000			
5000			
2000			
1000			
500			
200			
100			
50			

- Prepare a sheet of graph paper for plotting Z^2 versus X_L^2. You should make Z^2 the vertical axis and X_L^2 the horizontal axis. Each axis should be labeled and appropriate units indicated. The graph should have a title.

- Plot your data on the graph.

- Draw the best straight line through your data points by using method of least squares (see Appendix B).

- Calculate the percent error on the slope of the best straight line, where its accepted value is 1 (see Equation 8).

- Determine the y-intercept value and compare it to $R=100\Omega$.

6) Conclusions

- Discuss your results.