Kuwait University Physics Department
Physics 107

RL Circuit

Introduction

Inductor is an electric component that stores energy in its magnetic field. It is made of a low resistance conductor like copper, aluminum...etc. Thus, the DC voltage drop across an inductor after $\tau_L (\tau_L = L/R)$ is very small (near zero volt).

In an AC inductive circuit the current applied to the inductor is continually changing in amplitude and direction. Therefore, there is a continual change in the magnetic flux and according to the Faraday's law voltage is induced across the inductor.

In this experiment, you will study inductor as an AC component connected in series with resistors. You will also learn a tool to determine inductance of a coil.

Objectives

To determine the inductance of a coil by

- Voltage measurement.
- Current measurement.

Equipment to be Used:

- Variable box resistor
- AC voltage generator

- Coil (3200 turns)
- Wires
- Multimeter

Theory

Inductance is a measure of the ability of a coil to induce a voltage across itself as a result of changing current in its windings. It depends on the length, size, shape, number of turns and the kind of core material. It does not depend on the value of frequency of the applied voltage. The mathematical symbol for inductance is L and the unit of inductance is Henry (H).

In AC circuits inductance causes two things:

- **Inductive reactance**

  The inductive reactance is defined as an opposition to a current change. Therefore, it is found only in case of AC circuit (in a DC circuit, current and voltage do not change). Inductive reactance at a certain frequency can be found using the formula:

  $$X_L = 2\pi f L \tag{1}$$

  where X_L is the inductive reactance measured in Ω, f is the frequency of the applied voltage measured in Hz, and L is the inductance. From Equation (1), as the frequency f increases, the inductive reactance X_L increases also.

  The current passing through a purely reactive circuit (has only inductive reactance and no resistance, see Figure 1. below) can be found by a formula similar to Ohm's law

  $$I_L = \frac{V_L}{X_L} \tag{2}$$

  where V_L is the applied voltage. In this ciruit the current lags the voltage by $\pi/2$.

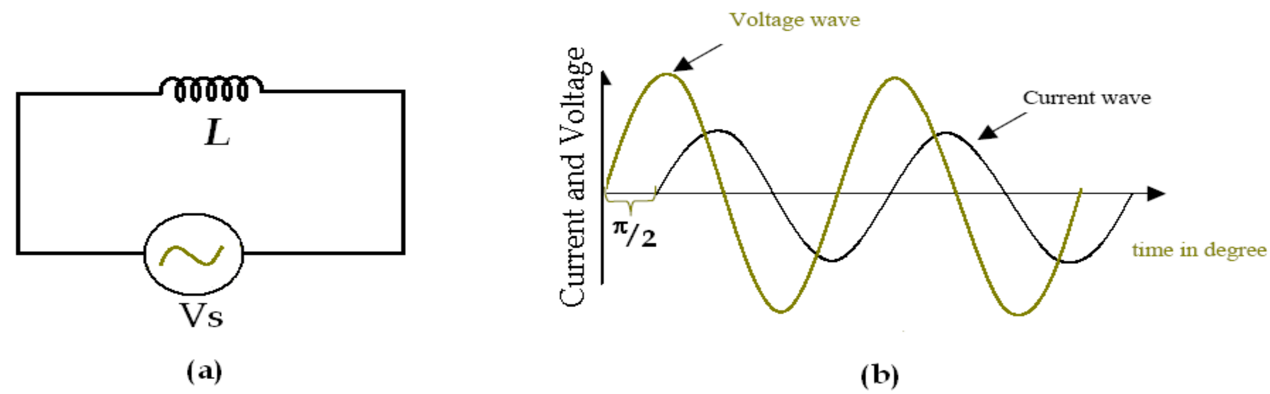


Figure 1. (a) schematic diagram of purely reactive circuit
(b) Voltage and current waveforms.

- **Delay of current in relation to voltage**

If in purely resistive circuit, as shown in Figure 2(a) below, an AC voltage is applied, then the current produced through the circuit will be in phase with the voltage applied (the phase shift being $\theta = 0^o$. See Figure 2(b).)

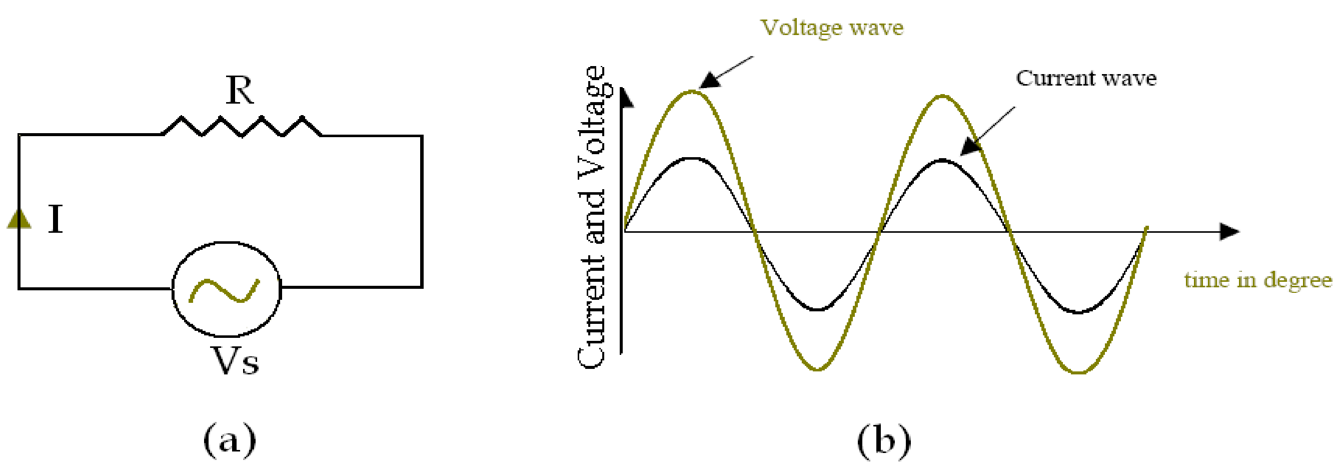


Figure 2. (a) schematic diagram of purely resistive circuit
(b) Voltage and current waveforms.

RL-circuit

For a circuit including a resistor and an inductor connected in series (Note:*the internal resistance of the inductor is a series resistor*), the phase shift between the voltage applied and the current passing through the circuit will be some where between 0^o to $\pi/2$. The greater the resistance in the circuit relative to the amount of inductive reactance, the smaller the phase angle. Thus, for

- $R > X_L$ — θ will be $[0^o - \pi/4)$
- $R = X_L$ — $\theta = \pi/4$
- $R < X_L$ — θ will be $(\pi/4 - \pi/2]$

There is a phase shift between the voltage of the resistor and the voltage across the inductor, since the voltage of the resistor will be in phase with the current passing through the circuit, but the voltage of the inductor leads the current by $\pi/2$. Then the voltage of the resistor lags the voltage of the inductor by $\pi/2$ as shown in the following *phase diagram*

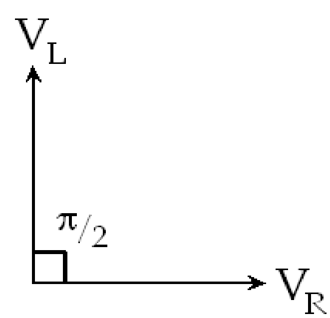


Figure 3. Phase diagram between V_L and V_R.

Therefore, voltages can not be added directly to find the total voltage of the circuit. Instead, the rule of squares formula must be used:

$$V_Z = \sqrt{V_R^2 + V_L^2} \tag{3}$$

This is also true for an impedance Z of the circuit determined from the resistance and inductive reactance, i.e.,

$$Z = \sqrt{R^2 + X_L^2} \tag{4}$$

In case the coil has internal resistance r, this will be in series with the external resistance R, and the phase diagram, that is previously illustrated in Figure 3, will change to

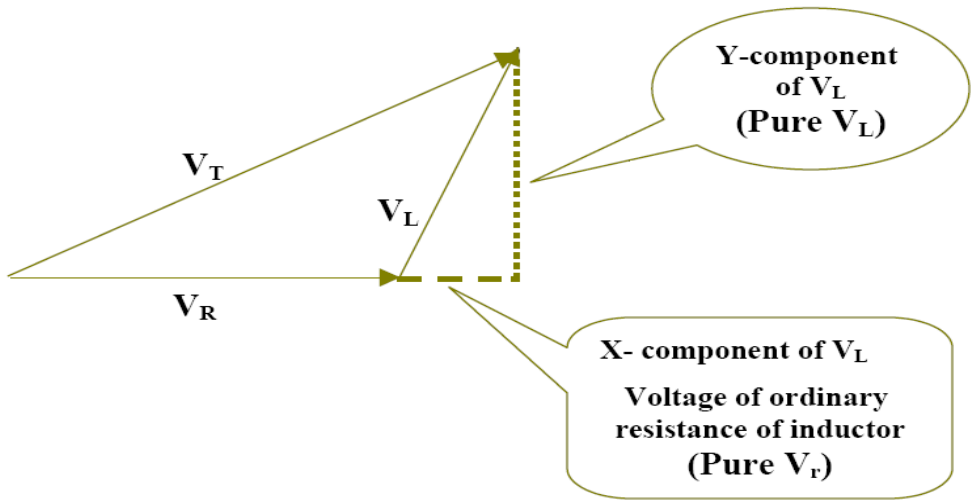


Figure 4. Phase diagram between V_L, V_R, and V_r.

The total voltage of the circuit will be modified to

$$V_Z = \sqrt{(V_R + V_r)^2 + V_L^2} \tag{5}$$

and the impedance of the circuit becomes

$$Z = \sqrt{(R + r)^2 + X_L^2} \tag{6}$$

The impedance of an RL circuit is defined as the total opposition to the flow of the alternating current made by both the resistor and the coil. This impedance is measured in Ω. If V_Z and the current passing through a circuit are known, the impedance is found by

$$Z = \frac{V_Z}{I} \tag{7}$$

Procedure

Part One: Determination of X_L and L from the graph of $(Z)^2$ versus $(R+r)^2$

1) **Set** the frequency of AC power supply-function generator to f=500 Hz.

2) **Adjust** the voltage V_{rms} of the power supply to 7 V.

3) From the box of inductors take out the inductor with 3200 turns. **Measure** the internal resistance r of the inductor using ohmmeter.

4) **Connect** the RL circuit as indicated in Figure 5 below.

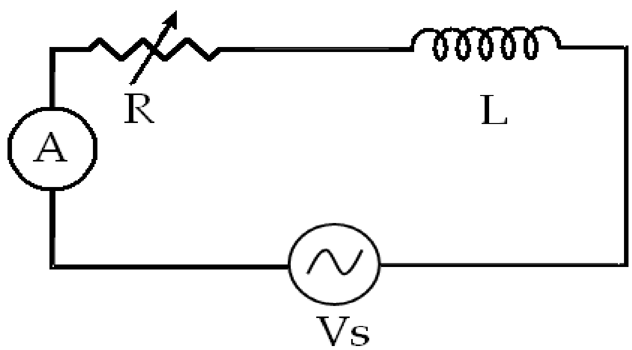


Figure 5. Circuit diagram of part one.

5) For each value of the variable resistor given in Table 1, **measure** V_Z and I_Z. **Record** the measured values in Table 1. you have to use the voltmeter and ammeter in AC mode.

6) As indicated to you in Equation (7), **calculate** Z using the measured values of V_Z and I_Z from step 5.

7) **Plot** a graph of Z^2 versus $(R+r)^2$.

8) From the point of interception with Z^2 axis or negative $(R+r)^2$ axis, **find** the inductance L of the coil.

Table 1.

Internal resistance r of the coil = ...Ω.

R (Ω)	$(R + r)^2$ $(\Omega)^2$	I (mA)	V_Z (v)	Z (Ω)	Z^2 $(\Omega)^2$
200					
400					
600					
800					
1000					
1200					

Inductive reactance X_L (from the graph) = ...

Inductance L (from Equation (1)) = ...

Part Two: Determination of L and r from the Phase Diagram

1) **Connect** your circuit as shown in Figure 6 below.

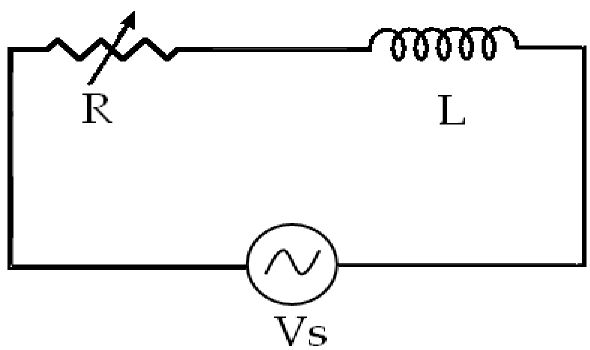


Figure 6. Circuit diagram of part two.

2) For each value of the variable resistor R given in Table 2, **measure** V_Z, V_R, and V_L. **Record** the measured values in Table 2.

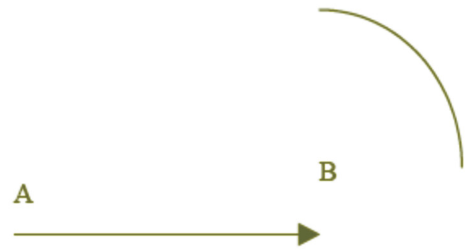
Table 2.

R (Ω)	V_Z (V)	V_R (V)	V_L (V)
400			
600			
800			

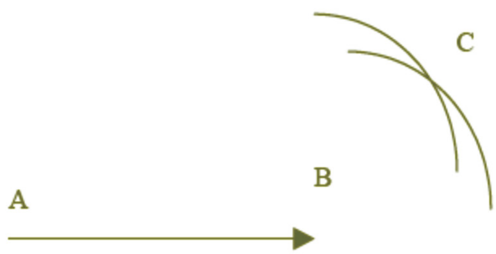
3) **Choose** any row of Table 2 to **draw** the phase diagram for the voltages of this row. Follow the guideline given below:

1- Take a reasonable scale and convert the voltages V_Z, V_R, and V_L into lengths. For example 1V: 1 cm

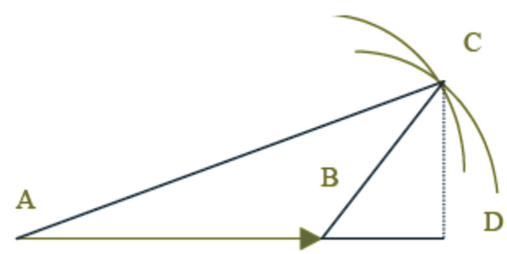
2- Draw horizontal arrow AB that represents the resistance voltage.



3- Open a compass to an opening equal to the voltage value of V_Z. Put one tip of the compass on point A while drawing an arc using the second tip.



4- Open the compass to an opening equal to the voltage value of V_R. Put one tip of compass on point B while drawing an arc using the second tip.



5- From the intercept point C draw line to point A, draw a second line to point B, and draw a line perpendicular to the horizontal.

Comment on the relation between the voltages.

....

....

Inductive reactance X_L (from the phase diagram) = ...

Internal resistance r of the coil = ...

Conclusion: