

*Experiment # 13***Conductors: Inductance****Principles***Electromagnetic Interactions*

It has been known for some time that electrical charges and currents interact with magnetic fields. We write \mathbf{B} for magnetic field which is measured in units of Tesla, T . These interactions are of three distinct types:

- (1) magnetic field \mathbf{B} exerts a force \mathbf{F}_B on electrical currents and moving electrical charges.
- (2) a conductor carrying current I produces a magnetic field \mathbf{B} ;
- (3) a changing or varying magnetic field \mathbf{B} mobilizes free electrons in a conductor thereby creating a potential difference across the terminals of the conductor.

We shall presently consider the second and the third interactions.

Ampere's Law

According to Ampere's law, every electrical current I produces a magnetic fields \mathbf{B} . There are no exceptions, no constraints and no preconditions either. We may say that, *where there is I , there is \mathbf{B}* . Ampere's law tells us that the magnetic field \mathbf{B} is directly proportional to the source current I_S and allows us to make a far reaching statement,

\mathbf{B} follows I_S faithfully

If I_S increases, \mathbf{B} increases; if I_S decreases, \mathbf{B} decreases and if I_S stays constant, \mathbf{B} stays constant. Again, if I_S were to vary (say) sinusoidally, \mathbf{B} will also vary sinusoidally; and if I_S is an alternating current (AC) of frequency f , then \mathbf{B} will also be an alternating magnetic field: alternating between north and south poles with the frequency of the AC supply. The magnitude of \mathbf{B} is given by Ampere's law while its direction is given by the right hand rule. The magnitude of \mathbf{B} depends on the geometrical shape and size of conductors that carry currents I_S . Below we describe three configurations of conductors and give the respective expressions for determining the field \mathbf{B} produced by them. These expressions have been calculated using Ampere's law.

(i) A conductor (rod or wire) in the form of a very long straight wire or rod

The magnitude of the magnetic field \mathbf{B} produced by the wire at some distance r from it, is given by the expression:

$$B = \left(\frac{\mu_o}{2\pi r} \right) I_S \quad \dots\dots\dots(1)$$

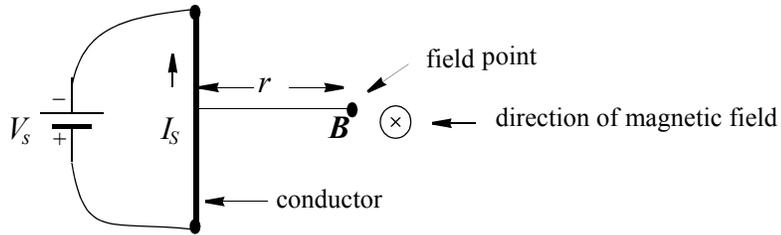


Fig (1) Magnetic Field Produced by a Straight Conductor

The field is generated perpendicularly to the page, and in the above example, is directed into the page.

(ii) A conductor (wire) in the form of a circle of radius r.

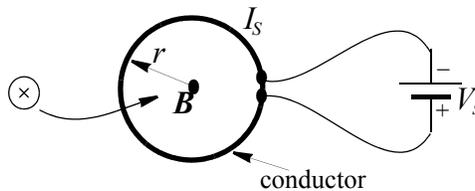


Fig (2) Magnetic Field Produced by a Circular Conductor

The conductor (wire) may have many loops or turns. All loops are lumped together to form a bunch. Let N is the number of loops in the bunch. Each loop carries current I_s . The equivalent current of all N loops is NI_s . Magnetic field B is generated along an axis passing through the center of the circle and, in the above example, it is directed into the page. Its magnitude is given by the equation:

$$B = \left(\frac{\mu_o}{2r}\right)(NI_s) \dots\dots\dots(2)$$

(iii) A conductor (wire) in the form of a coil of N loops (turns) and of length l .

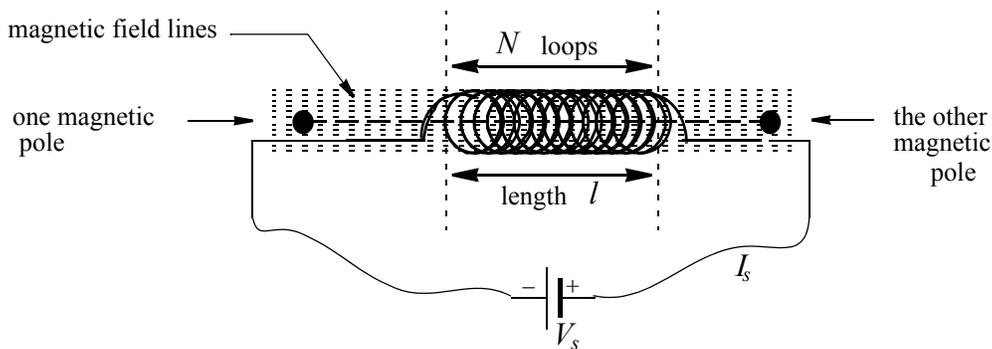


Fig (3) Magnetic Field Produced by a Coil

Each loop carries current I_s . The equivalent current of all loops is NI_s . Magnetic field B is generated along the axis of the coil and is given by the equation:

$$B = \left(\frac{\mu_o}{l}\right)(NI_s) \dots\dots\dots(3)$$

Such coils are extensively used as magnets and are better known as *electromagnets* or *solenoids*. They have replaced the traditional iron or steel magnets. One end of the coil is a *north* pole, the other, a *south* pole. In this experiment, we shall call it a *coil*.

The Coil: Basics

We shall now study the *coil* in greater detail. Fig (4) shows the three geometrical parameters of the coil: (i) length l (ii) area of cross-section A and (iii) number of loops (or turns) N . The magnetic field produced by it in a DC circuit, has been shown in Fig (3).

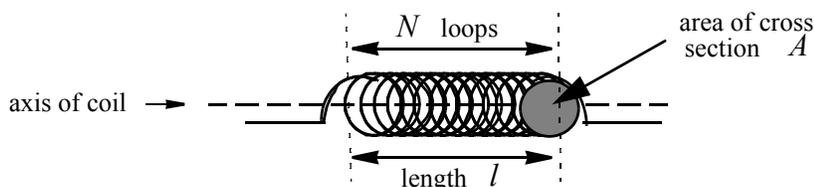


Fig (4) The Geometrical Parameters of the Coil

Because a coil is made of a conducting material (in the form of wire), it necessarily has resistance. Let this resistance be called R_L . Because of R_L , the coil will obey Ohm's law in a DC circuit. We may write:

$$V_L = R_L I_L \quad \dots\dots\dots(4)$$

The coil will also necessarily produce a magnetic field \mathbf{B} , in accordance with Ampere's law, as given by Eqn (3) above.

The presence of \mathbf{B} causes the coil to have *magnetic flux* Φ_B . Magnetic flux is a measure of the intensity of magnetic field, incident upon a *single* loop of the coil, perpendicularly to it. If the area of the loop be A , then *flux* is defined as the product of magnetic field strength B and the area A . Thus $\Phi_B = BA$. The flux through each loop is $\Phi_B = BA$, and that through all N loops of the coil is $N\Phi_B = NBA$.

From Ampere's law: \mathbf{B} follows I_S faithfully, we understand that \mathbf{B} , and hence the flux $N\Phi_B$ will vary linearly with source current I_S . If, therefore, we plot a graph of $N\Phi_B$ against I_S , we should get a straight line. Such a graph is shown in Fig (5).

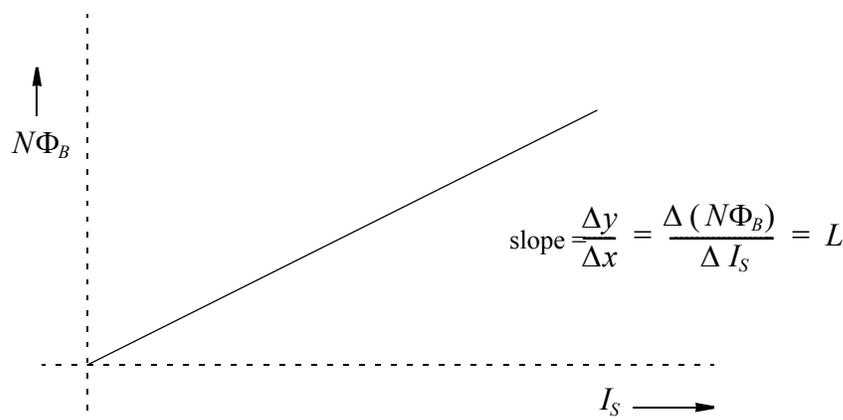


Fig (5) Studying the Dependence of Magnetic Flux of a Coil on Source Current

The slope of the graph has been worked out in the above graph and has been called L :

$$L = \frac{\Delta (N\Phi_B)}{\Delta I_S} \quad \text{.....(5)}$$

The Coil: Coefficient of Self Inductance

We consider $\Delta (N\Phi_B)$ in some detail. As N is constant,

$$\Delta (N\Phi_B) = N (\Delta\Phi_B)$$

But $\Phi_B = BA$

$$\Delta (N\Phi_B) = N \Delta (BA)$$

Now A is constant,

$$\Delta (N\Phi_B) = NA \Delta (B)$$

The value of B for the coil may be taken from Eqn (3)

$$\Delta (N\Phi_B) = NA \Delta \left[\left(\frac{\mu_o}{l} \right) (NI_S) \right]$$

Pulling out all the constant parameters and putting them together, we get:

$$\Delta (N\Phi_B) = \left(\frac{\mu_o N^2 A}{l} \right) (\Delta I_S) \quad \text{.....(6)}$$

Now we plug in this value of $\Delta (N\Phi_B)$ back into Eqn (5); we get:

$$L = \frac{\left(\frac{\mu_o N^2 A}{l} \right) (\Delta I_S)}{\Delta I_S}$$

or

$$L = \left(\frac{\mu_o N^2 A}{l} \right) \quad \text{.....(7)}$$

The entity L is known as the *Coefficient of Self Inductance* of the coil. It tells us how much electrical energy is stored in the magnetic field, inside the coil; as we shall see next.

The Coil: Storing Energy

Like the capacitor that stores electrical energy in the electric field, a coil stores electrical energy in the magnetic field present inside the coil. To find the magnitude of this energy, we go back to the graph of Fig (5) and explore the area under the straight line.

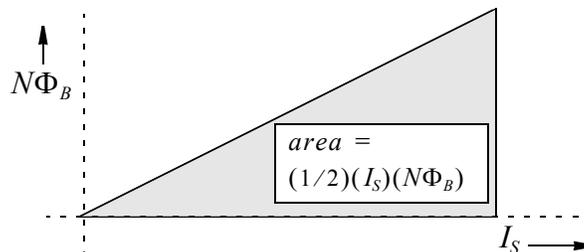


Fig (6) Electrical Energy Stored in the Magnetic Field of the Coil

Let us investigate the units of the area. Unit of I_S is A ; that of Φ_B is Tm^2 . But T itself is N/Am . Combining, we get

$$(A) (N / \text{Am}) (\text{m}^2) = \text{Nm} = \text{J}$$

The area, therefore, indeed represents the energy stored in the coil's magnetic field. We can write this energy in three different forms. First, as the straight line of Fig (5) passes through the origin, the slope can also be written as

$$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{y}{x} = \frac{N\Phi_B}{I_S} = L$$

This gives us

$$I_S = \frac{N\Phi_B}{L} \quad N\Phi_B = LI_S$$

Using these in conjunction with the expression for area, as given in Fig (6), we get:

$$U_B = \left(\frac{1}{2}\right)(I_L)(N\Phi_B) = \frac{(N\Phi_B)^2}{2L} = \left(\frac{1}{2}\right)(LI_L^2) \quad \dots\dots\dots(8)$$

where we have replaced I_S by I_L . Again using

$$N\Phi_B = NBA, \quad \text{and} \quad L = \left(\frac{\mu_o N^2 A}{l}\right)$$

we write;

$$U_B = \frac{(N\Phi_B)^2}{2L} = \frac{(NBA)^2}{2\left(\frac{\mu_o N^2 A}{l}\right)} = \left(\frac{B^2}{2\mu_o}\right)(Al) \quad \dots\dots\dots(9)$$

where (Al) is the volume of the space inside the coil. This prompts us to calculate energy per unit volume or *energy density* u_B :

$$u_B = \frac{B^2}{2\mu_o} \quad \dots\dots\dots(10)$$

Following is a summary of the above, presented in Table (1), below

Table 1: A Coil in a DC Circuit

#	Property	Mathematical Expression	#	Property	Mathematical Expression
1	length	$l, (\text{m})$	8	Ampere's law	$B = (\mu_o/l)(NI_L) (\text{T})$
2	Number of loops	N	8	magnetic flux	$\Phi_B = BA \cos \phi$
3	area of cross-section	$A, (\text{m}^2)$	10	total magnetic flux	$N\Phi_B = NBA, (\text{Tm}^2)$
4	volume	$Al, (\text{m}^3)$	11	total magnetic flux	$N\Phi_B = ((\mu_o N^2 A)/l)(I_L), (\text{Tm}^2)$
5	resistance	$R_L, (\text{ohm})$	12	coefficient of self Inductance	$L = (\mu_o N^2 A) / l, (\text{H})$
6	Ohm's Law	$V_L = R_L I_L, (\text{V})$	13	energy stored (J)	$\left(\frac{1}{2}\right)(I_L)(N\Phi_B) = (N\Phi_B)^2 / (2L)$ $= \left(\frac{1}{2}\right)(LI_L^2) = (B^2 / (2\mu_o))(Al)$
7	effective current	$NI_L, (\text{A})$	14	energy density	$B^2 / (2\mu_o), (\text{J/m}^3)$

Faraday's Law

Next we consider the third electromagnetic interaction, known as *Faraday's Law Interaction* or *Faraday's Law Effect*. Faraday's law may be regarded (with some reservations) as the converse of the Ampere's law. Unlike Ampere's law which has no prerequisites, here we have one prerequisite: the magnetic flux in the neighborhood of the conductor should keep changing all the time; i.e. it should not be stagnant. The changing magnetic flux mobilizes the free electrons in the conductor. These free electrons move in such a way as to produce a potential difference (emf) across the terminals of the conductor. If we want the induced emf to produce a current, we must provide a return path for the electrons. This requires the conductor to have a closed configuration, such as a loop. A conductor with a closed configuration will have an area A . Magnetic field \mathbf{B} crossing this area will generate flux Φ_B . In case of the coil of area of cross section A and number of loops N , it has been shown above that the total flux is $N\Phi_B = NBA$

Let this magnetic flux changes with time (i.e should not remain constant). We shall have

$$\frac{\Delta(N\Phi_B)}{\Delta t} \dots\dots\dots(11)$$

Faraday's law now tells us that this changing magnetic flux will induce an emf ε in the coil. We now enunciate Faraday's Law:

A changing magnetic flux induces an emf ε in a conductor.

Expressed mathematically, Faraday's Law reads:

$$\varepsilon = -\frac{\Delta(N\Phi_B)}{\Delta t} \dots\dots\dots(12)$$

It is interesting to note that the existence of a constant (non-varying) Φ_B will not induce *anything* at all! We may say that when Φ_B is constant, Faraday's law remains dormant, or sleeping or inactive.

The negative sign in Eqn. (12) is for reasons related to the law of conservation of energy (Lenz's Law). We shall not discuss it at this time. It should, however, be mentioned that the negative sign is not mandatory. We may keep it or we may not. The presence or absence of the negative sign will not affect physics. Retaining the sign will, therefore, be for our convenience.

Next, let's bring in the value of $\Delta(N\Phi_B)$ from Eqn (6) and plug it into Faraday's law, as given in Eqn (12). We get:

$$\varepsilon = -\frac{\left(\frac{\mu_o N^2 A}{l}\right) (\Delta I_S)}{\Delta t} = -\left(\frac{\mu_o N^2 A}{l}\right) \left(\frac{\Delta I_S}{\Delta t}\right) = -L \left(\frac{\Delta I_S}{\Delta t}\right)$$

As the emf ε is developed across the terminals of the coil, we may call it ε_L . Again, as the coil is the only component in the circuit, I_S will pass only through the coil and, as such, it may be called I_L . We then get:

$$\varepsilon_L = -L \left(\frac{\Delta I_L}{\Delta t}\right) \dots\dots\dots(13)$$

This equation tells us that the magnitude of the induced (or counter) emf ε_L generated in the coil, is proportional to the time-varying current $\Delta I_L / \Delta t$, that flows in the coil itself. The constant of proportionality is the previously determined *coefficient of self inductance* L .

The constant L has acquired a new meaning and has become more useful!

We use Eqn (13) to find the units of this coefficient. This is because the units of all other members of this equation are known; we couldn't say the same for Eqn (7)! It is easy to see that the unit of L is:

$$\text{volt} = (L)\left(\frac{\text{ampere}}{\text{second}}\right) \quad L = (\text{volt})\left(\frac{\text{second}}{\text{ampere}}\right) = \left(\frac{\text{volt}}{\text{ampere}}\right)(\text{second}) = (\text{ohm})(\text{second})$$

The unit $\frac{3}{4}\text{s}$ is named *Henry* and is written as H . It is a rather large unit and we often use smaller units, such as mH and μH , which respectively represent 10^{-3} and 10^{-6} of one Henry.

Inductance

We are now in a position to define **Inductance**. We find that a conducting material has the ability to interact with changing magnetic fields. An emf is then induced in the conductor. This property is called **Inductance**. Inductance is peculiar to conductors. Insulating materials do not have this capability.

Inductor: As a Device

An *Inductor* is a device that is made from conductors (in the form of wires) that utilizes the property *inductance* of conductors. When fed by a time-varying voltage, an emf ε , is induced in the inductor. A coil, as described above and shown in Figs (3) and (4) can also be called an inductor because it stores electrical energy in the magnetic field that it produces. The electrical symbol of an inductor is shown in Fig (7).

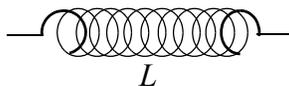


Fig (7) The Electrical Symbol of an Inductor

Inductor: Dependence on Shape & Size: Permeability.

Like conductance and capacitance, the inductance of a coil also depends upon the shape and size of the inductor. In fact we already stepped upon it (accidentally) while deriving Eqn (7). Analogously to conductance and capacitance, inductance also depends directly on area of cross section and inversely on the length (or thickness).

The constant μ_o , appearing in Ampere's Law (see Eqn s 1, 2, & 3), is called *Permeability*. It is a magnetic property that some (but not all) materials have. In fact μ_o is the magnetic permeability of free space or vacuum. Its value has been determined to be $\mu_o = 4\pi \times 10^{-7} \text{ Tm/A}$. For materials other than free space or vacuum, we write μ . Permeability of air is practically the same as that of free space. Permeability of iron is some 4000 times the permeability of free space.

Inductors & DC Electricity: The Ohm's Law

Fig (8) shows an inductor connected to a source of DC electricity. The circuit is very similar to the ones we used for the study of resistors and capacitors. As the circuit is switched on, current flows through the coil and a magnetic field is produced axially inside the coil, in accordance with Ampere's law. The magnitude of \mathbf{B} is given by Eqn (3). Faraday's law is not activated because the magnetic flux is constant. Ohm's law, however, is active and the current in the circuit is given by Eqn (4) which is reproduced here for ready reference:

$$V_L = R_L I_L \quad \text{Eqn (4)}$$

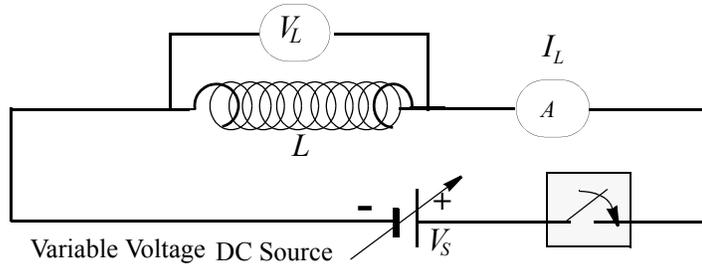


Fig (8) An Inductor in a DC Circuit

Inductors & AC Electricity

Fig (9) shows an inductor connected to a source of AC electricity.

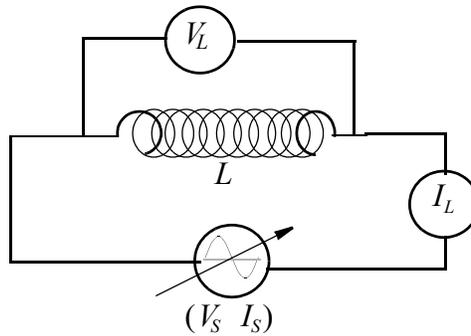


Fig (9) An Inductor in an AC Circuit

As the source current I_S is now a time-varying current, an emf is induced in the inductor given by Eqn (13), which is reproduced here for ready reference.

$$\epsilon_L = -L \left(\frac{\Delta I_L}{\Delta t} \right) \tag{Eqn (13)}$$

Reactance

The inductor equation, Eqn (13), is not exactly a *user friendly* equation. To make it *palatable*, we consider the rotation of the generator coil in the magnetic field. As the coil rotates, Φ_B changes, ϵ_L is induced and current I_L flows in the coil. The rotation of the generator coil may be represented either in terms of emf ϵ_L , or current I_L of the coil. Presently we shall consider I_L . The propagation of rotation results in a sine wave of I_L , as shown in Fig (10).

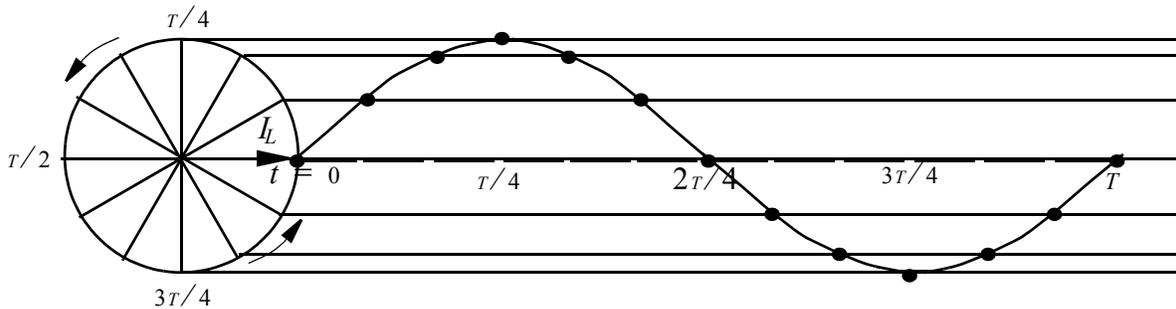


Fig (10) Propagation of Rotation of the Generator Coil in terms of I_L

For each cycle of the sine wave, I_L travels through one circumference of the circle of radius I_L , i.e. it traverses a circumferential distance $2\pi I_L$. The time period of the sine wave is T sec. We replace Δt by time period T in Eqn (13), and replace ΔI_L by $2\pi I_L$. We get:

$$\varepsilon_L = \frac{L(2\pi I_L)}{T}$$

As $1/T = f$, we find:

$$\varepsilon_L = L(2\pi I_L)(f)$$

Simple rearrangement of the terms leads to:

$$\varepsilon_L = (2\pi fL)I_L \quad \text{.....(14)}$$

It is very interesting to note that Eqn (14) is apparently in the form of Ohm's law and will indeed be so if the quantity in parentheses has the units *ohm*. We know that (2π) has no units; the unit of f is (1/sec) and that of L is (Ω sec). It turns out that $(2\pi fL)$ *does* have the unit *ohm*, after all. Having the unit *ohm* leads one to think that $(2\pi fL)$ is *resistance*. However, an inductor placed in an AC circuit, does not convert electrical energy into thermal energy. Thus it cannot be a true resistance. Hence it is only appropriate that we choose a new name for it. The name is *reactance* or, to be precise, *inductive reactance*: χ_L .

We write

$$\chi_L = 2\pi fL \quad \text{.....(15)}$$

Eqn (14) can now be written as:

$$\varepsilon_L = \chi_L I_L \quad \text{.....(16)}$$

Impedance

The inductor as we know, is basically a conductor and as such it necessarily possesses some true resistance that we have called R_L . This resistance is independent of the nature of the source voltage and hence has the same value both for DC and AC source voltages. This brings us to a challenging scenario: An inductor, placed in a DC circuit, has only one resistance: R_L ; but when placed in an AC circuit, it has two resistances: R_L and χ_L . Having two resistances is not a challenging scenario. The challenging part of the scenario is to find the net or the total or the combined or the equivalent resistance!

The scientific approach would be to seek (determine) the mutual relationship of the two resistances and then do the needful. The bad news is that the relationship there is none. This is because knowing one we cannot calculate or predict the other. The good news is that we can, *therefore*, use the Pythagorean theorem. Pythagorean theorem is a tool for combining two (completely) unrelated entities belonging to the same genre (units, in our case). The net resistive effect of the inductor is, then, given by:

$$\sqrt{(R_L^2 + \chi_L^2)}$$

The next bad news is that this hybrid entity is neither resistance nor reactance and as such it cannot be referred to, by any of these two names. As we look for a new name, we keep in mind that the net effect of resistances and reactances is to impede the motion of electrons as they move through the conductor. This prompts us to the name *Impedance*. We write Z for it.

$$Z = \sqrt{(R_L^2 + \chi_L^2)}, \text{ (ohms)} \quad \text{.....(17)}$$

One can say that, for an inductor in a DC circuit $Z = R$. One may define an *ideal* inductor as one whose resistance R is zero. In this case $Z = \chi_L$. There are, however, no ideal inductors and hence the impedance of an inductor will be given by Eqn (17); always.

The V-I Characteristics of Inductors: Summary

The voltage-current characteristics of inductors can now be written down.

(a) DC circuit:

$$V_L = R_L I_L \quad \text{Eqn (4)}$$

(b) AC circuit;

$$V_L = Z I_L \quad \text{.....(18)}$$

where ε_L is replaced by V_L :

(c) For ideal inductors (that do not exist)

$$V_L = (2\pi f L) I_L \quad \text{.....(19)}$$

where ε_L is replaced by V_L

Objectives of Experiment

(A) To determine the inductance L of the given inductor.

(B) To study the inverse dependence of inductor current I_L on source frequency f

Setting up

(A) One way of determining the inductance is to use Eqn (15) which relates L to χ_L . Following is a sequence of steps that will lead to χ_L .

(1) Use Eqn (4) to determine R_L in a DC circuit.

(2) Use Eqn (18) to determine Z in an AC circuit.

(3) Use Eqn (17) to calculate the value of χ_L from the values of R_L and Z found in steps (1) and (2) above.

(4) Use Eqn (15) to calculate L .

(B) Dependence of I_L on $1/f$

(5) Use Eqn (19) to study the inverse dependence of inductor current on the source frequency. Rearranging, we get:

$$I_L = \left(\frac{V_o}{2\pi L} \right) \left(\frac{1}{f} \right) \quad \text{.....(20)}$$

To use this equation, a constant value of V_s will be selected. It should be noted that Eqn (19) or (20) is for ideal inductors only. This will not affect the dependence that we are looking for. However, the value of L found here, will not be very accurate.

A plot of I_L against $1/f$ should yield a straight line. The slope of the line may be used to find a value of the inductance L .

Procedure

(A) Determining R .

- (1) Use one digital multimeter as voltmeter and set it to 20 V , DC, range.
- (2) For the first part of the experiment, we shall use a voltage supply of approximately 2.40 volts DC. This voltage will be obtained from the variable voltage part of the DC supply. The left side knob and the accompanying pair of red-black terminals, will be used. Connect the voltmeter to these terminals, switch on the DC supply, and adjust the position of the knob for a 2.40 volt output (or as close as possible). Switch off the voltmeter and the power supply. Remove the voltmeter.
- (3) We shall use the second multimeter as an ammeter. Set the second multimeter to 200 mA DC . Make sure it is off and carefully note the terminals to be used.
- (4) Set up the circuit of Fig (11) using the two digital multimeters and the DC voltage source (which has been set to 2.4 volts). Set the sliding contact of the rheostat for maximum resistance. All meters and the DC supply should be off at this point.

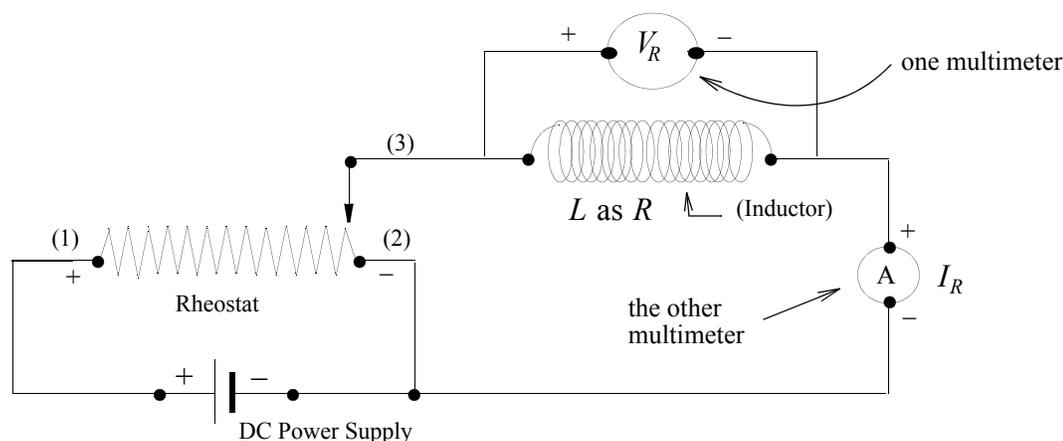


Fig (11) Circuit for Determining the Resistance of the Inductor

- (5) When the circuit has been checked by the instructor, switch on (a) the power supply (b) the voltmeter, and (c) the ammeter, in that order.
- (6) To apply 16 different voltages to the given inductor, select 16 different positions of the sliding contact, judiciously. For each position, read and record the values of voltages (in volts) and their corresponding currents (in mA).
- (7) Switch off the circuit in reverse order. (See step 5).

(B) Determining Z

- (8) We shall use the circuit of Fig (11) for this part of the experiment also.
- (9) Remove the voltmeter temporarily from the circuit and set it to 20 V , AC. Connect it to the output terminals of the AC supply (the function generator with amplifier). Switch on the supply and then the voltmeter. Adjust the volume control knob of the function gener-

ator such that the voltmeter reads 2.40 volts (or as close as possible). Switch off the voltmeter and then the AC power supply. Remove the voltmeter and connect it back in the circuit, where it was hooked up before.

- (10) Set the ammeter to 20 mA , AC (and not 200 mA). At this point, the two meters and the power supply must all be in the *off* positions. Set the sliding contact of the rheostat for maximum resistance.
- (11) Transfer the wires from the DC supply to the AC supply (the function generator with amplifier).
- (12) When the circuit has been checked by the instructor, switch on (a) the power supply (b) the voltmeter, and (c) the ammeter; in that order. The function generator will display a frequency of 1000 Hz .
- (13) To apply 16 different voltages to the given inductor, select 16 different positions of the sliding contact, judiciously. For each position, read and record the values of voltages (in *volts*) and their corresponding currents (in *mA*).
- (14) Switch off the circuit in reverse order. (See step 12).

(C) The Dependence of Inductor Current I_L on Frequency f

- (15) The circuit of Fig (11) will be used for this part of the experiment also. We shall select different frequencies on the function generator, using the frequency selection knob. The selected frequencies will be displayed digitally in the display window.
- (16) Set the voltmeter to 200 V scale but leave the ammeter unchanged.
- (17) Set the sliding contact of the rheostat to a position midway on the rheostat.
- (18) Switch on the circuit as per step (12) above.
- (19) Set the function generator to 500 Hz , using the frequency selection knob.
- (20) Adjust the voltage output control knob (the volume control knob) of the function generator, such that the voltmeter displays a voltage between 2.00 and 2.20 volts. This will be the V_0 voltage for this part of the experiment and will have to be kept constant. Record the value displayed by your voltmeter in the Data Table.
- (21) Read the ammeter and record the frequency (500 Hz) and the ammeter reading in the Data Table as the data for the first trial.
- (22) For the second and the subsequent trials, increase the frequency in steps of 50 Hz , (550 Hz , 600 Hz , 650 Hz ,..... 1500 Hz). For each frequency, make sure that the voltmeter reads the voltage V_0 . If not, adjust the position of the sliding contact such that the voltmeter shows V_0 correct to two decimal places.
- (23) With voltmeter showing V_0 , read the ammeter and record the value in the Data Table.
- (24) When all 21 trials have been completed, switch off the circuit, as per step (14).

Calculations & Graphs

(A) Determining the Inductance L

- (1) Plot a graph of voltage (on y-axis) against current as recorded in part (A) of the experiment. The current values should be left in mA even though it is not an MKS unit. This will lead to a better graph. Read the slope of the best-fit straight line as printed out by the computer. Multiply by 1000 to get the correct resistance R in ohms.
- (2) Repeat the above for the second set of data. The slope, when multiplied by 1000, will be the impedance Z of the inductor (in ohms) at 1.0 kHz .
- (3) Solve Eqn (17) for χ_L .
- (4) Solve Eqn (15) to find L , in henries. Remember that 1.0 kHz is 1000 Hz . Compare the value with the one given to you by the instructor and find percent error.

(B) Dependence of I_L on $1/f$

- (5) The third set of data is for the study of the dependence of I_L on $1/f$. Calculate $1/f$ for all frequencies. Plot I_L (in mA) on y-axis and $1/f$ on the x-axis. A straight line will establish the inverse dependence.
- (6) The slope of this graph has the value $V_o / (2\pi L)$, as shown in Eqn (20). Since we plotted the graph in mA , we need to divide the slope by 1000. Knowing V_o , calculate L and find its percent deviation from the value found in step (4).
- (7) Complete the report with “Results”.

Data & Data Tables

Name.....

Date.....

Instructor.....

Lab Section.....

Partner.....

Table #.....

(A) Determination of R.Voltmeter Scale set to: V, DC Ammeter Scale set to: mA, DC **Table 1: V-I Characteristics of the Given Inductor in a DC Circuit**

Serial Number	Inductor Voltage (V)	Inductor Current (mA)	Serial Number	Inductor Voltage (V)	Inductor Current (mA)
1			9		
2			10		
3			11		
4			12		
5			13		
6			14		
7			15		
8			16		

(B) Determination of ZFrequency of the Function Generator set to kHz Source Voltage set to: V, AC Voltmeter Scale set to: V, AC Ammeter Scale set to mA, AC **Table 2: V-I Characteristics of the Given Inductor in an AC Circuit**

Serial Number	Inductor Voltage (V)	Inductor Current (mA)	Serial Number	Inductor Voltage (V)	Inductor Current (mA)
1			9		
2			10		
3			11		
4			12		
5			13		
6			14		
7			15		
8			16		

(C) The Dependence of Inductor Current I_L on Frequency f Inductance of the given inductor: mH Voltmeter scale set to: V, AC Ammeter scale set to: mA, AC Voltage $V_o =$ V **Table 3: Frequency dependence of Inductor Current**

Serial Number	Frequency (Hz)	Inductor Current (mA)	Serial Number	Frequency (Hz)	Inductor Current (mA)
1	500		12	1050	
2	550		13	1100	
3	600		14	1150	
4	650		15	1200	
5	700		16	1250	
6	750		17	1300	
7	800		18	1350	
8	850		19	1400	
9	900		20	1450	
10	950		21	1500	
11	1000				

Additional Data or Information, (if any)