Magnetism Laboratory: Inductance

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1. INTRODUCTION

In this laboratory you will calculate the magnetic permeability of a range of ferrite materials. We will do this through calculating the inductance of coil wound around a ferrite toroid. Inductors, *L*, are one of the three main circuit elements, the others being resistors and capacitors. Inductors store the kinetic energy of moving electrons in the form of a magnetic field. An inductor's ability to store energy as a function of current results in a tendency for it to try to maintain current at a constant level. In other words, inductors tend to resist *changes* in current. When current through an inductor is increased or decreased, the inductor "resists" the change by producing a voltage between its leads in the opposing polarity to the change.

Here, we are considering the self-induction of the coil, which generates a potential in the opposite direction to the applied potential, thus reducing the current flow. We will use a RL circuit and methodology that is analogous to the RC circuit laboratory you used last semester. Wire was been coiled around a ferrite toroid and an oscilloscope was used to measure the driving potential and the potential across the resistor. You will find the data from these experiments in files on Blackboard. Once you have read this lab script, you will need to download these files and import them into the python script to calculate the inductance. You can then use this inductance to get the material's permeability.

You do not need to hand in a full lab report, just answer the questions at the end of this laboratory script.

2. BACKGROUND THEORY

We need to consider three fundamentals laws for this laboratory:

1. **Oersted's law**, which states that a steady current in a coil will generate a magnetic field.
2. **Faraday's law**, which states that a time-dependent change in a magnetic environment of a wire or coil will generate an electrical potential. (For example, if you move a magnet in and out of a coil then a potential is generated across

the coil. Likewise, a generator produces electricity by a coil spinning in a permanent magnetic field.)

3. **Lenz's law**, which states that current induced in a circuit due to a change in a magnetic field is directed to oppose the change in flux, i.e. the current in the coil flows such that it produces a magnetic field in the opposite direction.

Thus, consider a coil in a direct current (d.c.) electrical circuit. There is current flowing through the coil, hence a magnetic field is generated within the coil. However, as the current is constant with time, the magnetic field does not change. In theory, the current in a short-circuited inductor (Figure 1a) would continue flowing forever, if it was not for the resistance of the wires.

Now consider the same coil with an alternating current (a.c.); the current is changing so the magnetic field is changing (*Oersted's law*). The change in magnetic field generates a potential across the coil (*Faraday's law*), which is the opposite direction to the applied potential (*Lenz's law*) (Figure 1b).

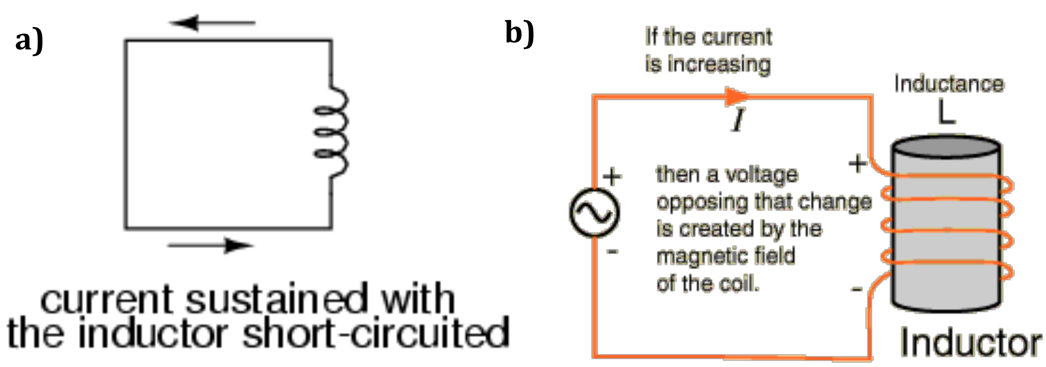

Figure 1a) Coil in a d.c. circuit. Note that there is no change in field so there is no induced emf. 1b) Coil in an a.c. circuit. The change in the current, changes the magnetic field in the inductor, leading to an opposing voltage being generated.

The potential (*emf*) across the coil is given by:

$$Emf = -L\frac{dI}{dt} \qquad \text{Equation 1}$$

where the negative shows it is in the opposite direction (Lenz's law) and L is the inductance. L is a constant that depends on the coil's geometry and any magnetic materials within it. It is measured in henrys [H]. This back e.m.f is known as *self-*

inductance and is, for example, the reason why you are supposed to fully unwind an extension lead before you use it (Figure 1b).

Toroid's are doughnut-shaped materials around which a wire is wound to form a coil. They are typically used in transformers which are devices used to up- or down- rate an a.c. voltage (e.g. taking voltage from 240 V to 12 V.) In a transformer, two coils are wound around the toroid and the magnetic field generated in one coil is used to induce a current in the second coil. As the inductance, and hence potential, depends on the number of turns in a coil, then the potential generated in the second coil is controlled by the ratio of the number of turns in the two coils (Figure 2).

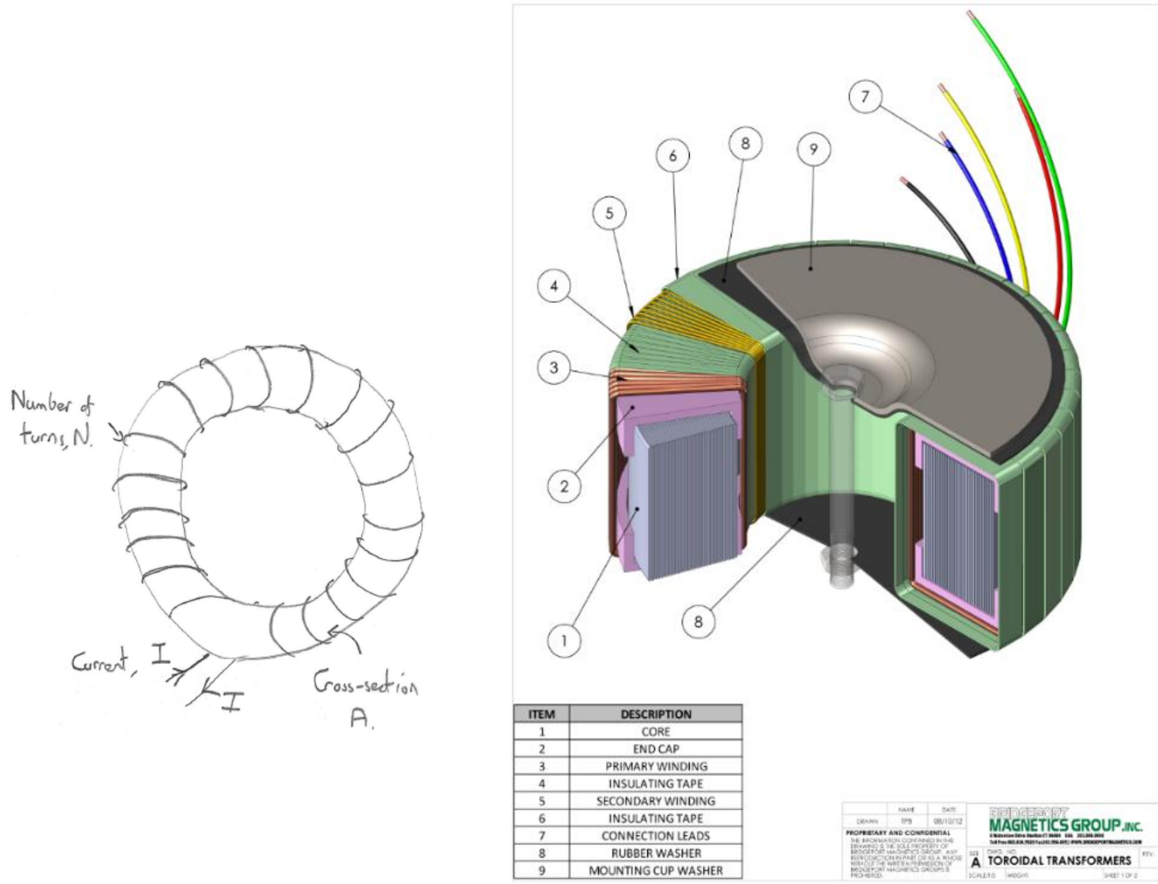

Figure 2a) A sketch of a single coil around a torroid. b) A cross-section of a typical transformer. The core is typically a high permeability ferrite. The a.c. current in the primary windings generates a potential in the secondary windings. The ratio of the potential in the primary and secondary windings is related to the number of windings.

The inductance, L, of a toroid is given by:

$$L = \frac{\mu_r \mu_0 N^2 A}{l}$$ Equation 2

where μ_r is the permeability of core, A is the cross-sectional area of the coil and l is the circumference of the coil (or "*effective magnetic path length*"). μ_0 is the permeability of free space and is equal to $4\pi \times 10^{-7}$ H·m^{-1})

Further reading, the website below is very good:
http://www.allaboutcircuits.com/textbook/direct-current/chpt-15/magnetic-fields-and-inductance/

Derivation of the inductance of a coil:
https://www.youtube.com/watch?v=OOExnj-xu1c

3. EXPERIMENT

The following describes the experiment conducted in the laboratory. You will find the data files collected on Blackboard (see later).

A circuit as shown in Figure 3 was used to collect the data. The oscilloscope recorded the potential across the resistor (V_r) and the total circuit voltage (V_T) against the common earth. The current, I, is the same through every element of the circuit and thus can be determined by calculating that in the resistor ($I = V_r$ / R). The voltage across the inductor, V_L, is calculated from $V_T = V_R + V_L$. As with your previous capacitance lab, the voltage is described by a sine wave with a phase shift. The impedance of the inductor is given by $z_L = V_L/I$, from which inductance is defined by:

$$L = \frac{z_L}{2\pi f}$$ Equation 3

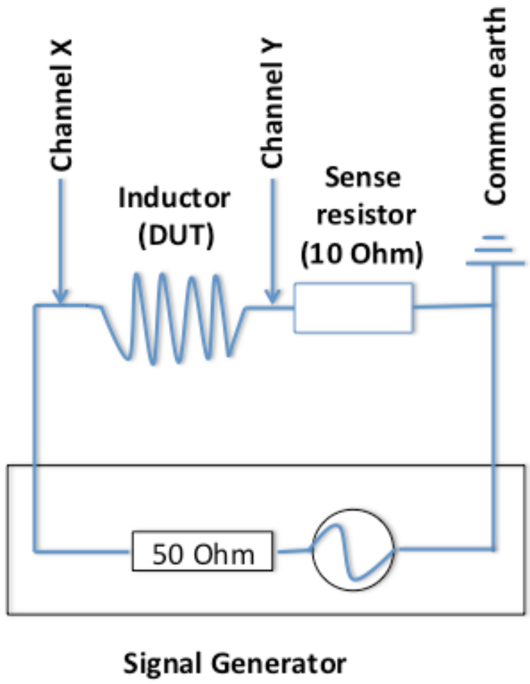

Figure 3: A schematic of the test circuit. Note that DUT stands for device under test. The channels need to be the correct way around for the python script to work.

3.1 Measuring permeability of the samples.

Toroid 1 was selected and 5 turns of wire was wrapped around it. The frequency generator was set to a produce a sine wave with the frequency as given in Table 2 found in the Appendix. The oscilloscope was set so that ~3 waves filled the screen. This data was saved as "TOR1_5.CSV". This measurement was then repeated for 10, 15 and 20 turns of wire around the coil with the files being saved as "TOR1_10.CSV", "TOR1_15.CSV" and "TOR1_20.CSV" respectively.

Open the notebook "Magnetism Lab" in an Anaconda Notebook. This is notebook is based upon the one you used for the capacitance lab except for it calculates inductance rather than capacitance. Insert the correct file name, frequency and sense resistance. Make a note of the inductance output in Table 1 in **Question 1**.

The measurement of L for 5,10, 15 and 20 windings for the remaining toroids using the frequencies in Table 2. Use to data to add to Table 1.

Now for each toroid, plot L vs N^2 and thus determine the relative permeability (**Q2**) from the straight line of this graph.

4. Software and data you will need to complete this lab.

- You will to install Anaconda (https://www.anaconda.com).
- You will also need to download the experimental data files and the Python lab script. These can be found on Blackboard in folder under *"Assessment& Feedback/Data for the Magnetism Lab"*. It is best to download the single Archive.zip file as this will keep all the CSV and script files together.
- Ensure that the CSV and Python Script files are in the same folder.
- Open Anaconda and selection one of the Jupyter workbooks.
- Open "Python Script" from where you saved it.
- Change the file name in the script to the CSV you want to analyse. Also ensure that the frequency is correct according to Table 2.
- Run the code and make a notes of the impedance value at the end in Table.

QUESTIONS

1. Complete the table below:

Toroid No	Number of coils	Inductance (mH)	Frequency (kHz)
1	5		
	10		
	15		
	20		
2	5		

Table 1: Table to complete with inductance values calculated using the files found on Blackboard and the frequencies given in Table 2.

(10 marks)

2. For each toroid, plot L vs N^2 and thus determine the relative permeability from the straight line of this graph. **(20 marks)**

3. Discuss possible sources of error in your calculations of the permeabilities. **(2 marks)**

4. State whether the ferrites in this lab hard or soft magnets? Justify your answer. **(2 marks)**

5. Consider a coil in a d.c. circuit with 10 A flowing through it. The circuit is suddenly broken and there is spark across the break. Discuss the origin of the high potential required to generate this spark. **(4 marks)**

APPENDIX

Table 2: Properties of the ferrite toroids used in this lab.

Nº	**Appearance**	**Product code**	**Cross-section area, A (mm^2)**	**Path, *l* (mm)**	**Suggested frequency (kHz)**
1	White and shiny	FT01599	48.9	60.2	10 kHz
2	White and labeled “2”	FT01595	30.9	55.8	10 kHz
3	Black	FT01596	30.9	55.8	100 kHz
4	White and labeled “4”	FT01597	30.9	55.8	200 kHz