Summary - Phys 211L
Spring 2010

## FINAL GRADE : 87

Note: I found Phys211L as a very ugly course for all the semester, I was used to do NOTHING to prepare the class. 3 days before the final I began to study and did this summary that was quite helpful... In fact, the best way to study phys 211 L is to follow in class (spending 15 minutes before the lab reading and printing the manual) and the most important is to understand the calculations of errors (linear regression, propagation of errors) !!

Done by Erik VZ (you can add me on facebook, if you have any question to ask me do not hesitate)

Please check out the following website!!
http://4greeneraub.blogspot.com/ (about environmental issues)

If you are interested, join its page on Facebook, named For a Greener AUB

## Preparation for final of 211L

There might be errors; it's only kind of a summary of the labs

## ERRORS

## 1- Linear Regression (finding the slope + error on the slope)

Many experiments yield a series of pairs of data values. Usually the $x_{i}$ values are selected and the $y_{i}$ values are measured. A graph is plotted with each pair ( $\mathrm{x}_{\mathrm{i}}, \mathrm{y}_{\mathrm{i}}$ ) representing a point. If the points of the graph are located within a narrow band, the variables $x$ and $y$ are said to be correlated, and a relation exists between $x$ and $y$.
(we write the formula under this form and we decide of $x$ and $y$ )
$y=A x+B$

We enter on the calculator: linear regression, $x, y$ M+
Shift 2
We take the value of $r$ (correlation coefficient which should be equal to 1 or 1)

The value of $A$ which is the $y$ intercept ( $B$ in our formula)
The value of $B$ which is the slope ( $A$ in our formula)

Y= slope*X + y intercept
$e_{i}=y-y_{i}=A x_{i}+B-y_{i}$
$\Delta=N \sum x_{i}^{2}-\left(\sum x_{i}\right)^{2}$
The error is : $\quad \sigma_{A}^{2}=\frac{N}{N-2} \frac{\sum e_{i}^{2}}{\Delta} \quad$ (don't forget to do the root square)
WE DRAW A TABLE

| $\mathrm{Y}_{\mathrm{i}}$ | $\mathrm{X}_{\mathrm{i}}$ | $\mathrm{X}_{\mathrm{i}}{ }^{2}$ | $\mathrm{e}_{\mathrm{i}}$ | $\mathrm{e}_{\mathrm{i}}{ }^{2}$ |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
| Sum | yes | yes | no | yes |  |  |

## 2- Propagation of error

In order to estimate the error in compound quantities, the following procedure is followed. If a number of measured quantities have arithmetic means $x, y$,
and $z$ with root-mean-square errors of $\alpha_{x}, \alpha_{y}$, and $\alpha_{z}$ respectively, then the root-mean-square error $\alpha_{F}$ in any function $F$ of $x, y$, and $z$ is given by
$\alpha_{F}=\sqrt{\left(\frac{\partial F}{\partial x} \alpha_{x}\right)^{2}+\left(\frac{\partial F}{\partial y} \alpha_{y}\right)^{2}+\left(\frac{\partial F}{\partial z} \alpha_{z}\right)^{2}}$

## 3- Errors of observation

Several measurements for the same thing. For example we measure 10 times the length of a rod.
Average:
$\bar{x}=\frac{\sum x_{i}}{N}$
Deviation: $d_{i}=x_{i}-\bar{x}$

Root mean square error: $\alpha=\sqrt{\frac{\sum d_{i}^{2}}{N(N-1)}}$
DRAW A TABLE

| $\mathrm{x}_{\mathrm{i}}$ | $\mathrm{d}_{\mathrm{i}}$ | $\mathrm{d}_{\mathrm{i}}{ }^{2}$ |
| :--- | :--- | :--- |
|  |  |  |
|  |  |  |
| Sum | No | Yes |

In this course, the quantity $\alpha$ should be rounded to one significant figure only (or two sometimes).
Note that the least significant figure in the result should be of the same order of magnitude as the uncertainty.

Very often in the process of calculations extra figures are accumulated and sometimes reported in the end result. This is a meaningless procedure. No figures should be included beyond the precision of the original data.

## 4- Accuracy

In this course you will state your final results as $\bar{x} \pm \mathrm{a}$. Furthermore, when the measured value $\bar{x}$ deviates from the accepted value by more than twice $a$, this is an indication of possible systematic errors. It becomes imperative to indicate the possible sources of these errors and justify such deviations.

## 5- Precision

$\% e r r o r=(\mid$ Calculated Value-Measured Value|/Calculated Value $) * 100$

## LAB 1 = OHM'S LAW

Ohmic devices: (ex: resistor)
$R$ is a constant,
$\mathrm{R}=\mathrm{V} / \mathrm{I}$
A metal rod is "ohmic" because its resistance is current-independent. Its V vs. I curve is a straight line, whose slope is the resistance $R$ of the rod. The resistance of a metal rod depends on its dimensions and the rod material, according to the following relation:
$R=\rho / / A$
Where $I$ is the length of the rod, $A$ is its cross-sectional area and $\rho$ is the resistivity.

## Nonhomic devices:

The resistance is generally a complex function of voltage and of the current and the voltage.

For a light bulb, the resistance of the filament depends on the temperature and will change as it heats up and cools down, depending on the current (on the frequency). Therefore, a plot of the voltage as a function current for a light bulb filament will not lead to a straight line.

A diode is another example of a non-ohmic device. It is unidirectional and allows current to flow in only one direction through it, once a certain forward voltage is established across it. For a diode, for example, the "backward" resistance is very large (of the order of $M \Omega$ 's), while the "forward" resistance is fairly small and depends critically on the forward voltage.

## LAB 2 = BASIC OSCILLOSCOPE

The cathode-ray oscilloscope (CRO) is one of the most common and most important laboratory instruments. It provides, basically, a calibrated two-dimensional display in which the vertical and horizontal deflections are proportional to the applied voltages. Under most common operating conditions, the horizontal deflection is proportional to time, and therefore the voltage against time is displayed on the screen of the oscilloscope.

Any phenomena that can be converted into a voltage can be measured with an oscilloscope, which provides two basic pieces of information, "how much" and "how long". The amplitude ("how much") is plotted on the vertical (Y-axis) and the time ("how long") is plotted on the horizontal (X-axis).

## Finding $\phi$ (useless I think)

With the TIME/DIV switch (23) in the X-Y position, signals at the CH 1 input connector (9) produce a horizontal deflection; while signals at the CH 2 input connector (10) produce a vertical deflection. With sinusoidal signals applied to the two inputs and using the $X-Y$ mode of operation, a graph on the scope screen is obtained, which is called a Lissajous figure, representing the vertical sine wave input signal plotted against the horizontal sine wave input signal. If the two sine waves have the same frequency $\left(f_{y}=f_{x}\right)$ and amplitude, the resulting pattern will be a straight line, an ellipse, or a circle depending on the phase difference between the two sine waves.

Consider

$$
\begin{align*}
& x=B \sin (\omega t) \quad \text { and } \quad y=A \sin (\omega t+\phi),  \tag{1}\\
& x / B=\sin (\omega t) \quad \text { and } \quad y / A=\sin (\omega t+\phi)
\end{align*}
$$

Solving one obtains:

$$
\begin{equation*}
\frac{y^{2}}{(A \sin \phi)^{2}}+\frac{x^{2}}{(B \sin \varphi)^{2}}-\frac{2 x y \cos \varphi}{A B \sin ^{2} \varphi}=1 \tag{2}
\end{equation*}
$$

This is the equation of a rotated ellipse as shown below.


At $x=0, y= \pm D= \pm A \sin \varphi$, while the maximum deflection in the $y$ direction is $\pm A$. Thus, $\sin (\phi)=D / A$. Therefore, by measuring 2 A and 2 D on the oscilloscope screen it is possible to find the phase difference between the horizontal and vertical signals.

What happens when $\varphi=0$ and $\varphi=90$ ?

- $\varphi=0$

From the equation (1) we have $x / B=y / A=>y=(A / B) x$
The signals are in phase, then the graph that we get is a straight line passing by the origin.

- $\varphi=90$
$x / B=\sin (w t) \quad y / A=\sin (w t+90)=-\cos (w t)$
$(x / B)^{2}+(y / A)^{2}=\sin ^{2}(w t)+\cos ^{2}(w t)=1$


## LAB 3 = ELECTRIC CI RCUITS

Measurement of electrical resistances of coils and a set of resistors, using a Wheatstone bridge; Measurement of the maximum power that can be delivered by a voltage source under various load conditions.

## The Wheatstone Bridge

The Wheatstone bridge is a common, convenient and precise instrument for measuring resistances by the comparison method. A conventional circuit diagram of the Wheatstone bridge is shown in Figure 1. The voltmeter is connected between points $B$ and $D$. The bridge is balanced when the resistances $R_{1}, R_{2}, R_{3}$, and $R_{4}$ are adjusted so that the points $B$ and $D$ are at the same potential and no current flows through the branch BD. The following relation can be derived for the balanced bridge by applying Kirchhoff's first and second law to the circuit in figure 1

$$
R_{x}=\left(\frac{R_{4}}{R_{3}}\right) R_{1}
$$

The above equation shows that an unknown resistance can be expressed in terms of the three known resistances.


Figure 1- Wheatstone bridge circuit.

In the experiment a slide-wire form of the Wheatstone bridge will be used as shown in Figure 2. The letters in Fig. 2 correspond to the connections in the conventional diagram of Fig. 1. The resistor between $A$ and $C$ is a uniform resistance wire (RW) that is wound as a 10 -turn spiral. The point $D$ is a slider that can move on RW. The resistances $A D$ and DCare proportional to the lengths of RW, $L_{1}$ and $L_{2}$, respectively, so that
$\mathrm{R}_{4} / \mathrm{R}_{3}=\mathrm{L}_{2} / \mathrm{L}_{1}$
In the case that the bridge is balanced the unknown resistance $R_{x}$ is given by

$$
R_{x}=\left(\frac{L_{2}}{L_{1}}\right) R_{1}
$$

The length $L_{2}$ is directly read on the dial. Notice that the dial has ten turns and that each turn is subdivided in one hundred divisions along the rim of the dial. The whole length of the RW is divided into 10.00 divisions, and the relation between $L_{1}$ and $L_{2}$ is, of course, given by:

$$
L_{1}=10.00-L_{2}
$$



Figure 2-Wheatstone


It can be shown that $\left(\mathrm{dV}_{\mathrm{BD}} / \mathrm{dL}_{1}\right)$ is maximum when $\mathrm{L}_{1}=\mathrm{L}_{2}$. Thus, the Bridge is most sensitive if balance occurs when
$L_{1} \sim L_{2}$. The Wheatstone bridge should, therefore, be used with the potentiometer dial as much as possible in the center of its range. This can be accomplished if $R_{1}$ is about equal to $R_{x}$. This is the reason why your Wheatstone bridge box has two different resistors $R_{1}(50$ and $500 \Omega$ ), which can be selected with a switch. On professional Wheatstone bridges, a whole range of values of $R_{1}$ can be selected.

## Power Matching:

Thevenin's theorem indicates that any combination of voltage/current sources may be replaced by an ideal source $V_{s}$ in series with a resistor $R_{s,}$ where $R_{s}$ is the characteristic output resistance of the source.

In this part of the experiment you will examine the power delivered to a load by a source (see Fig. 3). The power delivered to the load resistance $R_{L}$, as a function of $V_{s,} R_{S}$ and $R_{L}$ is given by:

$$
P_{L}=\frac{V_{S}^{2} R_{L}}{\left[R_{L}+R_{S}\right]^{2}}
$$

Therefore, the power delivered to the load varies as the load resistance varies. Show by differentiating the above equation with respect to $R_{L}$ that the power dissipated in the load resistance $R_{L}$ is maximized when $R_{L}$ is equal to $R$. Find also the power delivered to the load resistance when $R_{L}$ is zero and when $R_{L}$ is infinite. Next derive an expression for $\mathrm{P}_{\mathrm{L}} / \mathrm{P}_{\mathrm{s}}$, where $\mathrm{P}_{\mathrm{s}}$ is the power delivered by the source, as a function of $R_{L}$. What value does this expression assume if $R_{L}$ is equal to $R$.

We prove all this experimentally.

## LAB 4 = CAPACITANCE AND DIELECTRICS

To measure the capacitance of a number of unknown capacitors, in series and parallel combinations as well as that of a BNC cable. To also determine the dielectric constant of a sheet of an unknown material.

A capacitor is a device that can store energy in an electrostatic field, and that can be used in a variety of electrical circuit such as radio receivers and computer microchips. In its most general configuration, a capacitor consists of two conductors of any shape that are placed near each other without touching. A capacitor is said to be charged when the plates carry equal and opposite charges $+q$ and $-q$, respectively, which may be done by connecting the two plates to opposite terminals of a battery. If the magnitude of the potential difference between the two plates, upon charging, is $V$, then the capacitance of the capacitor, denoted by $C$, is equal to
$\mathrm{C}=\mathrm{q} / \mathrm{V}$

The value of C is expressed in farad F (Coulomb/Volt=C/V) and solely depends on the geometry of the device and the material that fills the space between the two plates.

The capacitance of the empty parallel plate capacitor shown in Figure 1, is
$C=\frac{\varepsilon_{0} A}{d}$
where $\varepsilon_{0}$ is the permittivity of free space, $d$ is the separation between the plates and $A$ is the area of plates.


If a sheet of dielectric of thickness $d$ is inserted between the two plates filling the space, the

Fig. 1 A parallel plate capacitor capacitance becomes
$C=\frac{k \varepsilon_{0} A}{d}=\mathrm{C}^{\prime}$
where $k$ is the dielectric constant of the material of the sheet.
$\mathrm{k}=\mathrm{C}^{\prime} / \mathrm{C}=\varepsilon / \varepsilon_{0}$
(Propagation of error on both C and on k )

One can also show that the capacitance of a coaxial cable, consisting of two long coaxial
conducting cylinders of radii $a$ and $b$ shown is Figure 2, is equal to:

Fig 2. Cross section of a coaxial cable


$$
C=2 \pi k \varepsilon_{0} \frac{L}{\ln (b / a)}
$$

where $L$ is the length of the cable and $k$ is the dielectric constant of the material that fills the space between the two conductors.

In an electrical circuit, capacitors can be connected in several ways. A series combination is shown in Figure 3, and the equivalent capacitance, $C_{e q}$ of such a combination of $n$ capacitors is given by
$\frac{1}{C_{\text {eq }}}=\sum_{n} \frac{1}{C_{n}}$


Fig. 3 Capacitors in series

On the other hand, when $n$ capacitors are connected in parallel, as represented in Figure 4, the equivalent capacitance, $C_{e q}$ is given by
$C_{e q}=\sum_{n} C_{n}$


## LAB 5 = RL AND RC CIRCUITS (EECE)

## RL Circuit



Figure 1 - RC circuit
When a DC voltage $V_{0}$ is suddenly applied (at $\mathrm{t}=0$ ) to an uncharged capacitor, $C$, in series with a resistor $R$, the charge on the plates is given by:

$$
q=C V_{0}\left(1-e^{-\frac{t}{\tau_{c}}}\right)
$$

The charge on the capacitor, $q$, increases, from it initial value of zero, to its final value of $\mathrm{CV}_{0}$, asymptotically. The time characterizing this rate of increase is $T_{c}(=R C)$, the capacitive time constant of the circuit. The time it takes to charge the capacitor to half its final value, $t_{1 / 2}$, is given by

$$
t_{1 / 2}=T_{c} \ln 2
$$

The charge on the capacitor is given by: $q=C V_{c}$, where $V_{c}$ is the potential difference across the capacitor. Thus, one can measure the charge on the capacitor, indirectly, by measuring the potential difference across it.

The change of the charge is due to the current in the circuit, I, which is simply the derivative of the charge on the capacitor with respect to time. Thus,

$$
I=\frac{d q}{d t}=\left(V_{0} / R\right) e^{-\frac{t}{\tau_{c}}} .
$$

This current can be measured, indirectly, by measuring $V_{R}=I R$. One finally has:

$$
V_{C}=V_{0}\left(1-e^{-\frac{t}{\tau_{c}}}\right) \text { and } \quad V_{R}=V_{0} e^{-\frac{t}{\tau_{c}}}
$$

## RL Circuit



Figure 2 - RL circuit
Similarly, when a DC voltage $V_{0}$ is suddenly applied (at $t=0$ ) to an inductor, $L$, in series with a resistor, $R$, the current in the circuit, I , is given by

$$
I=\left\{V_{0} /\left(R+R_{L}\right)\right\}\left(1-e^{-\frac{t}{\tau_{L}}}\right)
$$

Where $R_{L}$ is the wire resistance of the inductor. The current in the circuit increases, from it initial value of zero, to its final value of $V_{0} /\left(R+R_{L}\right)$, asymptotically. The time characterizing this rate of increase is $T_{L}=L /\left(R+R_{L}\right)$, the inductive time constant of the circuit and. The time it takes the current to reach half its final value, $t_{1 / 2}$, is given by

$$
t_{1 / 2}=T_{L} \ln 2
$$

The voltages across the resistor, $V_{R}=I R$ becomes:

$$
V_{R}=\left\{V_{0} R /\left(R+R_{L}\right)\right\}\left(1-e^{-\frac{t}{\tau_{L}}}\right)
$$

The current in the circuit can be measured, indirectly, by measuring the voltage across the resistor, $I=V_{R} / R$, while the voltage across the inductor $V_{L}=V_{0}-V_{R}$ is given by:

$$
V_{L}=\left\{V_{0} R /\left(R+R_{L}\right)\right\} e^{-\frac{t}{\tau_{L}}}+\left\{V_{0} R_{L} /\left(R+R_{L}\right)\right\}
$$

At $\mathrm{t}=0, \mathrm{~V}_{\mathrm{L}}=\mathrm{V}_{0}$, while at large t , the second term vanishes and $\mathrm{V}_{\mathrm{L}}=\left\{V_{0} R_{L} /\left(R+R_{L}\right)\right\}$.

## Analysis

$t_{1 / 2}=\tau_{c} \ln 2$
$\tau_{c}=t_{1 / 2} / \ln 2$

We find $t_{1 / 2}$ experimental. We compare it to the theoretical. (accuracy)
$\bar{x}=\frac{\sum x_{i}}{N}$
$d_{i}=x_{i}-\bar{x}$
$\alpha=\sqrt{\frac{\sum d_{i}^{2}}{N(N-\mathbf{1})}}$ (Root mean square error when we calculate several times the same thing and we do an average between the values).

What is the effect of the steel rod on the inductance of the coil? Explain.
$L=\frac{\mu_{0} N^{2} A}{I}$
The steel rod increases the inductance of the coil, since the inductance of the coil is directly proportional to the permeability and when the rod is inserted the permeability increases thus the value of $L$ will increase.

In addition to that since $\quad L=L / R_{\text {eq }}$
We notice that the experimental value of $\quad$ increased when the rod was inserted.
Since the value of $L$ is proportional to the value of $\angle$ then this means that the rod has increased the value of the inductance of the coil

## LAB 6 = MEASUREMENT OF CHARGE TO MASS RATIO OF ELECTRONS

To determine the ratio of the charge to mass of an electron.
When a moving electron passes through a magnetic field, it is subjected to a magnetic force:

$$
F_{m}=e v B \text { sina }
$$

Where $B$ is the magnetic field, $v$ is the velocity of the moving electron, $e$ is the charge of the electron, and $a$ is the angle between the direction of the magnetic field and the velocity. If the velocity and the magnetic field are perpendicular, then the expression of the force becomes:

$$
\begin{equation*}
F_{m}=e v B \tag{1}
\end{equation*}
$$

This force causes the electron to move in a circular orbit, the plane of which is pependicular to the magnetic field. The radius $r$ of the circle is such that the required centripetal force is furnished by the above force. Therefore

$$
\begin{equation*}
F_{m}=e v B=m v^{2} / r \tag{2}
\end{equation*}
$$

In which $m$ is the mass of the electron. If the electron aquires its velocity by being accelerated through a potential difference V . Its kinetic energy is:

$$
\begin{equation*}
1 / 2 \mathrm{mv}^{2}=\mathrm{eV} \tag{3}
\end{equation*}
$$

Combining equations (2) and (3) gives

$$
\begin{equation*}
\mathrm{e} / \mathrm{m}=2 \mathrm{~V} /\left(\mathrm{B}^{2} \mathrm{r}^{2}\right) \tag{4}
\end{equation*}
$$

Using this equation one can determine of the ratio of charge to mass of the electron if $V, B$, and $r$ are known.

## (to find the final formula REMEMBER: we do the sum of forces along $\mathbf{n}$ direction + conservation of kinetic and potential energy)

The principal part of the setup, as shown in Figure (1), is an evacuated tube (cathode tube) in which the beam of electrons is produced. The electron gun is composed of a straight filament wire $F$ along the axis of a cylindrical anode $A$ with a single axial slit S.

Electrons emitted from the heated filament are accelerated by the potential difference $V$ applied between F and A . Part of the electrons come out of the slit as a narrow beam. The tube contains low pressure mercury vapour. If the electrons have sufficiently high kinetic energy and collide with the mercury atoms, some of the
atoms are ionized. On recombination of these ions with stray electrons the mercury spectrum is emitted with its characteristic blue color. In this manner, the path of the electrons can be made visible.

The tube is placed at the center of the Helmholtz coils (separation of coils is equal to the radius), which provide the fairly homogeneous magnetic field needed to deflect the electrons in circular paths.

The identical pair of coils consist of N (indicated on the coils) turns of radius R ( $\sim 0.33 \mathrm{~m}$ ) and carrying a current I. The magnetic induction field $B$ at the center of the coils on the axis of coils is given by

$$
B=\frac{\mu_{0} N I R^{2}}{\left[R^{2}+(d / 2)^{2}\right]^{3 / 2}}
$$

## FORMULA FOR 2 COILS !!!!!!!

Where d is the separation of the coils, which is very close to the radius R , and $\mu_{0}=$ $4 \pi * 10^{-7} \mathrm{~Wb} / \mathrm{A} . B$ is expressed in Tesla. These Helmholts coils are connected in series with a 0-5 A meter to a power supply.. The circuit is given in Figure 2.


## How to determine the e/m ratio ??

We derive the formulas
We get $\mathrm{e} / \mathrm{m}=2 \mathrm{~V} /\left(\mathrm{B}^{2} * \mathrm{R}^{2}\right)$
We consider $1 / R^{2}$ as $y$ and $B^{2}$ as $x$
We calculate $B$ from the different values of $I$ that we have using $B=\frac{\mu_{0} N I R^{2}}{\left[R^{2}+(d / 2)^{2}\right]^{3 / 2}}$
We do a linear regression, find the slope, the error on the slope
From the formula we find $\mathrm{e} / \mathrm{m}$ and we do a propagation of error to find the error on this ratio.

How to cancel the effects of earth magnetic field on current?
$\bar{C}$ Current $0=>$ we measure the current by an ammeter it's not the current produced by the machine but the current produced by the magnetic field of the earth. We have to subtract this current to the later obtained values of I to obtain the effective current produced by the machine.
Why is it imperative to keep the tilt angle and the direction of the coils fixed during the experiment?

In order to cancel all the components of the earth magnetic field which is tilted at the same angle. (We can't neglect the earth magnetic field)
The earth magnetic field is directed inward thus the coils magnetic field is opposite, directed outward.

## LAB 7 = MEASUREMENT OF MAGNETIC INDUCTION FIELDS

Consider a circular coil, consisting of N turns of radius R and carrying a current I . The magnetic induction field $B$ at a point $P$ on the axis, a distance $x$ from the center of the coil is given by

$$
\begin{equation*}
B=\frac{\mu_{0} N I R^{2}}{2\left(R^{2}+x^{2}\right)^{3 / 2}} \tag{1}
\end{equation*}
$$

A solenoid is a long wire wound in a closed- packed helix (see figure 1). If the solenoid has a length of $L$ and $N$ is the number of turns of wire, then it can be shown, using equation 1 and integrating, that the magnetic induction field inside the solenoid, carrying a current of I , is

$$
\begin{align*}
& B=\frac{\mu_{0} N I}{2 L}\left[\cos \Theta_{1}-\cos \Theta_{2}\right] \\
& B=\frac{\mu N I}{2 L}[2 \cos \theta 1] \\
& B=\frac{\mu N I}{2 L}\left[2 \frac{L}{2} \frac{1}{\sqrt{L^{*} L / 4+R^{* R}}}\right]  \tag{2}\\
& B=\mu N I \frac{1}{\sqrt{L^{*} L+4 R^{* R}}}
\end{align*}
$$

where $\Theta_{1}$ and $\Theta_{2}$ are given in Figure 1 and $\mu_{0}$ is the permeability of free space. (at the center of the coil)


Figure 1.

## Procedure

We find experimentally the place in the coil where the magnetic field is the strongest (it will be the center where $x=0$ )

Derivate the formula valid at the center of the coil.
We measure B and I at the center of the coil.
We found a linear relationship between them, we do a linear regression, we find the slope, the error on the slope.

From the slope we find N the number of turns and we do a propagation of error to find the error on $N$ (which we round to the unit)

Don't forget accuracy and precision.
Outside the coil, we notice that $B$ is much smaller.
In the second experiment we're measuring $B$ at different distance $x$ from the center. We find $B$ by applying the formula (1) and by measuring. We find the error on the calculated value of $B$ by propagation of error and we do accuracy and precision.

## LAB 8 = RLC SERIES CIRCUIT

To study resonance in an inductor-resistor-capacitor (LRC) circuit.
The amplitude of the AC current (I) in a series LRC circuit depends on the amplitude of the

$$
\begin{equation*}
I=\frac{V_{\text {in }}}{Z} \tag{1}
\end{equation*}
$$

applied voltage $\left(V_{i n}\right)$ and the series impedance $(Z)$.
with

Where the inductive reactance, $X_{L}=\omega L$, the capacitive reactance $X_{C}=1 / \omega C$ and $R$ is the total

$$
Z=\sqrt{\left(X_{L}-X_{C}\right)^{2}+R^{2}}
$$

series resistance of the circuit. $\omega$ is the angular frequency ( $\omega=2 \pi \mathrm{f}$, where f is the frequency in Hz ). Since the impedance depends on frequency, the current varies with frequency. It can be easily seen that the current will go through a maximum as the frequency is varied. The current peak will occur when $X_{L}=X_{c}$, when the circuit is driven at its resonant frequency, $\omega_{\text {res }}:$

$$
\omega_{\text {res }}=\frac{1}{\sqrt{L C}}
$$

At resonance, the impedance $Z=R$ is at its smallest possible value, the current is at its largest possible value and the voltage across the DRB reaches its maximum value and is in phase with the input voltage. At other frequencies the phase difference $\Phi$ between the current and the input voltage is given by;

$$
\begin{equation*}
\Phi=\tan ^{-1}\left\{\left(X_{L}-X_{C}\right) / R\right\} \tag{4}
\end{equation*}
$$

We define the quality factor $Q$, which characterizes the sharpness of the resonance peak:

$$
\begin{equation*}
Q=\frac{\omega_{\text {res }}}{\Delta \omega} \tag{5}
\end{equation*}
$$

where $\Delta \omega=\left(\omega^{+}-\omega^{-}\right)$and $\omega^{+}$and $\omega^{-}$are, respectively, the frequencies greater and smaller than $\omega_{\text {res }}$ at which $I=I_{\text {res }} / \sqrt{2}$. It can be shown that $\Delta \omega=R / L$, and thus:

$$
\begin{equation*}
Q=\frac{\omega_{\mathrm{res}} L}{R} \tag{6}
\end{equation*}
$$

As R decreases, the $\mathbf{Q}$ increases, and the resonance peak of $/$ versus $f$ curve becomes sharper.
N.B. $R$ in the above equations is the sum $R_{D R B}+R_{L}$ where $R_{L}$ is the resistance of the inductor.

Remember
When the signals to the $x$ and $y$-inputs of the scope are sinusoidal voltages of the same frequency, one obtains a rotated ellipse as shown below.


At $\mathrm{x}=0, \mathrm{y}= \pm \mathrm{D}= \pm \mathrm{A} \sin \varphi$, while the maximum deflection in the y direction is $\pm \mathrm{A}$.
Thus, $\boldsymbol{\operatorname { s i n }}(\phi)=\mathbf{D} / \mathbf{A}$. Therefore, by measuring 2A and 2D on the oscilloscope screen it is possible to find the phase difference between the horizontal and vertical signals.
Note that you cannot get the sign of the phase difference from the Lissajous figure; you can measure the absolute value of the phase difference only.

## LAB 9 = TRANSFORMERS

Consider two coils in close proximity. If a voltage source is connected to the first coil, henceforth called "primary", a current flows in the primary coil, which sets up magnetic field in the region surrounding the coil. This field produces a self-flux through the primary coil $N_{p} \Phi_{p}$. Furthermore, if the second coil, henceforth called "secondary", is located in the proximity of the first coil, there will be a magnetic flux through the secondary coil $N_{s} \Phi_{s}$, due to the field produced by the primary. Np and Ns are the number of turns in the primary and secondary coils, respectively, while the flux $\Phi$ is defined as:

$$
\Phi=\int \mathbf{B} \cdot \mathbf{d A}
$$

where the integration is over the coil area.
The flux is a measure of the number of magnetic field lines crossing the coil area. The flux through the secondary coil depends on the flux linkage between the two coils (the number of lines that leave the primary and crosses the secondary). Thus $\Phi_{s}$ is expected to fall rapidly as the coils move away from each others, or if the coils are oriented so as to decrease linkage. The linkage depends also on the material that fills the space between the two coils. A ferromagnetic material is one whose atoms have unpaired electrons and therefore possess permanent magnetic moments. If such material is placed in an external magnetic field, the atomic dipoles become aligned with the external field (the medium is said to be magnetized). The magnetic field produced by these dipoles adds and enhances the external field. This enhancement can be sizeable. Furthermore, the lines of magnetic field tend to follow the ferromagnetic medium.

If an AC voltage $V_{p}$ is applied to the primary coil, it produces a changing magnetic field. The changing flux through the secondary coil, turn, will create an induced emf and consequently an AC voltage $V_{s}$ in the secondary coil. Thus,

$$
V_{p}=-N_{p}\left(d \phi_{p} / d t\right)
$$

and

$$
V_{s}=-N_{s}\left(d \phi_{s} / d t\right)
$$

A transformer consists of an iron (ferromagnetic) core onto which two coils are wound. An AC voltage is applied to the primary coil of the transformer, thus producing a changing magnetic flux in the iron core. Because iron is easily magnetized, it enhances the magnetic field compared to an air core, and the magnetic field lines are channeled through the iron core to the secondary coil. This in turn will create an induced emf and consequently an AC voltage in the secondary coil. Because of the presence of the iron core, the flux linkage is nearly perfect in a well-designed transformer. All the magnetic field lines that leave the primary cross the secondary. Consequently,

$$
\boldsymbol{\phi}_{s=} \boldsymbol{\Phi}_{p}
$$

And

$$
V_{p} / V_{s}=N_{p} / N_{s}
$$

If the number of turns of wire in the secondary coil is greater (smaller) than the number of turns in the primary coil, the voltage induced in the secondary coil will be greater (smaller) than the voltage in the primary coil. This results in a step-up (stepdown) transformer.
Note that the iron core acts to concentrate the magnetic field in the coils. When the core is removed, the field is more spread and the transformer is less efficient. Furthermore, the geometrical shape of the core affects the transfer efficiency of the magnetic flux from the primary to the secondary coil. Even in the best-designed transformers there is some flux loss with a subsequent decrease in the secondary emf.

A transformer is a passive device that cannot produce power amplification. In an ideal transformer, the power delivered to the primary is equal to the power delivered by the secondary. A well-designed transformer approaches this ideal efficiency within $1-2 \%$. Assuming ideal efficiency, power output is equal to the power input. Thus,

$$
V_{p} I_{p}=V_{s} I_{s}
$$

which leads to

$$
I_{p} / I_{s}=N_{s} / N_{p}
$$

## LAB 10 = MEASUREMENT OF THE FORCE BETWEEN TWO PARALLEL, CURRENT-CARRYING CONDUCTORS

Current distributions produce magnetic fields that may be calculated using BiotSavart law. The magnetic induction field B at a distance d from a long straight wire, carrying a current $i_{1}$ is

$$
\begin{equation*}
B=\frac{\mu_{0} i_{1}}{2 \pi d} \tag{1}
\end{equation*}
$$

 experiences a force

$$
\begin{equation*}
F=B i_{2} L \tag{2}
\end{equation*}
$$

Thus, a straight wire of length $L$ carrying a current $i_{2}$ that is parallel to a "long" straight wire carrying currents $i_{1}$ will experience a side-ways force of the magnitude

$$
\begin{equation*}
F=\frac{\mu_{0} L i_{1} i_{2}}{2 \pi d} \tag{3}
\end{equation*}
$$

where d is the separation between the wires. If $i_{1}=i_{2}=i$ then

$$
\begin{equation*}
F=\frac{\mu_{0} L i^{2}}{2 \pi d} \tag{4}
\end{equation*}
$$

The force $F$ is a repulsive force if the currents are in opposite directions. One can use the above equation to find $i$ in amperes if one measures the force $F$ in Newton, the length $L$ in meters and the separation $d$ of the two wires in meters. The electric current is therefore expressed in terms of the basic units of force and length. On the other hand if one measures the current with a calibrated ammeter, then equation (4) can be used to measure $\mu_{0}$, the permeability of free space. This is what you will be doing in this experiment.
N.B. In the SI system of units, the Ampere (A) is defined in terms of the force between two parallel conductors carrying equal currents: Given two long parallel
wires of negligible cross section separated, in vacuum, by a distance of 1 meter, the unit of current $(A)$ is defined as the current in each wire that would produce a force of $2 * 10^{-7} \mathrm{~N}$ per meter of length. The current balance is an instrument that makes this fundamental measurement possible.

## Description of experimental set-up:

Figure 1 shows the circuit of the experimental setup. The power supply (two power supplies connected in parallel) is connected in series with the digital meter and the


Figure 1- Diagram of the current balance circuit.
current balance. The current passes in opposite directions through the two parallel, horizontal bars, which are connected electrically in series. This leads to a repulsive force between the two bars. The lower bar is fixed while the upper bar is free to move with the beam. The upper bar can be balanced a few mm above the fixed lower bar, by adjusting a counterweight. This is the equilibrium position. The upper bar supports a small pan into which weights can be placed, thereby forcing the upper bar to move downwards towards
the lower bar.


Figure 2- Schematic of the mirror-based set-up used to measure distance between the two current carrying conductors.

Allow
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curre
nt to pass throu
gh
the
bars gene rates
an
upwa
rd
force
on
the
upper bar. The bar can then be restored to its equilibrium position by adding weights to the pan, as shown in Figure 3. The position of the upper bar can be measured by means of a mirror mounted on the beam of the upper bar. A laser beam falls on the mirror and is then reflected back onto a scale. Any change in the position of the upper bar, causes a change in the tilt of the mirror and therefore a change of the position of the laser spot on the scale.

## By Erik VZ

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