Physics 222 **Lab No. 6** Date: ___________________

Magnetic Induction

Name: ___________________

Lab Partner: ___________________

Section #: _____ Instructor: ___________________

(subtitle: Faraday's Law!)

Overview

Activities

- **#1.** Measurement of AC quantities with a multimeter.
- **#2.** Magnetic induction of an EMF - Qualitative Observations of Faraday's Law and Lenz's Law
- **#3.** Setting up a uniform, sinusoidally time-varying magnetic field of known value.
- **#4.** Quantitative observation of the EMF induced in various test coils, and Faraday's Law.
- **#5**. Quantitative predictions of Faraday's Law
- **#6.** The series LR circuit

Major Equipment Items

a. A digital oscilloscope, the Tektronix model TDS-210, and laser printer.
b. Digital multimeter (used as a AC voltmeter).
c. function generator, with digital frequency display
d. solenoid, various coils, inductors, resistance box

Appendices

I. **Basic Operations of the Tektronix model TDS210 Digital Oscilloscope**
II. **Some specifications and information concerning the Tektronix model TDS210 Digital Oscilloscope**

Meaning of the term, AC: AC is an abbreviation for Alternating Current. It commonly is used to refer to the 60 Hz, sinusoidal potential difference available at an ordinary wall outlet in the U.S. Occasionally it is used to refer to other frequencies, and occasionally other waveform shapes; usually the context makes the meaning clear.

RMS values:

a. **Do not let RMS values upset you!** Giving the RMS value is just as natural as giving the amplitude of a sinusoidal function; it's just a different convention.

b. **One does not have to endlessly insert factors of $(2)^{1/2}$ just because one is using RMS values.** For example, in this lab, an AC digital meter will yield the P.D. (RMS) across a resistor, from which you can calculate easily the current (RMS) in the circuit. Using this current (RMS), you can calculate the sinusoidal B field (RMS) in a solenoid, which you use later to predict the EMF (RMS) in a small coil placed in the solenoid.

The point is that you don't keep converting back and forth between RMS and amplitudes. Typically, you simply note which convention you are using.

c. **We use RMS values, not to torture you, but because most AC meters are calibrated to display RMS values.** This convention results primarily from the convenience of using RMS values when calculating power for ordinary AC devices. For example, if you measure the current through, and voltage drop across, a toaster, the power is given by I x V when RMS values are used, just like the corresponding calculation for a DC circuit! If instead one uses the amplitudes of the sinusoids, the power is given by 0.5 x I x V (because the average of $\sin^2(\omega t)$ or $\cos^2(\omega t)$ is 0.5). (Note that a power calculation or measurement is more involved if the device is not purely resistive, but rather has some capacitive or inductive character.)

d. An example of another common terminology is **2.00 VAC**, which stands for 2.00 volts AC, which means 2.00 volts RMS (since AC measurements typically are RMS measurements!)

Meaning of the term, "nominal": For one activity, the write-up suggests using a sinusoidal output of 5 kilohertz (**nominal** value). By **nominal** value, we mean you don't have to struggle endlessly with the settings of the function generator trying to get exactly 5000 Hertz. However, the actual frequency used should be recorded and used in the appropriate calculations.

Procedure

a. **The format of today's lab and your report:**

- This write-up has the format of a workbook, with spaces for you to answer questions, do some calculations, etc.
- The write-up is organized by Activities. Attach graphs associated with a particular activity to the pages for that activity.
- If there is not enough space for your work or comments at some point in the write-up, indicate "see below" or "see attached", and **use additional paper as needed.** This may happen because we did not leave enough space for your work, or you may need to redo some work, or because you write large, or whatever. Do not let the format of this write-up "force" you into some unprofessional habit, such as writing very small or illegibly, etc.. Instead, use some additional paper; it is very cheap compared to the value of your time and the value of high quality work and habits!
- In some portions of the write-up, there are detailed instructions or explanations. You should indicate that you have followed or read these as appropriate by, for example, making a check mark or writing a short comment, such as "done". Write more detail if that is appropriate. If you are in doubt whether a comment is needed, then write one! Most of us tend to write too little!
- Title printouts appropriately, such as: "Waveform observed while thrusting a magnet into the 1850 turn coil".
- We suggest that you number each printout within each activity, such as: Act. #3, PO #2 (that's activity #3, print-out #2).
- Make a notation at the appropriate point within the write-up each time you print a display, giving the number of the printout. Thus your write-up should indicate the existence of each of your printouts.
- At the end of the activities, the following statement appears:

Staple together the pages for this Activity and any related graphs, and place these in your folder at the end of the lab table for your instructor to review.

  Your instructor will discuss this work with you at various times during the period.
- **At the end of the lab period**, or when you finish (whichever comes first), staple together all your work **in order**, including the introductory pages of the write-up.

b. **Some Reminders:** As with all records of scientific work, you are expected to:

- **Use non-erasable pen** (except perhaps when making graphs or sketches);
- **Preserve any original data records**, and submit them with reports based on that data;
- **Show all your calculations!** Those who must rely on your work should not have to repeat your calculations to confirm or discover what you did.
- **Follow the professional practices enumerated in the Introduction to the lab manual.**

- **Review your work for each activity skeptically.** In particular,
  I. Does your report address the problems raised and the question(s) asked in the activity?
  II. Are the results reasonable? (For example, if a result is numerical, does it have a reasonable magnitude, or is it far too large or too small?)
  III. Is the mathematics and/or the logic in the report correct?
  IV. Is the work complete, with all appropriate steps shown?
  V. Do calculations and results include all appropriate (and correct!) units?
  VI. Is the work of professional quality? (Refer to the checklist on page 8 of the Introduction to the lab manual.)
  VII. If some of the work appears to be incorrect or in need of redoing, draw a line through the questionable work, make a notation of the problem or concern, and then redo that work.
  VIII. If appropriate, add any additional remarks of your choosing such as, "this work should be neater", or "I still do not know how to determine the frequency from the graph", or etc.

c. The Activities:

- Scan briefly the list of activities on page 1 (if you have not already done so).
- You are welcome to begin!

Name: ______________________________ Date: _________________

Activity #1: Measurement of AC quantities with a multimeter. (Subtitle: Comparing the RMS readings of an AC voltmeter with observations of the same sinusoidal waveform on an oscilloscope.)

A) Prepare the instruments for use.

A-1. For now, **turn off the outlet strip** into which your instruments are plugged (if it is on).

A-2. **Remove all wires and cables from the terminals of the instruments.**

A-3. **Suggestions for the initial settings of some controls.**

Digital Multimeter (DMM) (HP model 3476)	1. Set the power switch to **OFF**. 2. Set the meter to measure **AC volts.**

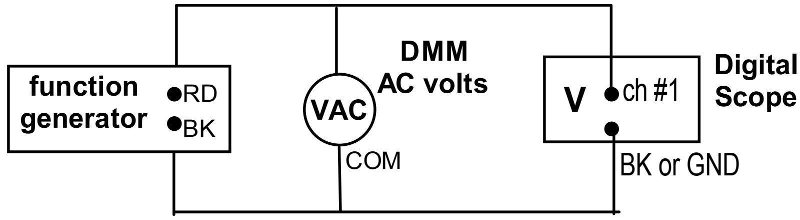
Function Generator (B&K Precision model 4011)	1. Set all four buttons in the middle of the front panel OUT; 2. Select a "sine" function shape for the output.

Digital oscilloscope (Tektronix model TDS210)	1. **Now turn on the outlet strip.** 2. So that you can refer to it as needed today, **remove Appendix I from the back of this write-up** and place it on your lab table for easy reference. 3. Now perform **steps #1, #2, #3, and #5** of the Basic Operations (see Appendix I). **For step #5, use the 1X setting for now.** 4. If you are unfamiliar with this scope, briefly read (without using yet!) the other Basic Operations in Appendix I.

Laser printer (HP L4 or higher)	To print the oscilloscope display on the printer on the computer cart: 1. The outlet strip on the computer cart should be on; 2. The printer will now be on (it does not have a power switch); 3. To save power, etc., the power switch of the computer and that of the monitor should be OFF (we will not be using the computer today); 4. **Read this later if you have problems printing:** Both the computer and the oscilloscope are connected to the printer through a two-input "auto-switch". When functioning properly, the light for each of the two input ports should light alternately. On the "True-Data" models, occasionally a reset button needs to be pressed. The auto-switch receives its power via the data cable from the printer or oscilloscope.

B) Assemble the circuit shown.

B-1. For connection to the function generator, use an adapter that allows you to connect two ordinary lab wires ("banana" wires) to the OUTPUT connector. (The OUTPUT connector is the right-most BNC-style connector.)



B-2. Use a similar adapter on Ch #1 of the oscilloscope.

B-3. Use the appropriate terminals of the multimeter for AC voltage measurements (labeled V and COM).

B-4. Turn on the function generator. We suggest you use a **sinusoidal output with a frequency of approximately 200 Hz.**

* A note: The frequency used is not particularly critical, as long as it is within the range for which the particular AC voltmeter used can make accurate measurements of the RMS value. For the HP multimeter we are using, this range is remarkably large, from 45 Hz to over 5000 Hz! Some AC voltmeters are calibrated to be accurate only near 60 Hz.

C) A prediction (made before turning on the AC meter!)

* Predict the reading of an AC voltmeter when connected across two points between which there is a sinusoidal potential difference with an amplitude of 1.0 volts. ____________

* Explain your reasoning.

____

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D) Measure the RMS value of a sinusoidal waveform (using an AC voltmeter) and compare this value to the measured amplitude (as determined using an oscilloscope).

D-1. We suggest that you adjust the output level of the function generator so that the sinusoidal waveform (as seen on the oscilloscope) has an **amplitude of 1.0 volts.**

* Such a waveform is said to have a **peak to peak amplitude of 2.0 volts.**

* **Tip: For this section, we suggest that you depress the "-20 dB" switch on the front panel of the function generator; this will reduce the output range by a factor of 10, and will allow you to obtain a peak to peak amplitude of 2.0 volts more reliably.**

* Choose an appropriate vertical scale for the oscilloscope display. For accurate measurements with the oscilloscope, the vertical extent of the waveform on the screen should not be too small.

D-2. Now measure the RMS value of this waveform with the multimeter.

RMS value (as measured with an AC voltmeter): ___________

D-3. Compare the RMS value as measured by an AC voltmeter to the amplitude (as measured using the oscilloscope screen).

* Calculate the percent difference between the reading of the AC voltmeter and your prediction for this reading.

Percent difference: ________

* Assume that the vertical calibration of the oscilloscope is accurate to ± 3%, and that the AC voltmeter also is accurate to ± 3%. In light of these specifications, discuss whether the difference between readings produced by the two instruments **is significant or not?**

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E) Comment on this activity in any way that you think appropriate; in particular, discuss any difficulties which you encountered.

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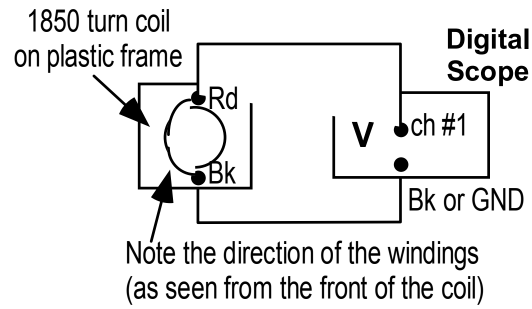
Staple together the pages for this Activity (#1) and any related graphs, and place these in your folder at the end of the lab table for your instructor to review.

Name: ______________________________ Date: _____________________

Activity #2: **Magnetic induction of an EMF - Qualitative Observations of Faraday's Law and Lenz's Law**

For this activity, we will use the plastic-covered bar magnet, and the 1850 turn coil on the plastic form connected directly to CH #1 of the scope. **HANDLE THE COIL WITH CARE; THE WINDINGS ARE FRAGILE!!!**



A) Assemble the circuit shown.

A-1. We suggest setting the scope controls, at least initially, as follows:

* vertical scale for Ch #1: 500 mV/Div
* horizontal scale: 500 ms/Div

A-2. You likely will notice **a small level of electrical noise** on the scope screen. This would be troublesome if we were making quantitative measurements in this activity. Much of this can be eliminated by carefully shielding the coil and the connecting wires to the scope, but we will not bother with such today.

B) Now use the bar magnet in various ways to generate an EMF that is detected by the oscilloscope.

B-1. Move and hold the magnet in various ways through or near the coil, until you become familiar with what actions or arrangements result in an induced EMF detected by the oscilloscope.

* Can you find any location of the magnet with respect to the coil at which the magnet generates an EMF in the coil when both the coil and magnet are at rest? _______

  If do, describe and/or sketch this location.

  ____

B-2. What effect does **increasing the speed of the magnet** have on the induced EMF that you observe?

____

Is this result consistent with Faraday's law? ______ Explain.

____

B-3. What effect does **reversing the orientation of the magnet** have on the induced EMF that you observe?

____

Is this result consistent with Faraday's law? ______ Explain.

____

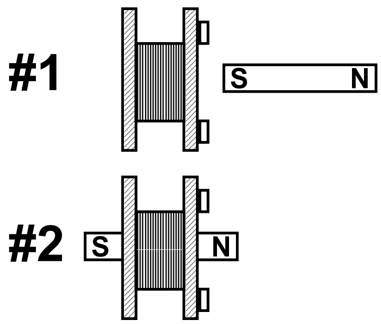
B-4. What effect does **reversing the direction of motion of the magnet** have on the induced EMF that you observe?

____

Is this result consistent with Faraday's law? ______ Explain.

____

B-5. Now try thrusting the magnet South pole first into the front face of the coil (positions #1 to #2 below).



a. Print and label appropriately a scope display showing this EMF.

b. Discern and record:

- the polarity of the EMF generated: ____________
- the direction of the induced current in the coil (CW or CCW, as seen from the front): ________
- the type of magnetic pole generated by this induced current at the front face of the coil: ______.

c. Explain whether your result for the direction of the current, or for the polarity of the induced magnetic pole is, or is not, consistent with Lenz's law.

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C) Comment on this activity in any way that you think appropriate; in particular, discuss any difficulties which you encountered.

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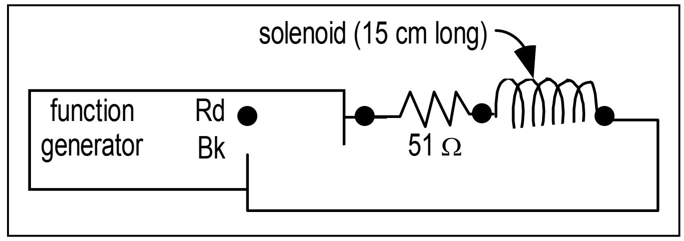
Staple together the pages for this Activity (#2) and any related graphs, and place these in your folder at the end of the lab table for your instructor to review.

Name: ______________________________ Date: _____________________

Activity #3: Setting up a uniform, sinusoidally time-varying magnetic field of known (RMS) value, and some simple tests of Faraday's Law.

A) Assemble a circuit that results in a sinusoidally-varying current flowing in the windings of a solenoid.

A-1. Assemble the circuit shown.



A-2. Set the function generator to produce:

- * a sinusoidally time-varying output;
- * with a (nominal) frequency of 5 kHz (i.e., 5000 Hz);

A-3. Adjust the output level of the function generator so that the PD <u>**across the resistor alone**</u> is some convenient and reproducible value. We recommend **2.00 V (RMS)** (as measured with a AC voltmeter).

- * Does the presence of the resistor in the circuit provide a way to determine the current in the solenoid? _____ Explain.

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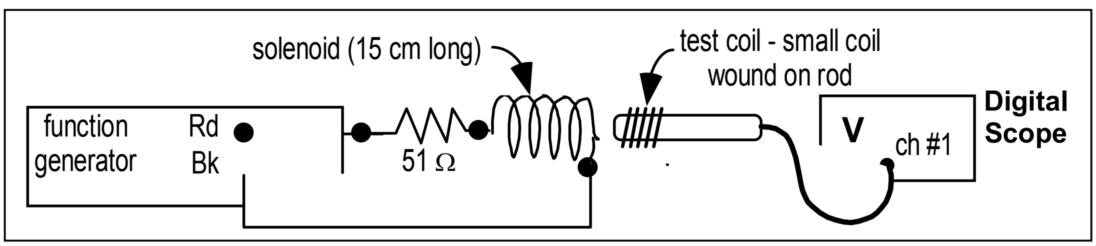
B) Detect and investigate the changing magnetic field present within and around the solenoid (by using a small test coil mounted on a rod).



B-1. Connect one of the available test, or "pickup" coils, to the oscilloscope, so that any EMF generated in the test coil can be measured.

- * If available, for now use coil #1 (100 turns, 1.0 " diameter); otherwise, use one of the other coils.
- * We suggest that you connect the (BNC-type) cable of the pickup coil directly to the BNC connector for CHannel #1 of the oscilloscope.

B-2. Now use the pickup coil (and oscilloscope) to detect the effect of the magnetic field both within and outside the solenoid. Record and comment upon your observations.

- * Where is the induced EMF largest? ___________________________________
- * Where is it relatively small? ___________________________________
- * Is the induced EMF the same, regardless of location (of the test coil) within the solenoid? _____

  If not, describe how the induced EMF varies within the solenoid.

  ____

- * Describe the time dependence, or shape as a function of time, of the EMF induced in the test coil?

  ____

* What does the time-dependence of the EMF tell you about the (time-dependence) of the magnetic field within the solenoid? ____ Explain your reasoning.

____

C) For reference in later activities, calculate the current (RMS) in the solenoid.

* **Hint!!!** Why do you think the 51 ohm resistor is in the circuit?

____

* Show your work below.

Current (RMS) in the solenoid: ________________________

D) Calculate also the sinusoidal magnetic field (RMS value) within the <u>solenoid</u> for the conditions described in A-3 above.

D-1. Note that the markings on the solenoid are a count of the windings, NOT a centimeter scale! (These markings are provided to save you the tedious task of counting windings!)

D-2. Note that the solenoids that we are using for this activity have **5 layers of windings**.

D-3. **Determine the number of turns per cm (in each layer) of the solenoid**. Record any necessary measurements and calculations below. (Assume that underlying layers are similar to the top layer of windings.)

Turns per cm (in each layer) of the solenoid: ______________________

D-4. **Calculate the sinusoidal magnetic field (RMS value) within the solenoid.** Show you work below.

magnetic field within the solenoid (RMS): ________________

E) A Puzzle!!! (An example of electromagnetic "shielding"!!)

E-1. Available to you are a pair of brass cylinders, about 4-5/8" long and 1-1/8" ID (inside diameter).

* Note that one of these cylinders is slotted along its length, the other is not.

* Each of these can be slipped easily over the 1" diameter test coil.

E-2. Now measure and record (in the table below) the EMF induced in the test coil under the following different circumstances:

a. while the test coil is located at the center of the solenoid (as you did previously):

b. while the test coil is also centered within the **"slotted" cylinder**, both centered within the solenoid;

c. and finally while the test coil is centered within the **complete cylinder**, both centered within the solenoid;

	Condition	EMF
a	No cylinder	
b	slotted cylinder	
c	complete cylinder	

E-3. Some explanation!

* In the case of the complete cylinder, a changing magnetic field along the axis of the cylinder will induce currents to flow completely around the cylinder; when the cylinder is slotted, such currents are blocked. The induced currents will flow so as to oppose the change which is inducing them (by Lenz's law). Hence, these induced currents will tend to keep the magnetic flux passing within and along the cylinder from changing.

* **Explain how your observations are, or are not, consistent with these remarks.**

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* **<u>A startling result</u>:** The uncut cylinder above can be thought of as a coil or solenoid with a single turn of "wire"! If the B field produced by the current flowing around this cylinder approximately cancels that produced by the solenoid, then that current is approximately equal to the total current circulating about the solenoid. And that current is N x I, where N is the total number of turns in the solenoid and I is the current in each turn; this total current is approximately:

  5 layers x 110 wires/layer x (2.0 V / 51 ohm) = 22 Amperes!

  The cylinder is acting like the secondary winding of a <u>transformer</u> in which the solenoid forms the primary windings. This crude transformer is an example of a so-called "step-down" transformer; the "voltage" of the secondary is "stepped-down" from that of the primary. But as we have noted, the current is "stepped up", being approximately 550 (i.e., 5 x 110) times larger than the current in the solenoid windings!

F) Comment on this activity in any way that you think appropriate; in particular, discuss any difficulties which you encountered.

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Staple together the pages for this Activity (#3) and any related graphs, and place these in your folder at the end of the lab table for your instructor to review.

Name: ______________________________ Date: _____________________

Activity #4: Quantitative observation of the EMF induced in various test coils, and Faraday's Law

In this activity, you will measure and record the EMF (RMS) induced in each of the three test coils listed in the table below when the coil is placed at the center of the solenoid.

A) Before making measurements, first make some PREDICTIONS!

* Predict how the EMF induced by a given magnetic field will vary from coil to coil, **for the three coils shown in the table below**. For example,

  1. Predict the ratio of the EMF induced in #2 to that induced in #1.
  2. Similarly, predict the ratio of the EMF induced in #3 to that induced in #1.

  Show any necessary work here, and write your predictions in the table below.

B) Before making extensive measurements:

* Check that the PD across the 51 Ω is 2.00 V (RMS) (or record whatever value you are using).

  V (RMS) across 51 Ω resistor: _______

* Record the actual frequency being used; the **nominal** value that we recommend is 5000 Hz.

  frequency: _____________

C) Carefully measure the EMF (RMS) induced in each of the three coils when located near the center of the solenoid. Record your observations in the table below.

* **Use either the AC voltmeter or the oscilloscope; it is your choice!**

  Instrument being used to measure the induced EMF: ____________________________

* As "first-order" checks on your results, compare the appropriate ratios of your measurements with your predictions made above.

Test coil	# of turns	diameter (inches)	Your prediction of ratio of EMF / EMF(coil #1)	EMF	observed ratio of EMF / EMF(coil #1)	
#1	100	1.00"	1 (by definition!)		1 (by definition!)	
#2	200	1.00"				
#3	100	0.5"				

D) Comment on this activity in any way that you think appropriate; in particular, discuss any difficulties which you encountered.

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Staple together the pages for this Activity (#4) and any related graphs, and place these in your folder at the end of the lab table for your instructor to review.

Name: ______________________________ Date: _____________________

Activity #5: Quantitative predictions of Faraday's Law

A) Determine the prediction of Faraday's law for the EMF induced in test coil #1 for the case where the coil is placed at the center of the solenoid under the conditions used in the previous activity.

- Since this calculation involves many factors, students whose work is **NOT** neat, careful and systematic will find this task **very** difficult.
- When both the calculations and the measurements are done correctly, the theoretical prediction of Faraday's Law typically agrees with the measured EMF to ± 5% or better.
- The analysis required here was outlined in detail at the beginning of the pre-lab.

EMF (coil #1, predicted by Faraday's law): ________________________________

B) **Compare (intelligently) the prediction of Faraday's Law and your observed value for the induced EMF.**

B-1. Calculate the percent difference between the measured EMF and the prediction of Faraday's Law. Show your work.

Percent difference between the predicted and measured induced EMF in coil #1: _____________

B-2. Assume that the resistor value is accurate ± 5%, the vertical calibration of the oscilloscope is accurate to ± 3%, and that the AC voltmeter also is accurate to ± 3%. In light of these specifications, discuss **very briefly** whether the difference between the measured EMF and the prediction of Faraday's Law **is, or is not, significant.**

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C) Comment on this activity in any way that you think appropriate; in particular, discuss any difficulties which you encountered.

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Staple together the pages for this Activity (#5) and any related graphs, and place these in your folder at the end of the lab table for your instructor to review.

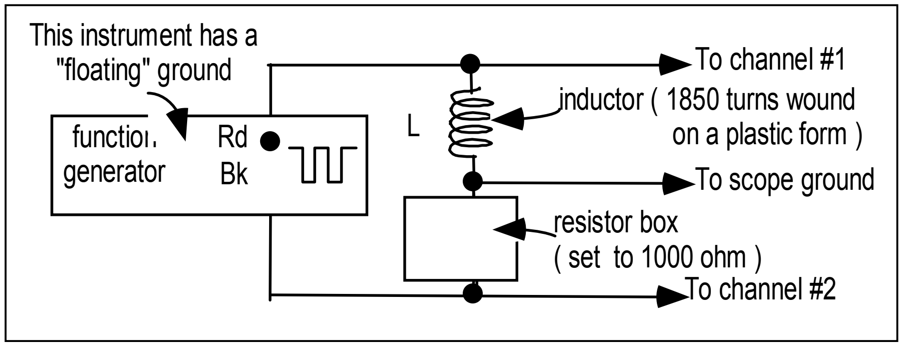
(This is **HOT** stuff if you have time for it!!)

Name: ______________________________ Date: _____________________

Activity #6: The series LR circuit: Observe the exponential increase and/or decay of the current in a series LR circuit that results from a sudden change in the P.D. across the circuit.

A) Assemble an appropriate LR circuit

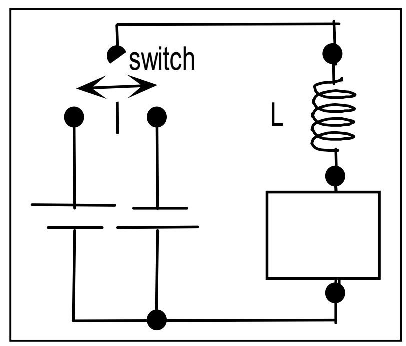
A-1. Assemble the circuit shown. For now, do NOT make the connections to the oscilloscope; assemble only the circuit itself!



A-2. Set the function generator controls:

- * select a square "wave" shape (i.e., a square-shaped function of time);
- * set the frequency to 500 Hz;
- * set the amplitude (Output Level) at about 1/2 of its maximum setting (this setting is not critical - adjust it as convenient).

A-3. Set the dials of the resistance box for a total resistance of 1000 Ω.



A-4. **Some explanation:** The circuit above, with the function generator set to produce a square wave output, is equivalent to the circuit shown at the right. The generator acts like an electronic switch, switching from one potential difference to another, much like a mechanical switch can switch between the potentials of two different batteries. Note that our generator can out-perform a mechanical switch; for example, it can switch back and forth very rapidly, up to several million times per second!

A-5 **An important technical detail for your instructor and interested students - the "floating" ground of the function generator:** For proper operation of the circuit above, the function generator must be powered so that its case is NOT connected to ground potential. Otherwise, both ends of the R box will connected to ground, one end via the third wire of the power cord of the generator and the other via the third wire of the oscilloscope. **Hence, the generator should be plugged into the two wire outlet of an isolation transformer.**

B) Using the oscilloscope, simultaneously observe the PD across inductor and the PD across the resistor in the LR series circuit. Do this for various values of resistance.

B-1. **Make the connections to the oscilloscope illustrated in the circuit above**, so that you are prepared to observe the PD between various points in the circuit.

B-2. **Use the oscilloscope to display simultaneous graphs of:**:

- *** the PD across the inductor;**
- *** the PD across the resistor.**

B-3. **For proper voltage readings, you may need to set Ch #2 for a X1 input (Press Ch 2 Menu, then select Probe as needed.)**

B-4. **Is the finite time required for a finite change in the current evident in any of your recorded waveforms?** (Or does it appear that the current can change instantaneous from one value to another?) Discuss this matter.

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B-5. **Observe the effect on the waveforms of using resistance values that are larger and smaller than 1 kΩ.**

* As the resistance gets larger, does it take more or less time for the current to approach its asymptotic value? ________
* Print and label appropriately any suitable scope displays that illustrate the effect of capacitors of different value. Be sure to label the waveforms appropriately (e.g., PD across the inductor, etc.)
* Summarize in words your observations, and discuss how these observations do, or do not, agree with the standard analysis of the LR circuit.

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The following section is only for Physics maniacs, geniuses or lab instructors!

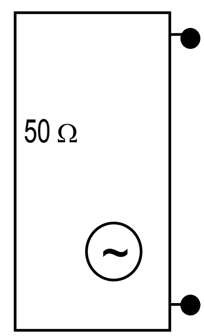
C) Using the "time constant" of the waveforms, deduce a value for the inductance of the coil.

Compare this with either the nominal value of inductance given on the label of the inductor, or a value determined using an accurate inductance meter, if one is available.

C-1. The total resistance of the LR circuit is, in effect, three resistances in series, namely,

* the resistance of the R box;
* the resistance of the wire of the inductor (nominally 105 ohms);
* and the so-called "output" resistance of the function generator, which is 50 ohms.

C-2 **Some culture!** The output of the function generator can be modeled as an ideal voltage source in series with a 50 ohm resistor. In this case, the voltage source is like an ideal battery, except its PD varies with time.



Model of Output of function generator

D) Comment on this activity in any way that you think appropriate; in particular, discuss any difficulties which you encountered.

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Staple together the pages for this Activity (#6) and any related graphs, and place these in your folder at the end of the lab table for your instructor to review.

Physics 222 - Lab No. 6
Magnetic Induction

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8	12	
9	13	
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junk:

Please discuss any difficulties which you encountered in this activity, or comment in any way you think appropriate on this activity.

Comment on this activity in any way that you think appropriate; in particular, discuss any difficulties which you encountered.