University of Toronto
The Edward S. Rogers Sr. Department of
Electrical and Computer Engineering

ECE110S ELECTRICAL FUNDAMENTALS - SUPPLEMENT

Laboratory Instructions

Page

University of Toronto
Department of Electrical and Computer Engineering
ECE110 Electrical Fundamentals
Laboratory

LABORATORY GUIDELINES

Objectives:

- To master the use of fundamental laboratory equipment, such as, DC power supply, function generator, digital multimeter, and oscilloscope.
- To verify experimentally, through the use of basic measurement techniques, the behavior of various individual electrical circuits studied in the lectures.

Each student is expected:

- To maintain a **bound** (i.e. no loose sheets) laboratory lab-book that includes preparations and documents of all work done in the laboratory. The Physics Lab-book sold at the UofT bookstore is highly recommended. You are not required to have a new one – you can continue to use one from an earlier course if you wish. The preparation includes a brief description of the experimental procedures **in your own words**. Always **write in pen**, never in pencil, into the lab-book, and never use white-out. If a mistake is found, it should be neatly crossed out and corrections should be added in pen. The lab-book is to be updated continually during each experiment and to include all measured data, tables, graphs, and descriptions of relevant measurement techniques, computations, and conclusions. The graphs and tables in the instruction sheets are samples only and should be copied by hand into the lab book.
- To review the operating instructions for DC power supplies, digital multimeters, function generators and oscilloscopes, and to read notes on conventions for protoboards and resistors used in the laboratory ("APPENDICES" posted on the course web site).
- To arrive **on time** and **be well prepared** at the beginning of each laboratory session. A complete preparation includes, aside from a description of the procedures, completion of the preparatory assignment for the experiment.
- To finish all parts of the experiment on time. To achieve this, thorough preparatory work is critical.

Other guidelines:

- **No food or drink** inside the laboratory
- Keep the laboratory neat and clean, and return items to their original locations at the completion of each lab session.

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Experiment 1

Electrical Charge

Objectives:

i) To demonstrate that there are two types of electric charges in nature.

ii) To compare the electrostatic properties of insulating and conducting materials.

Instrument: Wimshurst Electrostatic Generator

Preparation:

Study the instruction sheets for this experiment. In your lab book, write down in your own words and short-point form notes the procedures for each part.

PART 2.1 – TRIBOELECTRIC SCALE:

Purpose: To show through ***qualitative observations*** the following phenomena:

- Separation of electric charges by friction,
- Existence of two types of charges (+ and -),
- Existence of electrostatic forces between charged objects (Coulomb's law),
- Categorization of materials based on the "triboelectric[1]" effect.

Description:

Objects are usually electrically neutral; they contain equal amounts of positive and negative charge. Neutral objects neither attract nor repel each other electrically. Their balance of charge can be upset by rubbing or by the presence of other nearby charges (charging by induction).
In this exercise, the attractive and/or repulsive electric forces between charged objects will be observed using the needle point support setup shown in Figure 2.1. You will confirm the presence of electric charges and forces exerted by these charges. You will also classify various materials according to the triboelectric properties. The triboelectric properties of materials are summarized in the triboelectric series, which is a list of materials, arranged so that if a material placed low on the list is rubbed with a material that is higher on the list, the higher placed material will become positively charged and the lower placed material will become negatively charged.

Procedure:

Step 1: Rub both ends of a coloured plastic straw with the fur cloth. This will charge the straw negatively. Balance the charged straw on the needle-point support. Next, charge one end of a second coloured plastic straw in the same way and hold it close to the first straw. Note the nature (attractive or repulsive) and magnitude, (strong or weak) of the force exerted on the straw in the support. What rule have you confirmed? *Note that technique is critical here and you should discharge yourself by touching the bare metal plate (not its painted surface) at the back of the bench.*

[1]The word "triboelectric" comes from the Greek word *tribos,* which means "rubbing", therefore *electricity produced by rubbing.*

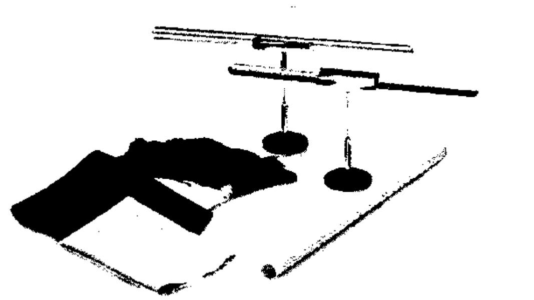

Figure 2.1 Needle-point support set-up

Step 2: Discharge the second straw and recharge it by rubbing it with the green felt cloth. Hold it close to the fur-charged straw balanced in the needle-point support. Note the nature and magnitude of the force exerted on the straw in the support. What type of triboelectric charge is on the felt-rubbed straw?

Step 3: Discharge the coloured straw in the stand and recharge it by rubbing with the felt cloth. Then charge one end of the clear plastic rod with the felt as well. Observe the electrostatic forces. What type of triboelectric charge is on the clear plastic rubbed by the felt cloth?

Step 4: Finally, discharge the clear plastic rod and recharge it using the fur. Leave the coloured plastic straw, already charged with the felt, in the support. Observe the forces as before.

Step 5: From the results of the previous three steps, define the order of the four materials used in the triboelectric scale.

The procedure in steps 1 through 4 was designed to demonstrate the triboelectric effects causing charge separation. The method used was based on observations of the force between two charged objects. In step 6 you will observe the force between a charged object and a neutral (uncharged) object.

Step 6: Touch the metal panel (not the painted surface) at the back of the bench to ensure that your body is not charged. Then remove all the charge on the two coloured straws by holding them closely together in your hands until they show no electrostatic forces when one is placed on the needle-point support and the other is brought nearby. Leaving one neutral straw in the support, charge the other straw by rubbing with felt or fur. Why is the neutral straw attracted to the triboelectrically charged straw? Explain the phenomenon. Discuss how this effect could lead you to draw the wrong conclusions in step 5.

PART 2.2 – WIMSHURST MACHINE:

Purpose:

i) To become familiar with the Wimshurst machine.

ii) To observe the storage and transfer of charge using Leyden jars.

Description:

A more efficient method of separating electric charges is accomplished using the Wimshurst machine, a few rotations should be sufficient to produce a spark. If this fails, get help from an instructor.

Procedure:

Step 1: Six Wimshurst machines are available in the laboratory, and they will have to be shared among several teams. To transfer the charges to your own station, bring the two Leyden jars labeled (+) and (-) to the Wimshurst machine and collect the charge from the discharge-spheres. A few rotations should be sufficient to produce a spark. If this fails, get help from an instructor. Have a Teaching Assistant show you how to transfer the charges safely.

Step 2: To verify that you actually have collected two types of charges, use the needle-point support set-up from PART 2.1. Charge the plastic straw negatively and place it in the support. Then charge a metallized Ping-Pong ball by touching one of the charged Leyden jars. Bring the ball close to the straw and observe the force on the straw. Is the polarity sign on the jar-label correct? Repeat using the other Leyden jar.

Triboelectric Charging

Taken from Morse, R.A., *Teaching about Electrostatics*, AAPT (1992) p.3-1

When two materials with different affinities for positive and negative charges are rubbed together or separated, one may end up with an excess of negative charge and the other with an excess of positive charge, giving the materials net negative and positive charges. This will occur to some extent with any two materials, but the results may not be obvious unless the materials are good inculators. This process is called *triboelectric charging*.

The actual mechanisms of contact charging are complex, depending on the nature of the materials, surface impurities, moisture, etc., and may involve both motion of electrons and ions. The contact between dissimilar surfaces seems to be the important feature, with rubbing acting to increase the number of contact points. (See *Science*, **256** (5055), p.362, Apr. 17. 1992).

Several experimenters have established lists of materials and their relative affinities for negative and positive charge when rubbed together. Such a list is called a *triboelectric series*. An example of such a series is given below.

More Positive

- Rabbit's Fur
- Glass
- Mica
- Nylon
- Wool
- Cat's Fur
- Silk
- Paper
- Cotton
- Wood
- Lucite
- Sealing Wax
- Amber
- Polystyrene
- Polyethylene
- Rubber Balloon
- Sulfur
- Celluloid
- Hard Rubber
- Vinylite
- Saran Wrap

More Negative

Leyden Jar

An early from of capacitor consisting of a glass jar with a layer of metal foil on the outside and a similar layer on the inside. Contact to the inner foil is by means of a loose chain or equivalent hanging inside the jar. It was invented in the Dutch town of Leyden in about 1745.

Wimshurst Machine

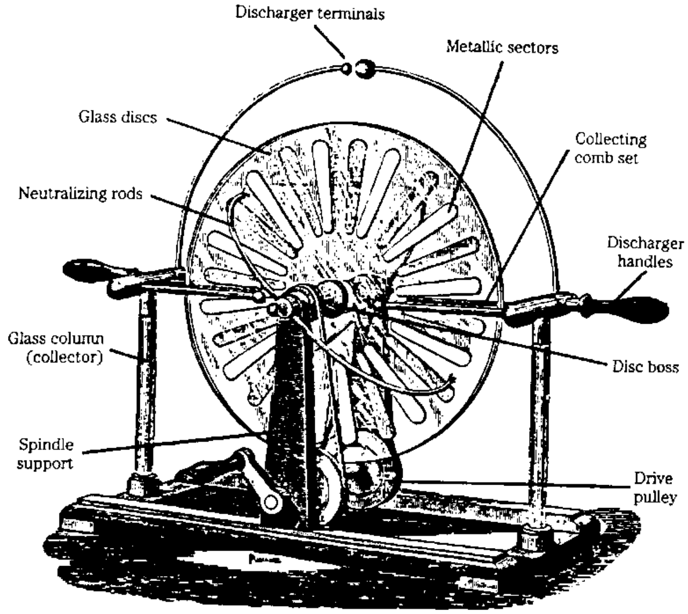

Fig. 2-2 James Wimshurst original design. (Electrical Influence Machines, John Gray, 1903)

The Wimshurst machine, shown in Fig. 2-2, provides an efficient method of separating electric charges by induction and not by friction; it is an electrostatic generator capable of throwing long sparks between two discharge-spheres mounted on swivel arms when Leyden jars are connected to them. This machine consists of two parallel non- conductive discs, hand driven so that they rotate in opposite directions about a common axis. Each plate has narrow metal strips arranged radially, equal distances apart around the rim. Two brushes connected to metal rods, one in front and one in back, transfer charges from one side of a disc to the other. Other metal brushes collect these charges and store them in two (+) and (-) Leyden jars. Attached to these jars are metal rods with discharge spheres at the end. When enough charge is collected in the jars and the electric field between the discharge-spheres exceeds the dielectric strength of the air, a spark jumps between the spheres discharging the jars. The Wimshurst machine requires an initial charge separation on the plates. This can be created triboelectrically and will be amplified as the plates rotate.

CAUTION

The Wimshurst electrostatic generators used in this laboratory produce voltages of 50,000 to 100,000 Volts. They are used to charge Leyden jars with up to 0.000001 Coulombs of electric charge. If you discharge a charged Leyden jar through your body you will experience a painful shock. You probably have experienced similar static shocks when you shuffle your feet on a rug on a dry day. You would receive a more severe shock from a car's ignition system. Your hand may feel numb for several minutes afterward but there will be no other negative effects or any other danger from the shock. To avoid this painful experience, use one hand only and grasp the Leyden jar at the end far from the pop can.

IF YOU HAVE A HEART CONDITION OR A HEART PACEMAKER, HOWEVER, IT WOULD BE WISE NOT TO HANDLE THE LEYDEN JARS AT ALL.

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Experiment 2 — Equipment Exploration

Objectives:

i) To learn how to operate the basic equipment (DMM, oscilloscope, protoboard etc.).

ii) To become familiar with the measurement techniques used in the study of DC and AC circuits.

There are three important rules that should be followed in laboratory practice:

Rule 1: Any signal (voltage or current) must be adjusted to the specified amplitude and frequency ***before*** it is applied to a circuit.

Rule 2: A measuring instrument must be set up for the required mode of operation ***before*** it is connected to a circuit.

Rule 3: The power supply must be switched off ***before*** making any changes to the circuit connections.

Components: a1 kΩ resistor and several resistors of random values

To become familiar with the laboratory equipment, follow all instructions in parts 1.1 through 1.5.

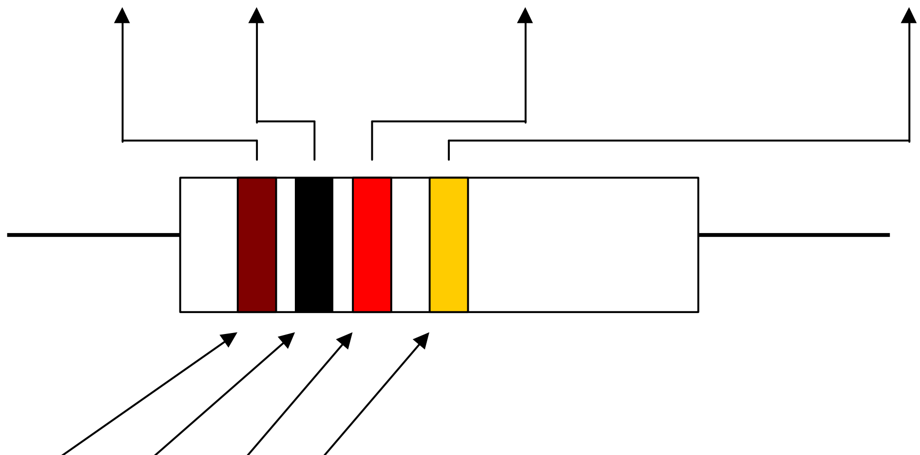
PART 1.1 – Resistor Color Codes:

- To get familiar with the resistor color codes.

Procedure:

The resistance of a resistor determines how much current it will carry when a given voltage is applied across it. A resistor's resistance is specified by a color code on the resistor. Identify and write down the color codes of the resistors provided, then determine their resistances using the table on the next page. **You should learn the resistor color code before performing experiments.**

COLOR	VALUE OF RESISTANCE			COLOR	TOLERANCE
Black		0	$10^0 = 1$	Red	2 %
Brown	1	1	$10^1 = 10$	Gold	5 %
Red	2	2	$10^2 = 100$	Silver	10 %
Orange	3	3	$10^3 = 1{,}000$	None	20 %
Yellow	4	4	$10^4 = 10{,}000$		
Green	5	5	$10^5 = 100{,}000$		
Blue	6	6	$10^6 = 1{,}000{,}000$		
Violet	7	7	$10^7 = 10{,}000{,}000$		
Gray	8	8	$10^8 = 100{,}000{,}000$		
White	9	9	$10^9 = 1{,}000{,}000{,}000$		
	1st band	2nd band	3rd band	4th band	



Example: Brown / Black / Red / Gold

1 0 10^2 5 % => $10 \times 10^2\Omega = 1\ k\Omega$ (5 % tolerance)

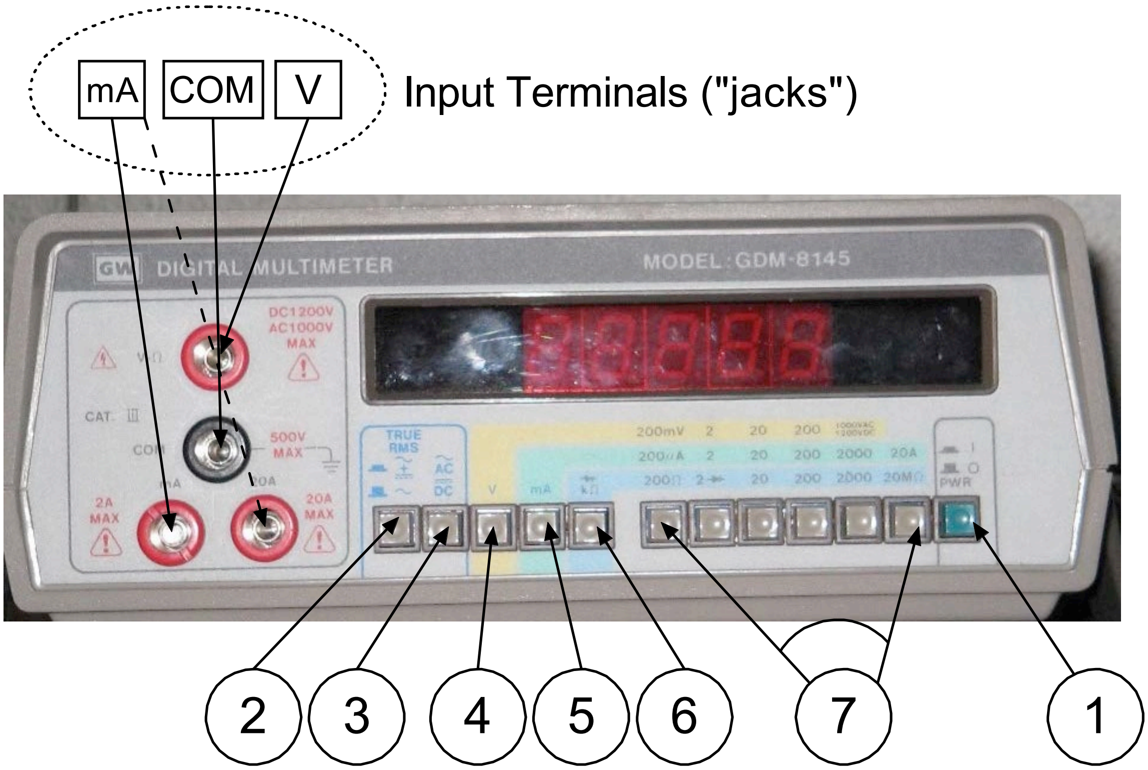
PART 1.2 – DC Voltage Measurement:

Purpose:

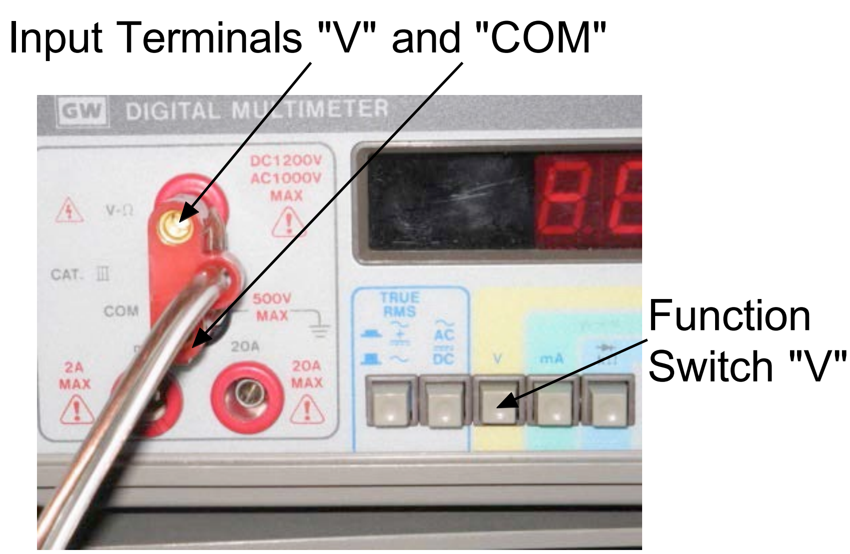
- To practice the setup procedure for the DC power supply.
- To learn how to use the digital multimeter (DMM) as a voltmeter to measure DC voltages.

Procedure:

- *In steps 1-3 you will practice setting the voltage of the DC power supply to a specified value.*



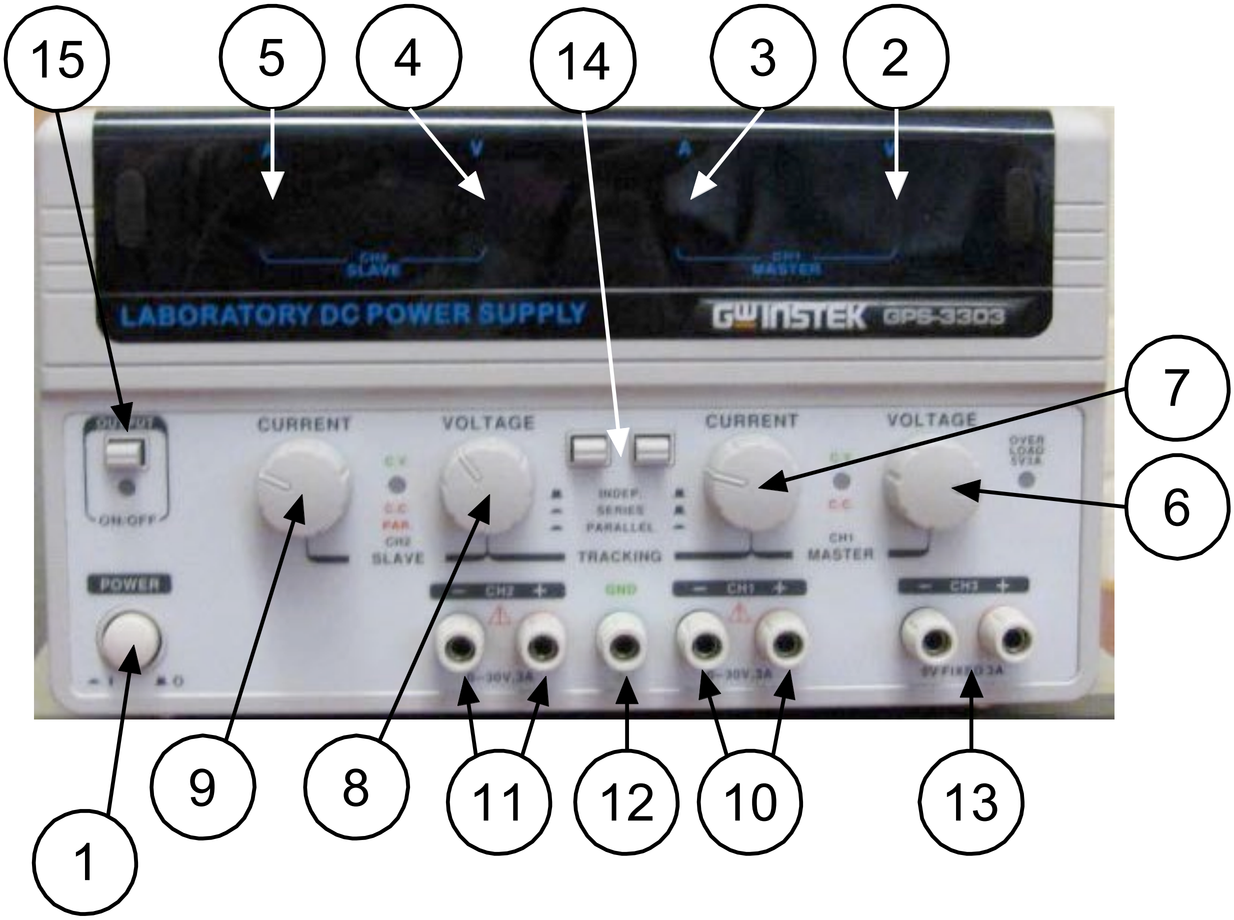
Step 1: Identify the digital multimeter (DMM), shown above, on your workbench and set it up to measure DC voltage, i.e. push in the power button (1), push in the "V" function key (4), make sure that (2) and (3) are **not** pushed in, and connect a double-banana lead as shown below:

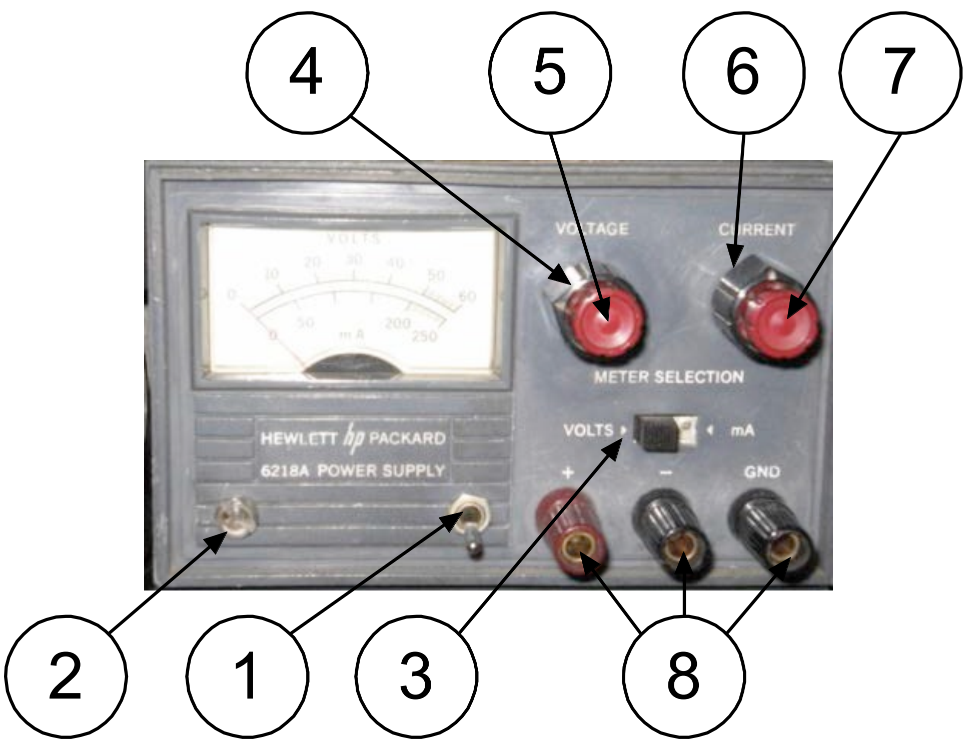


Voltage Measurement

Step 2: Select an appropriate range (7) for reading voltages of about 10V.

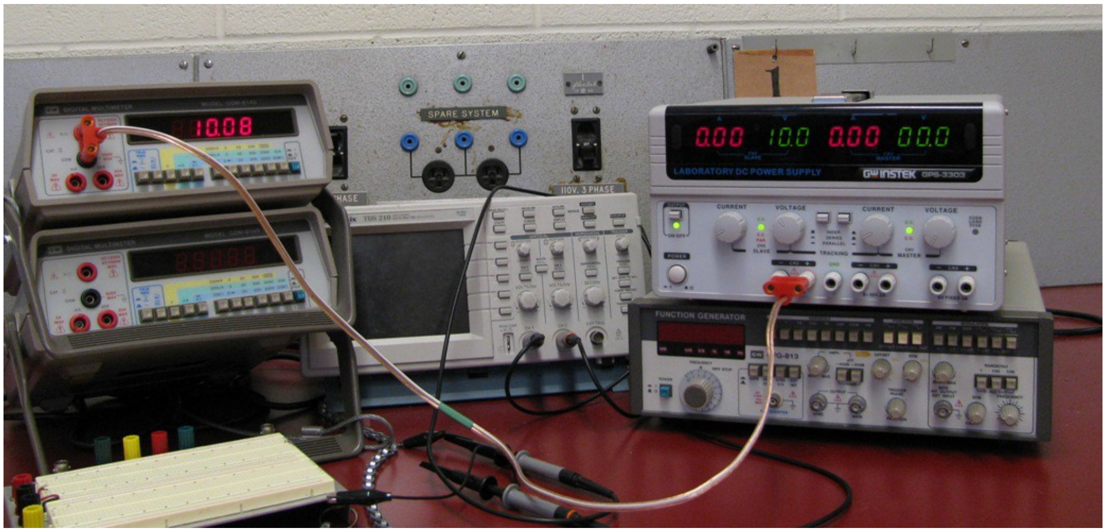
Step 3: Identify the DC power supply on your workbench. Two power supply models, the *GW-Instek GPS-3303* and the *HP Model 6218*, are shown on the next page. The GPS-3303 can be used as two independent power supplies.


15
5
4
14
3
2
LABORATORY DC POWER SUPPLY
GW INSTEK GPS-3303
7
6
CURRENT
VOLTAGE
CURRENT
VOLTAGE
INDEP.
SERIES
PARALLEL
TRACKING
SLAVE
MASTER
POWER
GND
9
8
11
12
10
13
1


4
5
6
7
VOLTAGE
CURRENT
METER SELECTION
VOLTS
mA
HEWLETT hp PACKARD
6218A POWER SUPPLY
GND
2
1
3
8

Step 4: Push the power button or switch (1). If you are using the GPS-3303 make sure both tracking mode switches (14) are “out”, i.e. disengaged.

Step 5: Connect the free plug of the two-wire lead that you connected to the DMM to the output of the DC power supply according to Figure 1.1 on the next page and as shown below. For the HP Model 6218A the output voltage appears between the (+) and (-) terminals (8) for the GPS-3303 between the (+) and (-) terminals of (10) or (11) depending on if CH1 or CH2 is used. If you are using the GPS-3303 push in the output button (15) – the output indicator light should be on.



Step 6: Adjust the applied voltage *V* of the DC power supply to +10V using the DMM reading. Try different range settings. Which is the BEST range and why?

Question: Are the voltage readings on the DMM and on the power supply in <u>reasonable</u> agreement?

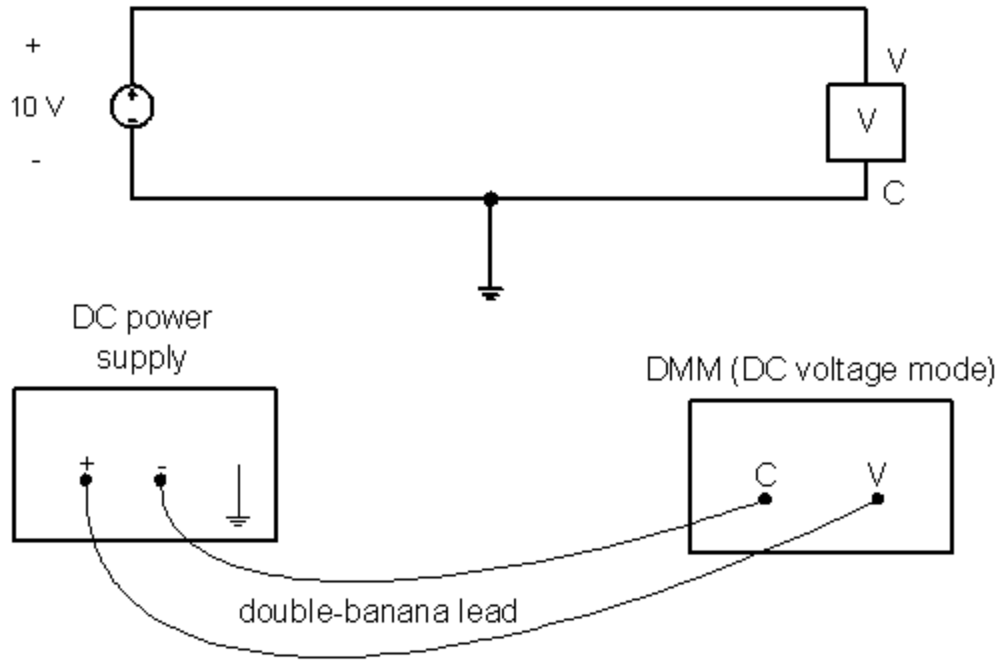


Figure 1.1

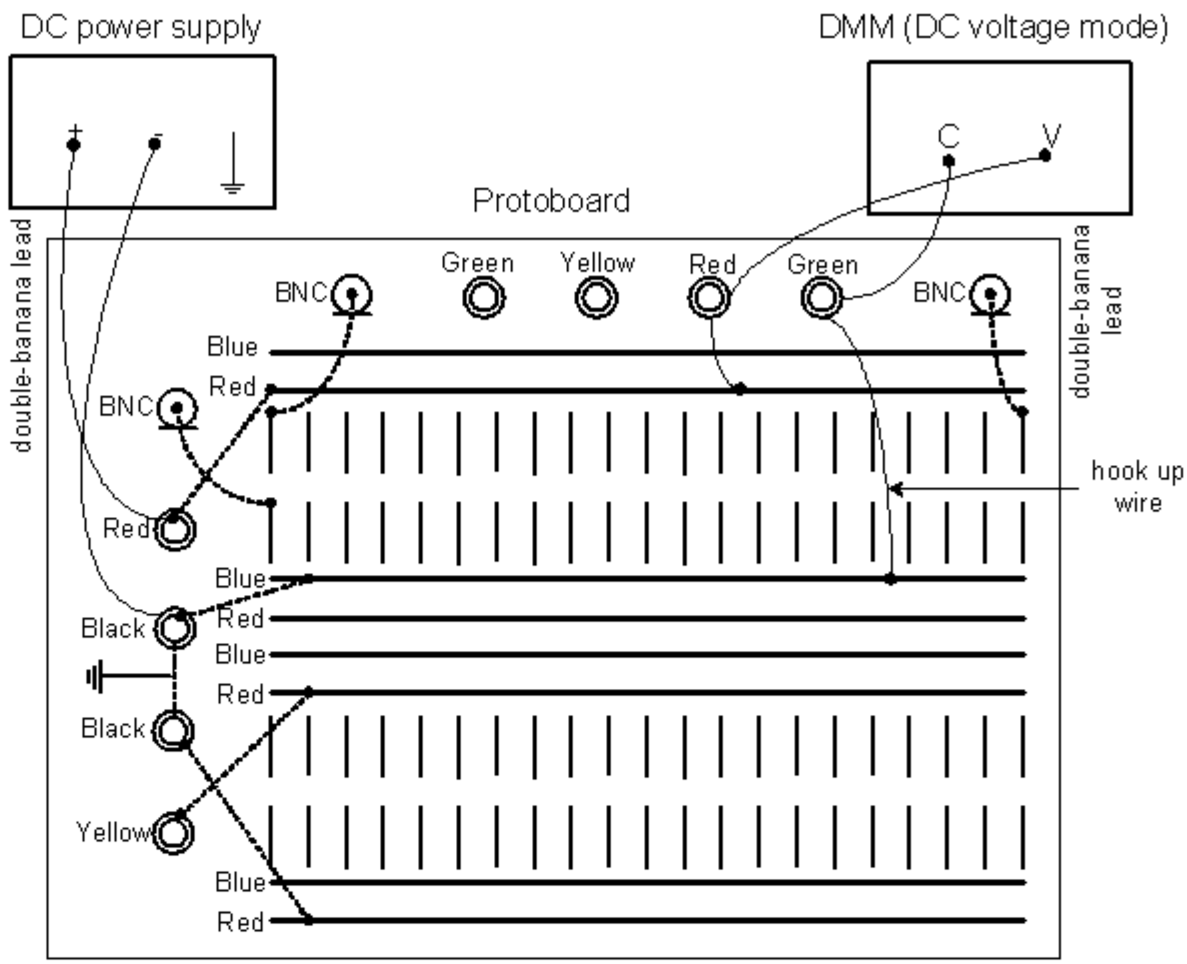
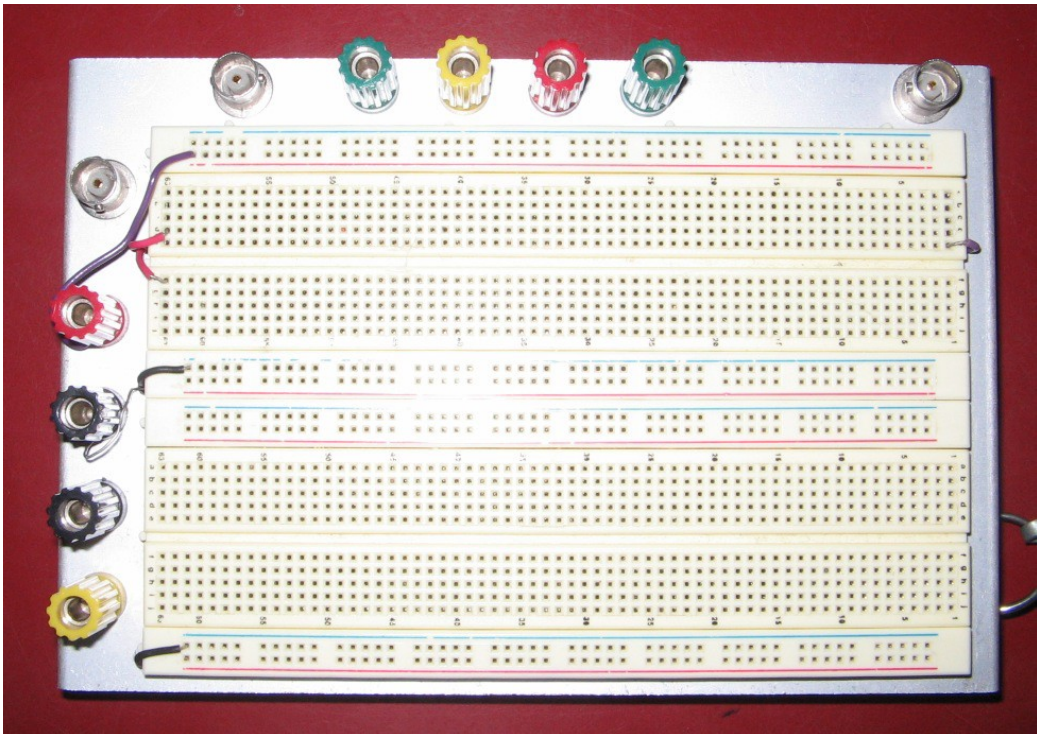
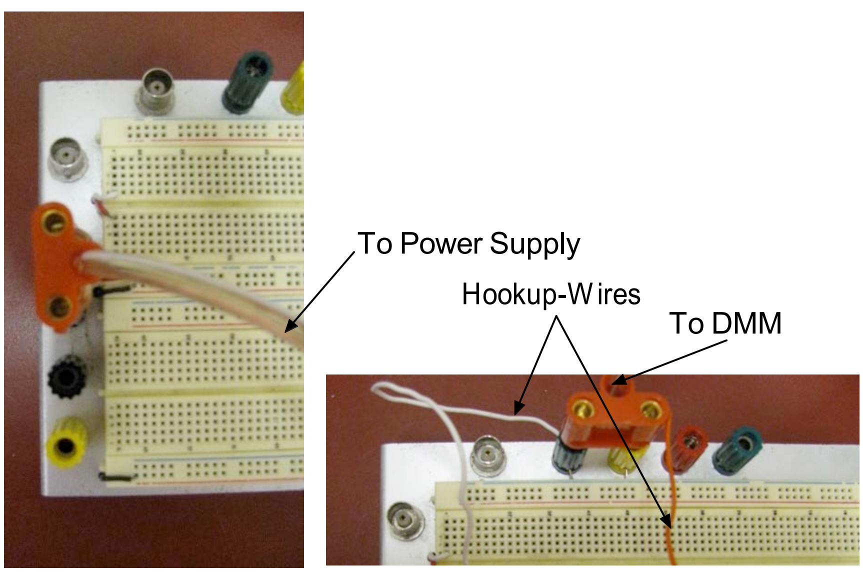


Figure 1.2

- *In step5, you will learn how to use a protoboard to build a circuit.*



Step 7: Connect the circuit with the hook-up wires shown in Figure 1.2 on the previous page. Rows and columns of "dots" that are electrically connected are indicated by the solid lines in Figure 1.2. Check to be sure that the wirings (dotted lines) are done as shown in the diagram. Report to a teaching assistant if there is any missing BNC connection on the protoboard.



Step 8: Connect the DMM and the DC power supply as shown in Figure 1.2. Record the DMM reading and the range of the DMM.

PART 1.3 – DC Current Measurement:

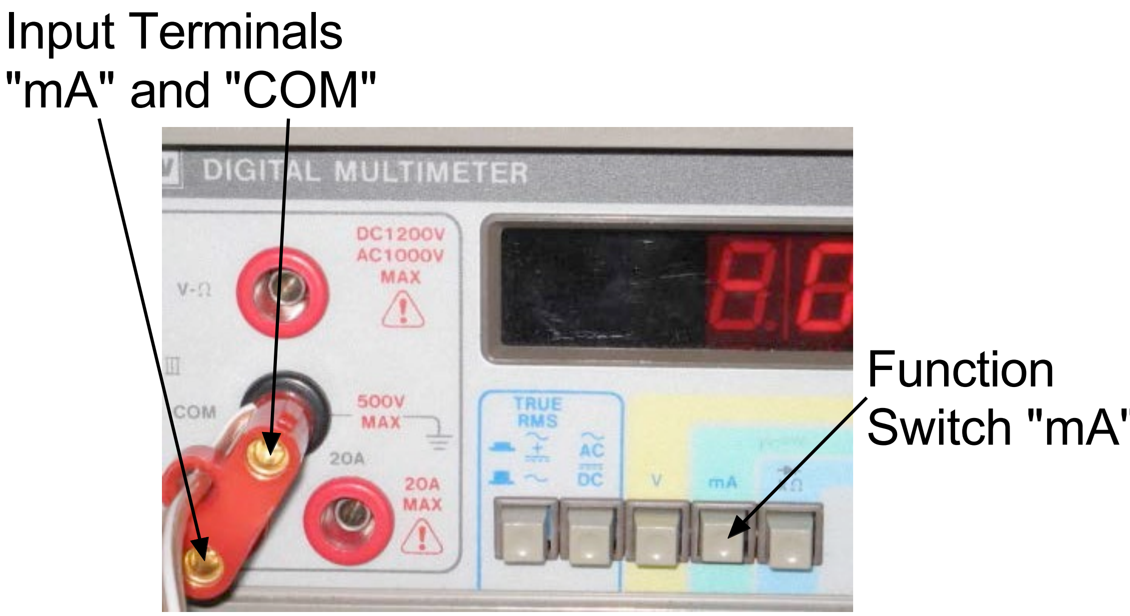
Purpose

- To learn how to use the DMM as an ammeter to measure DC current in a circuit.

Procedure:

- *In this exercise you will build a circuit with one resistor*

Step 1: Set up the DC power supply to +10V and the other DMM to the DC current mode of operation, i.e. push in the "mA" function key (5), making sure that (2) and (3) are not pushed in, and connect a double-banana lead as shown below:



Current Measurement

Step 2: Select the appropriate range. (*Hint: the current you will measure should be about 10 mA*).

Step 3: Connect the circuit as shown in Figure 1.3 on the next page, using hook-up wires and both DMMs as shown. This way the voltage across and the current through the resistor can be measured simultaneously.

Step 4: Measure the current *I* in the 1 kΩ resistor using the range that gives the most precise reading. Is the current reading positive or negative? What is the effect of reversing the connection to the ammeter?

Step 5: Change the voltage across the resistor *R* to -10V. This is obtained by reversing the polarity of the DC power supply. Measure and record the voltage across and the current through the resistor.

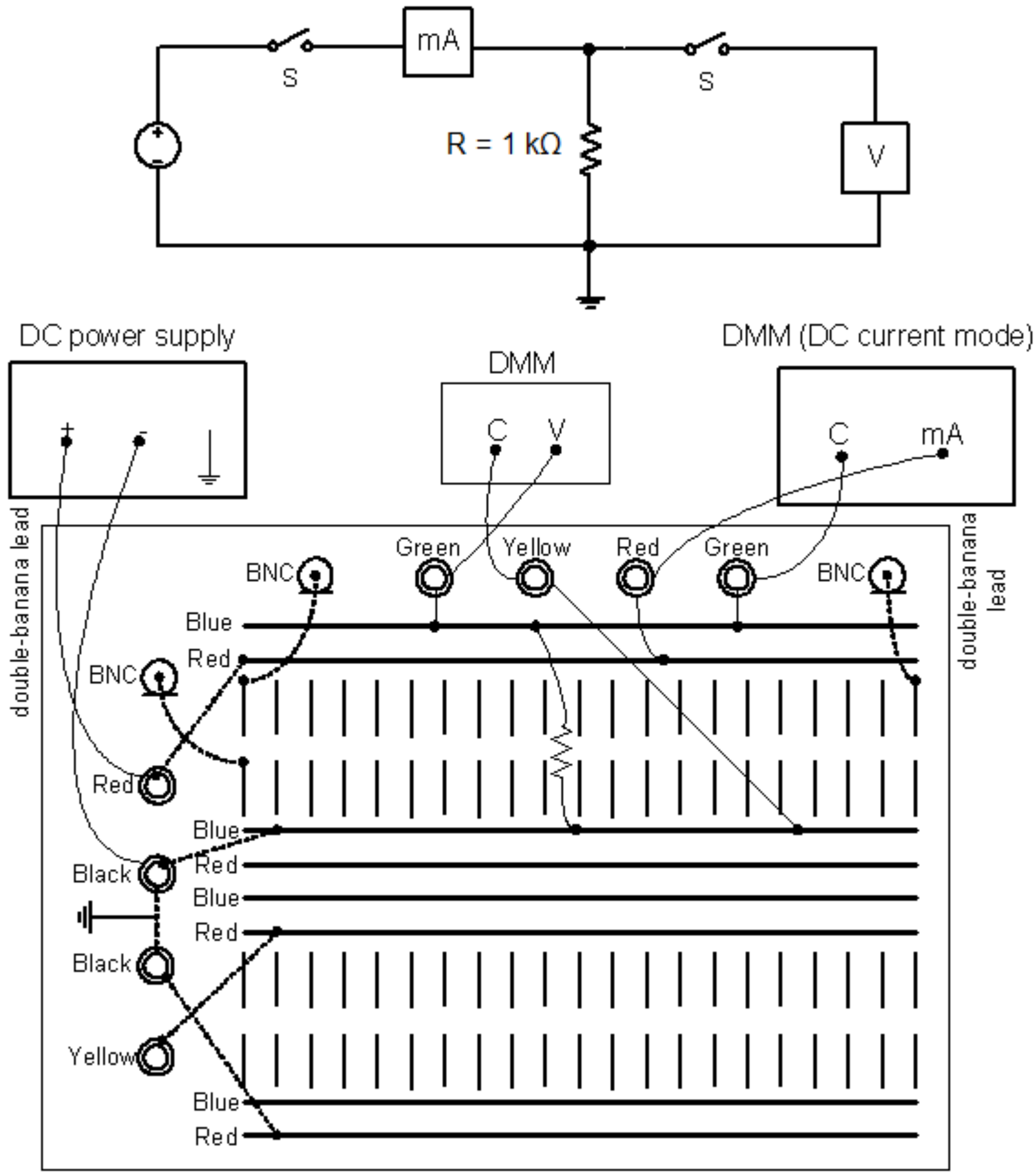

mA
S
S
R = 1 kΩ
V
DC power supply
DMM
DMM (DC current mode)
C
V
C
mA
double-banana lead
double-banana lead
Green
Yellow
Red
Green
BNC
BNC
BNC
Blue
Red
Red
Blue
Black
Red
Blue
Red
Black
Yellow
Blue
Red

Figure 1.3

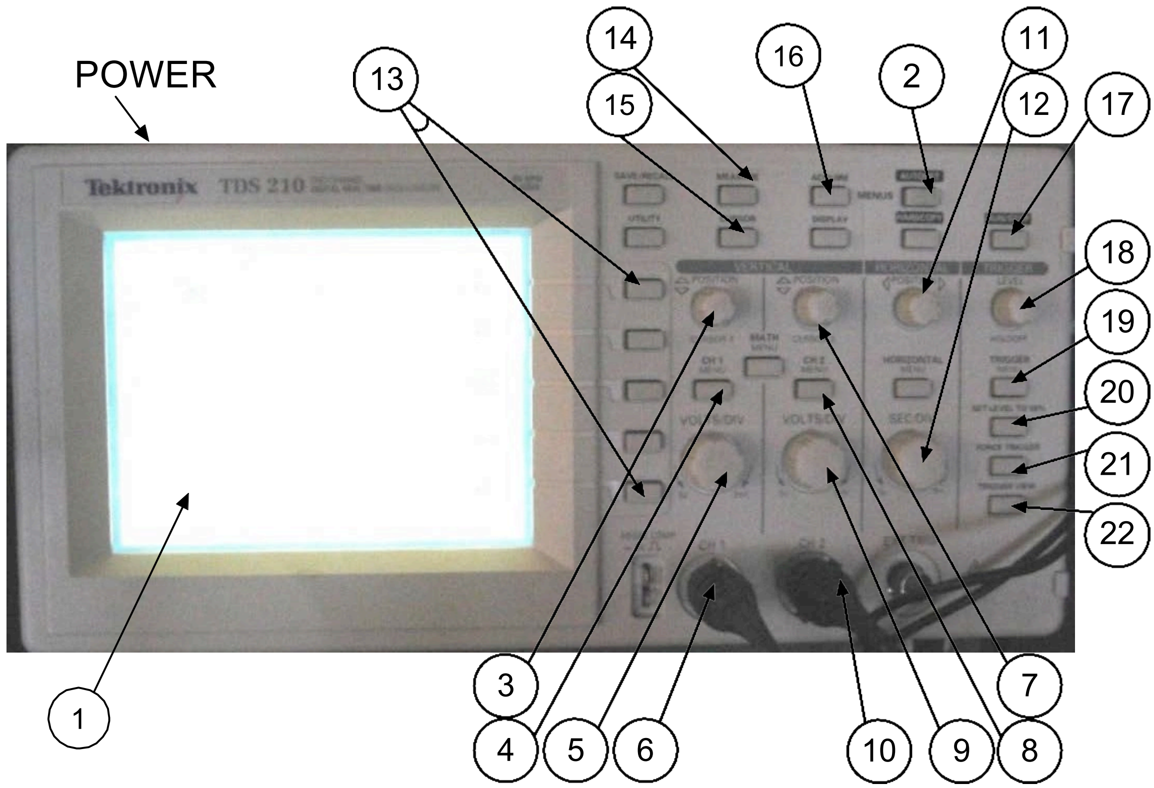
PART 1.4 – Setup of Oscilloscope and Function Generator:

Purpose:

- To learn how to setup the function generator and the oscilloscope.

Procedure:

Step 1: Identify the oscilloscope, shown below, on your workbench. Refer to this figure when setting up the oscilloscope.

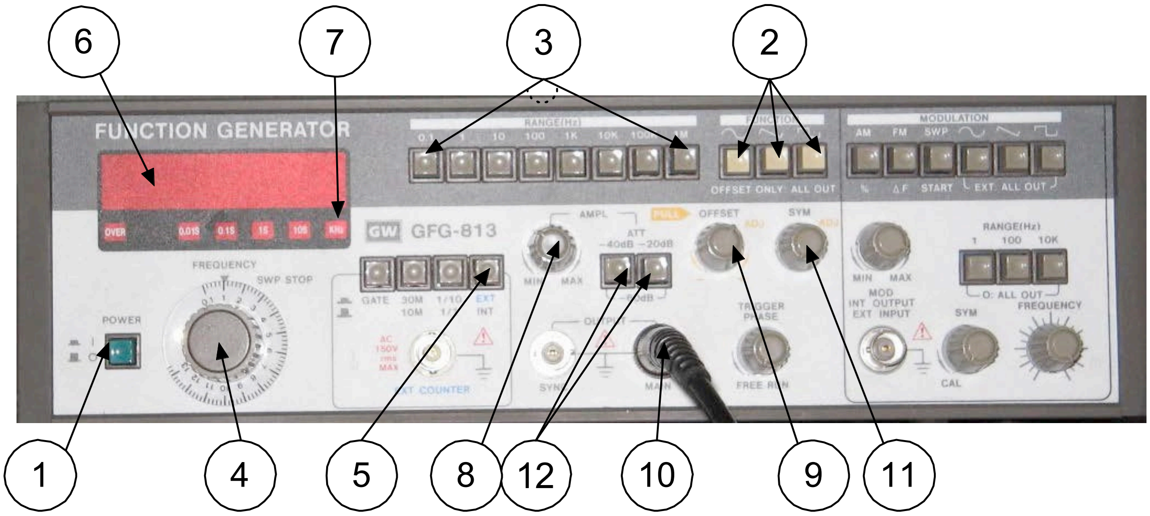


Step 2: Turn on the power by pushing the **Power** button and press **AUTOSET (2)**. You should see two traces, i.e. horizontal lines, on the display. If you do not see two traces, push the **CH 1 MENU** button **(4)** once, then **AUTOSET (2)** again. Should you still see only one trace, push the **CH 2 MENU** button **(8)** once, then **AUTOSET (2)** again.

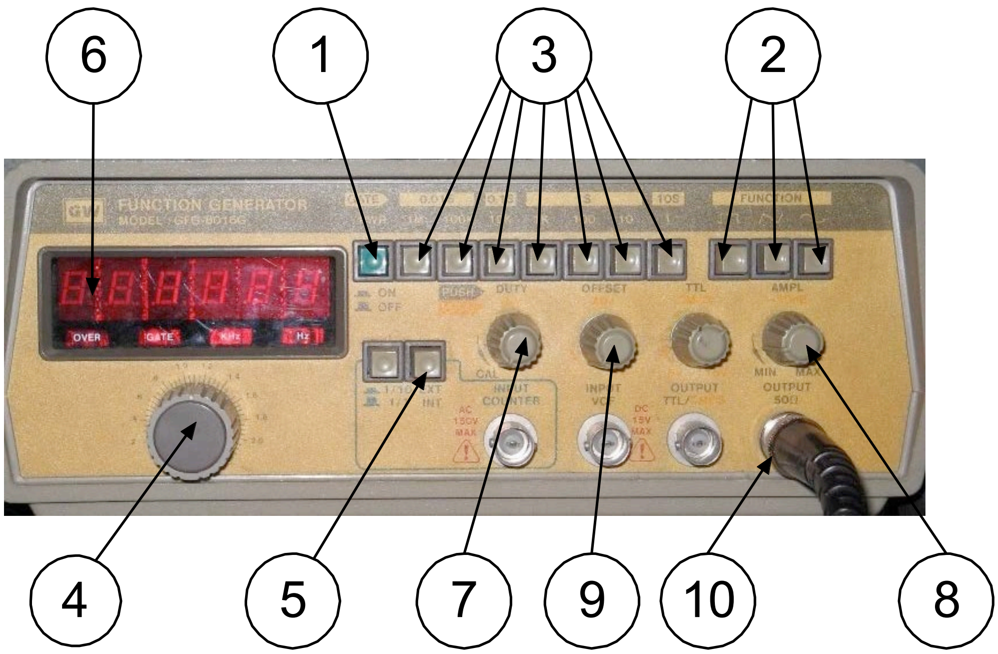
Step 3: Push the **CH 1 MENU(4)** button once. Check the right hand side of the display for the probe attenuation (PROBE). It should read 10X.If PROBE does not read 10X push the **softkey (13)** next to PROBE on the display repeatedly until it reads 10X. Check the oscilloscope probes if one or both have an **attenuation switch**. If so, make sure they are set to 10X as well

Step 4: Use the **Position** dial for CH 1 **(3)** to vertically align the trace with the center graticule line. Push **CH 2 MENU (8)** repeatedly until the second trace disappears. The oscilloscope is now set up to measure one waveform in CH 1.

Step 5: Identify the function generators, models GFG8016G and GFG-813, shown below, on your workbench. Select one to set up for your experiment. Refer to these figures when setting up one of them for 6 V peak-to-peak sinusoidal waveform, i.e. the amplitude of the sinusoid is 3 V, with a frequency of 1 kHz.



Model GFG-813



Model GFG8016G

Step 6: Push in the power switch (1). Push in the "~" function switch(2) and the 1 kHz frequency multiplier switch (3). Adjust the frequency dial (4) until the LED display (6) reads 1.0 kHz.

Step 7: Push the EXT/INT selector (5) out. If using the GFG8016G model push in the DUTY control (7), move it to the CAL position, and make sure that the Amplitude control (8) is pushed in. If using the GFG-813 make sure that both attenuation switches (12) are pushed out. Do not adjust the amplitude yet, this will be done in Part 1.5, using the oscilloscope.

Step 8: Connect a BNC-BNC cable to the waveform output BNC connector (10), labeled "MAIN" on the GFG-813 model and "50Ω" on the GFG8016G model

PART 1.5 – Measurement Using the Oscilloscope:

Purpose:

- To measure the amplitude of periodic signals using an oscilloscope.

Procedure:

Step 1: After setting up the oscilloscope and the function generator as specified in Part 1.4, connect the waveform to one of the BNC connectors on the protoboard as shown in Figure 1.4. Identify the column of "dots" on the protoboard the signal is connected to.

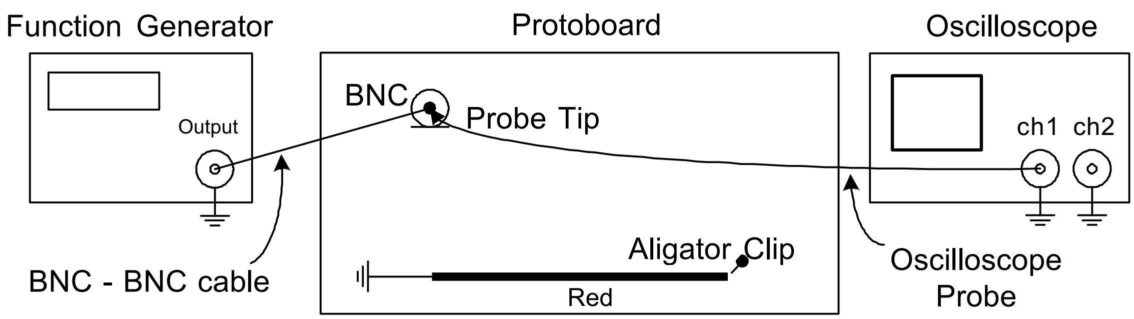
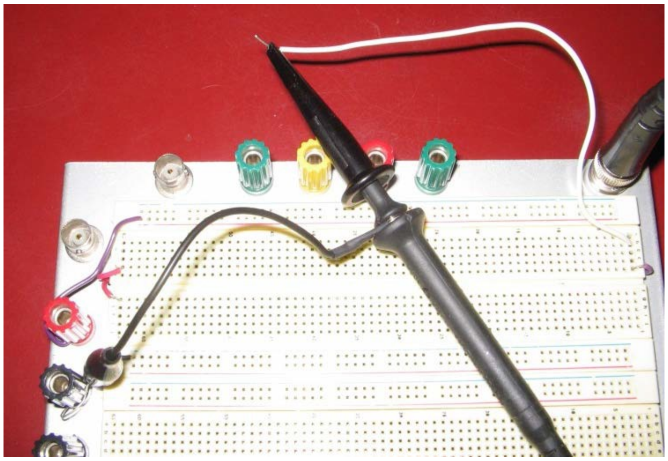


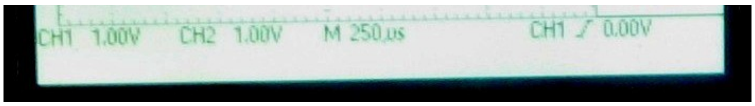
Figure EE.4

Note: *Always use the oscilloscope probes, **not** BNC-BNC cables, to connect signals to CH1 or CH2 of the oscilloscope.*

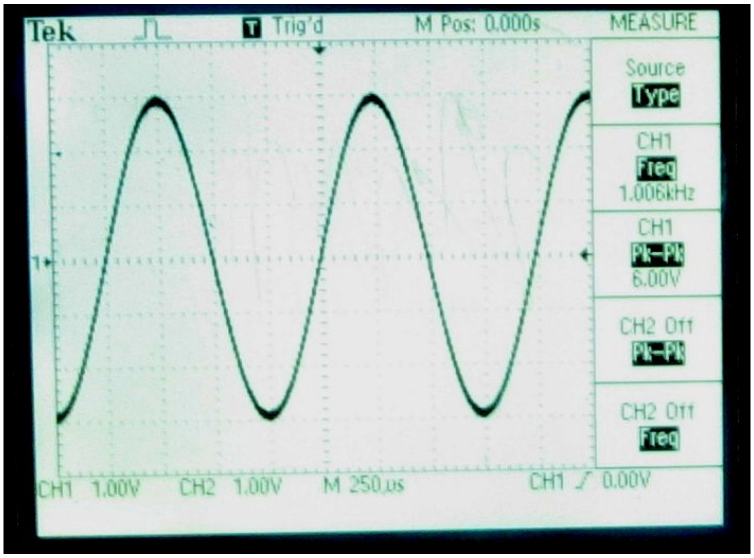
Step 2: Use a hook-up wire to connect the probe to the signal and connect the long lead to the ground terminal as shown:



Step 3: On the oscilloscope, the vertical (voltage) and horizontal (time) scales are shown as voltage per division and time per division at the bottom of the oscilloscope display. Use the VOLTS/DIV dial for CH1 (5) and the SEC/DIV dial (12) to set the vertical scale to 1V and the horizontal scale to 250 μs:



Step 4: Adjust the output voltage of the function generator to 6 V peak-to-peak by using the Amplitude Control (8), while observing the oscilloscope display. Once the amplitude is adjusted correctly, the waveform should look like this:.



Step 5: Draw the voltage waveform as seen on the screen. Record the VOLT/DIV, and TIME/DIV settings.

Before leaving the lab room:

- Disassemble the circuits, return the components and the connection cables to the allocated areas, and switch off the main power switch (on the gray metal panel).
- Make appropriate comments and observations in your lab book and have the book checked and signed by the Teaching Assistant assigned to you.

The techniques learned in this experiment will be used in subsequent laboratory sessions. Make sure that you understand how to use the equipment.

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Experiment 3 Magnetism and Induction

Objective:

i) To observe the magnetic field created by magnets and by a solenoid
ii) To observe the magnetic force on a current
iii) To observe and measure magnetic induction between two solenoids.
iv) To measure and understand the relationship between the inductance of a solenoid and its dimensions.

Equipment and Components:

1) Protoboard
2) Custom-made magnets and wire board (a 50 Ω resistor included)
3) Laboratory DC Power supply (GPS-3303 or PC-2405 or HP6218A)
4) Custom-made long field coil
5) Function Generator (GFG8016G or GFG-813)
6) Oscilloscope (Tektronix TDS-210)
7) LCR meter (LCR-815)
8) 7 test coils of various sizes (shared between two stations)

CAUTION

Item 2) above (custom-made magnets and wire board) is very **FRAGILE**! The thin wire has been carefully aligned to remain horizontal and at the same height as the center of the magnets. It is also equal-distance from the two magnets. **DO NOT TOUCH** the thin wire held in between the magnets. If the board looks damaged or the wire is not positioned properly, please **CONTACT a TA** immediately. Please do NOT rearrange the wire yourself.

Preparation:

1) Carefully Review the usage of equipment and components listed above: 1), 2), 4), 6) and7). Refer to the appropriate sections in the Introductory Lab.

2) Answer the following questions:
   a. How does one create a static magnetic field? (List more than one method)
   b. How does one determine the direction of the magnetic field (List more than one method)
   c. How does one determine the north and the south pole of an unknown magnet? (List more than one method)
   d. Given two identical looking iron bars, one is magnetized, one is not. How do you distinguish which one is magnetized without any external aid?

3) Review Sections28-8,29-5 and 30-7 of the textbook (Halliday) regarding the solenoid.

4) Read Part 3.2 and complete Columns 5, 6 and 7 in Table 3-1. See Step 1 in Part 3.2.

5) Read Part 3.3 and complete Columns 3 and 4 in Table 3-2. See Step 1 in Part 3.3.

6) **Bonus** – Read Part 3.3. How would you find the magnetic field B inside the large field coil after you have measured the induced emf on a test coil?

Time Saver: The experiment consists of 3 parts. Since there will be some sharing of equipment/components involved, roughly half of the groups should start with Part 3.2, and then Part 3.3, and finally Part 3.1. The remaining groups can proceed with the usual sequence.

PART 3.1 (Qualitative) Magnetic Force on a Current-carrying wire:

Purpose:

Determine the direction of the magnetic field by observing its force on a current-carrying wire.

Description:

A thin wire is placed between two closely spaced magnets as shown in Fig. 3.1. The magnets are placed such that the north pole of one magnet is facing the south pole of the other. However, the magnets are not labeled. Your task is to determine which one is the north pole.

Initially, there is no current going through the wire, and wire remains stationary. By applying a current to the wire, and carefully observing the movement of the wire right after the current is turned on, you can determine the direction of the force exerted on the wire by the magnetic field created by the magnets. You can also find out the direction of the current by tracing the circuit used to apply the current to the wire. As a result, you can determine which pole is the north pole.

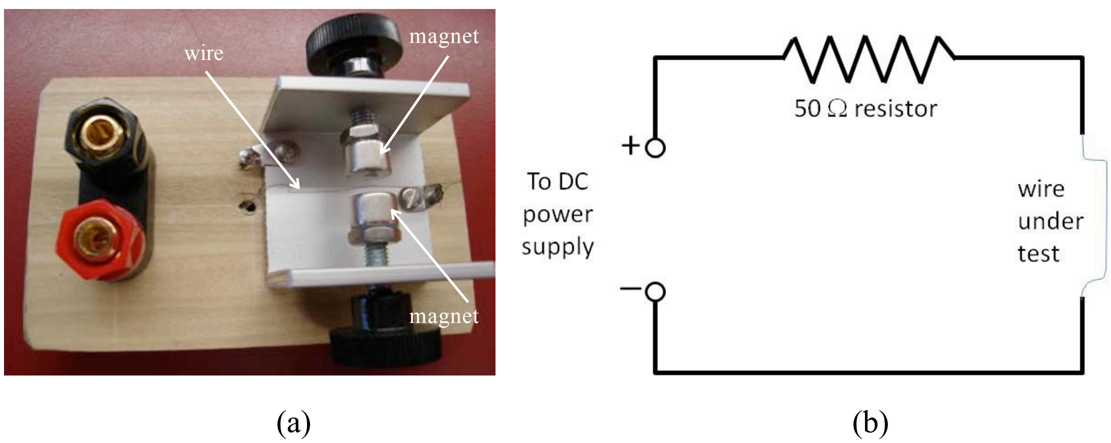

Figure 3.1(a) A board holding a thin wire in between two magnets. (b) The circuit connection behind the board. A 50 Ω resistor is connected in series with the wire but hidden from view.

Procedure:

Step 1: Set up the DC power supply appropriately (see below), but DO NOT connect it to the circuit yet.

If you are using a GPS-3303 power supply, turn on the DC power supply, but DO NOT enable the output yet. Make sure that you set the voltage to 6.0V and set the current limit to 0.15A.

If you are using a PC-2405 or HP6218A power supply, do not connect the circuit to the power supply yet. First, turn on the power supply and set the voltage to 6.0 V. Set the current to minimum. Then, connect the circuit to the power supply, turn on the power supply. *Slowly* turn up the current until the green LED under C.V. is lit. Now, turn off the power supply.

Step 2: If you are using a GPS-3303 power supply, before enabling the output, connect the power supply to the circuit. While closely observing the wire, *enable* the output of the DC power supply by pressing the "output" button. How does the wire move when the current is applied? (Note: the movement is minute, and requires very close observation.)

If you are using a PC-2405 or HP6218A power supply, turn off the power supply and then connect it to the circuit without turning it on. While closely observing the wire, turn on the power supply. How does the wire move when the current is applied? (Note: the movement is minute, and requires very close observation.)

Step 3: While closely observing the wire, *disable* or *turn off* the output of the DC power supply. Which way does the wire move when the current is cut off?

Step 4: Repeat Step 3 and 4 if necessary, until all members in the group have observed the movement of the wire and agreed with each other regarding the direction of the movement.

Step 5: Draw a diagram on your lab book, indicating the magnets, the wire, the direction of the current, and the direction of the movement of the wire when current is *applied*. Then, indicate the north and the south pole of the magnets on the diagram.

PART 3.2 (Quantitative) Inductance of a Solenoid:

Purpose:

Determine the relationship between the inductance of a solenoid and its physical dimensions.

Description:

In class, you have learnt that the inductance of an ideal solenoid is determined only by its physical parameters, namely, its length (l), cross-sectional area (A), and the number of turns per unit length (n). The formula given in the textbook (30-30) is:

$$L = \mu_0 n^2 l A \tag{3-1}$$

In this part of the experiment, you will verify the above relationship with real solenoids (test coils).

Note: A set of seven test coils (with serial numbers 11006.01 – 11006.07), shown in Fig. 1.2, is shared by two neighbouring stations. Six LCR meters are shared among all lab groups.

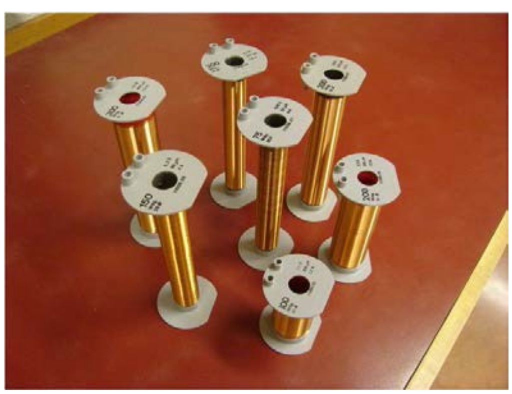

Figure 3.2 Test coils

Procedure:

Step 1: As part of lab preparation, you are asked to fill out Column 5,6, and 7in Table 3-1. The coil length l, was measured using a ruler or a caliper (See Fig. 3.3) and results are provided in Column 2. The coil diameter (Dia.) and the total number of turns (N) are printed on the plastic end cap (Fig. 3.4), and provided here in Column 3 and 4, respectively. Calculate the cross-sectional area A(Column 5) and the turns per meter n (Column 6) for each coil. Calculate L in Column 7 using Eq. 3-1 given above.

Step 2: Measure the inductance of the test coils using one of the LCR meters provided. Fill out Column #8 of Table 3-1.

Table 3-1 Parameters of the test coils

Serial #	l (mm)	*Dia.* *(mm)*	*Turns* *N*	A (m^2)	n (turns/m)	Calculated L (mH)	Measured L (mH)	% error
11006.01	160	41	300					
11006.02	160	33	300					
11006.03	160	26	300					
11006.04	108	41	200					
11006.05	54	41	100					
11006.06	160	26	150					
11006.07	160	26	75					

Step 3: Calculate the % error (Column 9) in Table 1-1 using:

$$\% error = \frac{(measured\ L - calculated\ L)}{calculated\ L} \tag{3-2}$$

Fig. 3.3 Measuring length of coil

Fig. 3.4 End cap of a test coil

Step 4: List in your lab book the factors contributing to the difference between the measured inductance and the calculated inductance.

PART 3.3 (Quantitative) Induction:

Purpose:

Observe the phenomenon of magnetic induction between two coils, and measure the induced voltage.

Description:

In this part of the experiment, a large field coil (Fig. 3.5) is used to generate a sinusoidally varying magnetic field. If one of the test coils (used in Part 3.2) is inserted into the hollow cavity of the field coil, the varying magnetic field will induce an emf **E**, described by Faraday's law:

$$\mathsf{E} = -N\frac{d\Phi_B}{dt} \tag{3-3}$$

where N is the total number of turns in the test coil, and Φ_B is the magnetic flux inside the coil. Your task is to measure this induced emf for various test coils.

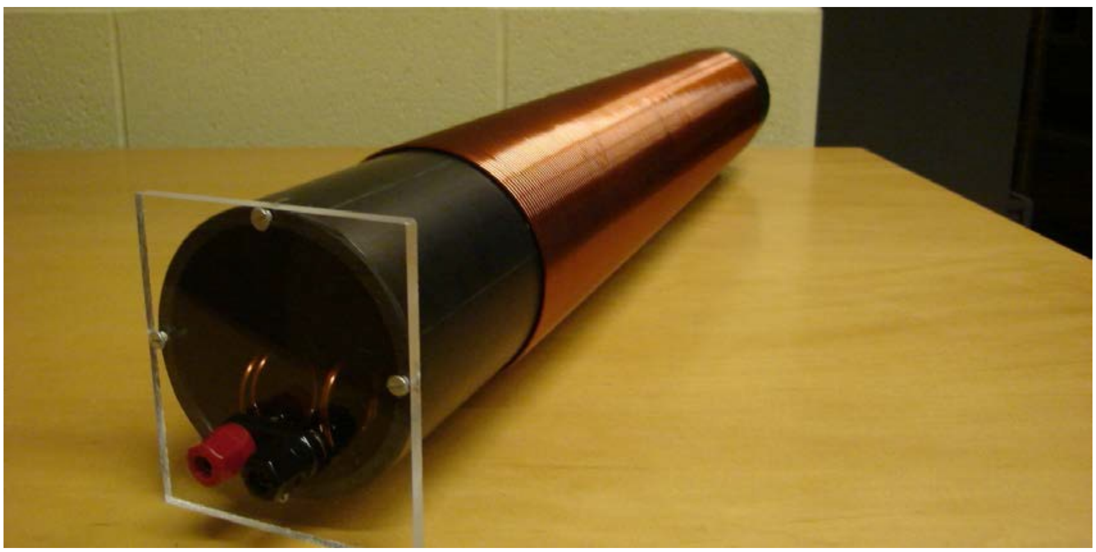

Figure 3.5 The large field coil

Procedure:

Step 1: As part of lab preparation, you are asked to fill out Columns3 and 4 of Table 3-2. Column 3 is the same as Column 5 in Table 3-1.

Step 2: Set the function generator to output a sinusoidal waveform of frequency 100kHz.

Step 3: Connect the Function Generator (FG) output to Ch. 1 of the oscilloscope. Observe the output waveform of the FG on the oscilloscope. (You need to set up the oscilloscope appropriately to observe a stable waveform of a few cycles.) Adjust the amplitude of the FG output to be 10V peak-to-peak.

Step 4: Connect the large field coil to the output of the FG. You may observe the FG output on the oscilloscope at the same time.

Step 5: Connect a pair of long cables to one of the test coils. It is preferable that the other end of the cable is terminated with a BNC connector, such that it is convenient to be connected to the oscilloscope.

Step 6: Observe the induced emf of the test coil on Ch.2 of the oscilloscope while inserting the test coil *slowly* into the hollow cavity of the field coil.

Step 7: Record the maximum induced emf in Column 5 of Table 3-2.

Step 8: Plot the induced emf versus ($N \cdot A$) on your lab book. What conclusion can you draw from this plot? Is this conclusion consistent with the induction theory you learnt in class? Why?

Step 9: Bonus – Calculate the magnetic field **B** inside the large field coil and complete Column 6 of Table 3-2.Calculate the average **B** and its standard deviation.

Table 3-2 Inductance and Induced EMF

Serial #	***N* (turns)**	***A* (m^2)**	***N· A* (turns· m^2)**	**Induced emf ($V_{p\text{-}p}$)**	**Magnetic Field B (μT)**
11006.01	300				
11006.02	300				
11006.03	300				
11006.04	200				
11006.05	100				
11006.06	150				
11006.07	75				

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Experiment 4 # DC Circuits

Objective:

To study the relationships among voltage, current and resistance, in DC circuits

Components: 510 Ω, 5.1 kΩ, 10 kΩ, 100 kΩ resistors

Preparation:

i) Study the instructions for this experiment. In your lab book, write the point form procedures, using your own words, and prepare all tables required for this experiment.

ii) Consider the circuit shown in Figure 4.1. Calculate the current I, and the voltages V_{R1} and V_{R2}, assuming that input resistance of the ammeter is zero and that of the voltmeter is infinity. Enter your results into Table 4.2, in your lab book.

iii) Draw a simplified diagram of the actual physical layout of the circuit including the protoboard, instruments and connecting wires, similar to Figure EE.3 from Introductory Lab. Trace the current flow in the circuit using a highlighter.

PART 4.1 – DC MEASUREMENT:

Purpose:

* Measurement of DC voltage, DC current, and resistance.

Procedure:

Step 1: Set up the two DMMs and the DC power supply as follows:

* Set one of the DMMs to the DC voltage mode of operation (to be used as a voltmeter)
* Set the other DMM to the DC current mode of operation (to be used as an ammeter)
* Set the DC power supply to +10.00 V (using the DMM to check for accuracy)

Step 2: Connect the circuit shown in Figure 4.1 on the protoboard using the prepared diagram from your preparation. ***Do not connect the voltmeter to the circuit yet***.

Step 3: Connect the power to the protoboard. Measure the current, I, and the voltages, V_{R1} and V_{R2}. Enter the values into Table 4.1.

Table 4.1

	I [mA]	V_{R1} [V]	R_1 [Ω]	V_{R2} [V]	R_2 [Ω]
Computed			using R_{nom}= 5.1 k		using R_{nom}= 10 k
Measured			using R_{nom}= 5.1 k		using R_{nom}= 10 k
Recomputed (Step 9)			measured in Step 8		measured in Step 8

Step 4: Compare the computed and measured values. List all the possible reasons as to why the measured and computed values may not be exactly the same.

Step 5: Disassemble the circuit.

Step 6: Set one of the DMMs to the resistance mode of operation (to be used as an ohmmeter).

Step 7: Measure the resistance of R_1 and R_2 in turn using the ohmmeter. The resistors must be disconnected from the rest of the circuit before making the measurement. Enter the measured values into Table 4.1.

Step 8: Re-compute the values of I, V_{R1} and V_{R2} in the circuit of Figure 4.1 using the measured values of R_1 and R_2. Comment on the results.

PART 4.2 – INTERNAL RESISTANCE OF A PRACTICAL AMMETER:

Purpose:

* To observe the effect of a practical ammeter on voltage and current measurements.

Note: When calculating the voltage and the current in Part 4.1, it was assumed that the ammeter and the voltmeter were ideal instruments. An ideal ammeter has a zero input resistance, so it has a zero voltage drop across it when current passes through the meter. However, a practical ammeter has finite input resistance (typically between 0.1 Ω and 100 Ω, depending on the range selected).

Procedure:

Step 1: Set the power supply to +10.00 V.

Step 2: Connect the circuit shown in Figure 4.2 on the protoboard, but ***do not connect the voltmeter to the circuit yet***.

Step 3: Close the switch and measure the loop current, I, using the range that gives the most precise reading, as indicated in Table 4.2.

Step 4: Connect the voltmeter across the ammeter and measure the voltage, V_{mA} across the ammeter.

Step 5: Record the measured data into Table 4.2, and compute the internal resistance of the ammeter R_{imA} using the following relationship:

$$R_{imA} = \frac{voltage\ across\ ammeter}{current\ through\ ammeter} = \left|\frac{V_{mA}}{I}\right|$$

Table 4.2

R	Current I [mA]	MilliammeterRange Selected	Voltage Across Milliammeter V_{mA}	Input Resistance R_{imA} [Ω]
510 Ω		20 mA		
5.1 kΩ		2 mA		
100 kΩ		200 µA		

Step 6: Replace the 510Ω resistor with a 5.1 kΩ resistor and repeat the measurements outlined in steps 3, 4 and 5.

Step 7: Now, replace the 5.1 kΩ resistor with a 100 kΩ resistor and repeat the measurements outlined in steps 3, 4 and 5.

Step 8: Comment on the results and write your conclusions by answering the following questions:

1. What percentage of the input voltage, V, is lost across the ammeter?
2. Is the input resistance of the ammeter dependent on the measurement range selected?
3. Consider a circuit with a power supply, V_s connected in series with a resistor R.

Choose the most suitable range on the ammeter to measure the current in the circuit if (a) $V_s = 0.1$ V and $R = 1$ kΩ (b) $V_s = 10$ V and $R = 100$ kΩ.

PART 4.3 – INPUT RESISTANCE OF A PRACTICAL VOLTMETER:

Purpose:

* To observe the loading effect of a practical voltmeter in a circuit.

Note: An ideal voltmeter has an infinite input resistance, which means that it behaves like an open circuit, draws no current, and thus has no loading effect on the circuit. However, a practical voltmeter has a finite input resistance (typically around 10 MΩ for a digital multimeter).

Procedure:

Step 1: Set the power supply to +10.00 V.

Step 2: Connect the circuit shown in Figure 4.3 on the protoboard. Measure the voltage, V_R across the resistor and the loop current, I_1.

Step 3: Disconnect the voltmeter from the circuit and measure the current, I_2. The difference, $I_1 - I_2$ constitutes the current drawn by the voltmeter. Which current is larger, I_1 or I_2? Explain.

Step 4: Record the measured data in a table similar to Table 4.3, and compute the input resistance of the voltmeter R_{iv} using the relationship:

$$R_{iv} = \frac{\text{voltage across voltmeter}}{\text{current through voltmeter}} = \left| \frac{V_R}{I_1 - I_2} \right|$$

Note: Because modern high-quality DMMs behave almost like ideal instruments, the observed changes in the measured current will only be in the last two significant digits.

Table 4.3

R [kΩ]	Voltage Across R V_R [V]	Current I_1 [mA]	Current I_2 [mA]	Current Drawn by the Voltmeter I_1-I_2	Input Resistance R_{iv}
100					
10					

Step 5: Replace the resistor R with a 10 kΩ resistor and repeat the procedure outlined in steps 2, 3 and 4.

Step 6: What percentage of current I_1 is drawn by the voltmeter (i.e. ${(I_1 - I_2)}/{I_1}$)? Comment on the results, and write your conclusions.

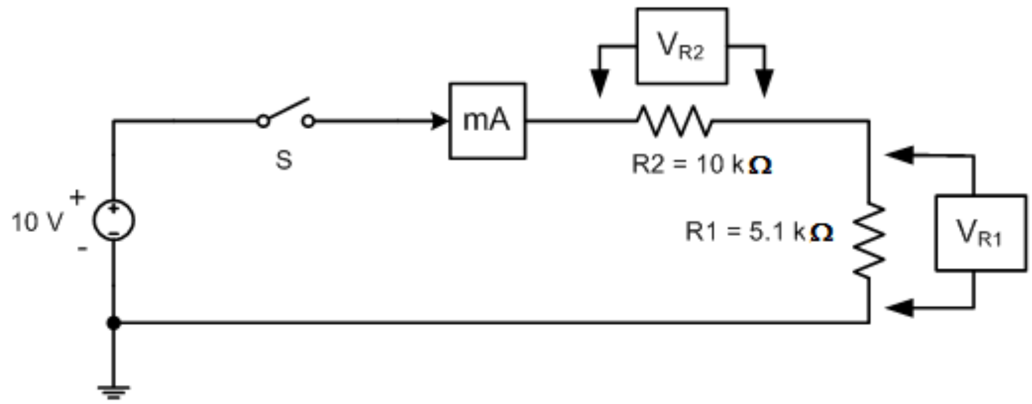

Figure 4.1

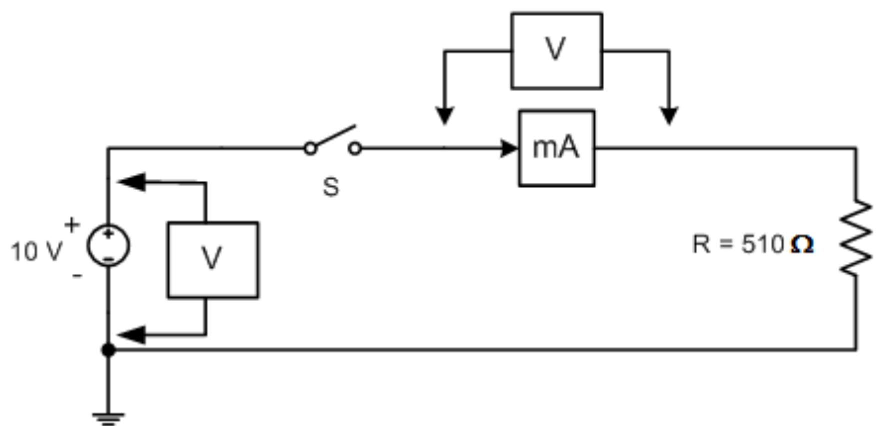

Figure 4.2

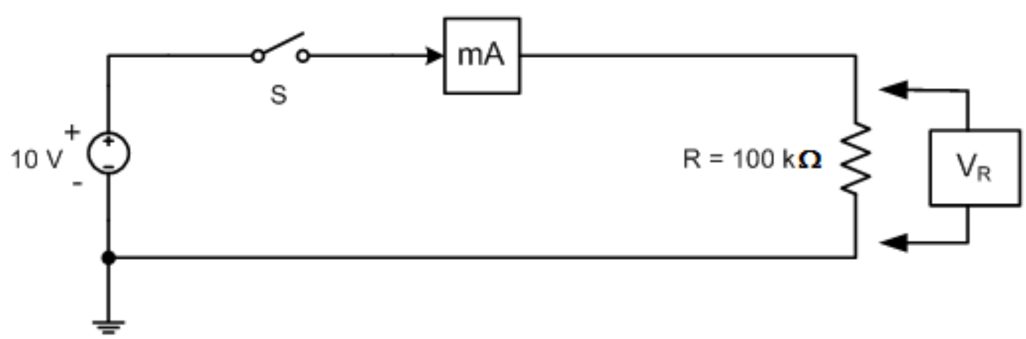

Figure 4.3

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Experiment 5 AC Measurements

Objectives:

i) To become familiar with the equipment used in the study of AC circuits namely, function generator, oscilloscope and AC voltmeter.

ii) To learn how to measure the frequency and the period of periodic signals using an oscilloscope.

iii) To measure and to understand the transient response of R-C circuits.

Components: 10 kΩ and 100 Ω resistors, 1 nF and 10 nF capacitors.

Preparation:

i) Study the instruction sheets for each part of this experiment and review the material relating to the transient response of RC Circuits.

ii) In your lab book write the point form procedures, using your own words, and prepare all tables required for this experiment.

iii) Draw a diagram of the actual physical layout of the circuit shown in Figure 5.3, including the protoboard, instruments and connecting wires.

iv) Fill in the theoretically expected values missing in Table 5.1 (refer to Figure 5.3)

PART 5.1 – Waveforms and AC Measurement:

Purpose:

* To measure the frequency and the period of periodic signals using an oscilloscope.

Procedure:

Step 1: Set up the front panel controls of the oscilloscope and the function generator.

Step 2: Connect the output voltage of the function generator to CH1 of the oscilloscope (using the protoboard) as shown in Figure 5.1.

Step 3: Set the voltage level on the function generator to 6 V_{p-p} sine wave, and adjust the frequency setting, so that the frequency dial shows roughly 1.00 kHz.

Step 4: Read the period, the frequency and the peak-to-peak voltage V_{p-p} of the displayed signal off the oscilloscope display.

Step 5: Draw the waveform as seen on the screen. Record the TIME/DIV and VOLT/DIV settings..

Step 6: Is the value of the frequency measured using the oscilloscope (Step 4), in agreement with the reading of the frequency display of the function generator?

Step 7: Set up the DMM to operate as an AC voltmeter.

Step 8: Measure the voltage of the displayed signal using the DMM. Compare your reading to the peak-to-peak voltage, V_{p-p}, from Step 4. Do both measurements agree? If so, why? If not, why not? Can you conclude what quantity (e.g. average voltage, RMS voltage, peak voltage amplitude, or peak-to-peak voltage) the DMM measures?

Step 9: Keep the voltage constant at 6 V_{p-p}, but change the signal frequency to 100 kHz. Use the oscilloscope, to measure the period and the frequency of the displayed waveform.

Step 10: Keeping the frequency constant, at 100 kHz, change the voltage level to 0.6 V_{p-p}. Use the oscilloscope to measure the peak-to-peak voltage, V_{p-p} , Sketch the waveform and record the VOLT/DIV setting used.

Step 11: Display a triangular waveform of 6 $V_{p-p,}$ and at a frequency of 10 kHz, on the oscilloscope. Sketch it in your lab book and label the axes clearly.

Step 12: Display a square waveform (with **no** DC offset) of 6 $V_{p-p,}$ and at a frequency of 1kHz, on the oscilloscope. Sketch it in your lab book and label the axes clearly.

PART 5.2 – RC Circuit Transient Response:

Purpose:

* To observe the relationship between the voltage, v_o(t) and the current, i (t) in the circuit using an oscilloscope.

Discussion:

In order to observe the transient response on the oscilloscope, the R-C circuit will be driven with a periodic square wave signal. This is equivalent to opening and closing the switch in the circuit in Figure 5.2. The period of the square wave should be much longer than the time constant, τ of the circuit (τ = RC), to allow the circuit to reach its steady state between successive transitions.

Because both vertical channels of the oscilloscope have one input terminal grounded, all measurements made by the oscilloscope use the ground as a reference (i.e. no "floating" measurements are possible). Currents cannot be measured directly with an oscilloscope. To allow monitoring of the current, *i(t),* a small resistor, R_c is placed in series with the capacitor, C, as shown in Figure 5.3 and its voltage is monitored. As long as $R_C << |X_C|$ and $R_C << R$, the voltage drop across R_c is small compared to the other voltages, and the effect of the resistor, R_c on the circuit can be ignored. The current, $i(t)$ can be obtained by $i(t) = \frac{1}{R_C} V_{Rc}(t)$.

Procedure:

Step 1: Set the function generator to a square-wave output. Use the oscilloscope to adjust the amplitude to 6 V_{p-p} (as in Step 12 of Part 5.1), but set the frequency to 500 Hz.

Step 2: Connect the circuit in Figure 5.3 as you have drawn it in part iv) of the preparation. Display simultaneously the capacitor voltage, $v_c(t)$, on *CH1*, and the voltage, $v_{Rc}(t)$ across the resistor, R_c on *CH2*.

Step 3: Sketch the voltage, $v_c(t)$ and the current, $i(t)$ waveforms. Use identical time scales, and align the origins. Label time, voltage and current scales.

Step 4: Explain in qualitative terms, the relationship between $v_c(t)$ and $i(t)$.

Step 5: Now, display simultaneously the voltage across the capacitor, $v_c(t)$ on CH1, and the input voltage, $v_i(t)$ on CH2, using DC coupling.

Step 6: Add the waveform of $v_i(t)$ to the existing $v_c(t)$ and $i(t)$ sketches from step 4. Align the corresponding time scales and explain the relationships of these signals.

Step 7: Measure the time constant, τ of the *RC*-circuit. The time constant is defined as the time it takes for the voltage across the capacitor, v_c(t) to complete 63% of its total change from the most negative to the most positive voltage. Enter the value of τ in Table 5.1.

Step 8: Replace the 10 nF capacitor with a 1 nF capacitor. Increase the frequency of the input signal to 5 kHz and measure the time constant, τ, again. Enter it in Table 5.1.

Step 9: Comment on the theoretically expected and experimentally obtained values of τ.

Table 5.1

$\tau = RC$	**Theoretically Expected τ [μsec]**	**Measured τ [μsec]**
10 kΩ, 10 nF		
10 kΩ, 1 nF		

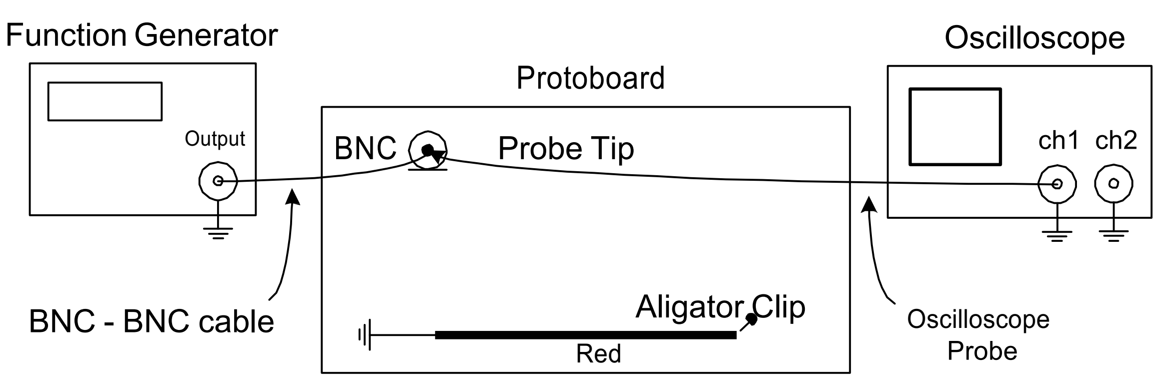

Figure 5.1

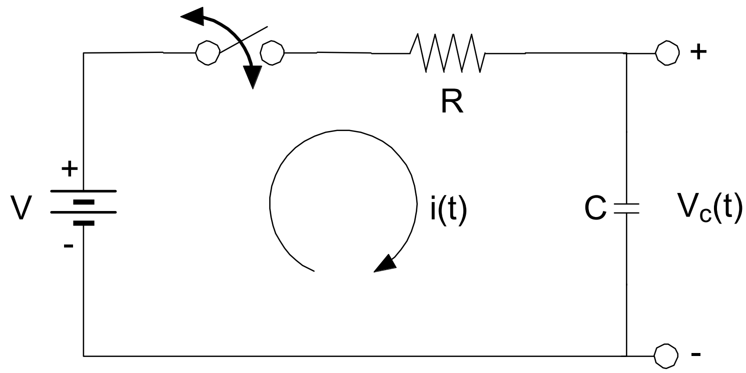

Figure 5.2

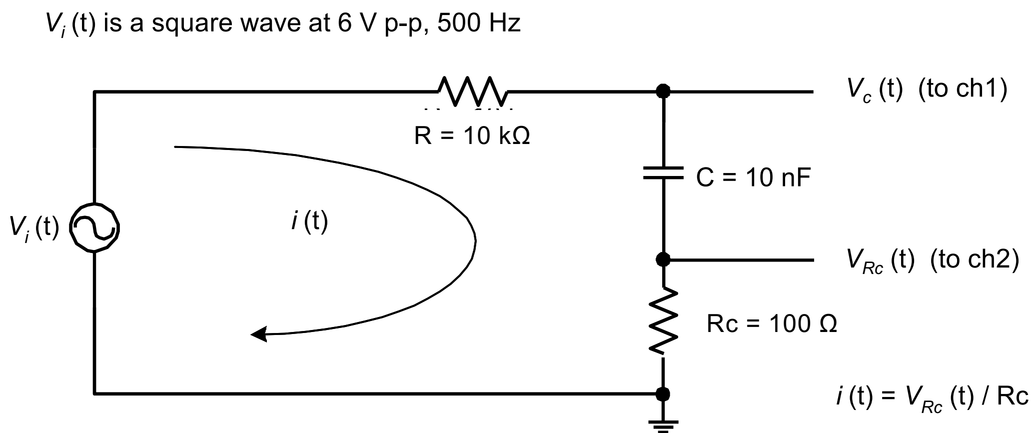

Figure 5.3