มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี
King Mongkut's University of Technology Thonburi

GENERAL PHYSICS LABORATORY II
PHY 192

DEPARTMENT OF PHYSICS
FACULTY OF SCIENCE
KING MONGKUT'S UNIVERSITY OF TECHNOLOGY THONBURI

Name……………………………………………………………………**Department**…………………………………

Student ID……………………………………………………………**Section(Day/Time)**……………………….

Contents

1. Introduction
1.1 First year physics laboratory

The first year physics experiments are aimed to give you an introductory grounding in experimental physics. This requires thinking about the experimental strategy, collecting, recording and analysing the data and then writing them in a lab notebook. The following guidelines apply:

1. Read the relevant section(s) of the lab manual before the lab session starts and think about objective of the experiment.
2. Set up the apparatus and test whether or not it is working as expected.
3. It is often advisable to collect a set of 'quick look' data. Apply these data to any formula needed to calculate the required quantity. Is the answer 'about right' or have you blundered somewhere? Check the calculations. Think. If there is a problem, return to Step 1.
4. Before collecting your serious data:
   - THINK about systematic errors: e.g. is your scale set to zero to begin with?
   - THINK about random errors: e.g. which quantity needs multiple measurements?
   - THINK about the overall plan. For example, should the data be taken at regular intervals in x? Is it better to concentrate on taking data at high values of x or over a range as wide as possible?
5. Write down the plan in your lab notebook.
6. Perform the experiment as planned. Take your sets of data, including the measurements that you need to estimate any uncertainties. Keep a well-documented lab notebook (see section 1.2 Keeping a good lab notebook).
7. Analyse your data for the results and for the uncertainties that may arise. Write down in your lab notebook.

There are 10 laboratory sessions in a term. In each session, you are expected to carry out the experiment in group and share data within the group but taking notes in lab notebook is an individual task. The quality of lab notebook will be assessed and marks are counted towards final examination at the end of the term.

By the end of term, we hope you will feel much more confident in your ability to

1. understand the physics related to the experiment;
2. perform experiments to measure a particular quantity or test a given theory;
3. keep efficient lab notebook;
4. use apparatus appropriately.

This lab manual does not attempt to reproduce theory which is readily available in textbooks. It is assumed that you will be familiar with any theory you are trying to test. Preliminary reading before coming to the laboratory is therefore helpful. You should never undertake elaborate measurements until you are sure that you know exactly what you are trying to accomplish. Measurements without thought are a waste of time.

1.2 Safety

Maintaining a safe working environment in the laboratory is paramount. The following points must be considered.

1) It is your responsibility to ensure that at all times you work in such a way as to ensure your own safety and that of other persons in the laboratory.
2) The treatment of serious injuries must take precedence over all other action including the containment or cleaning up of radioactive contamination.
3) None of the experiments in the laboratory is dangerous provided that normal practices are followed. However, particular care should be exercised in those experiments involving heat, electricity and laser. Relevant safety information will be found in the scripts for these experiments.
4) If you are uncertain about any safety matter for any of the experiments, you MUST consult a lab supervisor or teaching assistant.
5) All accidents must be reported to a laboratory supervisor or technician who will take the necessary action.
6) Please inform your laboratory supervisor and teaching assistant of any medical condition (for e.g. having a pacemaker) which may affect your ability to perform certain experiments.

2. Measurements & Significant figures

2.1 What is a significant figure?

For all measured quantities, there will always be an associated uncertainty. The uncertainty is often expressed by using $\pm$ sign after a quantity. Significant figures provides uncertainty without using $\pm$ sign. For example,

$$\text{height of Mt. Everest} = 8844.43 \text{ m} \pm 0.21 \text{ m}.$$

The $\pm$ is dropped and the uncertainty is implied by the figures that are shown. An individual digit is usually considered significant if its uncertainty is less than ± 5. In the case of Mt. Everest, the uncertainty is greater than 0.05 m; thus making the "3" uncertain. Rounding to the nearest 0.1 meter, we can write

$$\text{height of Mt. Everest} = 8844.4 \text{ m}.$$

This quantity has five significant figures (in fact a digit does not need to be precisely known to be significant).

Consider another example of significant figures representing errors. Quantities 2.3 and 2.30 are different. When you write 2.3, you are certain about the three tenths (digit 3) but the hundredths are uncertain; the value may be 2.31 or 2.32 so digit 3 is significant but digit after that is not. In contrast, writing 2.30 means that the hundredth is exactly zero, so digit 0 is significant.

In general, the rules for interpreting a value written this way are

- All non-zero digits are significant
- All zeros written between non-zero digits are significant
- All zeros right of the decimal AND right of the number are significant
- Unless otherwise indicated, all other zeros are implied to be mere place-holders and are not significant.

Consider the following examples. The significant digits are underlined.

24	2 significant figures
2400	2 significant figures* (2.4×10^{4})
2400.00	6 significant figures (2.40000×10^{3})
0.045	2 significant figures (4.5×10^{-2})
0.0450	3 significant figures (4.50×10^{-2})
0.004500	4 significant figures (4.500×10^{-3})

String of zeros before decimal can be indeterminate. In the above example, 2400 can have 2, 3 or 4 significant figures depending on the confidence level of obtaining the number. If you are sure only about the first zero, then 2400 has 3 significant figures. If you are also sure about the second zero, 2400 has 4 significant figures.

2.2 Manipulating significant figures

Addition and subtraction

When adding and subtracting numbers, the rules of significant figures require that the number of places after the decimal point in the answer is less than or equal to the number of decimal places in every term in the sum. (Treat subtraction as adding the same number with a negative sign in front of it.) If some of the numbers have no digits after the decimal point, use the same basic rule, but don't record any digits to the right of the last digit in the least significant number. Hopefully, some examples will clarify these rules.

```
2355.2342      15600.00      15600          13.7
+ 23.24      +    172.49    +  172.49      + 1.3
---------    ----------    ---------      ------
2378.47        15772.49     15800          15.0
```

Multiplication and division

When multiplying and dividing numbers, the number of significant digits you use is simply the same number of significant figures as is the number with the fewest significant figures. Some examples:

```
  13.1          13.10        13.100            15310           1.00
x  2.25       x  2.25      x  2.2500         x    2.3        x 10.04
-------      --------     ----------        --------        -------
  29.5          29.5        29.475            35000           10.0
```

Why different rules?

When you add two numbers, you add their uncertainties, more or less. If one of the numbers is smaller than the uncertainty of the other, it doesn't make much of a difference to the value (and hence, uncertainty) of the final result. Thus it is the location of the digits, not the amount of digits that is important.

When you multiply two numbers, you more or less multiply the uncertainties. Thus it is the percentage by which you are uncertain that is important -- the uncertainty in the number divided by the number itself. This is given roughly by the number of digits, regardless of their placement in terms of powers of ten. Hence the number of digits is what is important.

2.3 Are there exceptions?

In a way, yes. One is that you should always carry through all the digits you have available in a calculation until the very end, where you can then truncate your answer to the correct number of significant digits. In other words, during some intermediate step of the calculation, don't attempt to eliminate the final few digits on your calculator or write down an intermediate answer with fewer digits and then retype that new number into the calculator. By the guidelines given above, you might be tempted to round off midway through but doing so actually introduces a small (and sometimes non-negligible) amount of ``truncation error'' which is especially prone to happen if you have a complicated calculation involving many steps. This type of error is totally avoidable (as opposed to measurement errors, which we are stuck with) and therefore it is encouraged and even more correct to keep all those intermediate digits until the final answer.

As a corollary of the above statement, it is often desirable to add one more significant digit in your final answer than the rules we presented above would otherwise have you do. One example where this is desirable is if your result was to, in turn, be plugged into a future calculation where ``truncation errors'' could become important. Under what kind of situations this becomes important is beyond the scope of this short guide.

You should bear in mind the significant figure rules when doing calculations on the exams. There will be mark penalties for ignoring these rules. A particularly glaring illustration would be the case where your calculations involve division of 123 by 45. A calculator gives the answer 2.7333333 but the correct answer using the significant digit rules is 2.7; students who give the 2.7333333 answer will lose marks.

3. Multimeters

3.1 Analog multimeter

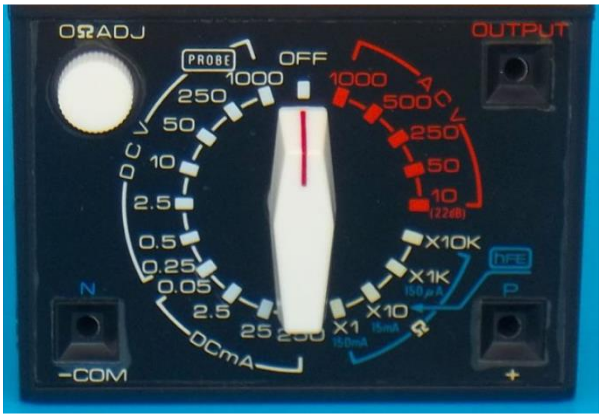


fig. 1

fig. 2

Reference table reading UN360-TR meter

Test	Range position (see fig.1)	Scale to read (see fig.2)	Multimeter
Resistance	×1	A	×1
	×10	A	×10
	×1K	A	×100
	×10K	A	×1000
DC Volt	DC 0.1 V	B 10	×0.01
	0.5V	B 50	×0.01
	2.5V	B 250	×0.01
	10V	B 10	×1
	50V	B 50	×1
	250V	B 250	×1
	1000V	B 10	×100
AC Volt	AC 10V	C 10	×1
	50V	C 50	×1
	250V	C 250	×1
	1000V	C 10	×1000
DC current	DC 50 µA	B 50	×1
	2.5 mA	B 250	×0.01
	25mA	B 250	×0.1
	0.25A	B 250	×0.001

Operating instruction:

Resistance measurement

- Plug the test leads into –COM and +sockets.

- place the range selector to a prescribed rang position.

- short the test leads as in the fig.3 and turn 0 Ω ADJ to set the pointer to zero position.

- Make sure that there is no voltage across the circuit to be tested.

- Connect the test there leads to the tested resistor as in the fig.4 and read the scale in accordance with the reference table.

DC voltage measurement

- Plug the red test lead into the + socket and the black one into the COM.
- Set the range selector to a selected DCV range position.
- Connect the read test lead to the positive polarity of the circuit test and tested and the black one to the negative as in the fig.5.
- Read the DCV, A scale referring to the reference table.

AC voltage measurement

- Plug the red test leads into the+ socket and the black into the –COM socket.
- Set the range selector to a chosen ACV range position.
- Connect the test leads to the circuit being tested regardless of the polarities.
- Read ACV scale with the reference table.

DC current measurement

- Plug the red test lead into the + socket and the black into the –COM.
- Set the range selector at a selected DCA range position.
- Connect the red test lead to the position polarity of the circuit tested and the black into the negative as in the fig.6.
- Red the DCV, A scale converted with the reference table

3.2 Digital multimeter

fig. 3

Operating instruction (fig. 3):

Resistance measurement

- Connect the red test lead to “VΩmA” jack and black test lead to the “COM” jack.(The polarity of red lead is positive “+”.)
- Set the rotary switch at desired “Ω” range position.
- Connect test leads across the resistor to be measured and read LCD display.

- If the resistance being measured is connected to a circuit, turn off power and discharge all capacitor before applying test probes.

DC voltage measurement

- connect the test lead to the "VΩmA" jack and black test lead to the "COM" jack.
- Set the rotary switch at desired DCV rang position. If the voltage to be measured is not known beforehand, set rang switch at the highest range position and then reduce it until satisfactory resolution is obtained.
- Connect the test leads across the source or load being measured.

-Read voltage value on the LCD display along with the polarity of the red lead connection.

AC voltage measurement

- Connect the red test lead to "VΩmA" jack and black test lead to the "COM" jack.
- Set the rotary switch at desired ACV position.
- Connect the test leads across the source or load being measured.
- Read voltage value on the LCD display

DC current measurement

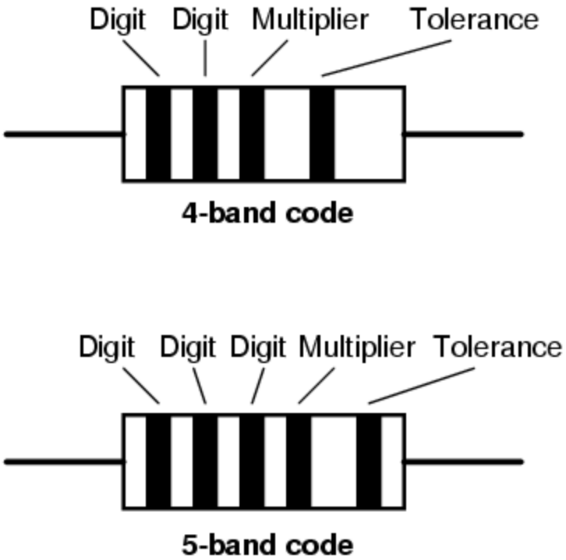
-Connect the red test lead to "VΩmA" jack and black test lead to the "COM" jack. For measurements between 200 mA to 10 A, remove red lead to "10A" jack.

-Set the rotary switch at desired DCA position.

-open the circuit in which the current is to be measured, and connect test leads in series with the circuit.

-Read current value on LCD display along with the polarity of red lead connection.

4. Color code reading on a resister



Color	Digit	Multiplier	Tolerance (%)
Black	0	10^0 (1)	
Brown	1	10^1	1
Red	2	10^2	2
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	0.5
Blue	6	10^6	0.25
Violet	7	10^7	0.1
Grey	8	10^8	
White	9	10^9	
Gold		10^{-1}	5
Silver		10^{-2}	10
(none)			20

fig. 4

Example:

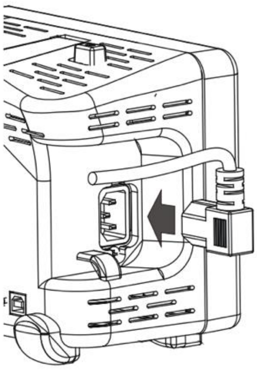
$$R = (\text{Yellow: } 4)\ (\text{Violet: } 7)\ (\text{Black: } 0) \times (10^{\text{brown:}1}) \pm (\text{Brown: } 1)\%$$

$$= 470 \times 10^1\ \Omega\ \pm 1\ \% = 4700 \pm 47\ \Omega$$

5. Oscilloscope

1. Power Cord (fig. 5 left)

After inspecting the instrument and the accessories, connect the power cord as shown in the following figure. Press the power key on the top of the oscilloscope. if the oscilloscope cannot be powered on, check the power cord connection. If the oscilloscope still cannot start up after the inspections, please contact RIGOL for help.



BNC Connection (Front Panel)

fig. 5

2. Connect the BNC (fig. 5 right)

As shown in the following figure, insert the the BNC cable to the BNC conector on the front panel, rotate clockwise to lock the BNC

3. Connect the Logic Analyzer, USB, and RS232 (fig. 6)

DS1000D Series Oscilloscopes provide the Logic Analyzer to meet users' requirement. Before connect the logic analyzer, please turn off the power source to avoid any possible damage during the connection.

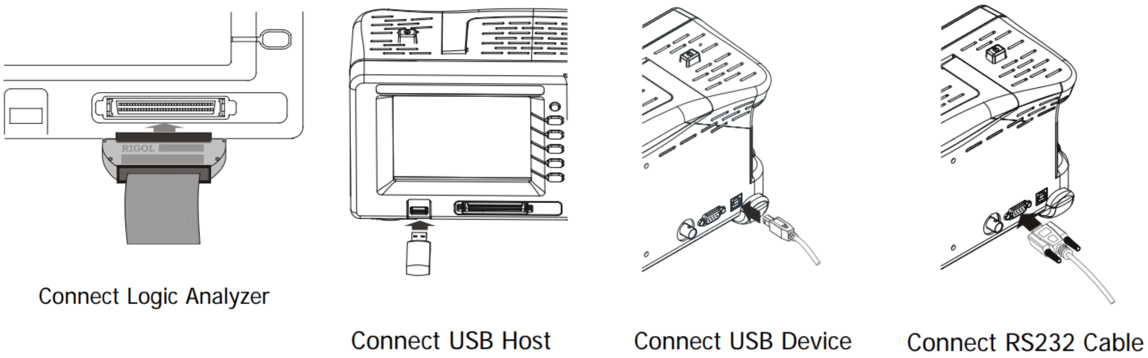


fig. 6

4. User Interfaces: DC/AC Coupling

The first thing to do with a new oscilloscope is to know its user interface (fig. 7), front panel and menus. This part helps you to be familiar with the layout of the knobs and buttons and how to use them.

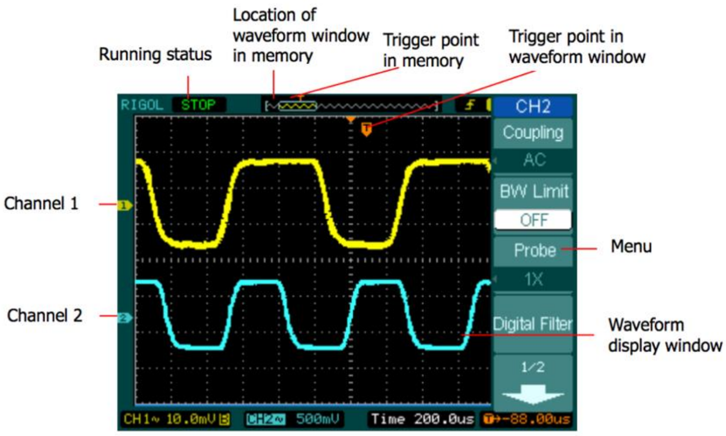


fig. 7

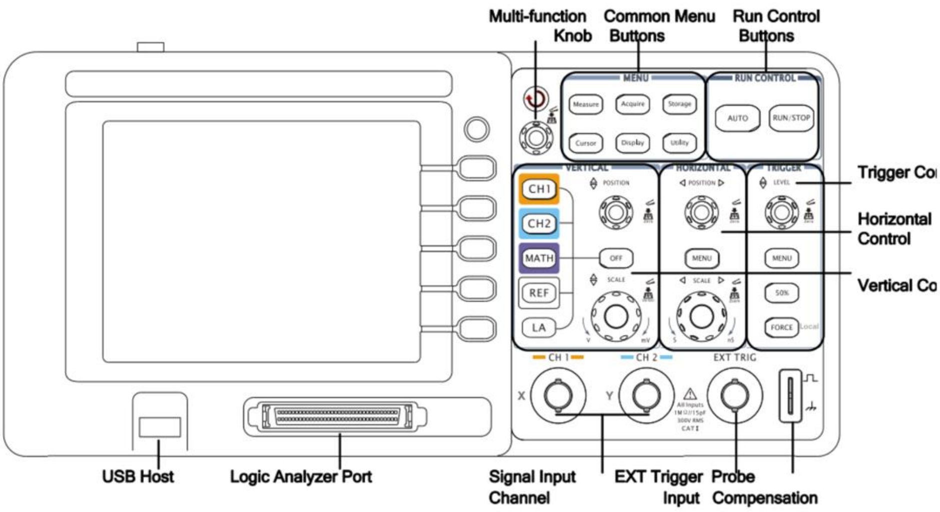


fig. 8

Front Panel (fig. 8); the knobs are used most often and are similar to the knobs on other oscilloscopes. The buttons allow you to use some of the functions directly but also bring up soft button menus on the screen, which enable the access to many measurement features associated with advanced functions, mathematics, and reference or to run control features.

This series oscilloscopes offer dual channels. Each channel has an operation menu and it will pop up after pressing CH1 or CH2 button. The settings of all items in the menu is shown in the table below.

Menu	Settings	Comments
Coupling	AC	Blocks the DC component of the input Signal
	DC	Passes both AC and DC components of the input signal
	GND	Disconnects the input signal
BW Limit	ON	Limits the channel bandwidth to 20MHz to reduce display noise.
	OFF	Get full bandwidth.
Probe	1X 5X 10X 50X 100X 500X 1000X	Set this to match your probe attenuation factor to make the vertical scale readout correct
Digital filter		Setup digital filter (See table 2-4)
⬇	1/2	Go to the next menu page (The followings are the same, no more explanation)

Menu	Settings	Comments
⬆	2/2	Back to the previous menu page (The followings are the same, no more explanation)
Volts/Div	Coarse	Selects the resolution of the SCALE knob Defines a 1-2-5 sequence.
	Fine	To change the resolution to small steps between the coarse settings.
Invert	ON	Turn on the invert function.
	OFF	Restore original display of the waveform.

DC/AC Coupling

A sine wave signal with DC shift is input to the system.

Press CH1→Coupling→DC, to set "DC" coupling. It will pass both AC and DC components of the input signal. The waveform is displayed as fig. 9 left

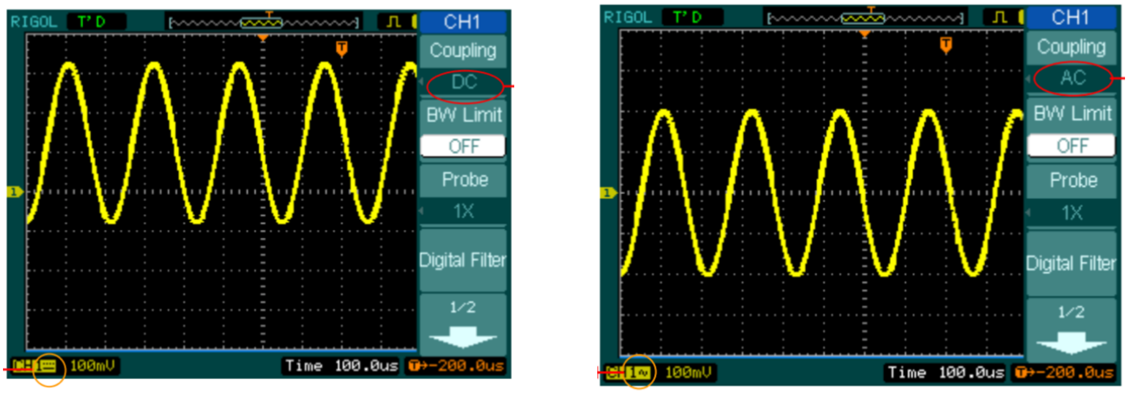


fig. 9

Press CH1→Coupling→AC to set "AC" coupling. It will pass AC component blocks the DC component of the input signal. The waveform is displayed as fig. 9 right

Experiments

Experiment 1: Multimeter

1. Objective:

Students will be able to use an analog multimeter to measure electrical resistance, voltage and current and to demonstrate the Ohm's law for DC current across resistors in parallel and in series.

2. Apparatus

1) An analog multimeter.
2) An application board and resistors R1 = 1kΩ and R2 = 470Ω.
3) A DC power supply unit.

3. Theory:

Connecting resistors in series and in parallel

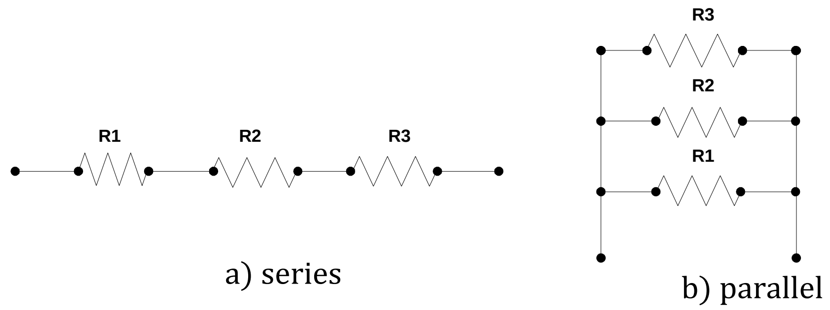


Figure 1.1 Resistors in combinations

Consider a system of n resistors combined in series and in parallel configurations as shown in Figure 1.1, equivalent resistance R_{eq} of the system can be calculated by

Resistors in series (see Figure 1.1a):

$$R_{eq} = R_1 + R_2 + R_3 + \dots + R_n$$

Resistors in parallel (see Figure 1.2b):

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

3.2 Voltage divider

In a system of n resistors combined in series configuration, voltage across a resistor R_i can be found by

$$V_i = \frac{R_i}{R_1 + R_2 + R_3 + \dots + R_n} V$$

when V is the voltage across the whole system, while **the current within this resistor series is a constant.**

4. Procedure (warning: *USE ONLY V AND mA RANGES PROVIDED IN THE INSTRUCTION*)

1) ***Multimeter as an Ohm-meter :*** Set your multimeter into the 'Ohm (Ω)'. Then, adjust the meter needle to zero by rotating the 0 Ω button.

2) Reconnect the circuits according to Figure 1.2, and use the meter to measure R1, R2 and R(eq) from the **series** and **parallel** combinations of R1 and R2.

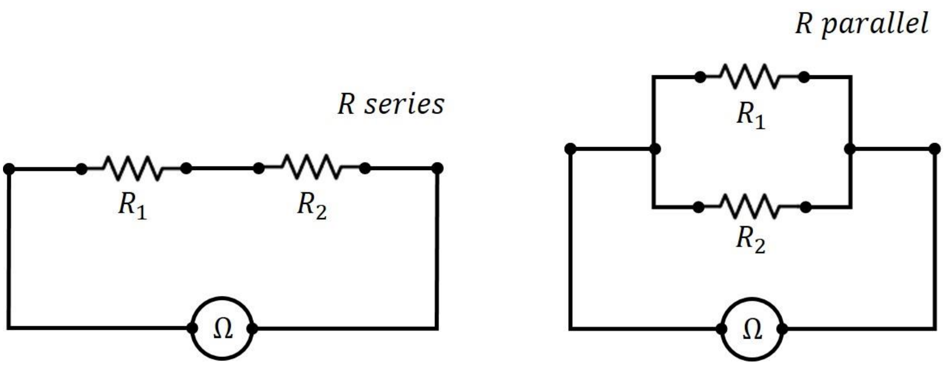


Figure 1.2

3) ***Multimeter as a Volt-meter:*** Set your multimeter into the 'DC V' mode.

3.1 Reconnect the circuits according to Figure 1.3, and use the meter to measure V_{s12}, V_{s1} and V_{s2} from the **series** combination of R_1 and R_2.

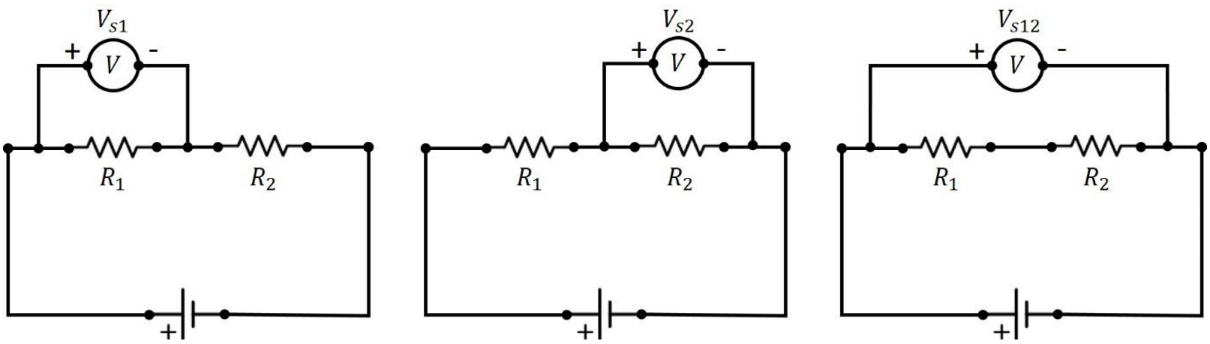


Figure 1.3

3.2 Reconnect the circuits according to Figure 1.4, and use the meter to measure V_{p12}, V_{p1} and V_{p2} from the **parallel** combination of R_1 and R_2.

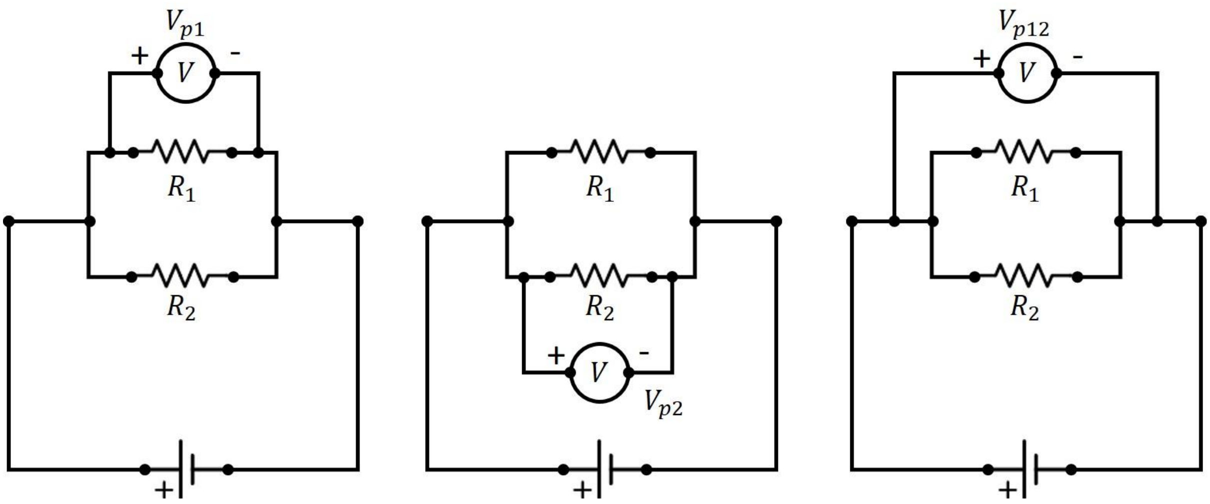


Figure 1.4

4) ***Multimeter as an Am-meter :*** Set your multimeter into the 'DC mA' mode.
5) Reconnect the circuits according to Figure 1.5(1) and (2), and use the meter to measure I1 within R1, I2 within R2 and I12 within the **series** and **parallel** combination of R1 and R2

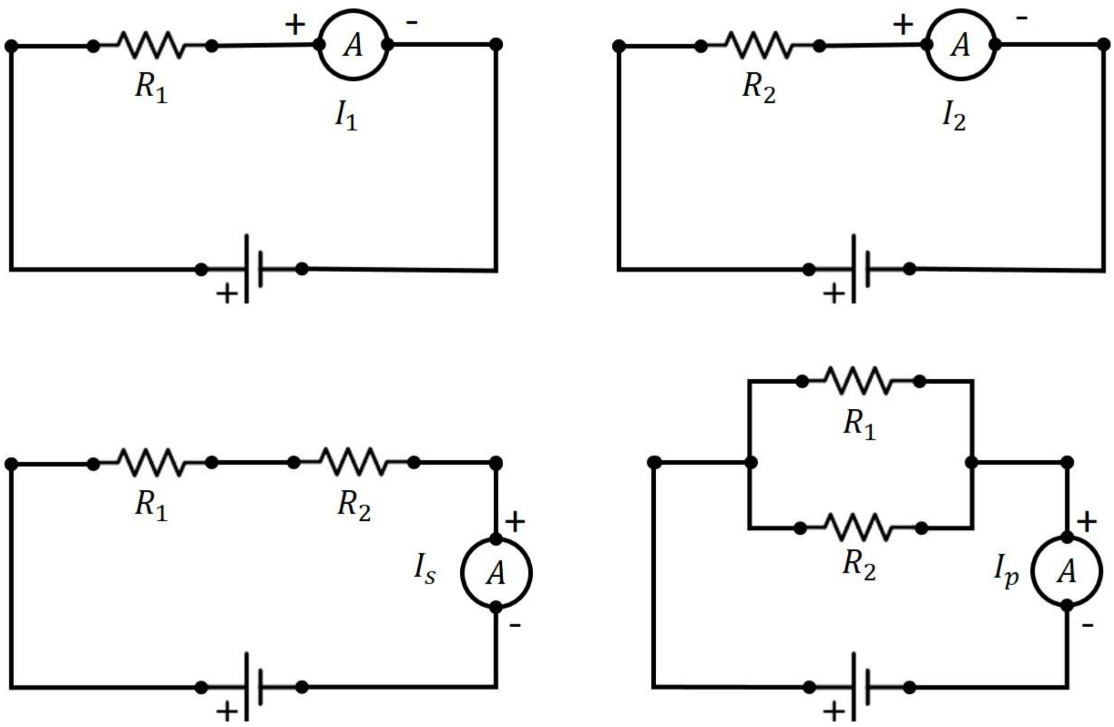


Figure 1.5 (1)

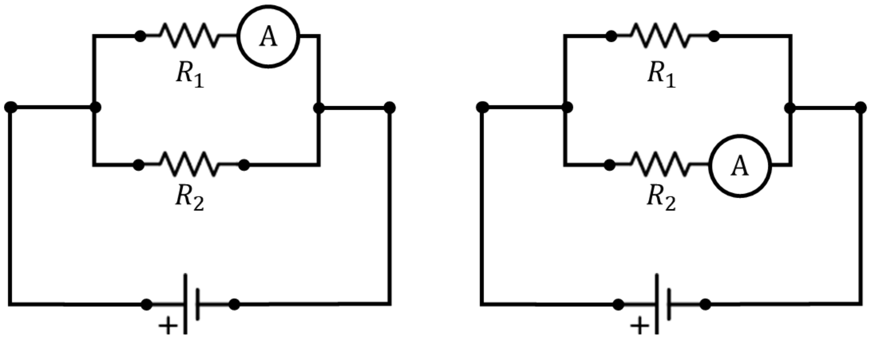


Figure 1.5 (2)

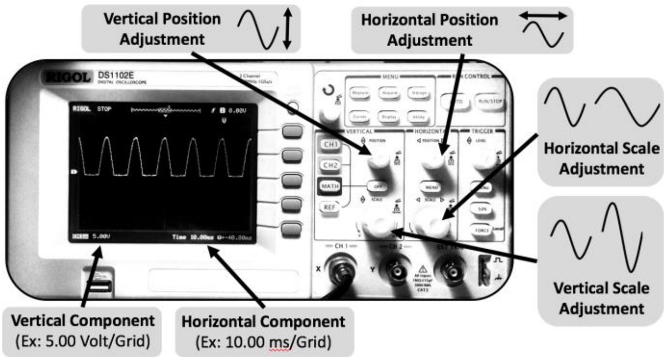
Experiment 2: Oscilloscope

1. Objective:

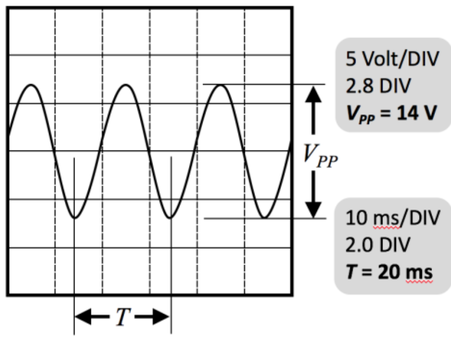
Introduce students to the basic use of a digital oscilloscope. Students will be able to measure the voltage of alternating current (AC) circuits and will be able to explain the principle of a diode clipping circuit.

2. Apparatus (see Figure 2.1):

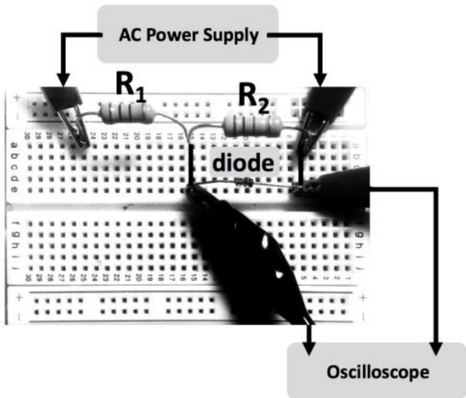
1) A digital oscilloscope (model: RIGOL DS1102E).
2) A protoboard with resistors R1 = 500Ω and R2 = 1kΩ, and a semiconductor diode.
3) An alternating current (AC) power supply unit



a) **RIGOL DS1102E Digital Oscilloscope**



b) an example of oscilloscope reading



c) a diode Clipper Circuit

Figure 2.1: experimental apparatus: **a) RIGOL DS1102E Digital Oscilloscope, b) an example of oscilloscope reading, c) a diode Clipper Circuit**

3. Theory

The **Diode Clipper**, also known as a *Diode Limiter*, is a wave shaping circuit that takes an input waveform and clips or cuts off its top half, bottom half or both halves together. This clipping of the input signal produces an output waveform that resembles a flattened version of the input. For example, the half-wave rectifier is a clipper circuit, since all voltages below zero are eliminated. **Diode Clipping Circuits** can be used a variety of applications to modify an input waveform using signal or to provide over-voltage protection for the circuits.

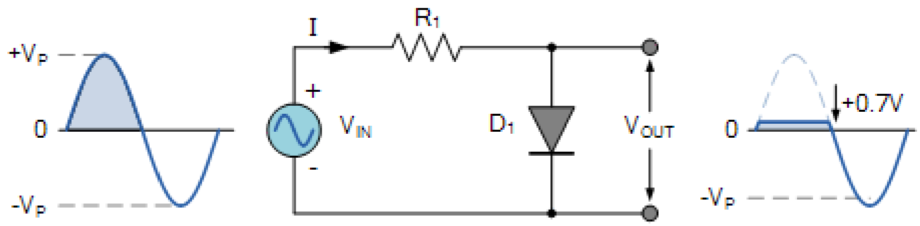


Figure 2.2: A positive diode clipping circuit

In the positive diode clipping circuit shown in Figure 2.2, the diode is forward biased (anode more positive than cathode) during the positive half cycle of the sinusoidal input waveform. For the diode to become forward biased, it must have the input voltage magnitude greater than +0.7 volts (0.3 volts for a germanium diode). When this happens, the diodes begins to conduct and holds the voltage across itself constant at 0.7V until the sinusoidal waveform falls below this value. Thus, the output voltage which is taken across the diode can never exceed 0.7 volts during the positive half cycle.

During the negative half cycle, the diode is reverse biased (cathode more positive than anode) blocking current flow through itself and as a result has no effect on the negative half of the sinusoidal voltage which passes to the load unaltered. Then the diode limits the positive half of the input waveform and is known as a positive clipper circuit.

4. Procedure (warning: *DO NOT CONNECT AC POWER SUPPLY ACROSS THE DIODE WITHOUT RESISTORS, OTHERWISE IT MIGHT RUIN THE DIODE.*)

1) Connect two resistors $R_1 = 500\ \Omega$ and $R_2 = 1000\ \Omega$ onto the protoboard in series. (Ex. You may connect two ends of R_1 into the grids 'a5' and 'a15', and two ends of R_2 into the grids 'c15' and 'c25')
2) Connect the AC power supply and the circuit in the protoboard to create an AC circuit as seen in Figure 2.3. Connect the oscilloscope probes across R_1, R_2 and R_1-R_2 and sketch the signal shapes seen in the oscilloscope for each case.
3) From the signal, measure V_{pp}, $V_0=V_{pp}/2$, $V_{rms}= V_0/\sqrt{2}$, period (T) and frequencies (f).

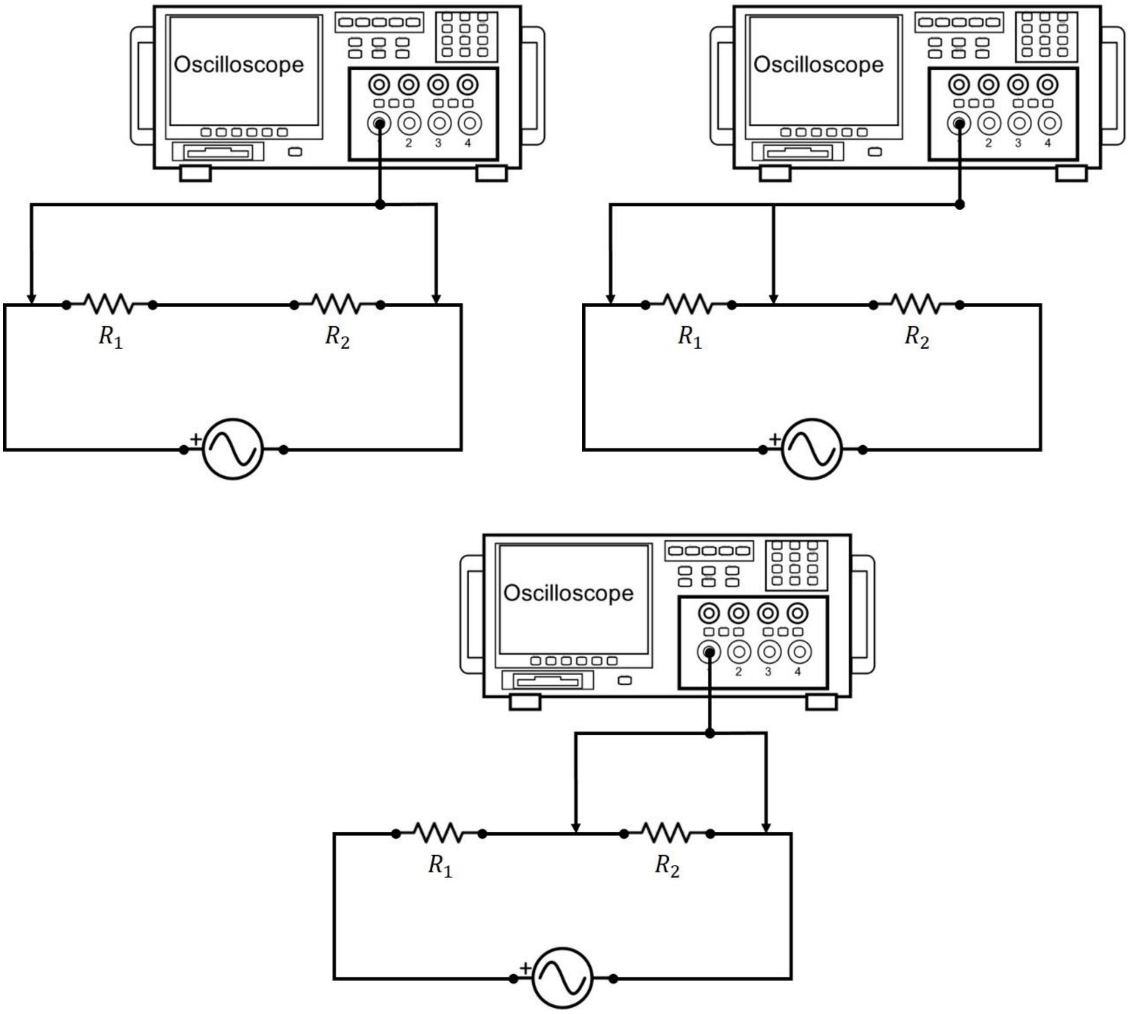


Figure 2.3: AC voltage measurements

4) Replace R_1 by a diode onto the protoboard (see Figure 2.4).

5) Connect the AC power supply to the diode clipper circuit and connect the oscilloscope probes across R_1, R_2 and R_1-R_2 and sketch the signal shapes seen in the oscilloscope for each case.

6) From the signal, write down positive and negative peak voltages. Discuss and answer the questions provided.

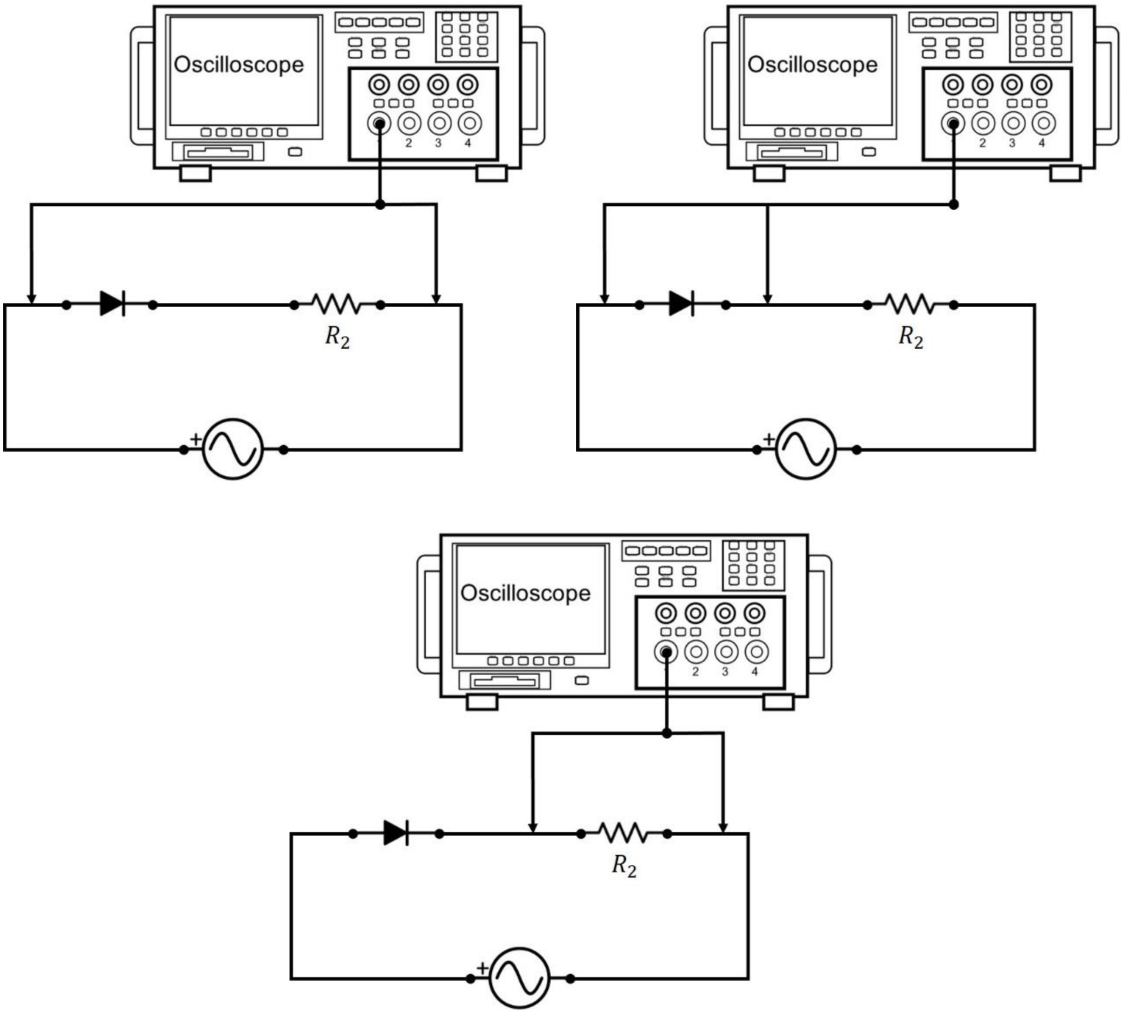


Figure 2.4: voltage measurements on a diode clipper circuit.

Experiment 3: RC Circuit

1. Objective:
To find the capacitive time constant $\tau = RC$ and the capacitance C of a capacitor from an RC circuit charging.

2. Apparatus (Figure 3.1):
1. A demonstrating RC circuit board equipped with a DC power supply
2. A Multimeter with internal resistance R
3. A capacitor with unknown capacitance C
4. Stopwatch

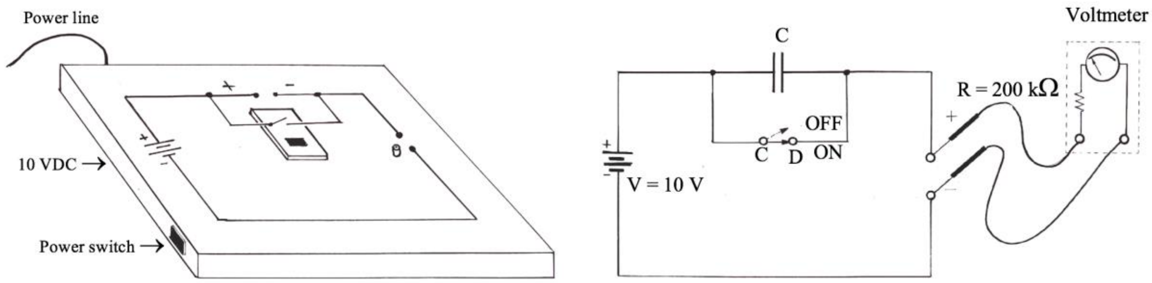


Figure 3.1: A demonstrating RC circuit board equipped with a DC power supply

3. Theory:
Charging an RC Circuit
Consider an RC series circuit in Figure 3.1. When the switch is turned off, the current from V_0 Volt DC power supply flows through the capacitor and the capacitor becomes charged, the voltage across R and C can be written as:

$$V_R + V_C = V_0 \quad \text{.......................}(2)$$

$$V_R = iR = R\frac{dq}{dt} \quad \text{.......................}(3)$$

$$V_C = \frac{q}{C} \quad \text{.......................}(4)$$

By solving equations (1)-(4), voltage across the capacitor C and resistance R can be obtained as followed:

$$V_C(t) = V_0(1 - e^{-t/RC}) \quad \text{.......................}(5)$$

$$V_R(t) = V_0 e^{-t/RC} \quad \text{.......................}(6)$$

Alternatively, equation (6) can be rewritten in terms of capacitive time constant $\tau = RC$ as:

$$\ln V_R = -t/\tau + \ln V_0 \quad \text{.......................}(7)$$

τ has the unit of time(s). Knowing the time constant from the slope of ($\ln V_R$ - t) and the internal resistance R of the voltmeter, it will be possible to calculate the capacitance C of the unknown capacitor.

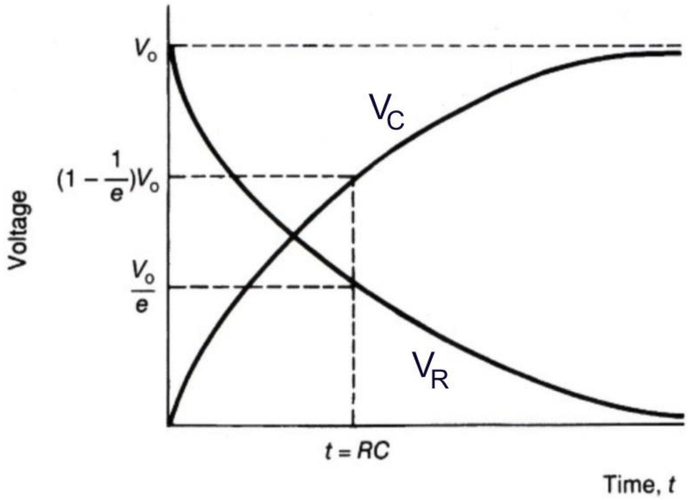


Figure 3.2: Voltage across C and R during a capacitor charging (Eq(5) and Eq(6))

4. Procedures:

1) Connect the demonstration board to the power, the capacitor, and the multimeter as shown in Figure 3.1
2) Turn on the switch on the demonstration board, read the voltage across the internal resistance of the multimeter (V_R). Record the voltage as V_0.
3) Turn-off the switch and start the timer simultaneously. Record the times when V_R decreases to 9.0 V, 8.0 V, …. , 2.0 V
4) Plot a graph between $\ln V_R$ and time *t*. Find the time constant $\tau = RC$ from the slope and the capacitance of the unknown capacitor

Experiment 4: Refraction

1. Objectives
Students will be able to use a simple method to observe light refraction through a transparent medium and calculate the refractive index

.

2. Apparatus (see Figure 4.1)
1. A rectangular prism.
2. Pins.
3. Graph paper.

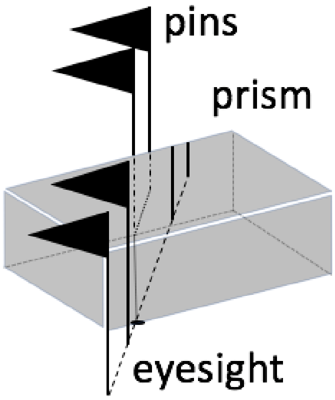


Figure 4.1: Experimental apparatus consisting a rectangular prism, pins on a graph paper. The pin positions represent the path of refracted light through the prism.

3. Theory
Refraction is due to change in the speed of light as it enters from one transparent medium to another and is according to Snell's law: The incident ray, the refracted ray and the normal to the interface of two transparent media at the point of incidence, all lie in the same plane. The ratio of sine of angle of incidence to the sine of angle of refraction is a constant, for the light of a given color and for the given pair of media. If α is the angle of incidence and β is the angle of refraction then,

$$\frac{\sin\alpha}{\sin\beta} = n \tag{1}$$

The constant n is called the refractive index of the second medium with respect to the first.

4. Procedure (see Figure 4.2)

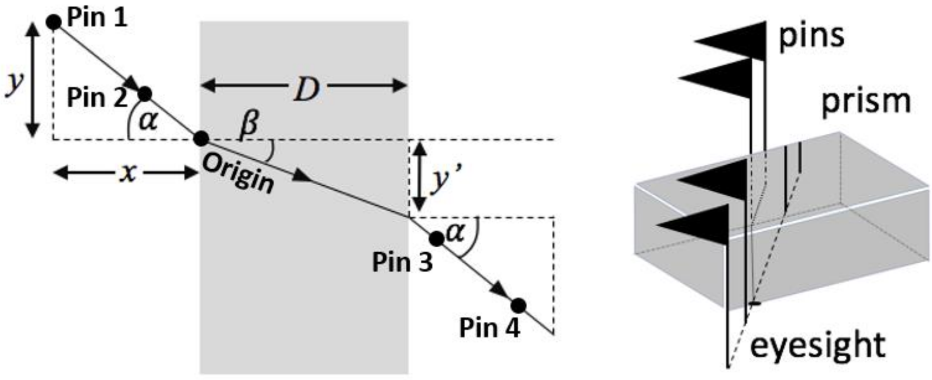


Figure 4.2

1. Place the prism onto a graph paper with sides of the prism parallel to the graph lines. Draw a mark close to the left corner of the prism to represent the origin (see Figure 4.3 left)
2. Put pins number 1 and 2 onto the graph paper. The pin number 1 stands at the position $x = 5\ cm$ and $y = 1\ cm$. The pin number 2 must stand above the same line as the pin number 1 and the origin.
3. Put pins number 3 and 4 onto the graph paper. All pins must stand above the same line when observing through the prism (but not necessary to be above the same line when observing through the air; see Figure 4.2 right).
4. Withdraw all pins and mark all the pinned positions on the graph. Try not to cause the prism to move. Repeat the processes from 2. And 3. But change the position of pin number 1 to y = 2, 3, 4 and 5 cm while **<u>x remains at 5 cm</u>**
5. Draw all the optical paths from each of the y distances. Then, measure the refracted angle β corresponding to the incident angle α and calculate the values of sin α and sin β.
6. Plot the values of sin α against sin β and try to calculate refractive index of the prism from equation (1).

Experiment 5: Wheatstone Bridge

1. Objectives

To study the Wheatstone bridge circuit and find the unknown resistance by slide-wire Wheatstone bridge method.

2. Apparatus

1. Slide-wire Wheatstone bridge
2. Power supply
3. Galvanometer
4. Resistor

3. Theory

A Wheatstone bridge is an electrical circuit used to measure an unknown electrical resistance as shown in figure 5.1. There are four resistances named R_1, R_2, R_3 and R_4, and G is galvanometer. Basically, the Wheatstone bridge is made up of two voltage dividers powered by dual-power supply or a single source. Among the junctions of the voltage dividers, a galvanometer (a very sensitive current meter) has been connected with the purpose of monitoring the current flow from one voltage divider to the other.

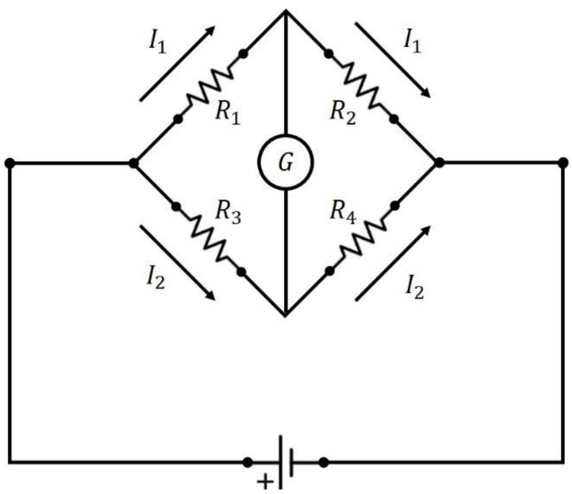


Figure 5.1 Wheatstone bridge circuit

When DC current does not flow through the galvanometer, we say that the Wheatstone bridge is balanced and the following is achieved:

$$I_1 R_1 = I_2 R_3 \tag{1}$$
$$I_1 R_2 = I_2 R_4 \tag{2}$$

Divide equation (1) by (2), we obtain

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \tag{3}$$

From the equation (3), if R_2 is the unknown resistance, the other three resistances are known, we can obtain the value of the unknown resistance.

Slide-wire Wheatstone bridge

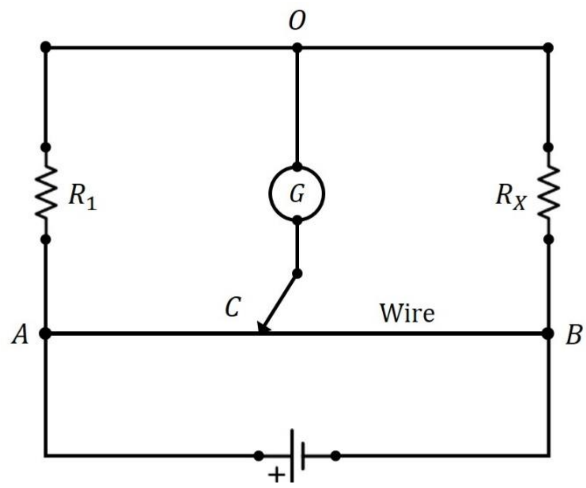


Figure 5.2 slide-wire Wheatstone bridge circuit

The slide-wire Wheatstone bridge circuit is as shown in figure 5.2. AB is the metal wire, the point C divides AB into AC and CB, and the resistances are R_3 and R_4. Each resistance is proportional to its length, so

$$R = \rho \frac{L}{A} \tag{4}$$

ρ is the resistivity, L is the length of wire and A is the wire cross-sectional area. So the ratio of R_3 and R_4 is equal to the ratio of AC and CB. If we can find a spot to make the reading become zero, and equation (4) can be written as:

$$\frac{R_1}{R_X} = \frac{AC}{CB} \tag{5}$$

or

$$R_X = \frac{CB}{AC} R_1 \tag{6}$$

R_1 is the known resistance.

4. Procedure

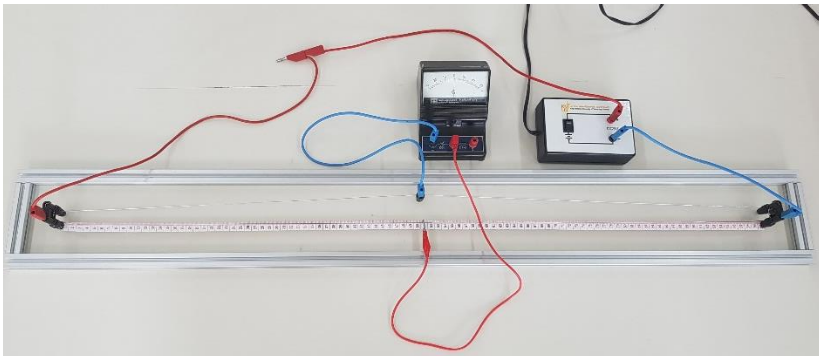


Figure 5.3

1) Set up the experiment as shown in figure 5.3. The value of R_1 is 220 Ω and the value of R_X is 270 Ω.
2) Turn on the power supply and push the probe to make it connect to the metal wire. The galvanometer deflects at this time, move the probe to make the galvanometer reading back to zero, then measuring the length of AC and CB. Calculate R_X from the experiment using equation (6).
3) Change the value of R_1 to 470 Ω and 1.0 kΩ, and R_X to 500 Ω and 1.2 kΩ respectively and following step 2).
4) Use the resistor R_1 is 220 Ω, and R_X for value 270 Ω, 500 Ω and 1.2 kΩ connected in parallel and then following step 2).

References

1. Julio R. García, 2007, "Lab 1 - Wheatstone Bridge", **TECH 167 Control Systems Laboratory Experiments Manual**, pp. 1 -3.

2. Atis Scientific Instruments Co., Ltd, n.d., **Wheatstone Bridge Experiment** [Online], Available: http://www.atis.com.tw [2019, December 19th].

Experiment 6: Finding Planck's constant using LEDs

1. Objective

To understand the lighting mechanism of light emitting diodes (LEDs) and to find Planck's constant using LEDs.

2. Apparatus

1. LEDs box kit which contains 6 different colours of LEDs, 100 Ω and 120 Ω resistors, and a variable resistor
2. Digital multimeter
3. 5V DC supply
4. 1 PVC pipe
5. 2 sets of conducting wires

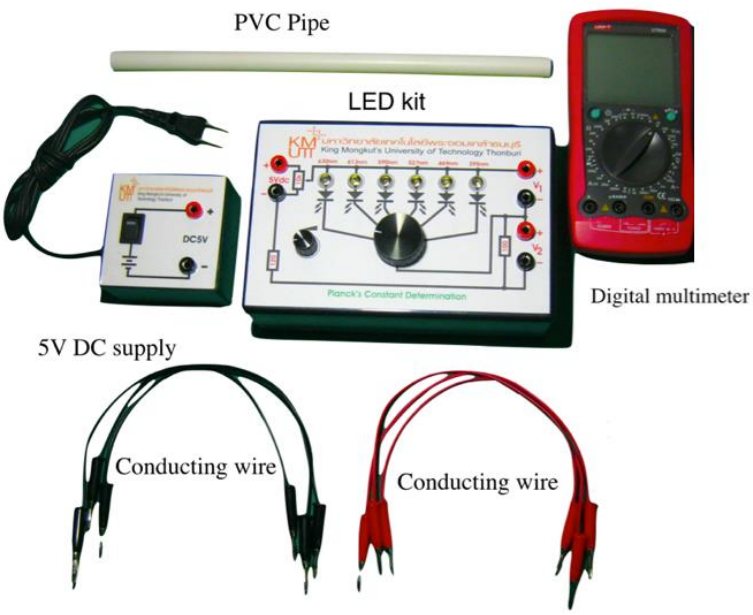


Figure 6.1 The apparatus used in the experiment

3. Theory

Planck's constant (h) was first introduced by Max Planck in 1900. He invented this constant while he was developing the theory of quanta of light in order to explain "black-body radiation." Planck incredibly initiated the idea of non-continuity of light energy which entirely contradicts with what physicists believed during that time as energy of light is continuous. Planck postulated that the energy of light seemed to come in little "chunks" of the frequency multiplied by a certain constant. This constant came to be known as Planck's constant and it has the value $6.626 \times 10^{-34}\ \mathrm{J \cdot s}$. This can be mathematically described as

$$E = hf = \frac{hc}{\lambda} \tag{1}$$

where E is the energy of a chunk of light (nowadays people call this chunk of energy as *photon)*, f is the frequency of light and λ is the wavelength of light. Note that the frequency and the wavelength of light are related through $c = f\lambda$, $c = 3 \times 10^8$ m s^{-1} is the speed of light.

Planck's hypothesis could be recognized as one of the biggest revolutions in physics history. As, before Planck's discovery of photon, people believed that the intensity of light is proportional to the energy transferred by light wave. For two different colours of light (hence different frequencies) with the same intensity, they both have the same amount of energy, namely, the red light and violet light which have the same intensity would have the same amount of energy. However, Planck's postulate claims that, <u>one chunk</u> of energy of the violet light has more energy than that of the red light since the frequency of the violet light is greater than that of the red light. In the case when the intensities of both colours of light are identical, the number of red photons must be larger than that of the blue photons so that both can have the same energy. This is shown in Figure 6.2.

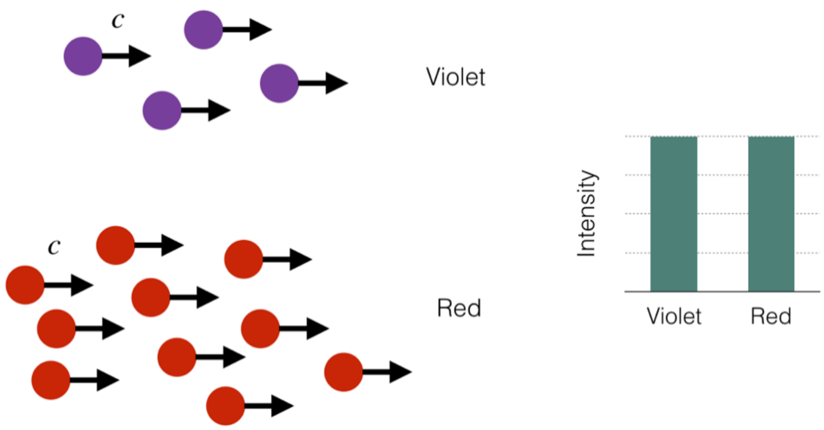


Figure 6.2 For both red and violet light to have the same amount of energy, the number of the red photons must be larger than that of the blue photons. This is because one violet photon has a larger energy than that of the red photon.

The discovery of Planck led to the beginning of the new branch in physics, known as quantum physics. Quantum physics is the theory used to describe the phenomenon in atomic scale and it is the best theory that we have ever had so far. It is the foundation of the new technology which have been discovered during the last century, such as, nanotechnology, electronic devices and material science.

Light emitting diodes (LEDs) is an electronic device which is used to control the direction of the current in the circuit. This use of LEDs is similar to those typical diodes. Unlike the typical diode, the LED can even produce light when the current flow through it. An LED is composed of two terminals – anode terminal and cathode terminal. The current can only flow from anode to cathode direction. Figure 6.3 shows a diagram of an LED and the symbol used in the circuit diagram.

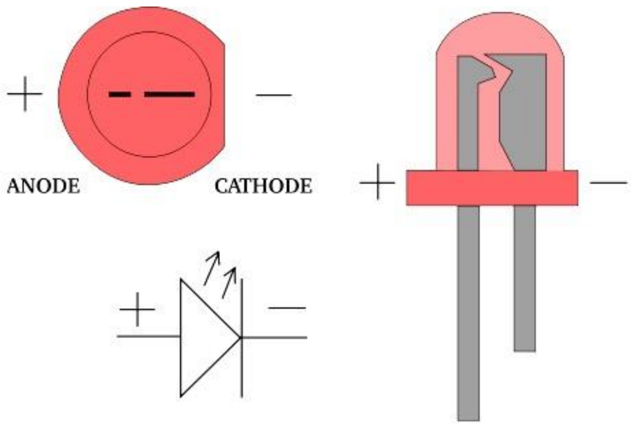


Figure 6.3 The picture of an LED and its symbol used in the circuit diagram. The anode terminal (positive terminal) has a longer leg than the cathode terminal (negative terminal). If looked from aside, the cathode is the one that has a bigger end than that of the anode.

In order to understand how the LED conducts electrical current, consider Figure 4. The figures show a simple circuit containing an LED which is connected in series with a battery V and a resistor R. In Figure 6.4 (a), the cathode terminal of the LED is connected to the negative terminal of the battery. In this case, the LED is forward biased and the current I can flow through it, causing the LED to emit light. In Figure 6.4 (b), the cathode terminal of the LED is connected to the positive terminal of the battery. In this case the LED is reverse biased and no current can go through it. The easy way to remember this is "the current can flow through the LED in the same direction as the triangle symbol of the LED points".

In practice, when the LED is forward biased, it will not immediately conduct electricity. One has to increase the potential difference (pd) across the LED upto a particular value so that the LED starts glowing. This pd is known as "threshold voltage V_{TH}" as it is the minimum pd in which the LED starts working. Once the pd across the LED is larger than V_{TH} the resistance of the LED drops dramatically and this allows a large amount of current to flow through the LED. The I-V characteristic of the LED is shown in Figure 6.5. And it is clearly seen that for the particular LED used to plot this graph, its V_{TH} is around 1.5 V. Beyond 1.5 V, the current sharply shoots up.

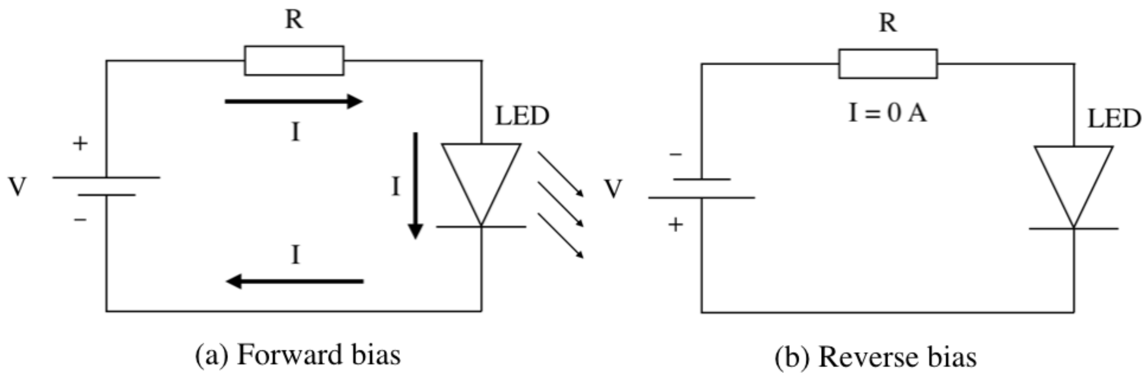


Figure 6.4 (a) The LED is forward biased, namely, the cathode terminal of the LED is connected to the negative terminal of the battery. In this configuration, the LED allows the current to flow through it. (b) The LED is reverse biased, namely, the cathode terminal of the LED is connected to the positive terminal of the battery. In this case, no current can flow through the LED.

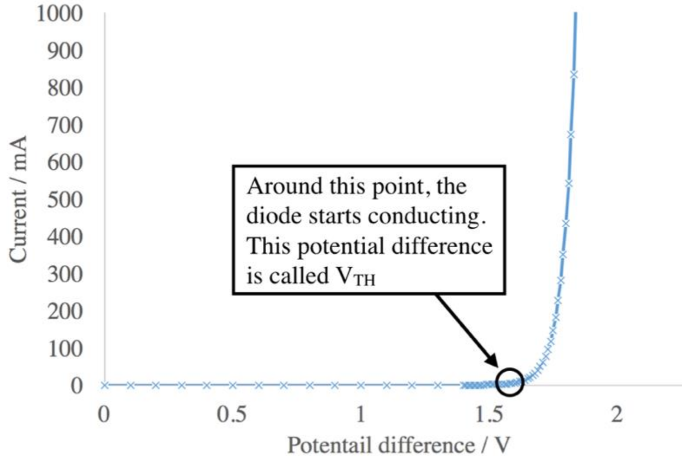


Figure 6.5 The relationship between the current and the potential difference across the LED when it is forward biased. When pd is above V_{TH} the LED immediately conducts electricity.

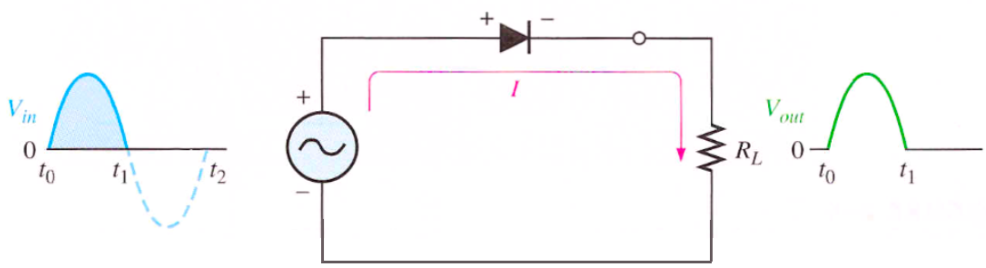


Figure 6.6 The LED or typical diode are typically used in a rectifier circuit which allows us to convert the AC signal to the DC signal. In this figure, the full-wave signal is converted into the half-wave signal; hence, this circuit is known as a half-wave rectifier.

Due to the uni-direction property of the LEDs, they are widely used in electrical circuits. For example, they can be used to convert the AC signal to the DC signal as shown in Figure 6.6.

The LEDs is made from semiconductor materials: p-type semiconductor and n-type semiconductor. These two semiconductors are joined together forming a p-n junction. P-type and n-type semiconductors are fabricated by doping the intrinsic semiconductors (IV-group element such as germanium (Ge), Gallium (Ga) and Silicon (Si) or the compound of these elements) with III-group and V-group elements such as phosphorus (P) or boron (B). Doping the intrinsic semiconductors causes the significant increase in the number of "charge carrier" in the semiconductors. To explain how doping can affect the number of charge carrier in the intrinsic semiconductors, one can use the bonding diagram. Figure 6.7 (a) shows an example of a pure intrinsic semiconductor made from silicon. In nature, Si has This forms a crystal structure of the Si. Since all of the valence electrons are used to form bonding, none of the electrons are left over; and hence, there are no free electrons left in this case. So it is said that there are no charge carriers and Si at 0 K cannot conducts electricity.

In Figure 6.7 (b), a very few Sb atoms (V-group element) is doped into the Si crystal. As an Sb atom has 5 valence electrons, when it forms covalent bonds with Si atoms, one of the valence electron is left over. It is said that the Sb atom donates one electron to the system and this electron becomes the charge carrier in the semiconductor. As electrons are negative, this type of semiconductor is known as n-type semiconductor. On the other hand, when the pure Si semiconductor is doped with B atoms (III-group element), one of the B atom can form three covalent bonds with 3 Si atoms. This causes a "hole" in one of the bonding. These holes act like the positive charge carriers which move in the same direction as that of the external electric field. It is said that B atom is an acceptor of electron (and hence "hole") as it can receive one more electron to fill the bond. This type of semiconductor is known as p-type semiconductor.

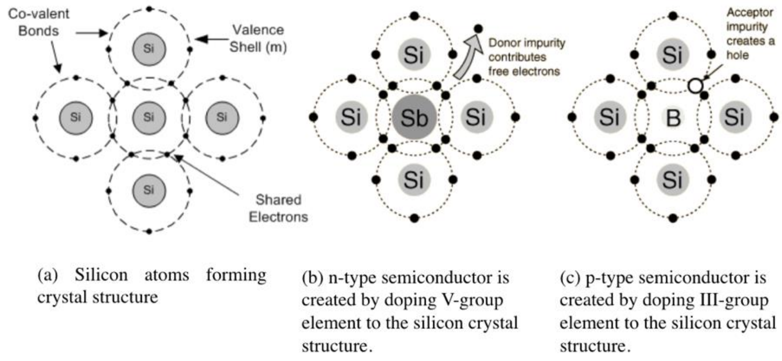


Figure 6.7 (a) The crystal structure of Si atoms. (b) The crystal structure of the n-type semiconductors. (c) The crystal structure of the p-type semiconductors.

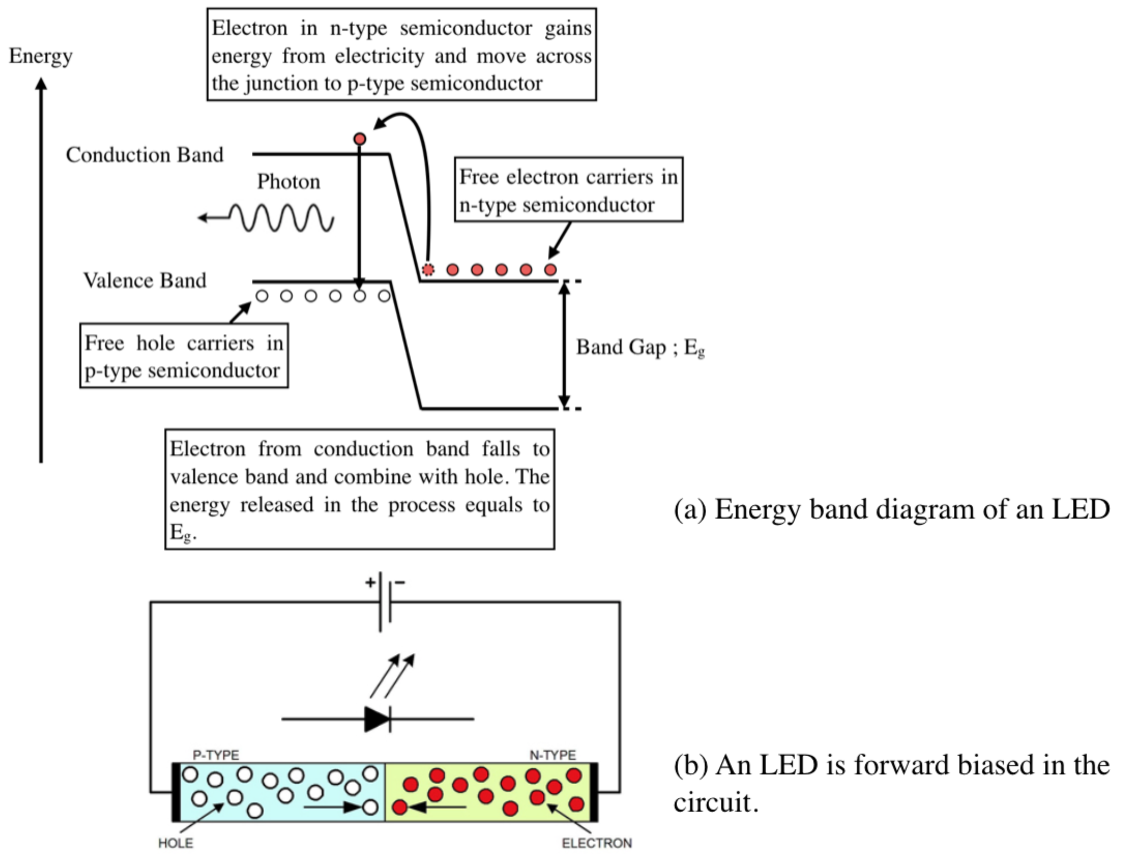


Figure 6.8 (a) The energy band diagram of the n-type and p-type semiconductor when they are brought to form the p-n junction. (b) A photon is emitted when one of the hole recombines with one of the electron at the p-n junction.

When the p-type and n-type semiconductors are brought into contact, forming the p-n junction, the energy of the p-type semiconductor will be higher than that of the n-type semiconductor as shown in Figure 6.8 (a). The difference in energy between these two semiconductors approximately equals to the band gap E_g between the conduction band and the valence band in each semiconductor. Therefore, when there is no pd across the LED, the electrons in the n-type semiconductor do not have enough energy to jump across the junction as there is the energy barrier. However, if the electrons are given enough energy (by applying the pd across the LED in the forward direction), these electrons can move across the energy barrier and recombine with the holes in the p-type semiconductor, producing photons. As can be seen, the minimum amount of energy required by an electron to move across the barrier is E_g and this required energy comes from the electrical energy due to the pd across the diode at V_{TH}. Hence one can write the relationship between V_{TH} and E_g as

$$eV_{TH} = \frac{hc}{\lambda} \qquad (2)$$

where eV_{TH} is the minimum electrical energy required by an electron to move across the barrier and $e = 1.6\times10^{-19}$ C.

4. Procedure (see Figure 6.9)

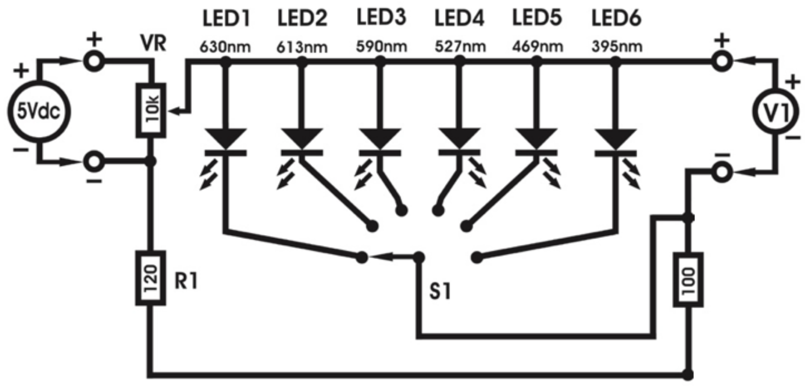


Figure 6.9 The circuit diagram used in the experiment.

1) Connect the LED box kit, the 5V DC supply and a digital voltmeter according to Figure 6.9.
2) Turn the large knob at the middle of the kit to LED1 which emits the light at wavelength of 630 nm.
3) Set <u>the small knob</u> to the original position by turning it counter-clockwise until it cannot be turned any further.
4) Gradually turn <u>the small knob</u> until the LED starts glowing. You can look at the LED through the PVC pipe in order to prevent the interruption due to the light in the room.
5) Record the pd V1 across the LED at the point when the LED starts emitting light. This value is V_{TH}.
6) Then you turn <u>the large middle knob</u> to the next LED and repeat step 3 to 5 to measure V_{TH} of each LED.
7) Record 3 values of V_{TH} for each LED in table 2 in the lab report.
8) Find the average value of V_{TH} for each LED and their associated uncertainties.
9) Plot the graph between the reciprocal of the wavelength $1/\lambda$ and the threshold voltage V_{TH}.
10) Calculate the slope of the line of best fit through the data and the Planck's constant from Equation (2)
11) Compare the calculated value from 10. to the theoretical value.

Experiment 7: RLC Circuit

1. Objectives

To demonstrate the effect of capacitive and inductive reactance and phases of the AC signals in a serial RLC circuit. Student will be able to find the reactance, inductance and capacitance from an AC circuit with known resistance.

2. Apparatus

1. An oscilloscope 2. A Function Generator 3. A resistor
4. An inductor 5. A capacitor

3. Theory

The current in a closed, DC circuit depends on the voltage of the power supply and the electrical resistance present in the circuit, Ohm's law, $V = IR$, describes this relationship (V is the voltage of the power supply, I is the current though the circuit, and R is the electrical resistance). The behavior of AC circuits can be more complex, as other circuit elements such as inductors and capacitors depend on the frequency at which the voltage oscillates in combination with the inductance and the capacitance.

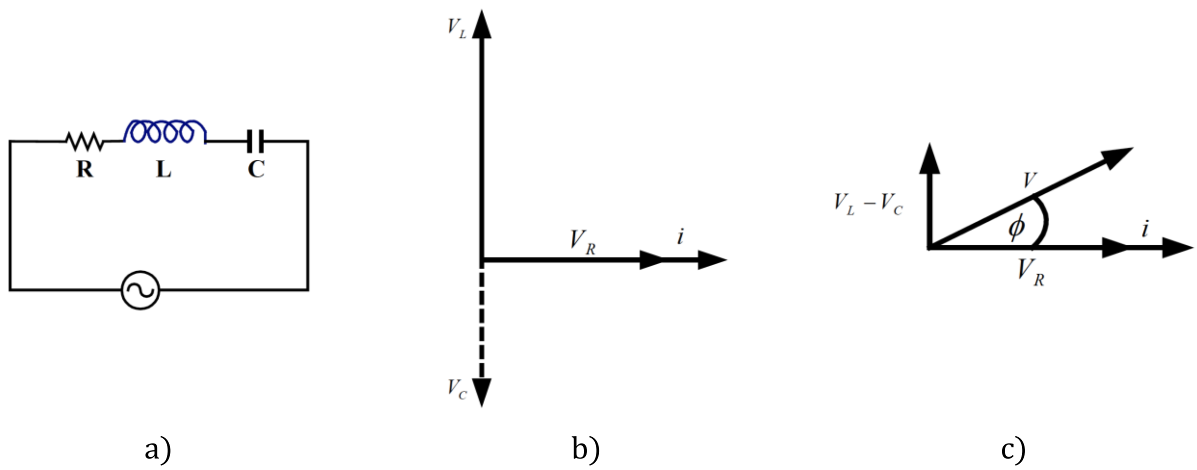


Figure 7.1

Resistors, capacitors and inductors in an AC circuit.

Consider an AC circuit in Figure 7.1, with a time-dependent current

$$i(t) = I_m \sin \omega t \tag{7.1}$$

Voltage across the resistors $V_R(t)$, $V_C(t)$ and $V_L(t)$ capacitors and inductors can be determined as followed:

$$V_R(t) = iR = I_m R \sin \omega t$$

$$V_C(t) = \frac{q}{C} = \frac{1}{C}\int i\, dt = -\frac{I_m}{\omega C}\cos \omega t \tag{7.2}$$

$$V_L(t) = L\frac{di}{dt} = \omega L I_m \cos \omega t$$

With defining resistive reactance $X_R = R$, capacitive reactance $X_C = \frac{1}{\omega C}$ and inductive reactance $X_L = \omega L$, the equations (7.2) can be rearranged into

$$V_R(t) = I_m X_R \sin \omega t$$

$$V_C(t) = I_m X_C \sin(\omega t - \frac{\pi}{2}) = -I_m X_C \sin(\omega t + \frac{\pi}{2}) \tag{7.3}$$

$$V_L(t) = I_m X_L \sin(\omega t + \frac{\pi}{2})$$

and the phasor diagram for the voltage V, V_R, V_C and V_L are also shown in Figure 7.1. The voltage across the inductor lead the current (which is in phase with the voltage across the resistor) by 90°, and it will be presented along the y-axis. The voltage across the capacitor lags the current by 90°, and is also presented along the y- axis (see Figure 7.1).

To obtain the resultant voltage V, we need to add voltages V_R, V_L and V_C as vectors. The vector addition is illustrated in Figure 7.1 and can be calculated by

$$V = \sqrt{V_R^2 + (V_L - V_C)^2} \tag{7.4}$$

The phase difference between the current i and the net voltage V shown in Figure 7.1 is given by

$$\tan \phi = \frac{|V_L - V_C|}{V_R} = \frac{|X_L - X_C|}{R}$$

$$\phi = tan^{-1}\frac{|V_L - V_C|}{V_R} = tan^{-1}\frac{|X_L - X_C|}{R} \tag{7.5}$$

4. Procedure

Section 1 Find the capacitance

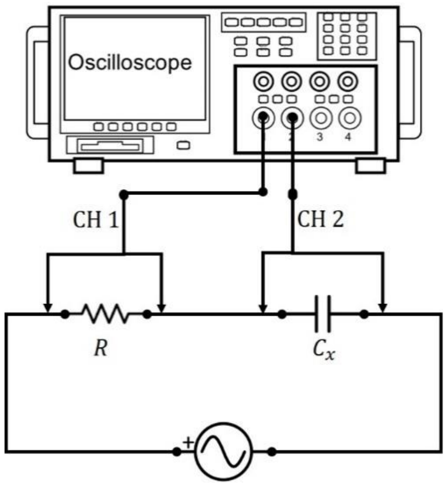


Figure 7.2

1.1 Connect the function generator at frequency 1.5 kHz and a series of a resistor (R)and a capacitor (C_x) create an AC circuit as seen in Figures 7.2.
1.2 Connect the oscilloscope CH 1 to measure the output voltage of function generator until the $V_{pp} = 10$ V (peak to peak) shown on the screen of the oscilloscope, then disconnect CH 1 from function generator.
1.3 Use CH 1 and CH 2 measuring voltage drop across resistor (V_R) and capacitor (V_C). Both CH 1 and CH 2 must have same ground.
1.4 Sketch the signal shapes seen in both channels. Record peak-to-peak voltages of both channels.
1.5 Find C_x

Section 2 Find the inductance

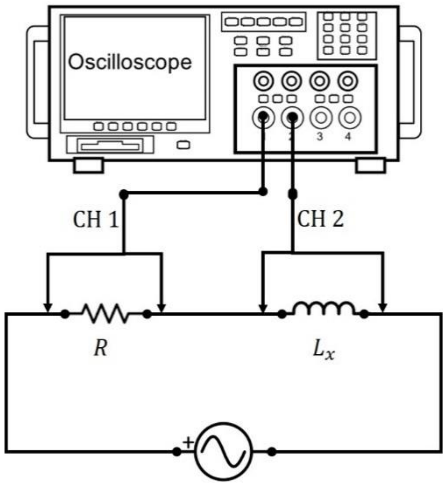


Figure 7.3

2.1 Replace the capacitor C with inductor L as shown in figure 7.3
2.2 Repeat step 1.2 – 1.5, but find L_x instead of C_x.

Section 3 Find the resonance frequency of RLC circuit

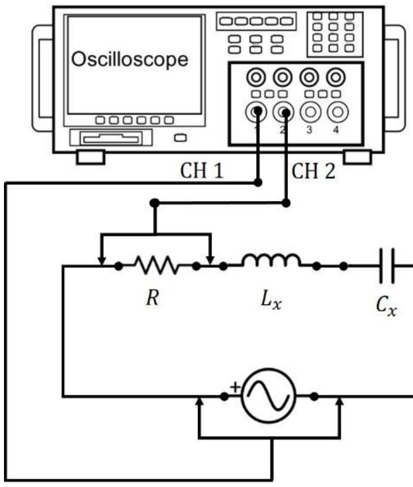


Figure 7.4

3.1 Connect the circuit as shown in figure 7.4
3.2 Slowly adjust frequency of function generator from 1.0 to 10.0 kHz until the highest voltage dropping across the resistor R is found (notice that the voltage dropping across the resistor and the output voltage from the function generator have same phase). Record the maximum voltage and resonance frequency.
3.3 Compare the resonance frequency to the equation

$$f = \frac{1}{2\pi}\left(\frac{1}{\sqrt{LC}}\right)$$

Experiment 8: Polarization

1. Objectives

To obtain the relationship between polarized light intensity through a pair of polarizers with the angle between two polarizers and evaluate the error in the experiment.

2. Apparatus

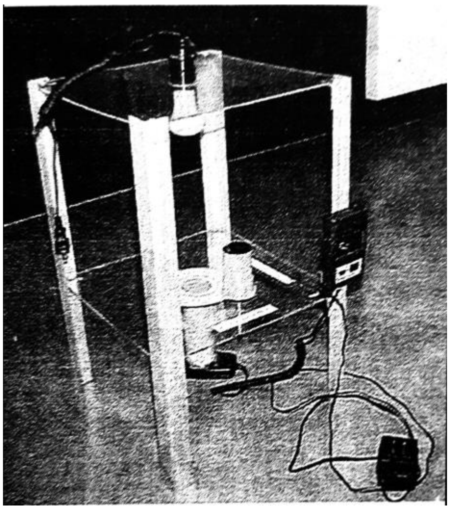


Figure 8.1 Polarization experimental set consisting a light source, two polarizers and a built-in lux-meter

3. Theory

<u>Polarizer</u>

A polarizer or polariser is an optical filter that lets light waves of a specific polarization pass through while blocking light waves of other polarizations. It can convert a beam of light of undefined or mixed polarization into a beam of well-defined polarization, that is polarized light. The common types of polarizers are linear polarizers and circular polarizers. Polarizers are used in many optical techniques and instruments, and polarizing filters find applications in photography and LCD technology. Polarizers can also be made for other types of electromagnetic waves besides light, such as radio waves, microwaves, and X-rays.

Malus's law

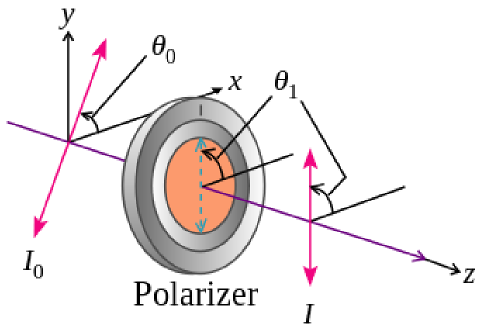


Figure 8.2 A diagram demonstrating Malus's law

Malus's law /mə'luːs/, which is named after Étienne-Louis Malus, says that when a perfect polarizer is placed in a polarized beam of light, the irradiance, I, of the light that passes through is given by

$$I = I_0 \cos^2\theta_i \qquad (1)$$

where I_0 is the initial intensity and θ_i is the angle between the light's initial polarization direction and the axis of the polarizer.

A beam of unpolarized light can be thought of as containing a uniform mixture of linear polarizations at all possible angles. Since the average value of $\cos^2\theta$. The transmission coefficient becomes 1/2. In practice, some light is lost in the polarizer and the actual transmission will be somewhat lower than this, around 38% for Polaroid-type polarizers but considerably higher (>49.9%) for some birefringent prism types.

If two polarizers are placed one after another (the second polarizer is generally called an analyzer), the mutual angle between their polarizing axes gives the value of θ in Malus's law. If the two axes are orthogonal, the polarizers are crossed and in theory no light is transmitted, though again practically speaking no polarizer is perfect and the transmission is not exactly zero (for example, crossed Polaroid sheets appear slightly blue in colour). If a transparent object is placed between the crossed polarizers, any polarization effects present in the sample (such as birefringence) will be shown as an increase in transmission. This effect is used in polarimetry to measure the optical activity of a sample.

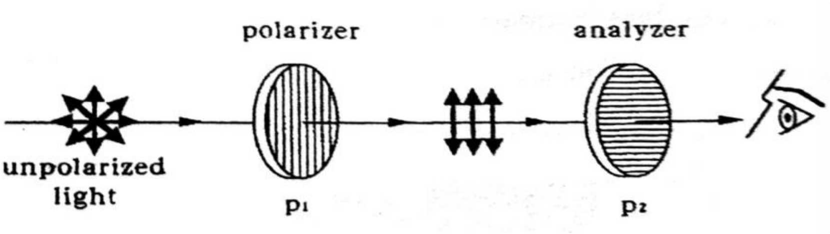


Figure 8.3 Polarization of light through a polarizer and an analyzer in this experiment.

4. Procedure

1. Turn the polaroid and keep reading read the light intensity value from lux meter until the maximum intensity (I_{Max}) is obtained. Set the current angle as $\theta = 0$ degree.
2. Obtain the base intensity (I_{Base}) from the I_{LUX} intensity at 90 degree.
3. Turn the knob by 10 degrees at a time (10-80 degrees). Record the light intensity from the lux meter.
4. Repeat the experiment three times and find the average value of light intensity.
5. Subtract the averaged intensities from lux meter at each angle by the base intensity, so that $I = I_{ave} - I_{Base}$ is obtained.
6. Calculate the I/I_0 and $\cos^2\theta$
7. Plot the linear graph and calculate the slope.
8. Discuss about the factors that cause the error in the experiment.

Experiment 9: Horizontal component of Earth magnetic field

1. Objectives:

To determine the horizontal component (B_H) of the earth's field.

2. Apparatus

1. 1 tangent galvanometer
2. 1 digital multimeter (ammeter)
3. 1 power supply
4. 3 connecting wires

3. Theory:

The horizontal component of earth's magnetic field, B_H, is the projection of earth's magnetic field on surface of the earth. Earth's magnetic field varies with longitude and latitude. To measure B_H, one can use the device known as tangent galvanometer (TG). Tangent galvanometer is an early measuring instrument for small electric currents. It consists of a coil of insulated copper wire wound on a circular non-magnetic frame. When a current is passed through the circular coil, a magnetic field (B) is produced at the centre of the coil in a direction perpendicular to the plane of the coil. The magnitude of the magnetic field intensity B is given by

$$B = \frac{\mu_0 N I}{2R},$$

where $\mu_0 = 4\pi \times 10^{-7}$ Wb A^{-1} m^{-1} is the permeability of free space, N is the number of turns of the coil, I is the current in the coil and R is the radius of the coil.

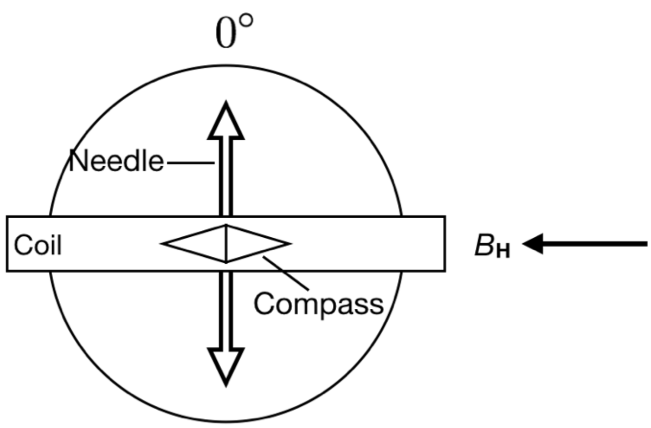


Figure 9.1 The directions of the needle and B_H shown when there is no current in the coil. Note that the compass and the needle are perpendicular to one another.

Without current, the needle of TG points perpendicular to the plane of the coil; and hence, perpendicular to the direction of the horizontal component of the Earth's magnetic field

B_H as shown in Fig 9.1. While the needle points perpendicular to B_H, the compass points along the plane of the coil. Once the current is passed through the coil, the magnetic field intensity B is created and the net magnetic field B_{net} can be obtained by adding B and B_H vectorially. As shown in Fig 9.2, the compass and the needle deflect through the angle θ and the compass points in the same direction as that of the net field.

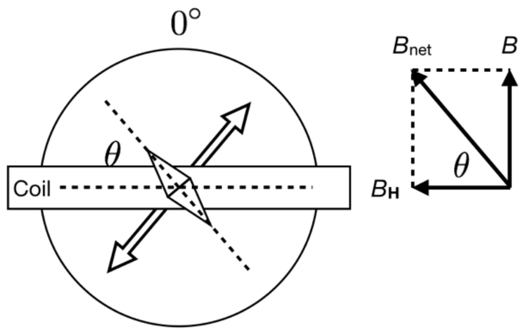


Figure 9.2 The needle and the compass deflect through the angle θ which is the direction the net magnetic field makes with respect to B_H.

Increasing the current in the coil causes more deflection of the needle according to the equation

$$\tan\theta = \frac{\mu_0 N I}{2 R B_{\mathrm{H}}}.$$

4. Procedure

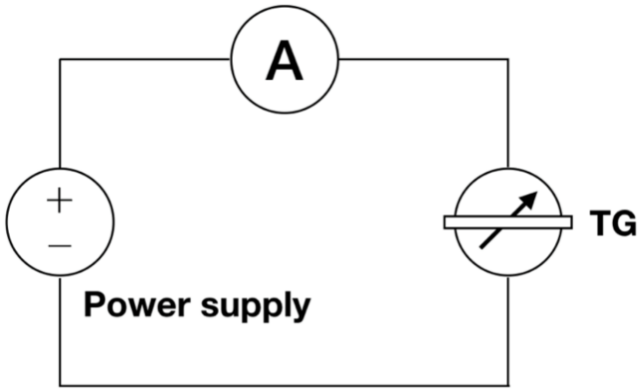


Figure 9.3 The schematic diagram shows the circuit used in the experiment.

1. Fig, 9.3 shows the experimental setup. The digital multimeter (ammeter) must be connected in series in the circuit. The live wire (the wire that bring the current out of the supply) must be connected to the + terminal of the supply and the channel written 500 turns (N= 500) on TG. The neutral wire is connected between the – terminal of the supply and the COM channel on the multimeter. The last wire connects the mA channel on the multimeter to the ground on TG.
2. Analyse equation $\tan\theta = \frac{\mu_0 NI}{2RB_\mathrm{H}}$ and decide how to plot a linear graph so that B_H can be determined.
3. Turn on the power supply. The current in the circuit can be adjusted by turning the knob for the voltage.
4. Record the deflection angle θ_1 and θ_2 for both sides of the pins, for different values of the current I. Then calculate the average angle $(\theta_1 + \theta_2)/2$
5. Plot the linear graph.
6. From the graph, determine the horizontal component of the Earth magnetic field B_H.

Experiment 10: Interference and diffraction

1. Objectives

To study diffraction and interference of light wave passing through a single slit and a double slit.

2. Apparatus (Figure 10.1)

1. Monochromatic 633 nm He-Ne laser
2. A slide of a single slits and a slide of double slits
3. A mount for holding the slides
4. A meter tape
5. A screen

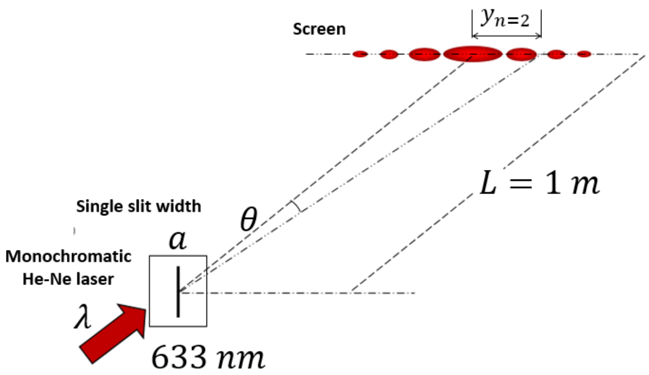


Figure 10.1

3. Theory

<u>Diffraction of light wave through a single slit</u>

In general, diffraction occurs when waves pass through small openings, around obstacles, or pass sharp edges. When monochromatic light from laser passes through a narrow slit and is then intercepted by a viewing screen, the diffraction pattern will appear on the screen as shown in Figure 10.1. The pattern consists of a broad and intense central maximum (bright fringe) and much weak bright fringes (called secondary maxima) alternating dark fringes that are on both sides of the central maximum. (see Figure 10.2)

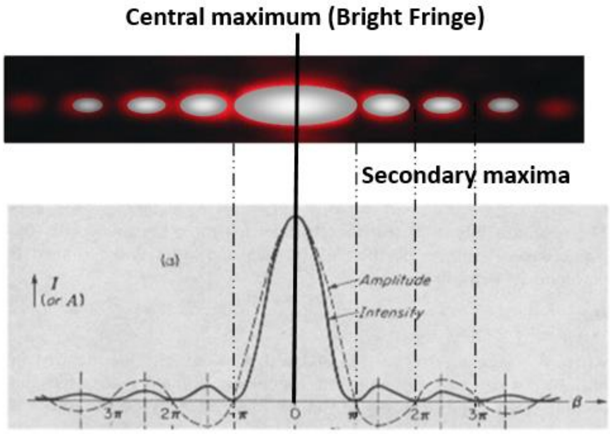


Figure 10.2

Locations of n[th]-order dark fringes from a diffraction pattern, making an angle θ_n to the normal axis (in line with the central maximum), which satisfy with the equation

$$a \sin \theta_n = n\lambda, \qquad n = \pm 1, \pm 2, \pm 3, \tag{10.1}$$

where a is slit width and λ is a wavelength of monochromatic light
Since the angle θ_n is small,

$$a \sin \theta_n \approx a \tan \theta_n = n\lambda$$

$$\frac{a y_n}{L} \approx n\lambda \tag{10.2}$$

when y_n is spacing between the central maximum and the n[th] order dark fringe, and
L is a distance between a single slit and the screen.

<u>Interference and Diffraction by a double slit</u>

When monochromatic light from laser passes through a double slit having a slit width a and the separation between the two slits d where $a < d$, as shown in Figure 10.3, the **interference** of light from two slits produces alternating **interference pattern** of bright and dark fringes due to the slit separation d. Moreover, the intensity of bright fringes from **interference pattern** is modified by diffraction **diffraction pattern** due to the slit width a.

Thus, the double-slit pattern displayed in Figure 10.3 combines inference and diffraction in an intimate way. In other words, interference fringes are filled in a diffraction pattern. Both are superposition effects, in that they result from the combining of waves with different phases at the given point.

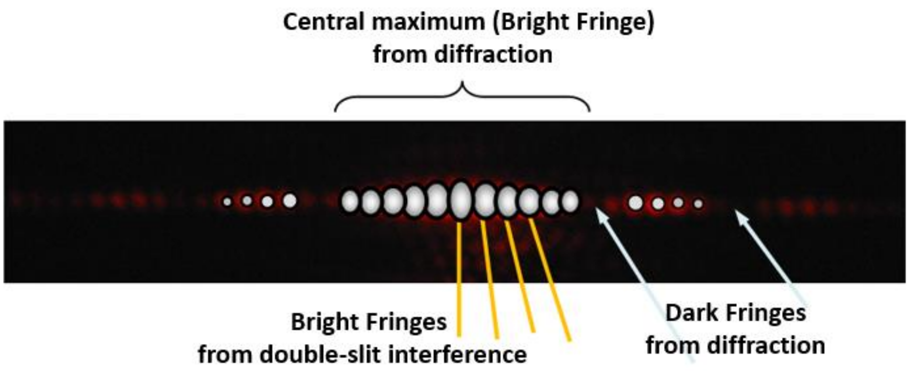


Figure 10.3

An mth-order **bright fringe of interference pattern** can be located with the following general equation,

$$d \sin\theta_m \approx d \tan\theta_m = m\lambda$$

$$\frac{dy_m}{L} \approx m\lambda \qquad (10.4)$$

when y_m is spacing between the central bright fringe and the mth order bright fringe, and L is a distance between a double slit and the screen.

4. Procedure

4.1 Single slit

1. Place the experimental apparatus according to the following diagram in Figure 10.1. Stick a paper one the screen to record the diffraction pattern.
2. Switch on a HeNe laser and insert a slide containing a single slit into a mount place in front of the laser. Adjust the slide until the reflected beam from the slide returns to the laser.
3. Let the laser beam illuminate on the slit and use a pen to mark the centers of **dark** fringes from **diffraction pattern** appeared on the screen.
4. Use at least **three** pairs of y_n and y_{-n} from the diffraction pattern to determine the slit width $\boldsymbol{a}$. Calculate the **average** of the slit width.

4.2 Double slit

1. Place the experimental apparatus according to the following diagram in Figure 5.1. Stick a paper one the screen to record the diffraction pattern.
2. Switch on a HeNe laser and insert a slide containing a double slit into a mount place in front of the laser. Adjust the slide until the reflected beam from the slide returns to the laser.
3. Let the laser beam illuminate on the slit and use a pen to mark the centers of dark fringes from **diffraction patterns** and mark the centers of bright fringes from **interference patterns** appeared on the screen.
4. Use at least **three** pairs of y_n and y_{-n} from the **diffraction pattern** to determine the slit width $\boldsymbol{a}$ and use at least **three** values of y_m and y_{-m} from the **interference pattern** to determine the separation between two slits $\boldsymbol{d}$. Calculate the **average** of the slit width and slit separation.