PHYS 222 OPTICS AND WAVES LABORATORY MANUAL

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TABLE OF CONTENTS

1. THIN LENS Experiment OW-1

2. PRISM SPECTROMETER Experiment OW-2

3. DIFFRACTION AND INTERFERENCE Experiment OW-3

4. POLARIZATION Experiment OW-4

5. GRATING SPECTROMETER Experiment OW-5

6. MICHELSON INTERFEROMETER Experiment OW-6

7. MICROWAVE OPTICS 1 Experiment OW-7

8. MICROWAVE OPTICS 2 Experiment OW-8

9. REFLECTION Experiment OW-9

10. OPTICAL ACTIVITY Experiment OW-10

11. SPECTRAL ENERGY DISTRIBUTION IN DIFFERENT FILTERS Experiment OW-11

THIN LENS EXP. OW-1

PURPOSE

-To measure the focal lengths of converging and diverging thin lenses

GENERAL

A simple lens has two surfaces that enclose a medium of a refractive index different from the medium in which it is used. It has the property of forming images. There are many types of lenses. But they all can be classified into two types depending on whether they make parallel light convergent or divergent. A "converging lens" is thicker in the center than at the edges provided that its refractive index is higher than the surrounding medium. A lens that is thinner at the center than its edges is a "diverging lens". Also, lenses are customarily divided into "thin lenses" and "thick lenses." However this division is entirely a matter of precision required for solving a given problem. The same lens may well be considered "thin" for a preliminary, and "thick" for a rigorous solution. The assumption which applies to the thin lens is that effect of finite lens thickness can be neglected. In this experiment the focal lengths of a converging and a diverging lens will be measured. It will be assumed that the lenses are thin.

The three methods that will be utilized for the measurement of the focal lengths are described below; "thin lens formula method", "Bessel's method" and "virtual object method". The first two methods can be used for measuring the focal length of a converging lens. The third one allows the measurement of the focal length of a diverging lens.

Thin Lens Formula Method: Referring to **Fig. 1**, for a thin lens, in the paraxial approximation, the relationship between the object distance s_o , image distance s_i , and the focal length f as measured from the lens center is given by the thin lens equation,

$$1/s_o+1/s_i=1/f \qquad \textbf{Eq. (1)}$$

where f is the focal length. By solving for f, we can rewrite the thin lens equation in the equivalent form,

$$f = s_i s_0 / s_i + s_0 \qquad \textbf{Eq. (2)}$$

Thus the focal length f of a thin lens can be determined using **Eq. (2),** when both the object distance s_o and image distance s_i are measured.

Bessel Method: Referring to **Fig. 2**, suppose an object and screen are a fixed distance *D* apart. A converging lens located between the object and screen will form a sharp image on the screen at two different positions whose separation is *d*. By locating these two positions we can determine the focal length *f* of the lens from the formula,

$$f = (D^2 - d^2)/4D \qquad \textbf{Eq .(3)}$$

Virtual Object Method: Focal length of a diverging lens cannot be determined directly as it is possible for a converging lens. In the virtual object method a converging lens with a known focal length is combined with a diverging lens of unknown focal length as shown in **Fig. 3**. The converging lens should be sufficiently strong to satisfy the relation below.

$$1/f_{converging} > \left| 1/f_{diverging} \right| \qquad \textbf{Eq. (4)}$$

Notice that if this requirement is not satisfied, then the diverging lens will cause the rays to diverge and a real image will not be formed. To utilize this method first a sharp image is formed using the converging lens only. Referring to **Fig. 3**, this is the **screen position #1**. Then the diverging lens is placed between the screen and the converging lens, at a distance *d* from the converging lens. The screen is adjusted until a sharp image again forms on the screen. This is **screen position #2**. The focal length $f_{diverging}$ of the diverging lens is then given by

$$\frac{1}{f_{diverging}} = \frac{1}{s_i'} - \frac{1}{s_i - d} \qquad \textbf{Eq. (5)}$$

where s_i is the distance between the **screen position #1** and the converging lens, and s_i' is the distance between **screen position #2** and the diverging lens. By solving for $f_{diverging}$, we can rewrite the above equation in the equivalent form.

$$f_{diverging} = \frac{s_i'(s_i - d)}{s_i - (s_i' + d)} \qquad \textbf{Eq.(6)}$$

EQUIPMENT

-Optics Bench

-Component Holders x 4

-Crossed Arrow Target

-150 mm focal length Diverging Lens

-Light Source

-Viewing Screen

-75 mm focal length Converging Lens

PROCEDURE

PART A: Thin Lens Formula Method

1. Set up the equipment according to **Fig. 1**. The Crossed Arrow Target will be used as the "Object". Turn on the Light Source and slide the Lens toward and away from the Object as needed to focus the image of the Object on the Viewing Screen.

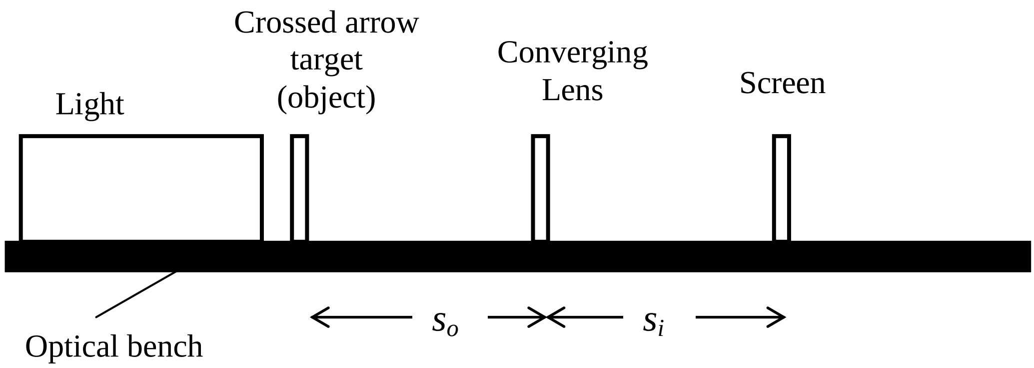

Figure 1. Thin lens formula method setup

2. Measure the object and image distances from the Lens and record these values in **Table 1**.

3. Repeat this measurement two more times with different object distances while recording your data in **Table 1**.

PART B: Bessel Method

1. Set up the apparatus according to **Fig.2**. The Object to Screen distance must be at least four times the estimated focal length of the Converging Lens.

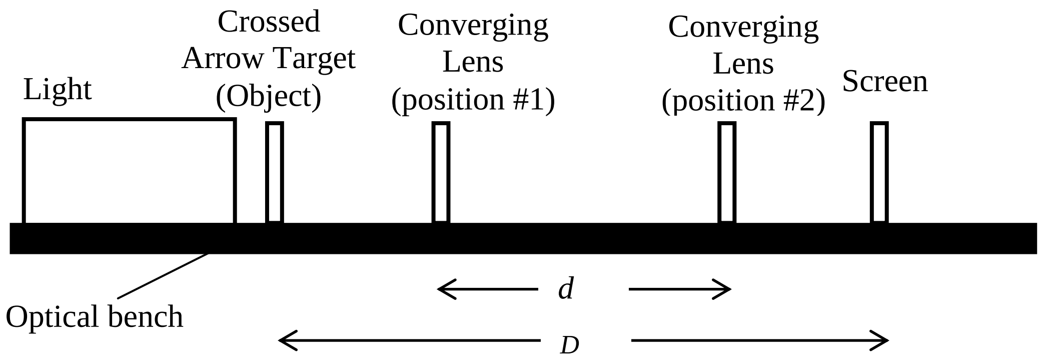

Figure 2. Bessel method setup

2. Determine the two positions (**positions #1** and **#2**) of the Lens which yield a sharp image on the Screen. Record the distance between Object and the Screen and two positions of the Lens in **Table 2**

3. Repeat this measurement two more times with different values for the object to screen distance, and record your data in **Table 2**.

PART C: Virtual Object Method

1. Referring to **Fig.3**, mount the 75 mm focal length Converging Lens on the Optical Bench, with 100 mm to 120 mm object distance s_o.

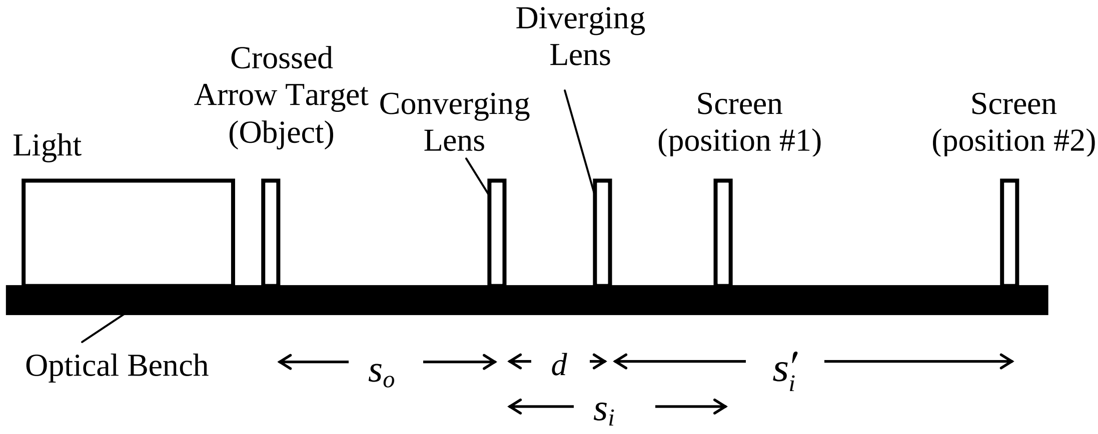

Figure 3.Virtual object method setup

2. Adjust the Screen to obtain a sharp image. Record the image distance s_i (from converging Lens to **Screen position #1**) in **Table 3**.

3. Mount the Diverging Lens between the Screen and the Converging Lens, about 50 mm from the Converging Lens.

4. Adjust the Screen to obtain a sharp image. Record the image distance s_i' (from Diverging Lens to **Screen position #2**), and the distance d between the two lenses in **Table 3**.

5. Repeat this procedure two more times, each time, starting with a different object distance s_o.

DATA and RESULTS

Name:______________________________ TA____________________________

Department:_________________________

Partners:____

PART A: Thin Lens Formula Method

Table1: Sample data for Thin Lens Formula Method

Object distance, s_o	Image distance, s_i	Focal length, f_m
$\bar{f} = \frac{\sum_{m=1}^{n} f_m}{n} =$	$\Delta \bar{f} = \sqrt{\frac{\sum_{m=1}^{n} (f_m - \bar{f})^2}{n-1}} =$	

Referring to **Table 1**;

1. Calculate the focal length, f_m, for each trial using **Eq.(2)** and record your results.

2. Calculate the average focal length, $\bar{f}$, and the error, $\Delta \bar{f}$, and record your results.

PART B: Bessel Method

Table 2: Sample data for Bessel Method

d	D	Focal length, f_m
$\bar{f} = \dfrac{\sum_{m=1}^{n} f_m}{n} =$	$\Delta \bar{f} = \sqrt{\dfrac{\sum_{m=1}^{n} (f_m - \bar{f})^2}{n-1}} =$	

Referring to **Table 2**,

1. Calculate the focal length, f_m, for each trial using **Eq.(3)** and record your results.

2. Calculate the average focal length, $\bar{f}$, and the error, $\Delta \bar{f}$, and record your results.

3. How well do your values for the average focal length obtained in **Part A** and **Part B** agree with each other and the manufacturer's specification? Discuss any discrepancy.

PART C: Virtual Object Method

Table 3: Sample data for Virtual Object Method

s_i	s_i'	d	Focal length, f_m
$\bar{f} = \dfrac{\sum_{m=1}^{n} f_m}{n} =$		$\Delta \bar{f} = \sqrt{\dfrac{\sum_{m=1}^{n} \left(f_m - \bar{f}\right)^2}{n-1}} =$	

Referring to **Table 3**;

1. Calculate the focal length, f_m, for each trial using **Eq.(6)** and record your results.

2. Calculate the average focal length, $\bar{f}$, and the error, $\Delta \bar{f}$, and record your results.

3. Is your result, $\bar{f}$, in agreement with the manufacturer's specification within the limits of error, $\Delta \bar{f}$? If not discuss the discrepancy.

DISCUSSION & CONCLUSION

1. What are the possible errors in the experiment?
2. What kind of approximations did you take into consideration while you were obtaining the physical quantities and how do they affect your results?
3. What discrepancies did you encounter between the calculated quantities and theoretical or literature values?
4. What is your overall conclusion?

PRISM SPECTROMETER EXP OW-2

PURPOSE

- Familiarization with the prism spectrometer.
- To measure the index of refraction of the prism material at several wavelengths and to find the dispersion relation.

GENERAL

A prism spectrometer is an optical instrument for producing and analysing spectra. It is composed of four essential parts: a collimator, a prism table, a prism, and a telescope. A simple schematic of the device is shown in **Fig.1**.

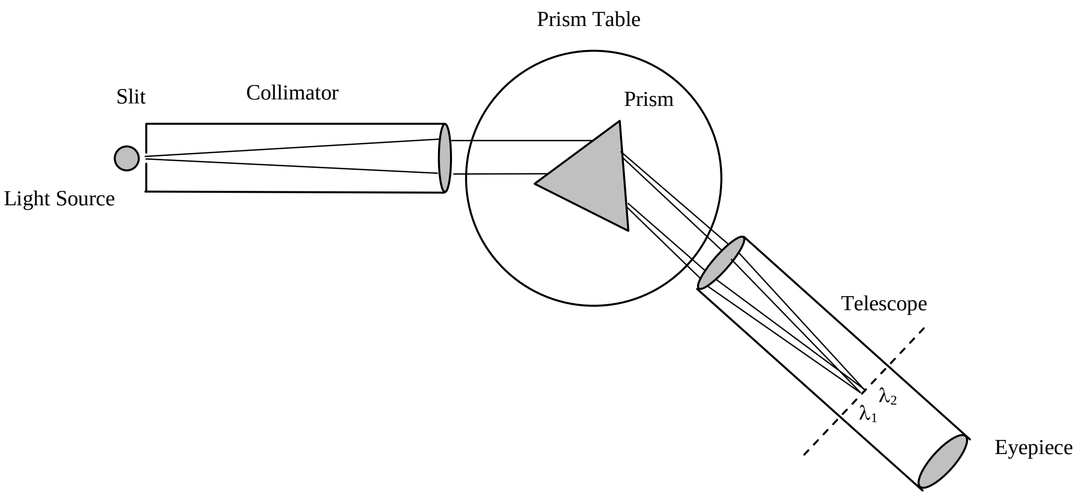

Figure 1. Layout of the prism spectrometer

The ideal operation of the spectrometer requires that parallel light beams should impinge on a surface of the prism. The collimator is a tube with an adjustable slit at one end and converging lens at the other end. Light rays enter through a slit and emerge parallel to the axis of the collimator at the other end. The collimated light then strikes a prism that has been appropriately positioned on the spectrometer table. The prism deviates and disperses the collimated light according to Snell's law and different wavelengths of light present in the light source. The sets of parallel rays (one set for each wavelength) then enter the telescope and form separate, distinct images of the collimator slit when viewed through the telescope. Cross hairs in the telescope may be positioned over each spectral line, thereby fixing the angular position of the telescope for each wavelength. The angular position of the telescope is determined with the aid of the circular scale, which is graduated in fractions of a degree.

In this experiment you will measure the refractive index of the prism material. Referring to **Fig.2**, when a ray of monochromatic light is refracted by a prism, the angle, δ, between the incident ray and the ray emerging from the prism is called the angle of deviation and it is dependent of wavelength. If the direction of incident ray is varied, it is found that the magnitude of deviation varies also, but for one particular angle of incidence the angle of

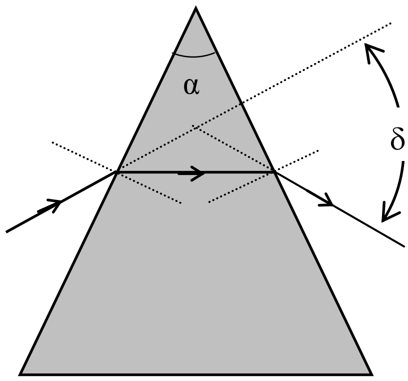

Figure 2. Refraction of light by a prism and the definition of the angles

deviation becomes a minumum , $\delta_{min.}$. This occurs when the angle of incidence is equal to the angle of emergence. Under these conditions, the index of refraction, *n*, of the prism material can be determined from the relation,

$$n = \frac{\sin\left(\frac{\alpha + \delta_{\mathrm{min}}}{2}\right)}{\sin\frac{\alpha}{2}} \qquad \textbf{Eq. (1)}$$

where α is the apex angle of the prism. The graph of index of refraction versus wavelength is called dispersion curve. The experimentally determined curve can be represented by an empirical equation due to Cauchy given by

$$n = A + B/\lambda^2 + C/\lambda^4 .... \qquad \textbf{Eq. (2)}$$

where *A*, *B*, *C*,.........are constants for a given substance. For many purposes it is sufficiently accurate to include first two terms only. The problem of this experiment is therefore essentially that of determining the constants in Cauchy's equation by determining n of prism material at several wavelengths through **Eq.(1).**

EQUIPMENT

-Student-type prism table spectrometer

-Hg, He, and Na lamps

PROCEDURE

Prism Spectrometer:

1. Examine the spectrometer and locate the collimator, the adjustable entrance slit, prism table, the graduated scale, vernier, and all clamps. The instrument must be handled with care. All movable parts such as the prism table and telescope move freely if the proper clamps are loosened. Never force anything.

Adjustment of the spectrometer for parallel light:

It is essential to make sure that parallel light from the collimator passes through the prism, and remains parallel as it enters the telescope, where it is brought to focus

1. Before placing the prism on the table, aim the telescope at a distant object. Move the eyepiece in and out so that image of the distant object is brought into clear focus in the plane of the cross hair (focal plane of the telescope). The telescope now is adjusted for parallel light; do not further change the focus of the telescope after this adjustment.

2. Next, adjust the collimator for parallel light. With the proper clamp loosened, bring the telescope into straight line with the collimator. Slightly open the adjustable slit by turning the knurled ring at the end of the collimator. Place an incandescent light source in front of the slit and look through the telescope. Slide the tube that holds the slit in and out of the barrel of the collimator and, if necessary, move the telescope sideways a little until a sharp image of the slit is seen in the center of the focal plane of the telescope. Set the slit exactly parallel. The collimator now is set to produce parallel light and should not be further disturbed.

Measurement of the prism angle, α

(Refer to Appendix 1 for reading the vernier scale).

1. Place the prism on the table of the spectrometer such that the angle α is toward the collimator and splitting the beam from the collimator, **Fig. 3**.

2. Find the direction of the light reflected off one face of the prism by moving the telescope into its path and viewing the image of the slit. The slit should be made as narrow as possible and yet remain visible. Adjust the position of the telescope until the image of the slit falls exactly on the cross hair. Read the angular position of the telescope (**telescope position #1**) and record this in **Table 1**.

3. Swing the telescope around to receive the light reflected off the other face of the prism. Read the angular position of the telescope (**telescope position #2**) and record this in **Table 1.**

4. Repeat these measurements two more times and record the data in **Table 1**.

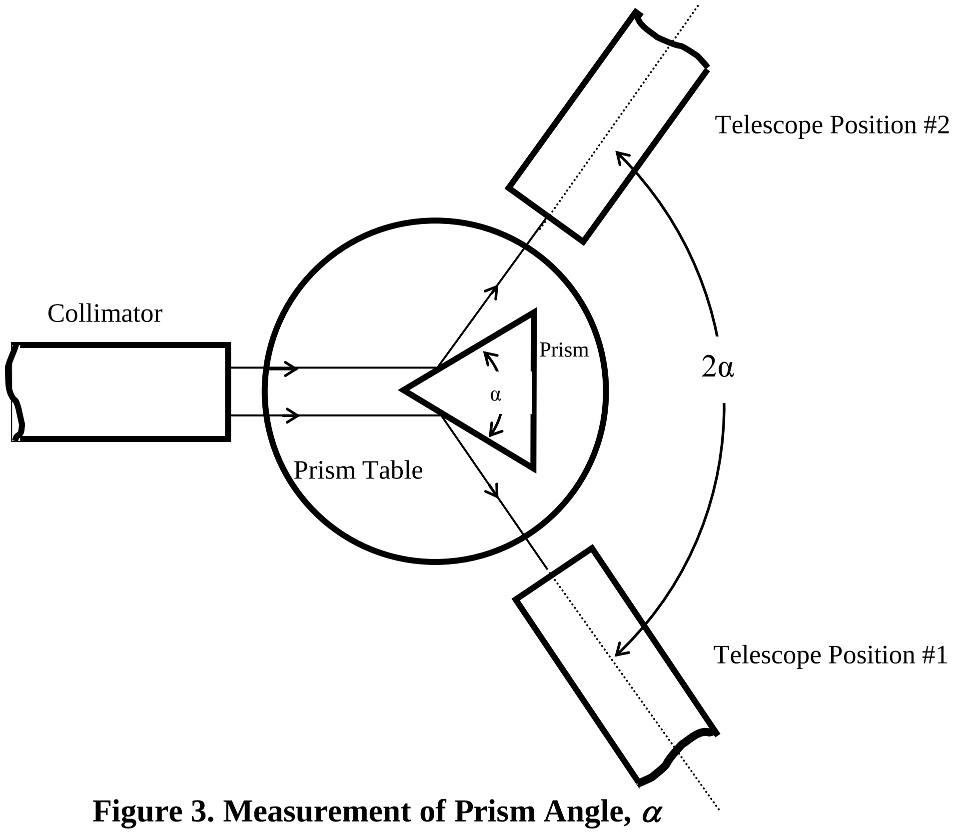

Figure 3. Measurement of Prism Angle, α

Measurement of the angle of minimum deviation, δ_{min}

(Refer to Appendix 2 for the wavelengths of the spectral lines).

1. Remove the prism. Swing the telescope around in line with the collimator and center the cross hair on the slit image. Make the slit fairly narrow, but not so narrow that a single-slit diffraction pattern occurs.

2. Read the position of the telescope (**telescope position #1**) and record this in **Table 2**.

3. Place the prism on the table of the spectrometer such that one face makes an angle about 45^{o} with the light coming from the collimator. Look through telescope while swinging it slowly, until the colored images of the collimator slit are seen. Align the cross hair of the telescope on one of the images of spectral lines.

4. To find the position of minimum deviation for that spectral line, rotate the prism table slowly until a position is found where the spectral line just reverses its motion regardless of which way the table is turned. Repeat this several times until the turning point is clearly determined. This is the direction of minimum deviation for the spectral line. Read and record the angular position of the telescope (**telescope position #2**).

5. Repeat the procedure outlined above to determine the position of the prism for the minimum deviation for the other lines.

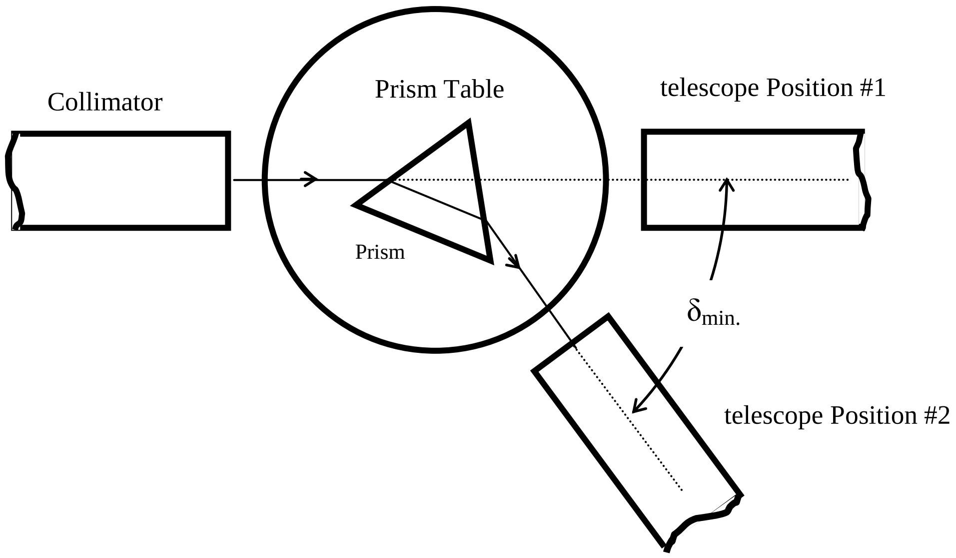

Figure 4. Measurement of the Angle of Minimum Deviation, δ_{min}

APPENDIX

1. Reading the Vernier Scale:

The angular scale is shown in **Fig.5**. You must first find the approximate position, on the main scale, of the zero mark of the vernier scale. In the figure, this is seen to be

$$(\text{reading}) = 153^o 30' + (\text{a little more})$$

To find out what this "little more" look through the vernier scale to find the position where a mark on the vernier scale aligns with a mark on the main scale. In the figure this happens at the $8'$ mark on the vernier scale, This reveals that the "little more" above is $8'$. Thus the final reading in the figure is

$$(\text{reading}) = 153^o 30' + 8' = 153^o 38' = 153.63^o$$

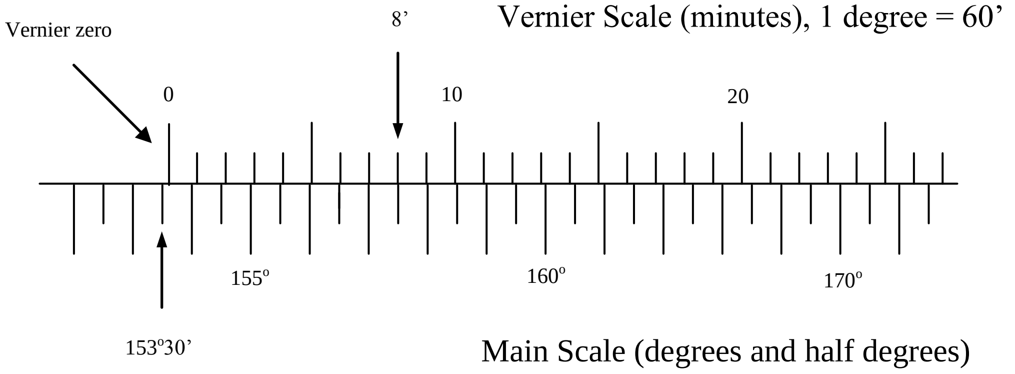

Figure 5. Angular Scale

2. Spectrum lines (in nm) to be used

HELIUM	HYDROGEN	MERCURY	SODIUM
483.7 Violet	410.1 Violet	404.6 Violet	449.7 Blue
447.1 Violet	434.0 Violet	407.8 Violet	466.8 Blue
471.3 Blue	486.1 Blue-Green	435.8 Blue	498.2 Blue-Green
492.1 Blue-Green	656.2 Red	491.6 Blue-Green	515.3 Blue-Green
504.7 Green		546.1 Green	588.9 Yellow
587.5 Yellow		577.0 Orange	615.4 Red
667.8 Red		579.1 Orange	
706.5 Red			

DATA and RESULTS

Name:________________________________ **TA**______________________________

Department:___________________________,

Partners:____

Table 1. Data for the Prism Angle, α

Position#1	**Position#2**	α_i
		$\overline{\alpha} = \frac{\sum_{i=1}^{N} \alpha_i}{N} =$

Table 2. Data for the Refractive Index vs. Wavelength

λ	**Position#1**	**Position#2**	δ_{min}	n

1. Plot a graph with indices of refraction as ordinates and wavelengths as abscissae.

2. Assuming that Cauchy`s equation gives the correct form of the relationship between *n* and λ, calculate the least square straight line for *n* versus $1/\lambda^2$. Plot this line on a graph with *n* as ordinates and $1/\lambda^2$ as abscissae. Show the experimental points on the graph. Write on the graph the values *A* and *B*.

DISCUSSION & CONCLUSION

1. What are the possible errors in the experiment?
2. What kind of approximations did you take into consideration while you were obtaining the physical quantities and how do they affect your results?
3. What discrepancies did you encounter between the calculated quantities and theoretical or literature values?
4. What is your overall conclusion?

DIFFRACTION and INTERFERENCE EXP OW-3

PURPOSE

- To observe diffraction and interference effects of light passing through various apertures.
- To use the diffraction patterns produced by single/double slit apertures and to calculate the wavelength of the light source which is used.

GENERAL

Certain optical phenomena may be accurately described by the hypothesis that light is an electromagnetic wave. These phenomena include diffraction and interference. Although it is customary to discuss interference and diffraction of light as separate topics, they are essentially similar. Both are special cases of superposition of waves. Roughly speaking waves emanating from more than one very small source may exhibit interference. Diffraction is interference of a wave with itself. According to Huygen's Principle waves propagate such that each point reached by a wavefront acts as a new wave source. Interference between secondary waves emitted from different parts of the wavefront can cause the bending of light around objects and cause intensity fluctuations much like the interference pattern from separate sources.

For the interference to be observed, the light has to be coherent, i.e.: the phase of the light wave is well defined at all times. For incoherent light, the interference is hard to observe because it is washed out by the very rapid phase jumps of the light.

Relative sizes and distances also affect the result of interference experiment. For instance when light propagates through and around objects whose dimensions are much greater than the wavelength, the wave effects are negligible so that it is behavior can be adequately described by ray optics. Consider also a situation where a point light source illuminates a slit. If both the light source and observation point are very far from the slit relative to its width, it is a good approximation to assume that incident and diffracted waves are plane. This condition is called Fraunhofer or far-field diffraction. Using this approximation, it is easy to compute the distance a wave must travel to reach the observation point from each part of the slit and then to use the principle of super position to deduce the observable intensity. The same method is used if the light source, the observer, or both are close to the slit, but the geometry harder to work out. This situation is called Fresnel or near-field diffraction.

In this experiment, under far field condition, diffraction and interference of light when it propagates through single and double slits will be explored. From the resulting diffraction patterns the wavelength of the incident light will be determined.

The main components used in the diffraction and interference experiments are a diode laser, a light sensor, a rotary motion sensor, linear translator and slit accessory (single slit disc and multiple slit disc):

DIODE LASER (see **Fig.1**)**:**

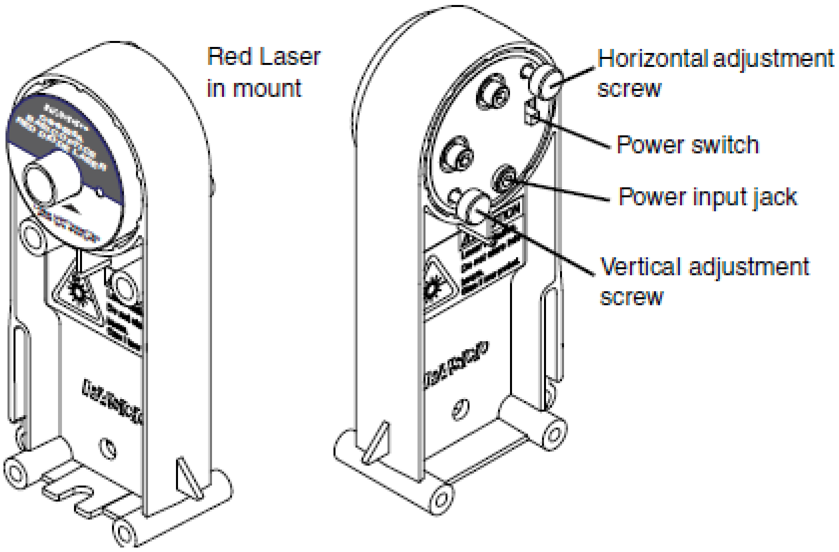

Figure 1

The diode laser has a wavelength $\lambda = 650 \pm 10$ nm. Output power is 0.9 mW. To turn the laser beam on firstly connect the AC adapter to a wall outlet and the power input jack. Then, slide the power switch on the back of the laser. Use the vertical and horizontal adjustment screws to aim the beam.

LIGHT SENSOR (see **Fig.2**)**:**

Figure 2

The CI-6504A is best suited for experiments performed at ambient light levels. At the lower end of the range, interference patterns of monochromatic light after it passes through single or multiple slits can be measured; at the higher end, measurements can be made of relative light intensities of daylight. The range switch settings (1X, 10X, and 100X) on the top of the sensor roughly correspond to maximum input light levels of 500, 50, and 5 lux.

ROTARY MOTION SENSOR (see **Fig. 3**)**:**

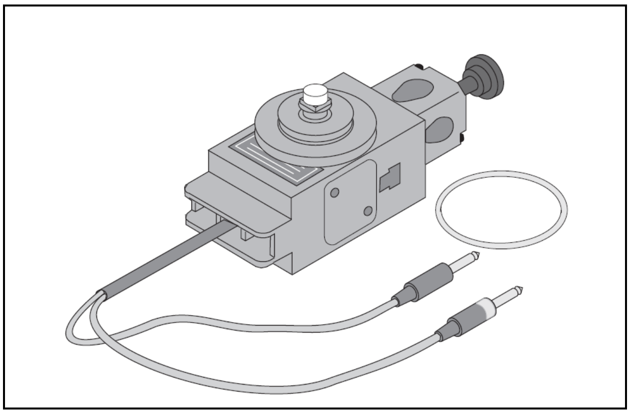

Figure 3

The Rotary Motion Sensor is a bidirectional position sensor. It contains an optical encoder which gives a maximum of 1440 counts per revolution (360 degrees) of the Rotary Motion Sensor shaft. The resolution can be set in the Science Workshop software to 360 or 1440 times per revolution (1 degree or 1/4 degree). The direction of rotation is also sensed.

LINEAR TRANSLATOR (see **Fig. 4**)**:**

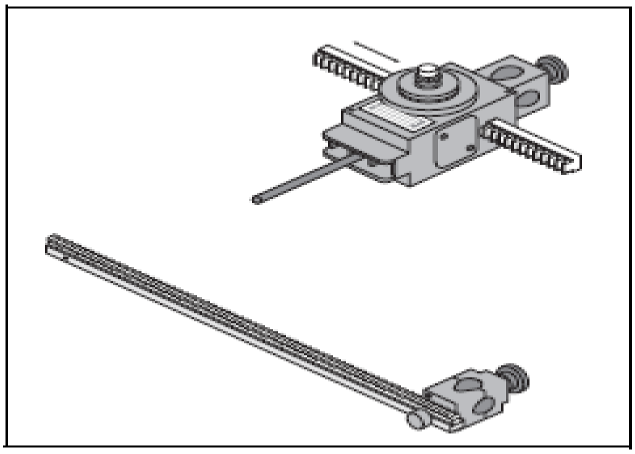

Figure 4

The Linear Motion Accessory is a 21 cm long rack that is inserted into the t-slot in the side of the RMS to convert a linear motion into a rotary motion. The teeth on the rack engage a gear inside the RMS, causing it to rotate as the rack is pushed through the slot. The rack may be inserted into either side of the RMS. Sensors can be mounted to the rack using the rod clamp which can be attached to either end of the Linear Motion Accessory rack.

SINGLE SLIT DISC (see **Fig. 5**)**:**

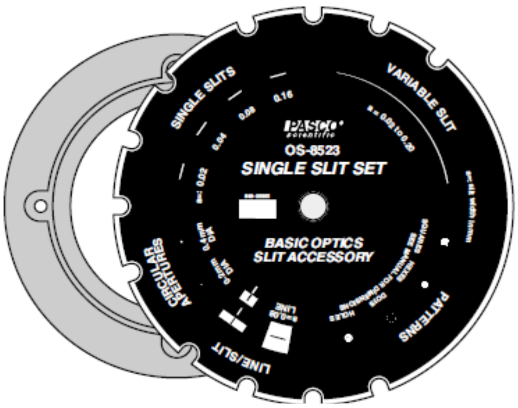

Figure 5

The contents of the Single Slit Disk are:

– 4 single slits (slit widths 0.02, 0.04, 0.08, 0.16 mm)
– 1 square pattern
– 1 hexagonal pattern
– 1 random hole pattern (hole diameter = 0.06 mm)
– 1 opaque line of width 0.08 mm
– 2 circular apertures (diameters 0.2 mm and 0.4 mm)
– 1 variable slit (slit width varies from 0.02 to 0.20 mm)
– 1 random opaque dot pattern (dot diameter = 0.06 mm)
– 1 slit/line comparison, line and slit have similar width (0.04 mm)

MULTIPLE SLIT DISC (see **Fig. 6**):

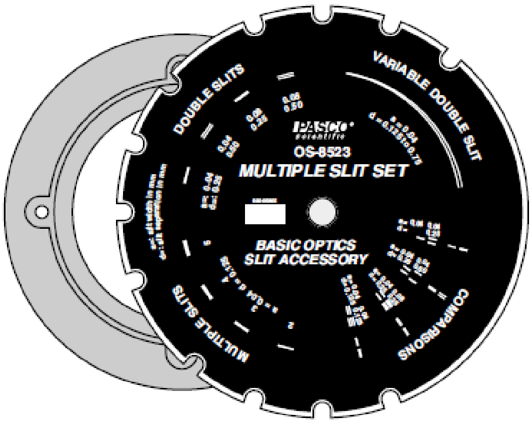

Figure 6

The contents of the Multiple Slit Disk are:

– 4 double slits (slit width/separation in mm: 0.04/ 0.25, 0.04/0.50, 0.08/0.25, 0.08/0.50)

– 4 comparisons: single/double slit with same slit width (0.04 mm)

– double/double slit with different slit widths (0.04, 0.08 mm), same separation (0.25 mm)

– double/triple slit with same slit width (0.04 mm), same separation (0.125 mm)

– set of 4 multiple slits (2, 3, 4, 5 slits) with same slit width (0.04 mm), same separation (0.125 mm)

– 1 variable double slit (slit separation varies from 0.125 to 0.75 mm with constant slit width 0.04 mm)

– double/double slit with same slit width (0.04 mm), different separation (0.25 mm/0.50 mm)

Single Slit Diffraction:

Intensity distribution (I_s) of the diffraction pattern produced by a single slit of width d, illuminated by plane wave of wavelength, λ is given by

$$I_s = I_0\,[\sin\alpha/\alpha]^2 \qquad \textbf{Eq. (1)}$$

where

$$\alpha = \pi a \sin\theta / \lambda \qquad \textbf{Eq. (2)}$$

and I_0 is the intensity at the middle of central maximum, and θ is the observation angle (Fig.7).

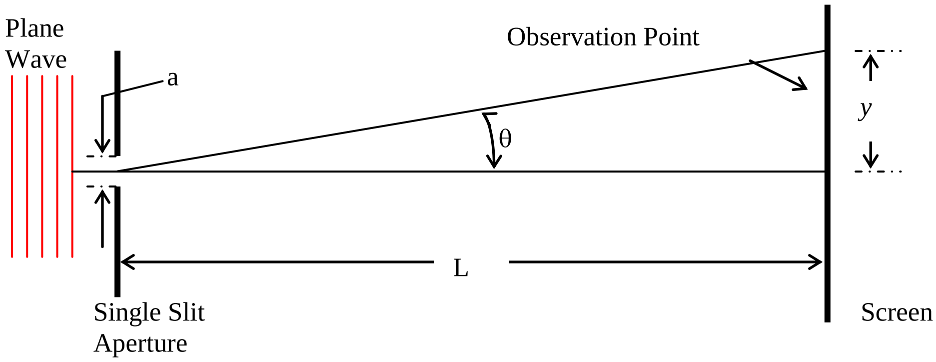

Figure 7. Definition of distances and angle for single slit diffraction measurements

A plot of I_s as a function of $\sin\theta$ is shown in **Fig.8**.

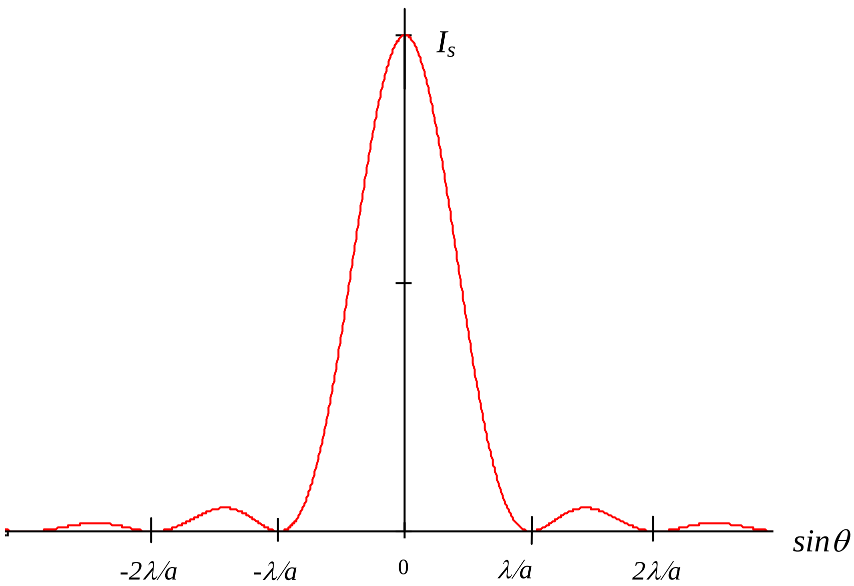

Figure 8. Single Slit Diffraction Intensity Pattern

The pattern has a peak at $\theta = 0$. The intensity is minimum when

$$n\lambda = a \sin\theta \qquad n = 1, 2, 3 \qquad \textbf{Eq. (3)}$$

Assuming the distance L to the slit to be much larger than the slit width a, then

$$\sin\theta \approx \tan\theta = y / L \qquad \textbf{Eq. (4)}$$

where y is the distance from central maximum to the observation point. Because the distance between adjacent minima are all the same **Eq. (3)** along with **Eq. (4)**, permits the following expression

$$\lambda = a\bar{y}/L \qquad \textbf{Eq. (5)}$$

where $\bar{y}$ is the distance between adjacent minima.

Double Slit Diffraction:

Intensity distribution (I) produced by a double slits of separation b (ignoring the effect of the slit widths) is given by the interference term

$$I = 4I_s \cos^2\beta \qquad \textbf{Eq. (6)}$$

with β

$$\beta = (\pi b/\lambda)\sin\theta \qquad \textbf{Eq. (7)}$$

where θ is the observation angle (see **Fig. 9**).

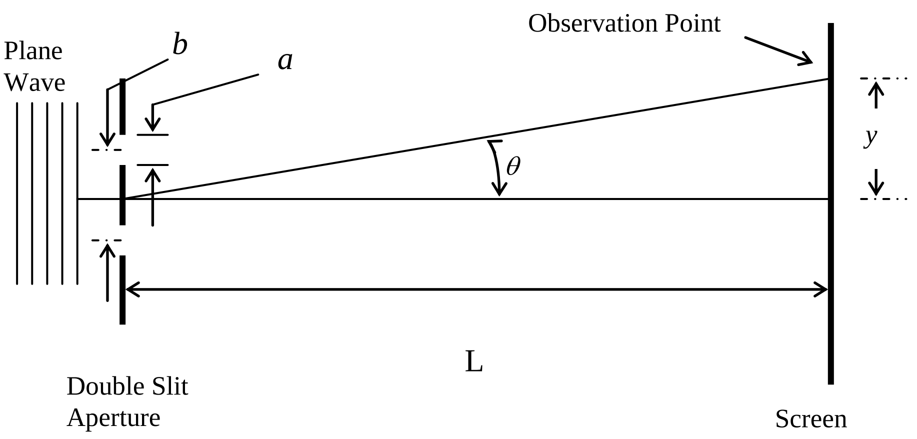

Figure 9. Definition of distances and angle for double slit diffraction measurements

Here it is assumed that the intensity (I_s) from each slit is constant. However, recall that the intensity from a single slit depends on the angle θ through diffraction, so **Eq. (6)** along with **Eq. (1)** give the following expression for the double slit diffraction intensity distribution (I).

$$I = 4I_0\, [\sin\alpha/\alpha]^2 \cos^2 \beta\,. \qquad \textbf{Eq. (8)}$$

Double slit diffraction is thus the product of interference factor $\cos^2 \beta$ and diffraction factor $[\sin\alpha/\alpha]^2$. Diffraction factor in the above expression constitutes an envelope for the interference fringes as shown in **Fig. 10**

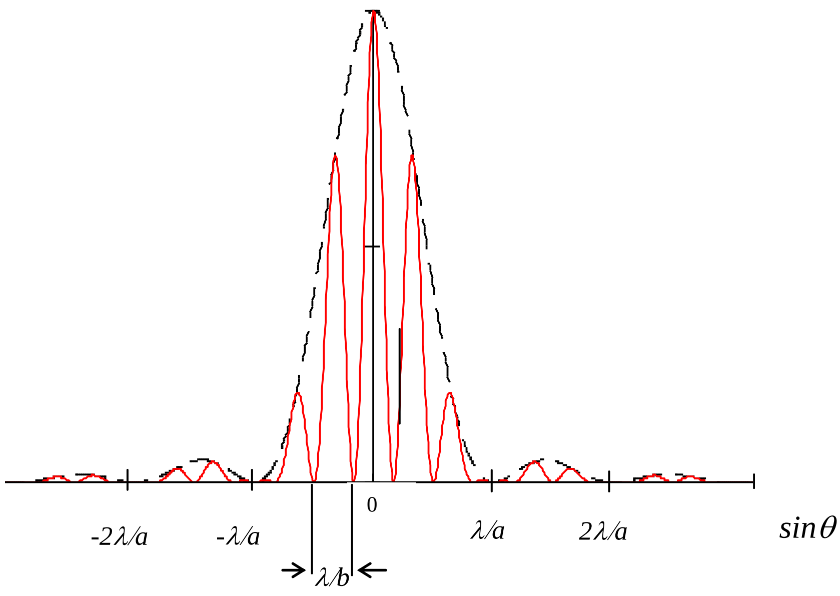

Figure 10. Double Slit Diffraction Intensity Pattern

Eq. (8) indicates that an interference minimum, $I=0$, will occur when

$$\beta = (n+1/2)\,\pi \qquad n = 0, 1, 2, 3, \ldots\ldots\ldots\ldots \qquad \textbf{Eq. (9)}$$

and interference maxima occur when

$$\beta = n\pi \qquad n = 0, 1, 2, 3, \ldots\ldots\ldots\ldots \qquad \textbf{Eq. (10)}$$

As assumed previously if L is much greater than b, the angle θ can be approximated by

$$\sin\theta \approx \tan\theta = y / L \qquad \textbf{Eq. (11)}$$

Because distance between all the adjacent minima and maxima are the same, **Eq. (9)** and **Eq. (10)**, along with **Eq. (11)** permit the following expression

$$\lambda = b\bar{y}'/L \qquad \textbf{Eq. (12)}$$

where $\bar{y}'$ is the distance between either adjacent maxima or minima

EQUIPMENT

- Optics Bench
- Aparture Bracket
- Diode Laser
- Rotary Motion Sensor
- Light Sensor
- Linear Translator
- Slit Accessory

PROCEDURE

The light source in this experiment is a Diode laser which produces a monochromatic beam with a wavelength of λ = 650 nm. The output power of our lasers is about 0.9 mW, small amount, but still enough to damage your retina if you look directly into the beam.
CAUTION: Never Look Directly To Laser Beam

Firstly, you will spend a few minutes to explore diffraction patterns of apertures of various size and combination at near field and far field regions. You need not make any measurements or calculations in this part.
In **Part A** and **Part B** the wavelength of the incident laser light will be measured using diffraction patterns produced by single and double slit set discs respectively.

Part A :

1. Set up the apparatus for Fraunhofer diffraction according to **Fig. 11**.

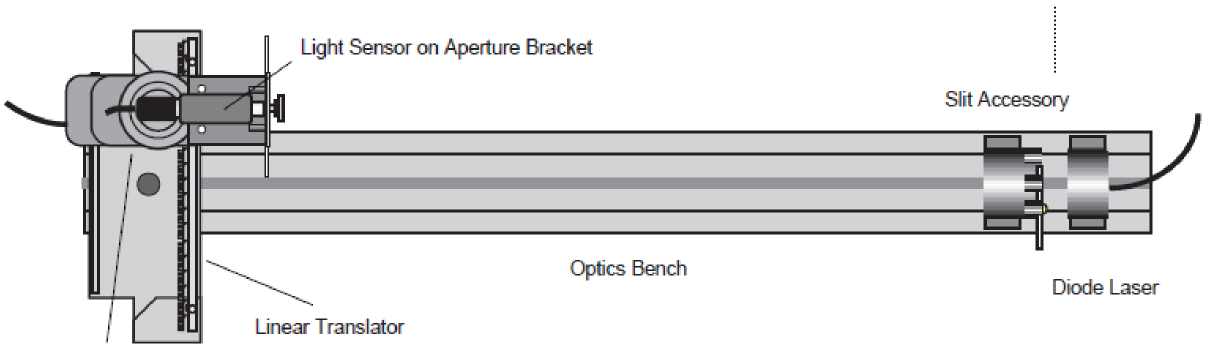

Figure 11. Diffraction and interference

In this setting the laser is placed at one end of the optical bench. The diffraction plate is mounted on a holder near the laser on the optical bench.

2. Plug in the power supply for the Diode Laser. Turn on the laser.

3. Rotate the Single Slit Set disk on the Slit Accessory until a slit pattern is in line with the laser beam (see **Fig. 12**). Use the adjustment screws on the back of the Diode Laser to adjust the beam if necessary.

4. Rotate the pulley on the top of the Rotary Motion Sensor to move it along the rack on the Linear Translator. Move the Rotary Motion/Light Sensor until the white screen on the front of the Aperture Bracket shows the diffraction pattern.

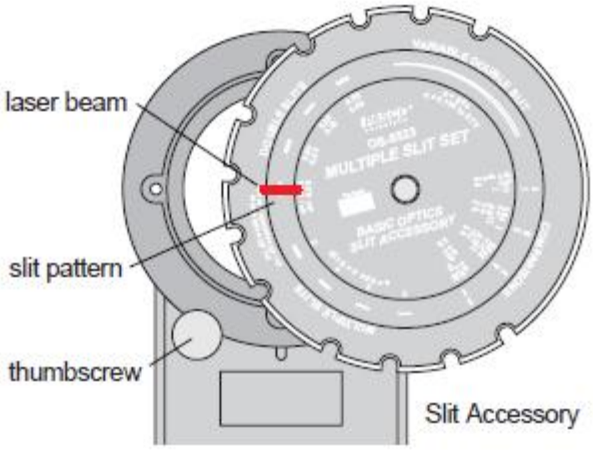

Figure 12

5. Examine the diffraction pattern on the white screen. If the pattern is not horizontal, loosen the thumbscrew on the Slit Accessory. Slowly rotate the Slit Accessory until the laser beam is *centered* on the slit pattern you want and the diffraction pattern is *horizontal* on the white screen on the Aperture Bracket (see **Fig. 13**). Tighten the thumbscrew on the Slit Accessory to hold it in place.

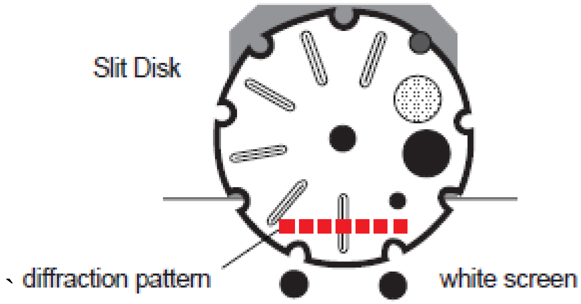

Figure 13

6. Rotate the Aperture Disk on the front of the Aperture Bracket until the narrowest slit opening is in front of the Light Sensor opening. This reduces the amount of ambient light that can enter the Light Sensor while the Light Sensor is between maxima of the diffraction pattern.

7. Move the Rotary Motion Sensor/Light Sensor along the rack on the Linear Translator until the *center* of the diffraction pattern is aligned with the center of the narrow slit on the Aperture Disk of the Aperture Bracket. Loosen the Rotary Motion Sensor rod clamp and adjust the Aperture Bracket and Light Sensor up or down if necessary.

8. Turn on the interface. Before starting to take data, open the graph icon from the main menu.

9. Be sure that vertical axis of the graph must be light intensity (caused by laser detected by light sensor) and horizontal axis must be **Linear** position (detected by rotary motion sensor-rack option).

10. Then start taking data by pushing the play button once on the keyboard of the interface.

11. Move the Rotary Motion Sensor/Light Sensor along the rack on the Linear Translator from left to right or vice versa.

12. In order to stop the measurement, push the play button once more.

13. Go back to the main menu by pushing the home button on the interface and choose the files icon. In this sub menu you will see your measurement data as untitled file. You should rename and save it.

14. Then plug in your flash disk to the interface and send data to it.

15. Change the slit openings and repeat the above procedure for different slit widths.

16. Turn off the laser and the interface.

17. Record the data in corresponding tables.

Part B

Repeat the above to explore the diffraction patterns of the double slit experiment using Multiple Slit Set disc.

DATA and RESULTS

Name:________________________________ TA__________________________________

Department:___________________________

Partners:____

PART A: Single Slit

Table 1. Sample data for single slit patterns A, B, and C

Pattern	A	B	C
Width of the slit, a			
Distance from the slit to the screen, L			
Average distance between minima, $\bar{y}$			
$\bar{\lambda} = \dfrac{a\bar{y}}{L}$			
Error Δy on $\bar{y} = \sqrt{\dfrac{\sum_{i=1}^{N}\left(y_i - \bar{y}\right)^2}{N-1}}$			
Error $\Delta\lambda$ *on* $\bar{\lambda} = \dfrac{a}{L}\Delta y$			
$\lambda = \bar{\lambda} \pm \Delta\lambda$			

Referring to **Table 1**

1. Use the values obtained for $\bar{y}$ to estimate the wavelength $\bar{\lambda}$.

2. Calculate the error $\Delta\lambda$ on $\bar{\lambda}$.

PART B: Double Slit

Table 2: Sample data for double slit patterns D, E, and F

Pattern	D	E	F
Distance between the center of the slits, *d*			
Distance from the slits to the screen, *L*			
Average distance between minima, $\bar{y}$			
$\boldsymbol{\bar{\lambda} = \frac{d\bar{y}}{L}}$			
Error Δy on $\bar{y}$ $= \sqrt{\frac{\sum_{i=1}^{N}\left(y_i - \bar{y}\right)^2}{N-1}}$			
Error $\boldsymbol{\Delta\lambda}$ ***on*** $\boldsymbol{\bar{\lambda} = \frac{d}{L}\Delta y}$			
$\lambda = \bar{\lambda} \pm \Delta\lambda$			

Referring to **Table 2**

1. Use the value obtained for $\bar{y}$ to estimate the wavelength $\bar{\lambda}$.

2. Calculate the error $\Delta\lambda$ on $\bar{\lambda}$.

3. How well do your values for the wavelength obtained in **PART A** and **PART B** agree with each other and with the expected value of 650 nm? Discuss any discrepancy.

DISCUSSION & CONCLUSION

1. What are the possible errors in the experiment?
2. What kind of approximations did you take into consideration while you were obtaining the physical quantities and how do they affect your results?
3. What discrepancies did you encounter between the calculated quantities and theoretical or literature values?
4. What is your overall conclusion?

PURPOSE

- To verify Malus' law

GENERAL

According to the wave model, light is a transverse electromagnetic wave. Electric and magnetic fields associated with the wave oscillate perpendicular to the direction of propagation. The electric field of an electromagnetic wave, in particular, can be represented by two orthogonal components. These two orthogonal components do not interfere in amplitude but are additive according to vector algebra. For an unpolarized light there is no well-defined phase relationship between these two components. The planes of oscillations of the resultant field change randomly. Light is said to be polarized when a fixed phase and amplitude relationship is maintained between the two orthogonal field components. Resultant wave formed by the orthogonal components can have various states of polarization. Referring to **Fig. 1**, three basic types of polarized light are:

1. Linearly, or plane, polarized light. Oscillation is confined to a plane. The resultant electric field vector traces out a straight line.

2. Circularly polarized light. The resultant electric field vector traces out a circle.

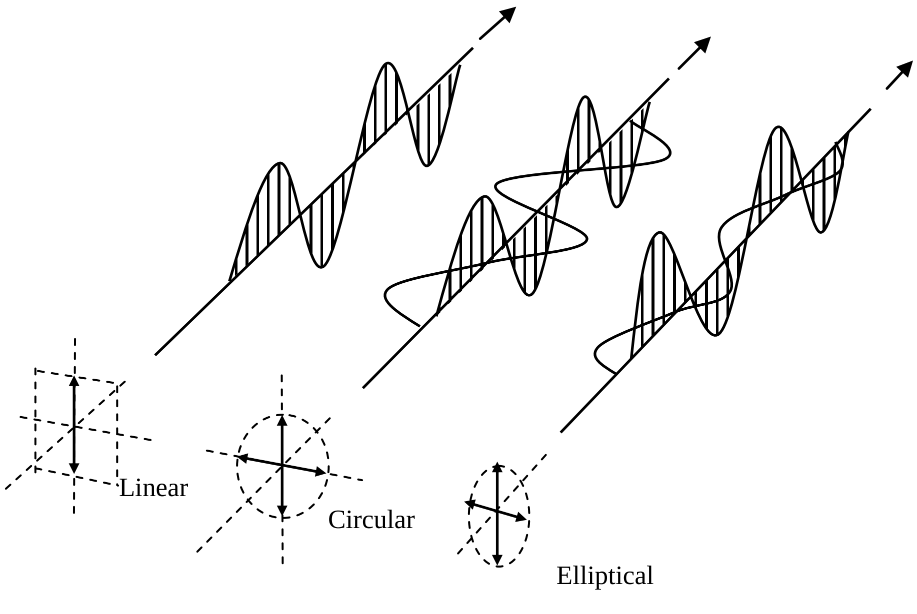

Figure 1

3. Elliptically polarized light. The resultant electric field vector traces out an ellipse. This is the most general state of polarized light.

Processes of preferential absorption in a dichroic material, reflection and transmission at oblique incident, double refraction in a birefringent material, and scattering by particles can be used for producing polarization. An ideal polarizer transmits only light whose electric field component is parallel to the transmission axis of the polarizer and blocks light whose the electric field components are perpendicular to it,

Fig. 2.

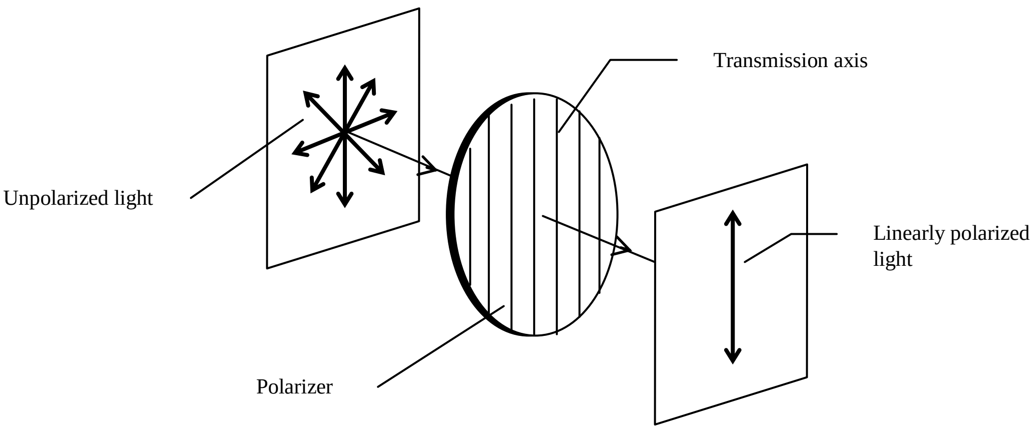

Figure 2

Real polarizers are not perfect and transmit light with minimum intensity when polarizer axis is perpendicular to the polarization of purely linearly polarized light. The maximum transmitted intensity occurs when the polarizer axis is parallel to the incident polarization direction.

In the present experiment Malus' law is verified. Suppose, as illustrated in **Fig. 3**, we have two linear polarizers made of dichroic material. The first is called polarizer and produces plane polarized light by strongly absorbing the component of the incident electric field perpendicular to its axis. The second is called the analyzer. Let the angle between the axis of the polarizer and analyzer is θ. It is easily shown that if the intensity of the **unpolarized light** incident on the analyzer is I_{in} , then the intensity , $I(\theta)_{out}$, of the polarized light leaving the analyzer is given by

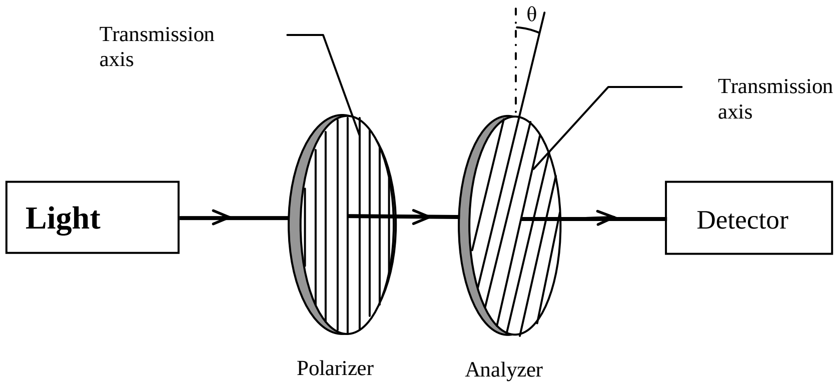

Figure 3

$$I(\theta)_{out} = I_{in}\left[H_{90} + \left(H_0 - H_{90}\right)\right]\cos^2\theta \,. \qquad \textbf{Eq. (2)}$$

This is the Law of Malus, where the quantity $H_0 = \frac{1}{2}\left(k_1^2 + k_2^2\right)$ is the transmittance of the parallel pair, and $H_{90} = k_1 k_2$ is the transmittance of the crossed pair. k_1 and k_2 are called principal intensity transmittances where k_1 is the intensity transmittance which the polarizer exhibits when inserted in a linearly polarized beam and turned to the angle that maximizes the intensity of the emerging beam, and k_2 is the intensity transmittance found when the polarizer is turned so as to minimize the intensity. When k_1 and k_2 have the ideal values of 1 and 0, **Eq. (2)** reduces to

$$I(\theta)_{out} = \frac{1}{2} I_{in} \cos^2\theta \qquad \textbf{Eq. (3)}$$

EQUIPMENT

- Optical Bench
- Polarizer (2)
- Interface
- Laser
- Light Sensitive Detector
- Rotary Motion Sensor

PROCEDURE

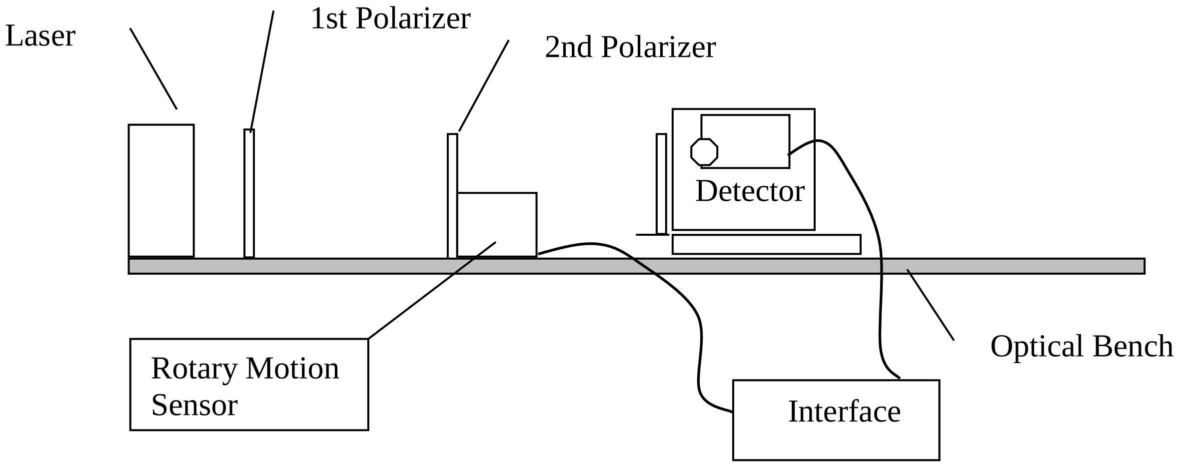

Figure 4

1. Turn on the laser. Adjust the position of the both polarizers so that their transmission axes become parallel.
2. Turn on the interface. Before starting to take data, open the graph icon from the main menu.
3. Then start taking data by pushing the play button once on the keyboard of the interface.
4. Next slowly rotate the **2nd Polarizer** up to **400º, more than full cycle** (i.e. polarizer which is connected to the rotary motion sensor.)
5. In order to stop the measurement, push the play button once more.

6. Go back to the main menu by pushing the home button on the interface and choose the files icon. In this sub menu you will see your measurement data as untitled file. You should rename and save it. Then plug in your flash disk to the interface and send your saved file to it.

7. Turn off the laser and the interface.

DATA and RESULTS

Name:______________________________ TA__________________________

Department:________________________

Partners:____

1. Plot a graph with measured intensities $I(\theta)$ as ordinates and the angle θ between the polarizers as abscissa. Does it appear to fit to a function of the form $I(\theta) = a + b\cos^2\theta$? If yes explain.

2. Which type of polarization do you observe? (i.e. Linear, circular or elliptical polarization)

DISCUSSION & CONCLUSION

1. What are the possible errors in the experiment?
2. What kind of approximations did you take into consideration while you were obtaining the physical quantities and how do they affect your results?
3. What discrepancies did you encounter between the calculated quantities and theoretical or literature values?
4. What is your overall conclusion?

GRATING SPECTROMETER EXP OW-5

PURPOSE

- Familiarization with the grating spectrometer
- To observe and measure the discrete wavelengths emitted from a gas discharge lamp

GENERAL

A grating spectrometer is in every way similar to a prism spectrometer such as the one we have used in EXP.OW-4 with the exception that a plane diffraction grating replaces the prism as the dispersing element. The relevant parts of the system are illustrated in **Fig. 1**.

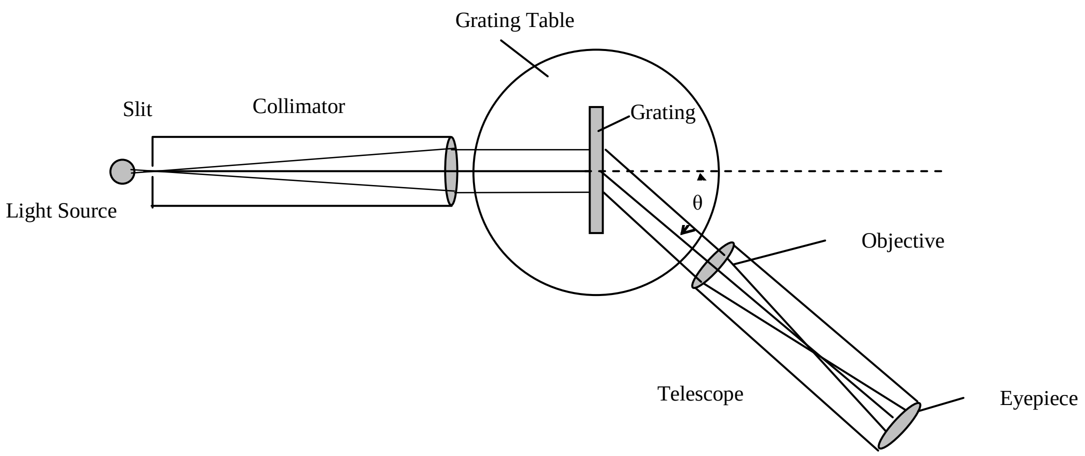

Figure 1. Layout of the grating spectrometer

The diffraction grating used in this experiment is a transmission diffraction grating and consists of a very large number of closely spaced parallel slits in a piece of otherwise opaque material. They all have the same width and spacing. They are much longer than they are wide. Therefore we ignore their lengths. Then the only parameters that define the grating are the slit width, their spacing from each other, and their number. A diffraction grating can have several thousand slits per centimeter.

When a parallel beam of polychromatic light from collimator falls on a transmission diffraction grating, each slit diffracts the light so that on the other side of the grating, the diffracted light from many slits may interfere (constructively or destructively) at some point P on a distant screen. In the spectrometer, the screen is replaced by a telescope adjusted to accept parallel rays of diffracted light from the slits. The principles for the formation of the fringe pattern are similar to those of the double slit experiment described in EXP.OW-3, except that, owing to the much larger number of slits participating in the interference, bright fringes produced by the grating are much narrower and better defined. Diffraction angle θ shown in **Fig. 1** is unique for each wavelength present in the light source. For a general N-slit grating of slit widths a, and spacing d, the intensity distribution due to each wavelength is given by

$$I(\theta) = I_0 \left(\frac{\sin\beta}{\beta}\right)^2 \left(\frac{\sin N\alpha}{\sin\alpha}\right)^2 \qquad \textbf{Eq. (1)}$$

where I_0 is the intensity in the θ = 0 direction emitted by any one of the slits. α and β are (assuming that the angle of incidence of the rays illuminating the grating is perpendicular to the grating surface) given by

$$\beta = \frac{\pi a}{\lambda}\sin\theta \qquad \textbf{Eq. (2)}$$

and

$$\alpha = \frac{\pi d}{\lambda}\sin\theta \qquad \textbf{Eq. (3)}$$

In the fringe pattern the separation of diffraction minima is always larger than the separation of interference maxima. Thus the diffraction factor $(\sin\beta/\beta)^2$ constitutes an envelope over the interference factor $(\sin N\alpha/\sin\alpha)^2$ in **Eq.(1).** Referring to **Fig.2**, interference maxima will occur whenever the optical path length difference between the light from adjacent slits at a given position is equal to an integer number of wavelengths; that is

$$\boldsymbol{d\sin\theta = m\lambda} \qquad \textbf{for} \quad \boldsymbol{m} = 0, \pm 1, \pm 2, \ldots \qquad \textbf{Eq. (4)}$$

The pattern with $m=0$ is called zeroth order, that with $m = \pm 1$, first order, etc. Thus for a given order other than zeroth order ($m=0$) the incident light is diffracted at an angle θ given by $\sin\theta = m\lambda/d$. Since d is the grating constant and m is constant for a given order, the angle θ varies with wavelength. For each order ($m = \pm 1, \pm 2, \ldots$) different wavelengths are separated out and observed as distinct spectrum. However, since the spectral lines in adjoining orders may overlap, one must be careful in interpreting the spectral lines observed in the focal plane of the telescope.

On the other hand, diffraction minima will occur when

$$a\sin\theta = m\lambda \qquad m = \pm 1, \pm 2, \ldots \qquad \textbf{Eq. (5)}$$

If at some position a diffraction minimum happens to be at the same place as the interference maximum, the result will be a dark fringe. This phenomenon is known as the missing order due to diffraction minima.

In this experiment we use a grating spectrometer to make wavelength measurements on the spectrum of light obtained from a gas discharge lamp (Hg, He, or Na).

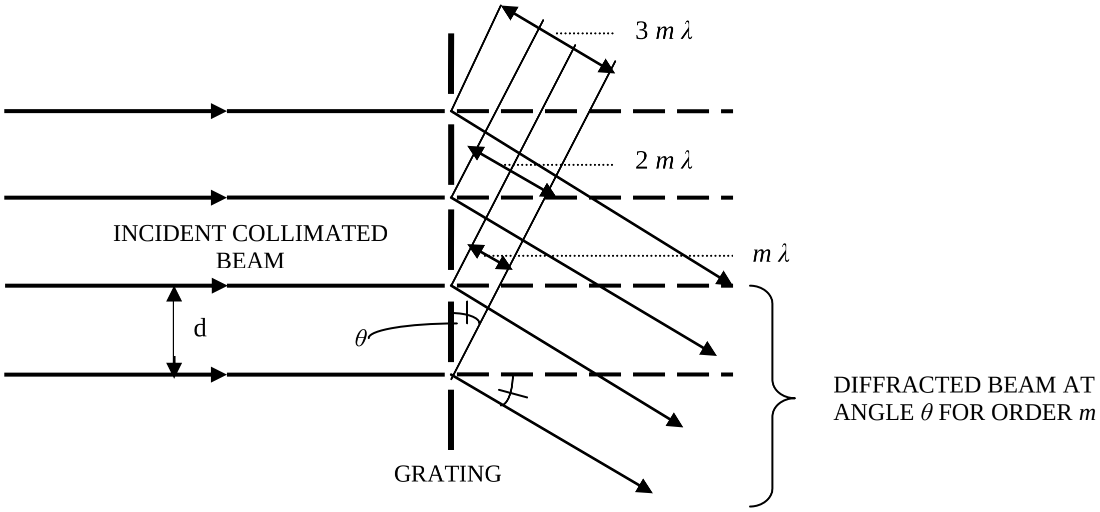

Figure 2

EQUIPMENT

- Student-type grating spectrometer
- Hg, He, or Na lamps

PROCEDURE

1. Place the discharge lamp adjacent to the collimator and switch it on. It will take about 10 minutes before the intensity of the light becomes constant. Looking through the collimator you should see a small rectangle of light coming from the discharge lamp. The rectangle is formed by the slit on the end of the collimator.

2. It is necessary to adjust the spectrometer so that the collimator produces parallel light and the telescope receives parallel light from the grating. Refer to EXP.OW-3 for this adjustment. When this procedure is complete the telescope and the collimator should not need further adjustment.

However the eyepiece may require some repositioning to accommodate individual eyesight variation.

3. Fix the mount for the grating to the spectrometer table. Place the grating into the mount. The table height should be set so that the full width of the collimated beam falls on the grating, without obstruction by the table or grating mount.

4. Rotate the table of the spectrometer until the grating plane is perpendicular to the axis of the collimator and with the ruled surface facing the telescope.

5. Look through the telescope. You should see a sharp image of the slit in the center of the field of view. This is the central maximum ($m=0$). Qualitatively scan the spectrum by rotating the telescope in either direction from the on-axis alignment with the collimator, in order to determine how many orders are visible.

6. Realign the telescope arm of the spectrometer with the collimator. Looking through the telescope you should again see the image of the slit. Use the fine adjustment screw of the telescope rotation to set the cross hairs into coincidence with the center of image. Read the angle on the vernier scale without moving the telescope and the collimator. If you did not observe the zero order exactly at zero ($\theta = 0^o$), then you record this reading and make all subsequent measurements relative to this value.

7. Look through the telescope while swinging it around slowly, until a series of coloured spectral lines are seen again. Align the cross wires of the telescope on the spectral lines observed and measure the angle θ that corresponds to angular location of these lines. Record your values in **Table 1**.

8. Repeat the same series of measurements on the opposite side of the zero position and fill your values in **Table 1**.

APPENDIX

1. Reading the Vernier Scale:

The angular scale is shown in **Fig.3**. You must first find the approximate position, on the main scale, of the zero mark of the vernier scale. In the figure, this is seen to be

$$\text{(reading)} = 153^o30' + \text{(a little more)}$$

To find out what this “little more”is, look through the vernier scale to find the position where a mark on the vernier scale aligns with a mark on the main scale. In the figure this happens at the $8'$ mark on the vernier scale, This reveals that the “little more” above is $8'$. Thus the final reading in the figure is

$$\text{(reading)} = 153^o30' + 8' = 153^o38' = 153.63^o$$

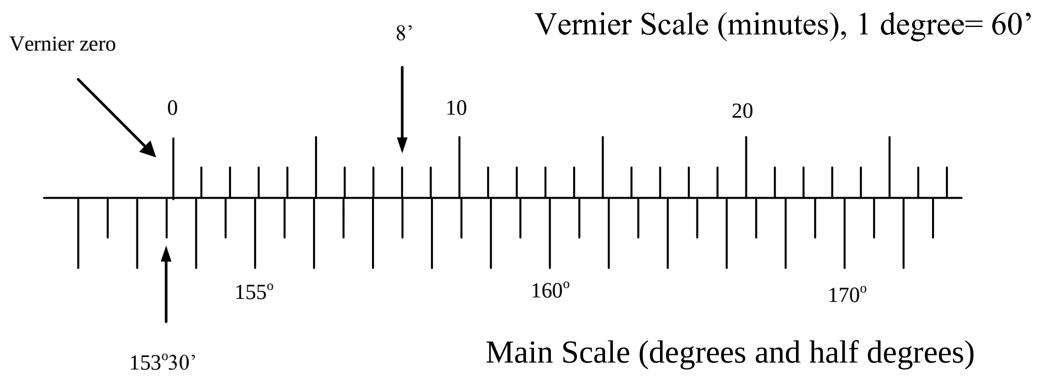

Figure 3. Angular Scale

2. Spectrum lines to be used

HELIUM	MERCURY	SODIUM
447.1 Blue-Violet	404.6 Violet	449.7 Blue
471.3 Blue	407.8 Violet	466.8 Blue
501.7 Green	435.8 Blue	498.2 Blue-Green
587.5 Yellow	491.6 Blue-Green	515.3 Blue-Green
667.8 Red	546.1 Green	588.9 Yellow
706.5 Red	577.0 Orange	615.4 Red
	579.1 Orange	

DATA and RESULTS

Name:____________________________ TA_________________________

Department:________________________

Partners:____

Table1

Gas Discharge Lamp=				Grating Spacing (d) =		
Color	θ^{o} (Clockwise Rotation)	θ^{o} (Counter-Clockwise Rotation)	θ^{o} (Average)	λ (Calculated)	λ (Literature)	% error

1. Determine the average values of θ for the observed spectral lines and fill them in **Table 1**. **Note:** For an ideal adjustment, a given spectral line in a given order should occur at equal angles both to the left and to the right of central maximum. However, errors in the alignment of the grating may give rise to measurable differences. These errors will be largely cancelled by averaging the two values of θ obtained on either side of the central maximum.

2. Using this information and **Eq. (4)**, calculate the wavelengths of the spectral lines and fill your values in **Table 1**.

3. Record the literature values of the wavelengths in **Table 1** and complete the table by calculating the % error.

4. Define the resolving power for grating spectrometers.

5. Calculate the theoretical resolving power of the grating spectrometer you have used in first, second, and third order.

6. What is the wavelength difference between two adjacent spectral lines that this spectrometer theoretically can resolve near the 500 nm wavelength region?

DISCUSSION & CONCLUSION

1. What are the possible errors in the experiment?
2. What kind of approximations did you take into consideration while you were obtaining the physical quantities and how do they affect your results?
3. What discrepancies did you encounter between the calculated quantities and theoretical or literature values?
4. What is your overall conclusion?

MICHELSON INTERFEROMETER EXP OW-6

PURPOSE

-To become familiar with the use of an interferometer.

-To measure the wavelength of the light source used (He-Ne laser).

-To measure the refractive index of air.

GENERAL

We learned previously that there were two main methods of obtaining interference: (1) division of wave front, and (2) division of amplitude. You saw the method (1) in EXP.OW-4. This experiment will introduce the method (2) by using a particular type of interferometer called Michelson Interferometer. A Michelson interferometer in its simplest form consists of two mirrors and a beam splitter (see **Fig. 1**). The beam splitter has a partially reflective coating on its one surface, so a beam from the laser source falling on a beam splitter is split into two coherent beams, one is reflected toward the fixed mirror M_1, the other is transmitted toward the movable mirror M_2.

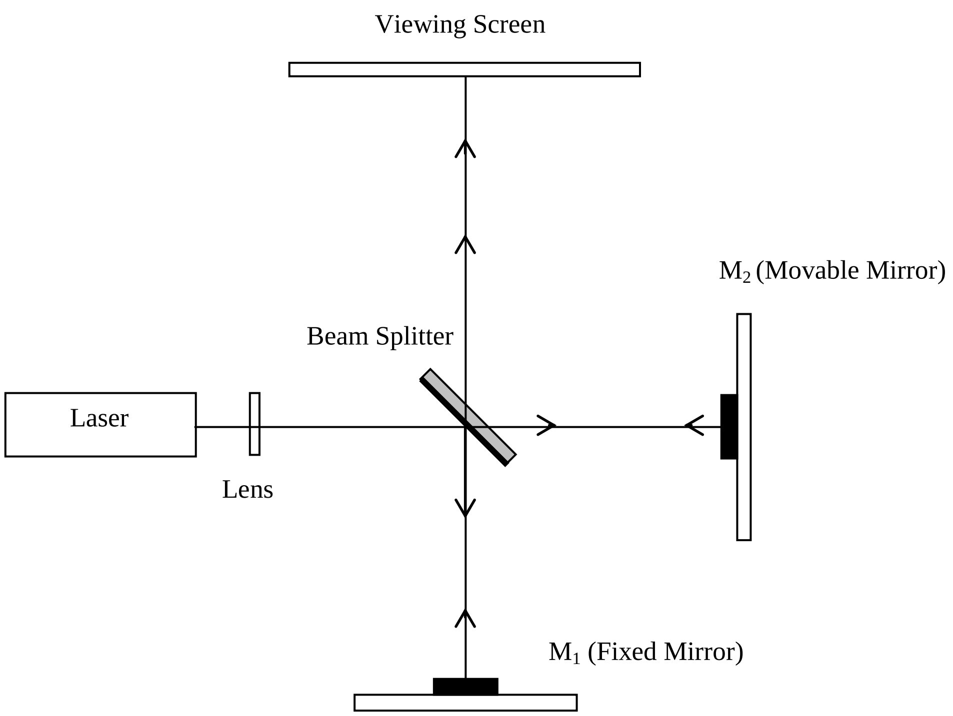

Figure 1. **Schematic Diagram of Michelson Interferometer** (refraction is ignored for the sake of clarity).

The two mirrors return the light to the beam splitter where they recombine and proceed toward the viewing screen (observer), where interference is observed. The He-Ne laser beam, we use, makes a small spot, so interference is hard to see. To make it bigger we insert a lens between laser and the beam splitter. This spreads out the beam and makes it easier to see the interference. However this spreading also means that only the central ray of the laser beam is still travelling on a straight line through the interferometer. All the surrounding rays are travelling at some angle, depending on how close to the center of the beam they are. If the mirrors precisely aligned such that their planes are exactly perpendicular to one another, thus ensuring that path differences over different regions of the mirrors are constant, the fringe pattern will be seen to consist of a series of bright and dark concentric rings. Each ring will correspond to different angle of travel of the surrounding rays. The interference is constructive or destructive, i.e. bright and dark rings, depending on the relative phases of the beams reflected from M_1 and M_2. This phase difference includes phase changes from reflections and different total distances that the two beams travel. What we care about in this experiment are the changes in phase. Once we set up the interferometer, we can count how many fringe cycles go by as we adjust something such as arm length. For example, if two beams start in phase but one travels farther than the other, then it will have greater phase by the time the two intersect. The amount of phase $\Delta\phi$ a beam accumulates by moving mirror M_2 a distance d is given by

$$\Delta\phi = 2\pi\left(\frac{d}{\lambda/n}\right) = 2\pi n\left(\frac{d}{\lambda}\right) \qquad \textbf{Eq. (1)}$$

where λ is the vacuum wavelength and n is the index of refraction of the medium in which the light beam is moving. Thus, if the interference pattern goes from constructive to destructive to constructive cycle N times when one mirror is moved a distance d, then from **Eq.(1)** we obtain,

$$N\lambda = 2n\,d \qquad \textbf{Eq. (2)}$$

In Part A of this experiment, λ will be determined by counting N and measuring Δd. Since N can be quite large with a coherent source like a laser, this determination can be extremely accurate.

In Part B, we are going to leave the arm lengths fixed and vary n by placing a small vacuum chamber along one of the arms (see **Fig.1**, in the diagram anti-parallel rays are slightly displaced for the sake of clarity) and pump out some of the air. As we lower the pressure, we change the refractive index of air in the chamber, because the air becomes less dense. If everything else stays constant in the interferometer, by counting the fringe cycles as the pressure is changed, the index of refraction of air is determined from the relation:

$$n_{atm} - 1 = (N/\Delta P)(\lambda/2d)P_{atm} \qquad \textbf{Eq. (3)}$$

where, n_{atm} is the refractive index of air at atmospheric pressure, N is the number of fringe cycles counted, $\Delta P=P_{final}-P_{initial}$ is the associated pressure change inside the chamber. P_{atm} is the atmospheric pressure, d is the length of the vacuum chamber, and λ is the wavelength of the light source in vacuum. Here it is assumed that the temperature and the volume of the vacuum chamber remain constant.

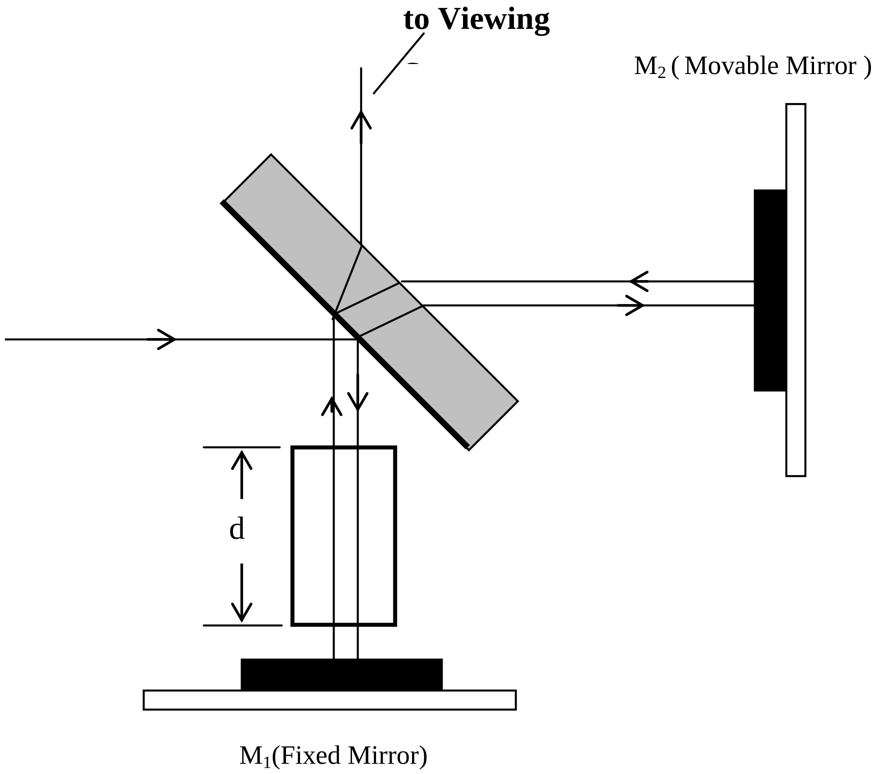

Figure 2. Vacuum chamber is placed at one arm of the interferometer

EQUIPMENT

- PASCO Interferometer
- Beam Expanding Lens with Holder
- Viewing Screen
- Vacuum Pump
- He-Ne Laser
- Vacuum Cell for measuring the refractive index of of air

PROCEDURE

PART A: Measuring the wavelength of the laser

1. Align the laser and interferometer as described in the Appendix until a nearly circular (or elliptical) interference pattern is clearly visible on the screen.

2. Adjust the micrometer knob so the lever arm is approximately parallel with the edge of the interferometer base. In this position the relationship between knob rotation and the mirror movement is mostly linear.

3. Turn the micrometer knob one full turn counterclockwise. Continue turning counterclockwise until the zero on the knob is aligned with the index mark.

4. Select a mark on the screen, then slowly turn the micrometer counterclockwise and watch the fringe patterns march across the screen. Carefully count a number of fringes as they move past the mark and record the final position of the micrometer. It is suggested that you count about 30 or more fringes. Fill the number of fringes N and the distance d the mirror moves in **Table 1**. Note that each division of micrometer knob corresponds to one micron (10^{-6} m) of mirror movement.

5. Obtain at least 4 different measurements of N and d , also filling your data in **Table 1**.

PART B: Measuring the refractive index of air

1. Align the laser and the interferometer as before.

2. Insert the vacuum chamber in the fixed arm of the interferometer (see **Fig. 2**) and connect it to the hand operated vacuum pump provided. Notice that the banana plug of the vacuum chamber is free to rotate. For accurate measurements, the end plates of the vacuum chamber must be perpendicular to the laser beam.

3. Adjust the alignment screws of the fixed mirror so that the center of the interference pattern is clearly visible on the viewing screen.

4. Make a reference mark on the viewing screen.

5. Evacuate the vacuum chamber with the small hand-operated pump provided. Stop evacuating after about four squeezes of the pump since too much pressure can damage the pump. Let the air return slowly by gradually opening the stop valve on the pump while recording N for several values of P_{final}. Fill your data in **Table 2** (Note that vacuum gauge measures vacuum pressure with respect to the atmospheric pressure. For example, when the gauge reads 32 cm Hg, it means that the pressure is actually 32 cm Hg below the atmospheric pressure). Alternatively, you may record the number of fringes *N*, as they pass your reference mark for several values of P_{final} while you slowly and carefully pump out the air from the chamber. Use whichever method you find easier for controlling the air flow.

APPENDİX

Alignment of the interferometer (*)

Before beginning the alignment of the interferometer you should fully understand that one must never touch the mirror surfaces or bump, or drop any part of the apparatus as it is delicate and expensive!. One must not use force to move any part of the instrument. As you have been warned in a previous lab, you must never look directly into a laser beam, or into a mirror that is reflecting a laser beam!

The alignment of the Michelson Interferometer is accomplished in several logical steps.

1. Referring to **Fig. 3**, place the Laser and the Interferometer on the Optics Bench, approximately 10-20 cm apart. Be sure that the edges of both units are flush against the alignment rail of the bench. Place the Viewing Screen. A blank sheet of white paper taped to the Screen Holder provides a viewing screen.

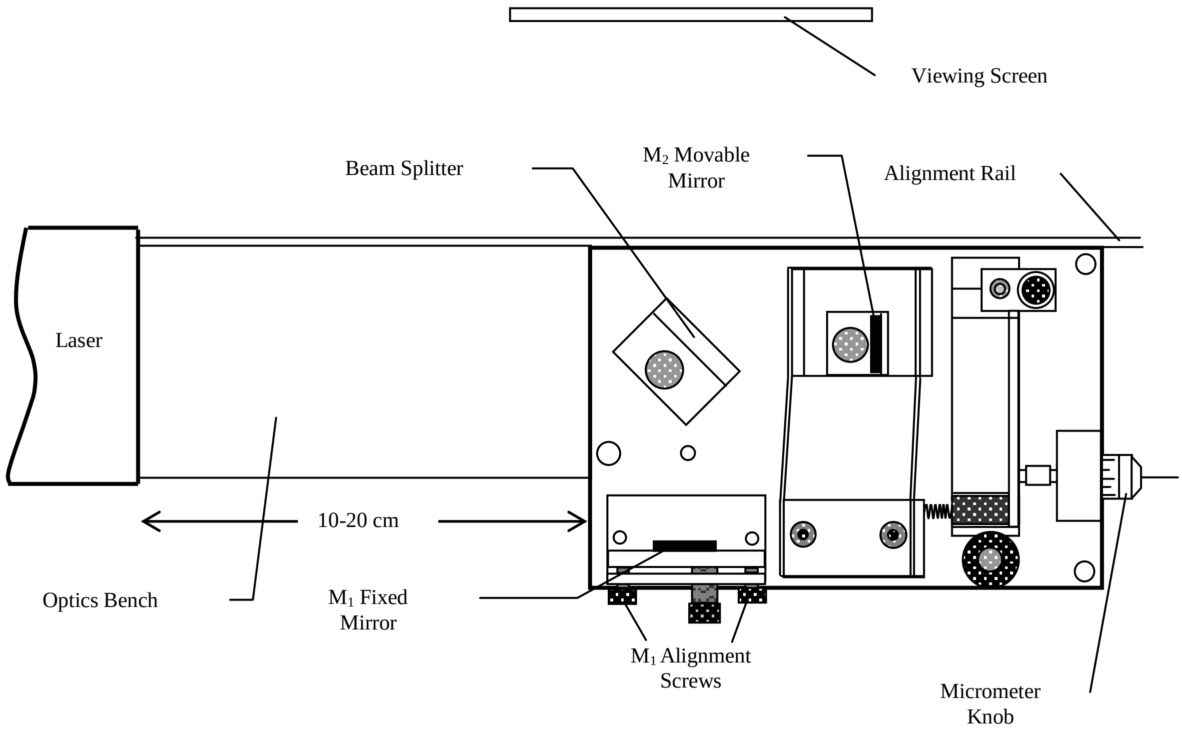

Figure 3. Adjustment of Michelson Interferometer

2. Referring to **Fig.4**, turn on the laser. Loosen the thumbscrew that holds the beam splitter and rotate the beam splitter so it is out of the beam path. Then loosen the thumbscrew that holds the movable mirror M_2. Adjust the rotation of M_2 so the laser beam reflected directly back toward the aperture of the laser. (The reflected beam should not to be at the same height as

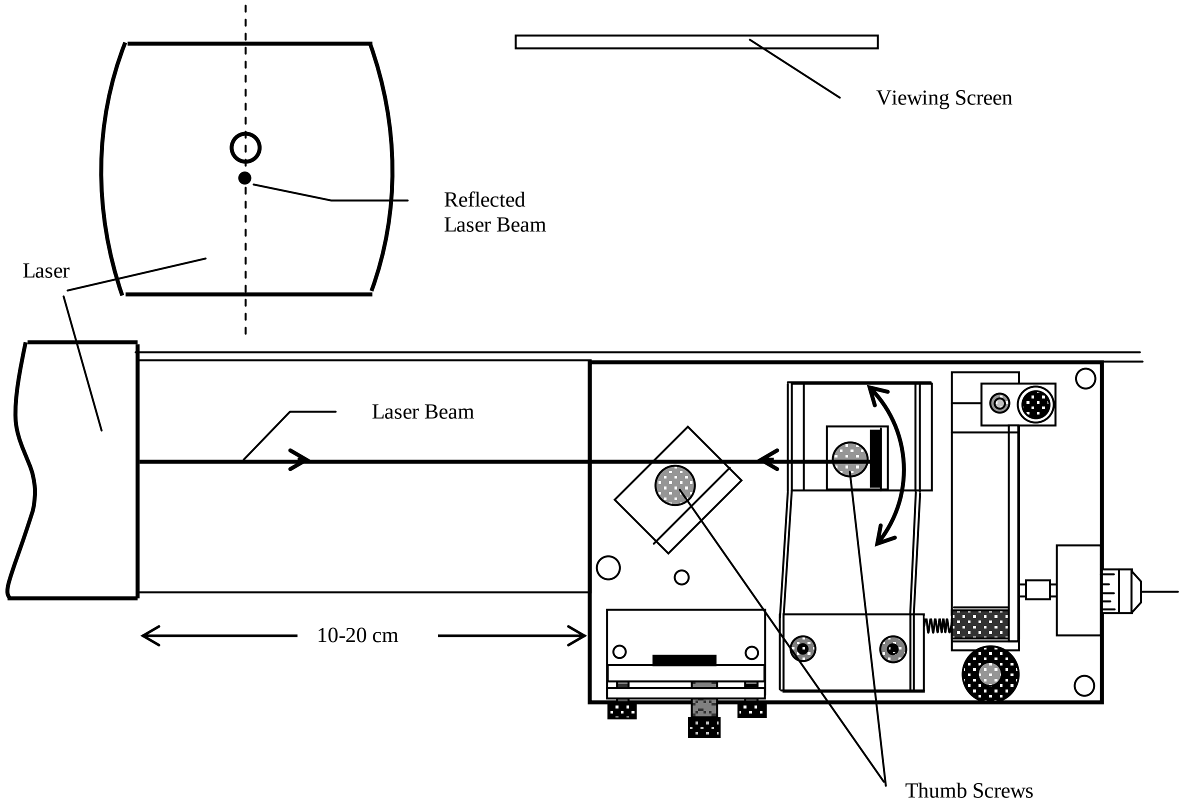

Figure 4. Adjustment of M_2

the incident beam, but it should strike the front panel of the laser along a vertical line through the aperture). Hold M_2 in position and tighten the thumbscrew.

3. Referring to **Fig. 5**, rotate the beam splitter so its surface is at an angle approximately 45^o with the incident beam. Now, you will see two sets of laser spots on the screen. (These two sets corresponds to the two paths via M_1 and M_2 of the laser beam reaching the screen., the additional laser spots in the sets are due to multiple reflections within the beam splitter.) Adjust the beam splitter so the laser spots are as close as possible. Hold the beam splitter in position and tighten the thumbscrew.

4. In this step the adjustment is made so the mirrors M_1 and M_2 are perpendicular to one another. To accomplish this adjust the alignment screws on the back of mirror M_1 until you can overlap two brightest spots of the sets on the Viewing Screen.

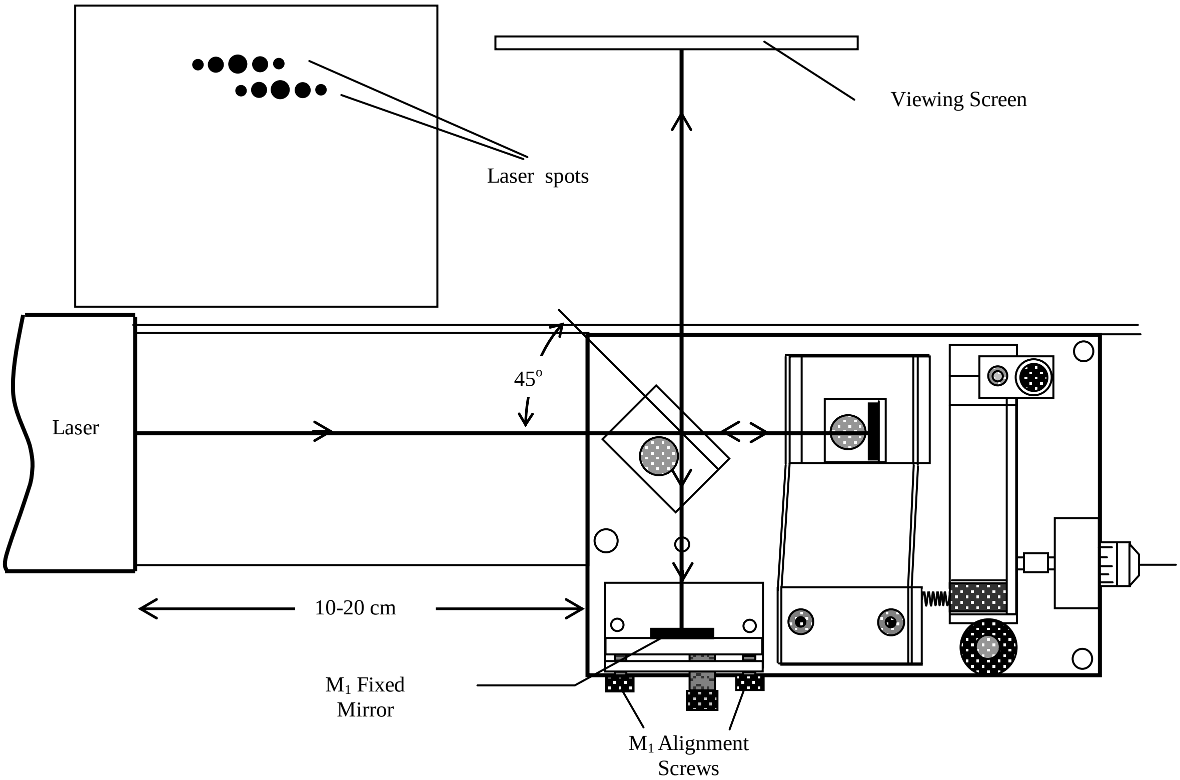

Figure 5. Alignment of the laser spots

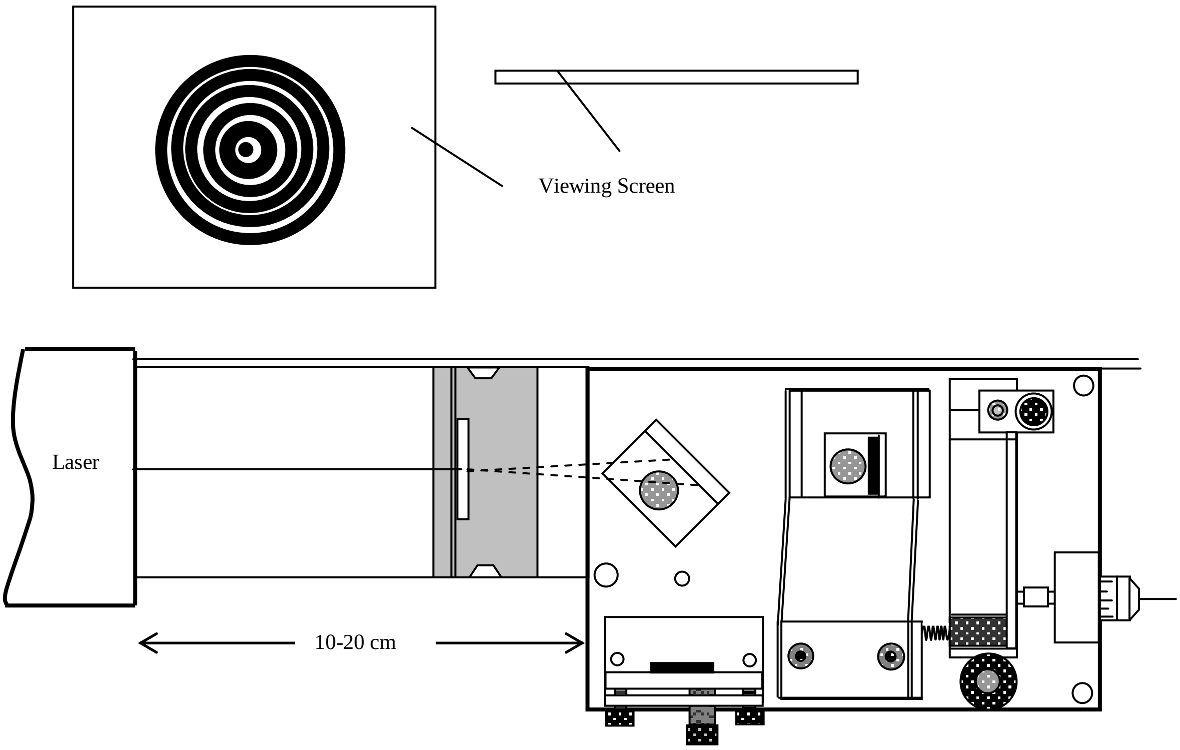

Figure 6. Positioning the lens

5. Insert the lens holder between the laser and the beam splitter. Be sure its edge is flush against the alignment rail. Then attach an 18 mm focal length lens on the lens holder. If the alignment is done correctly, an interference pattern of concentric rings will appear on the viewing screen.

(*) This section is based on instructions suggested by PASCO scientific

DATA and RESULTS

Name:______________________________ TA___________________________

Department:__________________________

Partners:____

PART A: Measuring the wavelength of the laser

Table1

d_i					
N_i					
λ_i					

$$\bar{\lambda} = \sum_{i=1}^{m} \lambda_i \Big/ m =$$

$$\Delta\lambda = \sqrt{\sum_{i=1}^{m} \left(\lambda_i - \bar{\lambda}\right)^2 \Big/ m-1} =$$

$$\lambda = \bar{\lambda} \pm \Delta\lambda =$$

1. Calculate λ_i for each trial, and fill these values in **Table1**.

2. Calculate from these results an average value and a standard deviation for the laser wavelength λ and fill these values in **Table1**.

3. Is your result in agreement with the specified value of λ = 632.8 nm within the error limits of the measurement?

4. Derive **Eq.(2).**

5. Your apparatus have not contained a compensator plate. What effect does this have on your results? Explain the purpose of a compensator plate and why it might be essential for certain measurements.

PART B: Measuring the Refractive Index

Table 2.

$\Delta P_i = P_{final} - P_{initial}$						
N_i						
n_{air_i}						

$\bar{n}_{air} = \sum_{i=1}^{m} n_{air_i} \Big/ m =$

$\Delta n_{air} = \sqrt{\sum_{i=1}^{m} \left(n_{air_i} - \bar{n}_{air} \right)^2 \Big/ m-1} =$

$n_{air} = \bar{n}_{air} \pm \Delta n_{air} =$

1. Calculate n_{air} for each trial and fill these values in **Table 2**.

2. Calculate from these results, an average value and a standard deviation for refractive index of air and fill these values in **Table 2**.

3. Compare your result to the literature value.

3. Derive **Eq. (3)**

   (Hint: Assume that the amount by which n_{air} is greater than 1 depends linearly on pressure. Thus if n_{air} at P_{atm} is $1 + \delta$, it becomes $1 + \delta/2$ at half the P_{atm} pressure).

DISCUSSION & CONCLUSION

1. What are the possible errors in the experiment?
2. What kind of approximations did you take into consideration while you were obtaining the physical quantities and how do they affect your results?
3. What discrepancies did you encounter between the calculated quantities and theoretical or literature values?
4. What is your overall conclusion?

MICROWAVE OPTICS 1 EXP OW-7

PURPOSE

- Measurement of wavelength from standing wave pattern
- Deducing the velocity of waves in a dielectric medium
- Production of a circularly polarized beam from an initially linearly polarized beam

GENERAL

The microwave region of electromagnetic spectrum has wavelengths of order of centimeters. Using these long wavelengths, one can transform the scale of the variables of the traditional optics experiments into centimeter range that are easily seen and manipulated. It is going to be verified that microwaves do undergo the same phenomena as waves of wavelengths in the optical region.

The main components of the microwave system used are a transmitter unit and a microwave receiver unit:

Gunn Diode Transmitter:

The Gunn Diode Microwave Transmitter provides 15 mW of coherent, linearly polarized microwave output at a wavelength of 2.85 cm. The unit consists of a Gunn diode in a 10.525 GHz resonant cavity, a microwave horn to direct the output, and an 18 cm stand to help reduce table top reflections. The Transmitter may be powered directly from a standard 115 or 220/240 VAC, 50/60 Hz outlet by using the provided power supply. Other features include an LED power-indicator light and a rotational scale that allows easy measurement of the angle of polarization. The Gunn diode acts as a non-linear resistor that oscillates in the microwave band. The output is linearly polarized along the axis of the diode and the attached horn radiates a strong beam of microwave radiation centered along the axis of the horn. **If the angle of the transmitter is 0^{o} and the indicator lamp of the transmitter faces upward, the polarization of the microwave radiation is vertical.** To operate the microwave transmitter simply plug the power supply into the jack on the Transmitter's bottom panel and plug the power supply into a standard 115 or 220/240 VAC, 50/60 Hz outlet. The LED will light indicating the unit is on.

CAUTION: ***The output power of the Microwave Transmitter is well within standard safety levels. Nevertheless, one should never look directly into the microwave horn at close range when the Transmitter is on.***

Microwave Receiver:

The Microwave Receiver provides a meter reading that, for low amplitude signals, is approximately proportional to the intensity of the incident microwave signal. A microwave horn identical to that of the Transmitter's collects the microwave signal and channels it to a Schottky diode in a 10.525 GHz resonant cavity. The diode responds only to the component of a microwave signal that is polarized along the diode axis, producing a DC voltage that varies with the magnitude of the microwave signal. Special features of the Receiver include four amplification ranges—from one to thirty—with a variable sensitivity knob that allows fine tuning of the amplification in each range. The receiver is battery powered and has an LED battery indicator; if the LED lights when you turn on the Receiver, the battery is working. As with the Transmitter, an 18 cm high mount minimizes table top reflections, and a rotational scale allows convenient measurements of polarization angle.

The detector diodes in the Receiver are non-linear devices. This non-linearity will not cause any problem in most experiments. It is important however, to realize that the meter reading is not directly proportional to either the electric field (E) or the intensity (I) of the incident microwave. Instead, it generally reflects some intermediate value.

The INTENSITY selection settings (30X, 10X, 3X, 1X) are the values you must multiply the meter reading by to normalize your measurements. 30X, for example, means that you must multiply the meter reading by 30 to get the same value you would measure for the same signal with the INTENSITY selection set to 1X. Of course, this is true only if you do not change the position of the VARIABLE SENSITIVITY knob between measurements.

EQUIPMENT

– Transmitter
– Receiver
– Component Holder x 2
– Goniometer
– Dielectric Blocks x 3
– Metal Reflector
–Polarization Grille

PROCEDURE

PART A: Standing Waves, measurement of wavelength

1. Set up the equipment as shown in **Fig. 1**. Adjust the Receiver controls to get a full-scale meter reading with the Transmitter and Receiver as close together as possible. Slowly move the Receiver along the Goniometer arm, away from the Transmitter. How does this motion affect the meter reading?

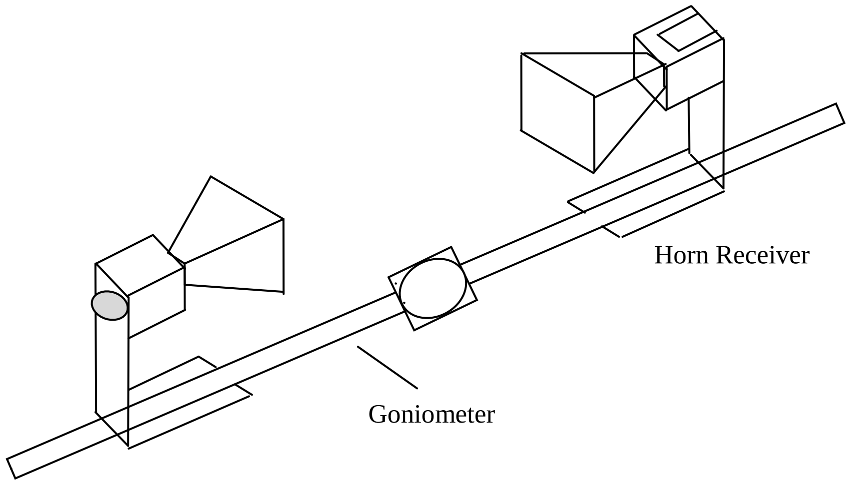

Figure 1. Setup for Part A

The microwave horns are not perfect collectors of microwave radiation. Instead, they act as partial reflectors, so that the radiation from the Transmitter reflects back and forth between the Transmitter and Reflector horns, diminishing in amplitude at each pass. However, if the distance between the Transmitter and Receiver diodes is equal to $n\,\lambda/2$ (where n is an integer and λ is the wavelength of the radiation), then all the multiply-reflected waves entering the Receiver horn will be in phase with the primary transmitted wave. When this occurs, the meter reading will be a maximum. (The distance between adjacent positions, in order to see a maximum, is therefore $\lambda/2$).

2. Slide the Receiver one or two centimeters along the Goniometer arm to obtain a maximum meter reading.

3. While reading the meter, slide the Receiver away from the Transmitter. As you move the transmitter slowly, minima and maxima will be detected, corresponding to nodal points of standing wave pattern.

4. Read the position of receiver for at least 10 minimum (or maximum) meter readings. Record your results in **Table 1**.

PART B: Velocity of microwaves in a dielectric

When an electromagnetic wave propagates through vacuum, it travels at the constant speed of $c = 3\text{x}10^8$ m/s. However, when it travels through a material the electric and magnetic fields of the wave induce a polarization in the electron clouds of the material. This polarization makes it more difficult for the wave to travel through the material, so its speed is reduced by a factor n (index of refraction) compared to the vacuum. The speed of wave, v, within a material of refractive index n is then $v = c/n$. This equation shows that a high refractive index means slow propagation speed. Higher refractive indices generally occur in materials with higher densities, since a high density implies a high concentration of electron clouds slowing the wave.

Since the interaction of the electromagnetic wave with the material depends on the frequency of the propagating wave, i.e. the refractive index, the speed is also dependent on the wave frequency.

1. Arrange transmitter and receiver according to **Fig. 2**.

2. Set the transmitter and the receiver on operating conditions.

3. Insert one Perspex block of thickness 25 mm in front of the transmitter in such a way as to delay half the beam. By inserting the block we change the optical path length in that local region from L for air to nL , where L and n are the thickness and the refractive index of the block, respectively. This introduces a phase difference of about a half cycle between parts of the beam, i.e. $L(n-1) \cong \lambda/2$. The total received signal is now zero due to destructive interference.

4. Insert a second identical block on the path of the other half. This introduces an identical phase shift so that the signal is now restored.

5. Remove the second block and cover the first block with a second block of equal thickness. Observe that the signal is again restored.

6. From your observations deduce the velocity, v , of microwaves in Perspex. Record your value in **Table 2**.

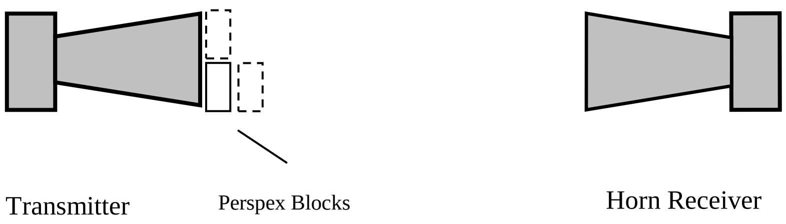

Figure 2. Setup for Part B

PART C: Producing Circular Polarization

A plane polarized wave is the superposition of two orthogonal polarizations. Phase shifting one of these polarizations by ¼ of the wavelength creates circularly polarized wave.

1. Arrange the equipment as shown in **Fig. 3**, where the polarization grille with its rods vertical is placed about 28 mm in front of the reflector (The grille can stand on the feet of the reflector).

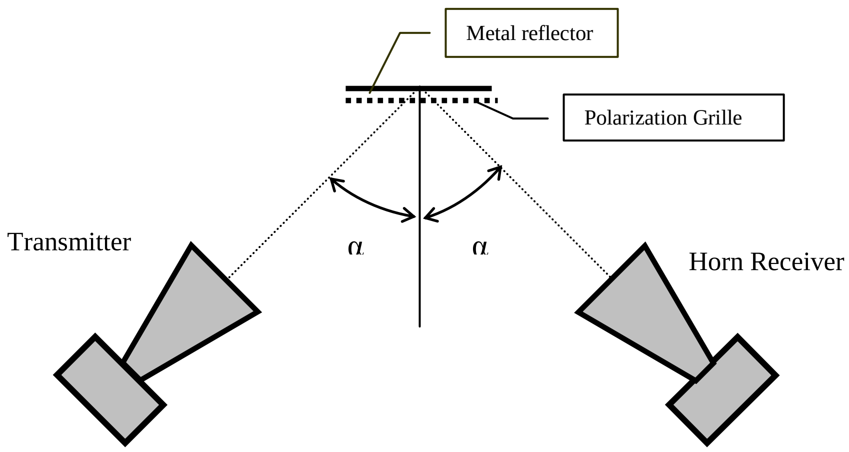

Figure 3. Setup for Part C

2. Rotate the transmitter about its long axis so that the transmitted *E* field is at 45^o to the horizontal.

3. Set the transmitter and the receiver on operating conditions. The reflected signal is the superposition of a vertical *E* field, reflected off the grille, and of a horizontal *E* field, reflected off the metal plate.

4. Measure the reflected signal at various angles by rotating the receiver about its long axis from 0 to 360^o. Record your values in **Table 3**. If vertical *E* field equals the horizontal *E* field, then the receiver can receive the reflected signal equally well (however rotated about its long axis). For the best results it is necessary to carefully vary the spacing between the grille and the metal reflector.

DATA and RESULTS

Name:________________________________ TA______________________________

Department:___________________________

Partners:____

PART A: Standing waves

Table 1. Sample data for standing waves

i	1	2	3	4	5	6	7	8	9
Position of minima (x_i)									

$$\bar{\lambda} = 2\frac{\sum |x_{i+1} - x_i|}{N-1} =$$

1. Use your results to determine an average value for the wavelength of the microwave radiation and record this in **Table 1**.

PART B: Velocity of microwaves in a dielectric

1. Indicate configurations of the perplex blocks which make the intensity zero and explain the reason why the readings become zero.

Table 2

V= c / n	

PART C: Creating circular polarization

Table 3

Receiver angle								
Intensity readings								

1. Do you observe any zero intensity during the full cycle of the receiver? (You should NOT observe zero intensity!) Are the intensity readings equally well? If not, please explain what you observe.

DISCUSSION & CONCLUSION

1. What are the possible errors in the experiment?
2. What kind of approximations did you take into consideration while you were obtaining the physical quantities and how do they affect your results?
3. What discrepancies did you encounter between the calculated quantities and theoretical or literature values?
4. What is your overall conclusion?

MICROWAVE OPTICS 2 EXP OW-8

PURPOSE

- Exploring the interference of microwaves by division of wave front
- Illustration of interference of microwaves by division of amplitude; thin film interference

GENERAL

The microwave region of electromagnetic spectrum has wavelengths in the order of centimeters. Using these long wavelengths, one can transform the scale of the variables of the traditional optics experiments into centimeter range that are easily seen and manipulated. It is going to be verified that microwaves undergo the same phenomena as waves of wavelengths in the optical region.

The main components of the microwave system used are a transmitter unit and a microwave receiver unit:

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CAUTION: The output power of the Microwave Transmitter is well within standard safety levels. Nevertheless, one should never look directly into the microwave horn at close range when the Transmitter is on.

Microwave Receiver:

The Microwave Receiver provides a meter reading that, for low amplitude signals, is approximately proportional to the intensity of the incident microwave signal. A microwave horn identical to that of the Transmitter's collects the microwave signal and channels it to a Schottky diode in a 10.525 GHz resonant cavity. The diode responds only to the component of a microwave signal that is polarized along the diode axis, producing a DC voltage that varies with the magnitude of the microwave signal. Special features of the Receiver include four amplification ranges—from one to thirty—with a variable sensitivity knob that allows fine tuning of the amplification in each range. The receiver is battery powered and has an LED battery indicator; if the LED lights when you turn on the Receiver, the battery is working. As with the Transmitter, an 18 cm high mount minimizes table top reflections, and a rotational scale allows convenient measurements of polarization angle.

The detector diodes in the Receiver are non-linear devices. This non-linearity will not cause any problem in most experiments. It is important however, to realize that the meter reading is not directly proportional to either the electric field (E) or the intensity (I) of the incident microwave. Instead, it generally reflects some intermediate value.

The INTENSITY selection settings (30X, 10X, 3X, 1X) are the values you must multiply the meter reading by to normalize your measurements. 30X, for example, means that you must multiply the meter reading by 30 to get the same value you would measure for the same signal with the INTENSITY selection set to 1X. Of course, this is true only if you do not change the position of the VARIABLE SENSITIVITY knob between measurements.

In EXP OW-7, you've seen how two waves moving in opposite directions can superpose to create a standing wave pattern. A somewhat similar phenomenon occurs when an electromagnetic wave passes through a two-slit aperture. The wave diffracts into two waves which superpose in the space beyond the apertures. Similar to the standing wave pattern, there are points in space where maxima and minima are formed. With a double slit aperture, the intensity of the wave beyond the aperture will vary depending on the angle of detection. For two thin slits separated by a distance *d*, maxima will be found at angles such that $d \sin\theta = n\lambda$. (Where θ is the angle of detection, λ is the wavelength of the incident radiation, and n is any integer) (See **Fig. 1**). Refer to a textbook for more information about the nature of the double-slit diffraction pattern.

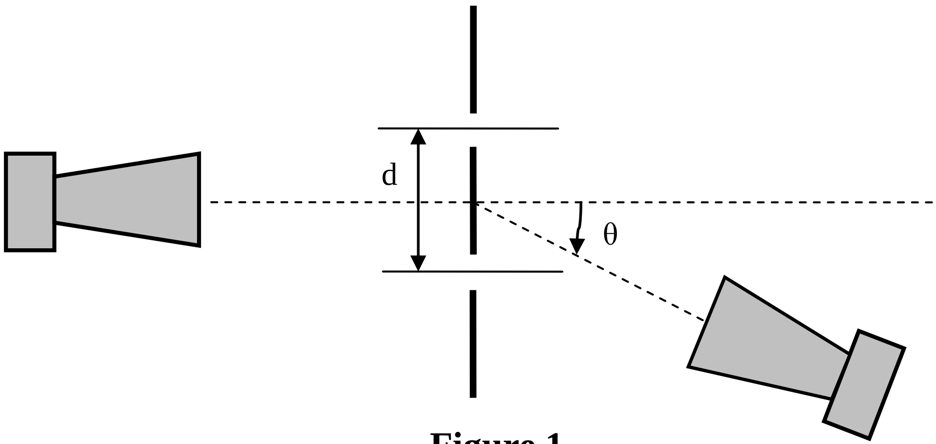

Figure 1

EQUIPMENT

- Transmitter, Receiver
- Component Holder
- Slit Extender Arm
- Partial Reflector
- Goniometer, Rotating
- Narrow Slit Spacer
- Wide Slit Spacer

PROCEDURE

PART A: Double Slit Interference

1. Arrange the equipment as shown in **Fig. 2**. Use the Slit Extender Arm, two Reflectors, and the Narrow Slit Spacer to construct the double slit. (We recommend a slit width of about 1.5 cm.) Be precise with the alignment of the slit and make the setup as symmetrical as possible.

2. Adjust the Transmitter and Receiver for vertical polarization (0°) and adjust the Receiver controls to give a full-scale reading at the lowest possible amplification.

3. Rotate the rotatable Goniometer arm (on which the Receiver rests) slowly about its axis. Observe the meter readings.

4. Reset the Goniometer arm so the Receiver directly faces the Transmitter. Adjust the Receiver controls to obtain a meter reading of 1.0. Now set the angle to each of the values shown in **Table 1**. At each setting record the meter reading in the table. (In places where the meter reading changes significantly between angle settings, you may find it useful to investigate the signal level at intermediate angles.)

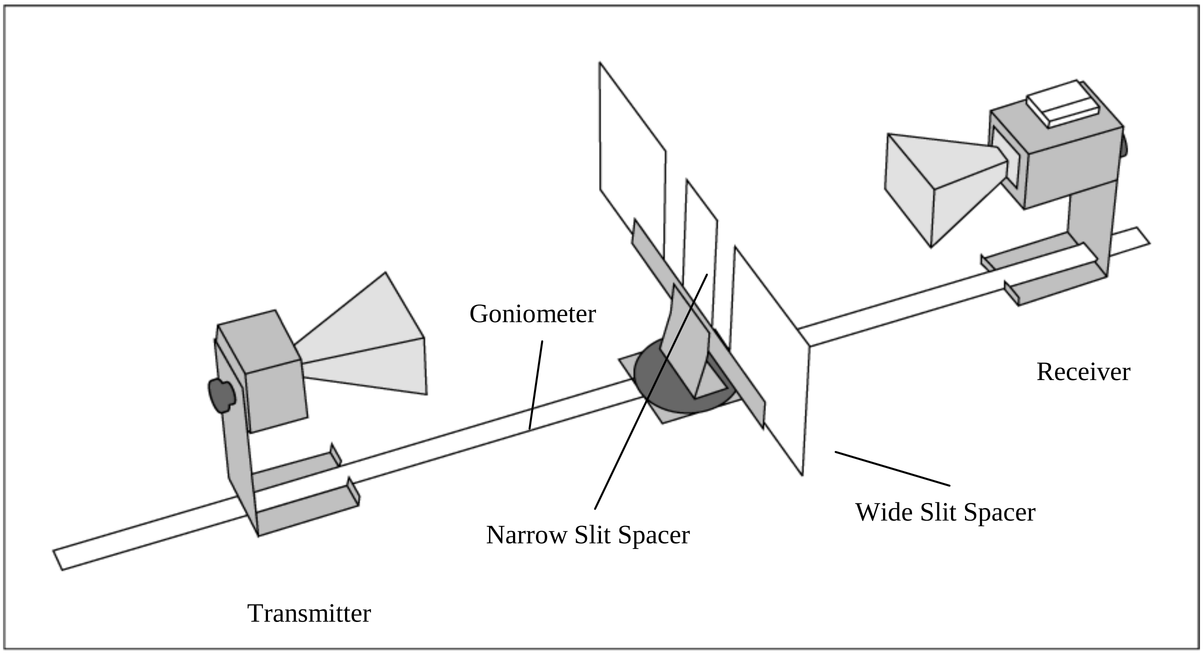

Figure 2

5. Keep the slit widths the same, but change the distance between the slits by using the Wide Slit Spacer instead of the Narrow Slit Spacer. Because the Wide Slit Space is 50% wider than the Narrow Slit Spacer (90 mm versus 60 mm) move the Transmitter back 50% so that the microwave radiation at the slits will have the same relative intensity. Repeat the measurements. (You may want to try other slit spacings as well.)

PART B: Thin-Film Interference

1. Arrange the equipment as shown in **Fig. 3**, where the transmitter is directed to a partial reflector. The receiver is placed a little behind the transmitter to prevent picking up a direct signal. A metal reflector is placed closely behind and parallel to the partial reflector.

NOTE: When an electromagnetic wave encounters a partial reflector, part of the wave reflects and part of the wave transmits through the partial reflector.

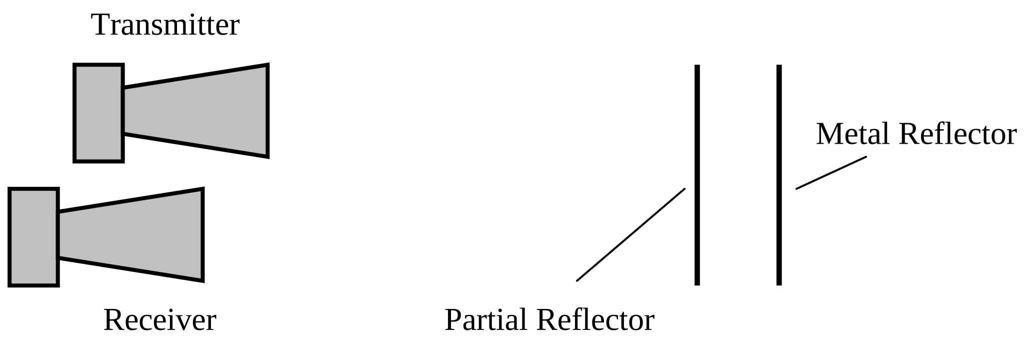

Figure 3

2. Set the transmitter and the receiver at operating condition.

3. Align the receiver to receive the reflected signal.

4. Slowly move the partial reflector on the goniometer to observe the change in meter as you do. You should see a series of maxima and minima, as the signals reflected at the partial reflector and the metal reflector interfere constructively and destructively.

5. Read the position of the partial reflector for a number of minima (or maxima). Record your results in **Table 2**.

DATA and RESULTS

Name:________________________________ TA______________________________

Department:___________________________

Partners:____

PART A:

Table 1.

Angle	Clockwise Intensity Reading	Counterclockwise Intensity Reading	Angle	Clockwise Intensity Reading	Counterclockwise Intensity Reading
0°			45°		
5°			50°		
10°			55°		
15°			60°		
20°			65°		
25°			70°		
30°			75°		
35°			80°		
40°			85°		

1. From your data, plot a graph of meter reading versus θ. Identify the angles at which the maxima and minima of the interference pattern occur.

2. Calculate the angles at which you would expect the maxima and minima to occur in a standard two slit diffraction pattern—maxima occur wherever $d \sin \theta = n \lambda$, minima occur wherever $d \sin\theta = n \lambda/2$. (Check your textbook for the derivation of these equations, and use the wavelength measured in experiment OW-7.) How does this compare with the locations of your observed maxima and minima? Can you explain any discrepancies?
(What assumptions are made in the derivations of the formulas and to what extent are they met in this experiment?)

3. Can you explain the relative drop in intensity for higher order maxima? Consider the single-slit diffraction pattern created by each slit. How do these single slit patterns affect the overall interference pattern?

PART B:

Table 2

Reflector positions for minima (or maxima)						

1. Is the distance between successive minima or maxima one half the wavelengths? Explain why?

DISCUSSION & CONCLUSION

1. What are the possible errors in the experiment?
2. What kind of approximations did you take into consideration while you were obtaining the physical quantities and how do they affect your results?
3. What discrepancies did you encounter between the calculated quantities and theoretical or literature values?
4. What is your overall conclusion?

REFLECTION	EXP OW-9

PURPOSE

-Verify Fresnel's Equations of Reflection

GENERAL

Application of Maxwell's equations to a beam of light incident at an angle θ_i to the normal at the boundary between two dielectrics of refractive indices n_1 and n_2 relates the amplitude of incident light, $E^{(i)}$, to that of reflected, $E^{(r)}$, and transmitted, $E^{(t)}$, fractions.

It is found that in addition to the dependence on θ_i, the fraction reflected depends upon the orientation of the plane of polarization of the incident light relative to the plane of incidence formed by the incident beam and the normal to the boundary.

If the plane of polarization is parallel to the plane of incidence, then the fraction of reflected light is given by

$$r_{parallel} = \frac{E^{(r)}_{parallel}}{E^{(i)}_{parallel}} = \frac{n_2 \cos\theta_i - n_1 \cos\theta_t}{n_2 \cos\theta_i + n_1 \cos\theta_t} \qquad \textbf{Eq. (1)}$$

where θ_t is the refraction angle. For perpendicular polarization the equivalent quantity is

$$r_{perpendicular} = \frac{E^{(r)}_{perpendicular}}{E^{(i)}_{perpendicular}} = \frac{n_1 \cos\theta_i - n_2 \cos\theta_t}{n_1 \cos\theta_i + n_2 \cos\theta_t} \qquad \textbf{Eq. (2)}$$

According to Snell's law θ_i and θ_t are related by

$$n_1 \sin\theta_i = n_2 \sin\theta_t \qquad \textbf{Eq. (3)}$$

From equations (1), (2), and (3), $r_{parallel}$ and $r_{perpendicular}$ can be written as

$$r_{parallel} = \tan(\theta_i - \theta_t) / \tan(\theta_i + \theta_t) \qquad \textbf{Eq. (4)}$$

$$r_{perpendicular} = \sin(\theta_i - \theta_t) / \sin(\theta_i + \theta_t) \qquad \textbf{Eq. (5)}$$

For $n_1 < n_2$, $r_{perpendicular}$ is finite overall θ_i , but $r_{parallel}$ vanishes at an angle given by

$$\theta_i + \theta_t = 90^o \qquad \textbf{Eq. (6)}$$

where the denominator in Eq. (4) goes to infinity. The incident angle at which this occurs is known as the Brewster angle θ_B. From equations (3) and (6) θ_B is given by

$$\theta_B = \tan^{-1}\frac{n_2}{n_1} \qquad \textbf{Eq. (7)}$$

Since $R_{parallel} = 0$, any light reflected from an unpolarized beam incident at θ_B will be completely polarized in the perpendicular plane, **Fig 1**.

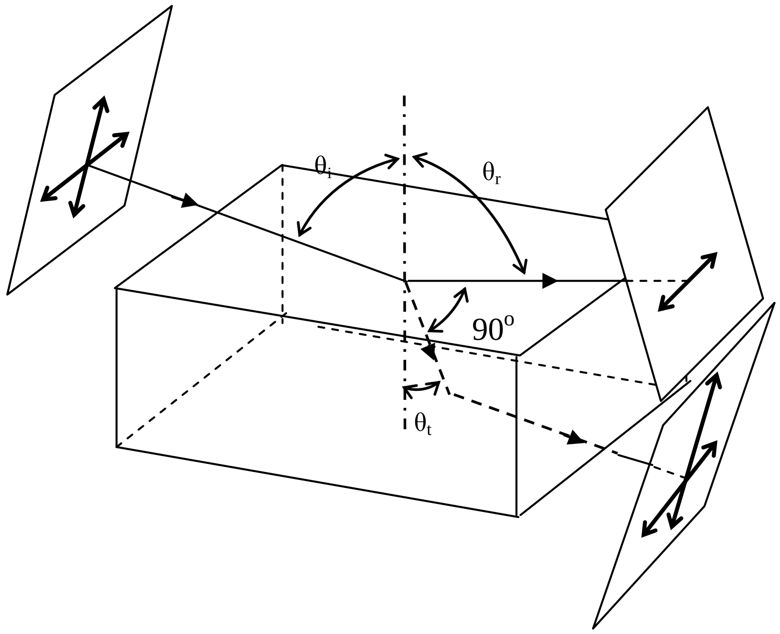

Figure 1

EQUIPMENT

- Optical Bench
- 2x Polarizer
- Angular Translator
- Light Sensitive Detector
- Laser
- Slit Collimator
- Interface
-Square Analyzer

PROCEDURE

In this experiment, the ratio of reflection coefficients for parallel and perpendicular polarizations will be measured and then plotted as a function of incidence angle, θ_i. This will be compared with the theoretical curve obtained from **Eq. (4)** and **Eq. (5).**

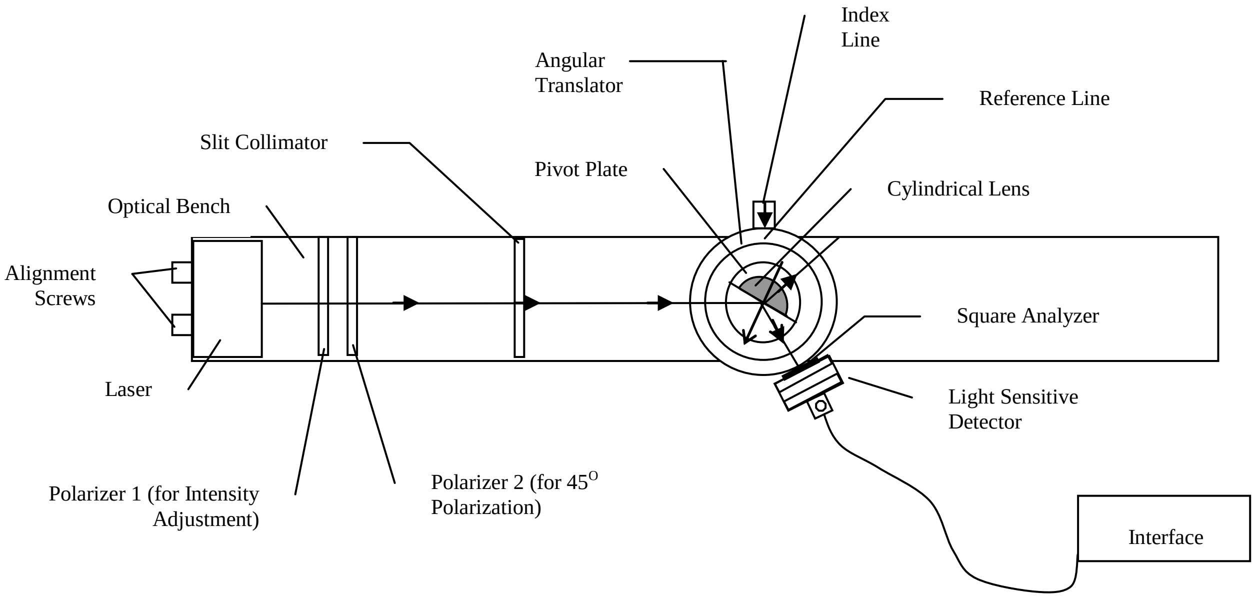

Figure 2

1. In order to align the laser beam, first mount the Slit Collimator far away from the laser. Let the laser beam cross through the slit #5. Set the angle of the Angular Translator to 0^o or 180^o by matching with the Index Line and position the Light Sensitive Detector exactly in front of the Laser. By turning the Alignment Screws of the Laser, make the laser beam pass through the center of the detector aperture (Use Detection Slit: 1.5mm). **Check the Pivot Plate that it should NOT rub the Angular Translator.**

2. Mount the Polarizer 1 between the Slit Collimator and the Laser for adjusting the intensity of the incoming beam. Mount the Polarizer 2 between the Polarizer 1 and the Slit Collimator.

3. Set the Polarizer 2 at a degree of 45^o (the indicator is the bottom lip on the lens holder) in order to produce a beam with two linear electric field components which are perpendicular to each other.

4. Turn on the Interface. Select the Light Sensor on the Interface. Open the METER icon from the main menu. Set the METER to measure the Light Intensity. Reset the METER and adjust the maximum intensity reading to an appropriate scale by rotating the Polarizer 1.

5. Put the Cylindrical Lens on the Pivot Plate and make the flat surface of the Cylindrical Lens face the laser beam. **In order to make the laser beam go through the symmetry axis of the Cylindrical Lens, slide the Cylindrical Lens left or right slightly without moving any plates until the laser beam illuminates the location, where it passes through the detector before.**

6. The dielectric interface is formed between air and the flat surface. Make sure that this surface is accurately aligned with the reference lines of the Angular Translator and the Pivot Plate. The center of the Cylindrical Lens is coincident with the rotation axis of the detector arm of the Angular Translator.

7. Without disturbing the alignment of the lens, rotate the plates. Notice the beams produced as the incident beam is reflected and refracted at the flat surface of the lens.

8. Set the incoming beam to be incident on the flat face at an angle, $\theta_i = 20^o$ by turning the Pivot Plate. Move the Angular Translator as much as the Pivot Plate is turned. Now the Angular translator and the Pivot Plate are at the same angle. Turn the Angular Translator from that angle to where the laser beam is refracted with maximum intensity. The refraction angle, θ_t, is the angle, between the symmetry axis of the Cylindrical Lens and the position of the refracted laser beam. Measure the refraction angle by using the Angular Translator and note the angle of refraction in **Table 1**. Repeat the same procedure for the rest of the angles of incidence.

9. Bring the Square Analyzer in front of the detector to a horizontal position. **Note that, when the Square Analyzer is horizontal, the light passing through the Square Analyzer is the horizontal component (perpendicular to the surface of the Cylindrical Lens) of the light reflected from the flat surface of the Cylindrical Lens.** In this orientation, the Square Analyzer is blocking the light that is polarized parallel to the flat surface of the Cylindrical Lens. Thus, when the incident angle is such that the reflected light is 100% polarized parallel to the flat surface of the Cylindrical Lens (Brewster’s Angle), the horizontal component will be zero.

10. Record the reflected light intensity for the corresponding reflection angles ($\theta_i = \theta_r$) and fill in **Table 2.** Then bring the Square Analyzer to a vertical position and repeat the same procedure above and record the intensity readings for **Table 3. ATTENTION: For each reflection angle record the horizontal intensity and vertical intensity values AT THE SAME TIME then proceed the following reflection angle!**

DATA and RESULTS

Name:________________________ TA________________________

Department:________________________

Partners:____

Table 1.

θ_i	20^o	30^o	40^o	50^o	60^o	70^o	80^o
θ_t							

Table 2.

θ_i	20^o	25^o	30^o	35^o	40^o	45^o	50^o	55^o	60^o	65^o	70^o	75^o	80^o
$I(\theta_i)_{\text{parallel}}$													

Table 3.

θ_i	20^o	25^o	30^o	35^o	40^o	45^o	50^o	55^o	60^o	65^o	70^o	75^o	80^o
$I(\theta_i)_{\text{perpendicular}}$													

1. Referring to **Table 1**, plot $\sin\theta_i$ against $\sin\theta_t$. From the slope of this line determine the refractive index n_2 of the cylindrical block of material. (While plotting the **Trendline** of the graph by using **EXCEL**, use **Linear Type** and specify **the equation of the Trendline**.)

n_2	

2. Locate the Brewster angle.

θ_B	

3. Referring to **Table 2** and **Table 3**, compute the ratio $I_{\text{parallel}} / I_{\text{perpendicular}}$ for the **reflected beam** and plot this as a function of incident angle, θ_i. (While plotting the **Trendline** of the graph by using EXCEL, use **4 degree Polynomial Type**)

4. Using **Eqs. (4)** and **(5),** plot theoretical curve $[r_{\text{parallel}}/r_{\text{perpendicular}}]^2$ as a function of incident angle, θ_i

5. Compare the experimental ($I_{\text{parallel}} / I_{\text{perpendicular}}$ vs θ_i) and the theoretical ($[r_{\text{parallel}}/r_{\text{perpendicular}}]^2$ vs θ_i) curves.

DISCUSSION & CONCLUSION

1. What are the possible errors in the experiment?
2. What kind of approximations did you take into consideration while you were obtaining the physical quantities and how do they affect your results?
3. What discrepancies did you encounter between the calculated quantities and theoretical or literature values?
4. What is your overall conclusion?

OPTICAL ACTIVITY	EXP OW-10

PURPOSE

- To measure optical activity manifested by a solution of sugar molecules in water and to observe the relationship between optical activity and the concentration of the solution.

GENERAL

Optical Activity is the rotation of the polarization plane of a beam of linearly polarized light while it is passing through a medium. Mediums having that kind of ability are called **optically active** and known to have **chiral** molecules or **asymmetrically arranged** non-chiral molecules. Basically the chiral molecules can be defined as the molecules that do not have a plane of symmetry. In other words, they are not superimposable on their mirror images, e.g. sugar molecules and amino acids. A very simple illustration of an optically active material is shown in Fig 1.

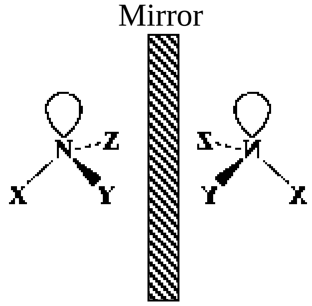

Figure 1

In this experiment a plane polarized beam of light is sent towards a tube which contains a solution of sugar/water molecules. It has known that the linearly polarized light can be denoted as the summation of the right-hand circularly polarized (RHC) and left-hand circularly polarized light (LHC),

$$\mathbf{E_\theta = E_{RHC} + e^{i2\theta} E_{LHC}} \qquad \textbf{Eq. (1)}$$

where E and 2θ represent the electric field of the linearly polarized light and the relative phase difference between two circularly polarized lights respectively. Also the refractive indices of the

RHC and LHC polarized lights are different in an optically active medium which suggests that they have different velocities passing through the medium. Therefore this gives rise to a phase shift between the components of the plane polarized light. As a result the chiral molecules in the tube (here the sugar molecules) interact differently with the RHC and the LHC polarized light which leads to the rotation of the polarization plane of the light. The amount of the observed rotation **α** depends on the path length **L** (length of the tube), the concentration of the solution **C**, and the intrinsic ability of the molecules that indicates the interaction with the polarized light, which is called specific rotation **[α]** or rotation power.

$$[\alpha] = \frac{\alpha(\mathrm{deg})}{L(dm)C(g/mL)} \qquad \textbf{Eq. (2)}$$

The unit for the specific rotation is found to be **deg dm^{-1} g mL^{-1}** according to the above relation. However we will just use the unit of **degrees** for the specific rotation as it is used in scientific notation. Every chiral compound has a unique specific rotation and they can be classified in two groups according to the direction of the rotation: (i) **Dextrorotatory compounds**, rotate the plane of polarization to the right whereas (ii) **Levorotatory compounds**, rotate the plane of polarization to the left with respect to the observer.

EQUIPMENT

- Laser
- Polarizer
- Solution of sugar molecules in water
- Analyzer

PROCEDURE

1. Place your reference tube #0 on the holder and make sure that the polarizer and analyzer are perpendicular by keeping the first polarizer fixed and rotating the analyzer until you obtain minimum transmission
2. Note the position where you obtained minimum position.
3. First place the solution #4 (the least dilute solution) in order to determine the direction of the polarization rotation. The rotation angle should be less than 180^o.
4. Next place the solution tube #1 on the holder.
5. Again rotate the polarizer until you get minimum transmission and record this position. Repeat this measurement three times.
6. Follow same procedure with the rest of the solution tubes.
7. Record your results to **Table 1**.

DATA AND RESULTS

Name:______________________________ TA_____________________________

Department:_________________________

Partners:____

TABLE 1: *ROTATION OF PLANE OF POLARIZATION.*

SOLUTIONS	θ_1	θ_2 -180^o	θ_3	AVERAGE
SOLUTION #1				
SOLUTION #2				
SOLUTION #3				
SOLUTION #4				

1. According to your measurements is the solution dextrorotatory or laevorotatory?

2. Concentration of the tube #1 is 1.01 g/mL. The error is given as ± 0.01 g/mL for concentration. The concentration of the enumerated solutions is half of the preceding ones. The degree of 2° may be taken as the error of the angle measurements. **Measure the angles of minimum transmission for the full cycle of the analyzer. DO NOT forget to subtract 180^o from the value** θ_2 !

3. Plot the angle of rotation versus the concentration graph.

4. Using the graph find the rotation power **[α]** of the sugar molecules**.**

Note that, while drawing the graph in order to calculate the rotation power (specific rotation), draw the best and the worst lines and calculate the error of the specific rotation from the slope of the lines. Be careful while using Eq. 2 and DO NOT forget to write down the names and the units of the axes. Indicate your findings in correct units!

DISCUSSION & CONCLUSION

1. What are the possible errors in the experiment?
2. What kind of approximations did you take into consideration while you were obtaining the physical quantities and how do they affect your results?
3. What discrepancies did you encounter between the calculated quantities and theoretical or literature values?
4. What is your overall conclusion?

SPECTRAL ENERGY DISTRIBUTION IN DIFFERENT FILTERS — EXP OW-11

PURPOSE

- To measure transmittance and absorbance of different types of colored filters (longpass and bandpass) by a spectrophotometer.

GENERAL

A spectrophotometer is an instrument composed of a light source, a wavelength selector (monochromator), a sample compartment, and a detector as shown in **Figure 1.** The wavelength selector splits the light spectrum into its component colors and selects a narrow band of this spectrum. Either a prism or a grating may be used as a dispersing element to split the light. The spectrum is generally projected on an opaque wall containing a slit. The physical width of the slit determines the band width of the selected light. The wavelength of the selected light may be adjusted by changing the angle of the dispersing element, so that the desired wavelength passes through the slit. The selected light passes into the sample compartment, through the sample and to the detector. This is how a single beam spectrophotometer operates in transmission mode. By measuring transmittance, absorbance can be determined.

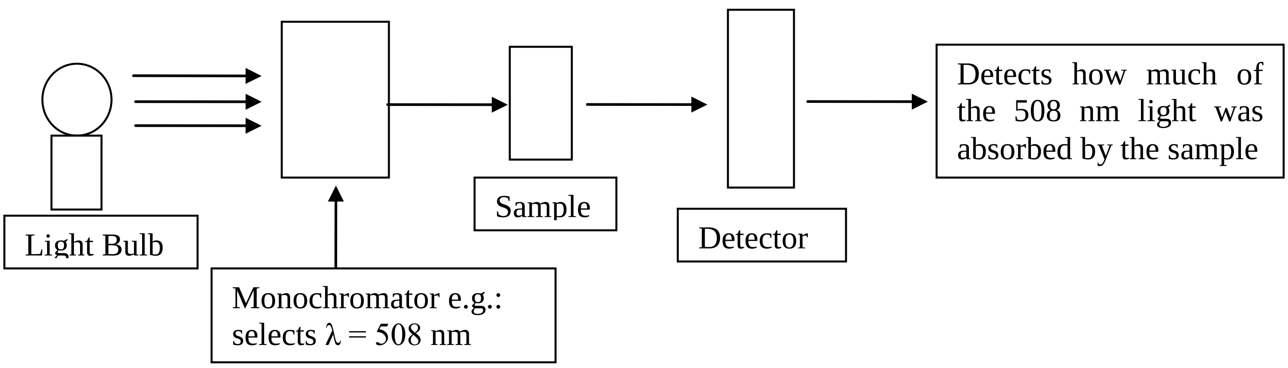

Figure 1

Transmittance and Absorbance:

Transmittance is the fraction of incident light at a specified wavelength that passes through a sample. In other words, the transmittance of a sample is the ratio of the intensity of the light that has passed through the sample to the intensity of the light when it entered the sample as shown in **Figure 2.**

$$T = \frac{I}{I_0}$$ **Eq. (1)**

T –Transmittance

I_0 – Light intensity entering a sample

I – Light intensity passing through the sample

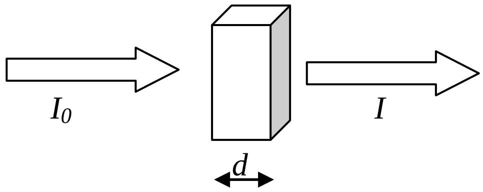

Figure 2

Absorbance is a logarithmic measure of the amount of light absorbed (at particular wavelength) as the light passes through a sample .

$$A = \ln\left(\frac{I_0}{I}\right)$$ **Eq. (2)**

$A = \alpha d$ – Absorbance (Optical Density)

α – Absorption coefficient

d – sample thickness

<u>Optical filters:</u>

Optical filters selectively transmit light having certain properties (often, a particular range of wavelengths), while blocking the remainder.

1) Longpass filters

A longpass (LP) filter is an optical interference or colored glass filter that attenuates shorter wavelengths and transmits (passes) longer wavelengths over the active range of the target spectrum (ultraviolet, visible, or infrared). Longpass filters, which can have a very sharp slope (referred to as edge filters), are described by the cut-on wavelength at 50 percent of the peak transmission.

2) Shortpass filters

A shortpass (SP) filter is an optical interference or colored glass filter that attenuates longer wavelengths and transmits (passes) shorter wavelengths over the active range of the target spectrum (usually the ultraviolet and visible region).

3) Bandpass filters

If we combine an LP filter and an SP filter we will get a Bandpass (BP) filter. These filters have usually lower transmittance values than SP and LP filters, and block all wavelengths outside of a selected interval, which can be wide or narrow, depending on the number of layers of the filter.

EQUIPMENT

- Spectrophotometer
- Optical Filters
- Data traveller

PROCEDURE

1. Turn on computer and spectrophotometer (the ON/OFF switch of the spectrophotometer is back of it).

2. Wait a few minutes until the spectrophotometer ends all checks.

3. Firstly select the wavelength range from 350 to 1100 nm in the spectrophotometer.

4. Then take a background selecting “background” in the spectrophotometer when the sample holder is empty.

5. After that, put the filter in the sample holder. Select “scan” from the spectrophotometer.

6. To obtain the data, open the related program in the computer and select “take reading”.

7. After obtaining data, save them using “**clipboard**” in the program.

8. Open a “text” file and **paste** the data and save.

9. Repeat above procedure for all filters.

DATA and RESULTS

Name: ____________________

Department : ________________

Partners : ____

Filters	λ_{cut-on}	λ_{max}

1. **1.** Plot Transmission spectrum (T vs λ) for each filter and obtain λ_{cut-on} , λ_{max} .
2. **2.** Plot Absorption spectrum (A vs λ) for each filter.
3. **3.** Identify which filters are longpass and bandpass by examining your graphs.
4. **4.** By using the transmittance and absorbance values do you think there is any reflection?

Explain briefly how do you decide for this?

NOTE : λ_{cut-on} is cut on wavelength for the longpass filters.
λ_{max} is the wavelength where the transmission value is maximum for bandpass filters.

DISCUSSION & CONCLUSION

1. What are the possible errors in the experiment?
2. What kind of approximations did you take into consideration while you were obtaining the physical quantities and how do they affect your results?
3. What discrepancies did you encounter between the calculated quantities and theoretical or literature values?
4. What is your overall conclusion?