Lab Team #:__________ Section:__________ Date: March 21, 2019

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Polarization of Light

Purposes:

To study the properties of polarized light.
To measure the index of refraction of glass by measuring Brewster's angle.
To use polarized light to measure induced stress in a plastic "L" bracket.

Required Equipment and Supplies:

He-Ne laser and mount, two linear polarizers mounted on rotational stages (only one needed if laser is polarized), optical power meter, computer/printer with Excel software, large polarizing sheet, acrylic "L" bracket with mount and slotted weight set (15, 100 gram weights), microscope slide mounted on rotational stage.

Caution:

Even though the lasers used in this lab are low power they can cause retinal damage if the beam enters your eye. Never look directly into the laser beam and be cautious not to allow reflections of the beam from shiny objects to enter your eye.

Theory:

As we discussed in lecture, plane polarized light (also called "linearly polarized") vibrates so that the electric field of the wave is in a single plane. For example, if a beam of vertically polarized light is coming toward you its electric field would be in the vertical direction and its magnetic field would be horizontal. To save confusion, when we discuss polarization we only talk about the orientation of the electric field, the magnetic field is ignored (although it is always present).

For light passing through a polarizing filter we have the relation (the law of Malus),

$$I_{transmitted} = T_{\max} I_0 \cos^2 \theta$$ plot I vs $\cos^2\theta$

where I is the irradiance (or intensity) in watts/m^2, T_{max} is the maximum transmission of the filter (as a decimal fraction) and θ is the angle between the light's polarization direction and the transmission axis (TA) of the filter.

Brewster's Angle is afd particular angle of incidence at which TM (transverse magnetic) polarized light will pass through a transparent materia with no reflection (in the ideal case). The relative index of refraction of the material is related to Brewster's angle θ_B by the following expression

$$n_r = \tan \theta_B$$ Derive this

error prop

Procedure

Part 1: Finding naturally polarized light.

1. We can make polarized light in the lab but nature beat us to it! Assuming it is a clear day, take a polarizing filter out side the classroom and look through the filter at the blue sky. Danger: Do not look directly at the sun! The filter will not protect your eyes from retinal damage. Look in a direction perpendicular to the direction of the sun's rays. Slowly rotate the filter as you look through it noting the direction of the filter's TA. What do you observe. Explain and discuss in the box below.

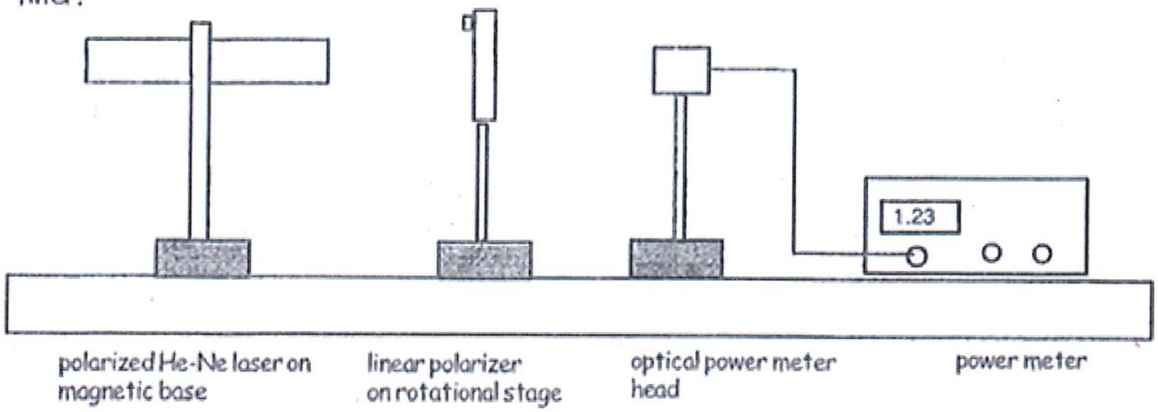
A partially cloudy sky was observed through a polarizing filter about midday at Moorpark College. Starting with the filter TA in the "up" position, the sky looked less shiny with a reduction of intensity. As the filter was rotated clockwise 90° the intensity varied slightly, less intense at 45° and about the same intensity at 90° as at the "up" position. This test was repeated several times due to unclear changes in the intensity as the filter was rotated. It's clear* (pun), however, that the general intensity level of the sky was reduced while looking through the filter, greatly eliminating glares and reflections.

2. Now take the same filter and look at the sunlight (or room light) reflecting off of a smooth, non-metallic surface (the reflecting pool around the College's fountains works nicely). Follow the same procedure as you did in the part above and explain your observations in the box beow.

The surface of a black desk in a well-lit room was observed through a polarizing filter. Starting with the filter's TA in the "up" position, the black-level of the desk looked about the same but with reduced intensity. As the filter was rotated clockwise 90° the black-level decreased, giving the surface a lighter complexion. Because reflected light from shiny horizontal surfaces is partially horizontally polarized, having the filter's TA at the 90° position allowed the reflected light to pass through the filter, while having the TA in the up position filtered the reflected light.

Part 2: Transmission of a Linear Polarizer

1. Set up the apparatus as shown below. If your laser is unpolarized you will need a second polarizing filter.



2. Rotate the linear polarizer until the output minimizes. (Placing the optical power meter head very close to the polarizer and turning off the room lights should get you very close to "zeroed".) Rotate the polarizer in steps of 10° and record the transmitted laser power in mW. Keep rotating the polarizer in steps of 10° and recording your power until the power readings have maximized and again returned to minimum (a total of 180°). Enter all of your data in the table below and plot power vs. angle on a spreadsheet.. Using the Law of Malus, discuss the results of your graph in the box on the next page.

angle (degrees)	P (mW)
0	0.155
10	0.145
20	0.135
30	0.115
40	0.091
50	0.066
60	0.044
70	0.024
80	0.011
90	0.006

angle (degrees)	P (mW)
90	0.006
100	0.010
110	0.023
120	0.044
130	0.066
140	0.093
150	0.118
160	0.136
170	0.150
180	0.155

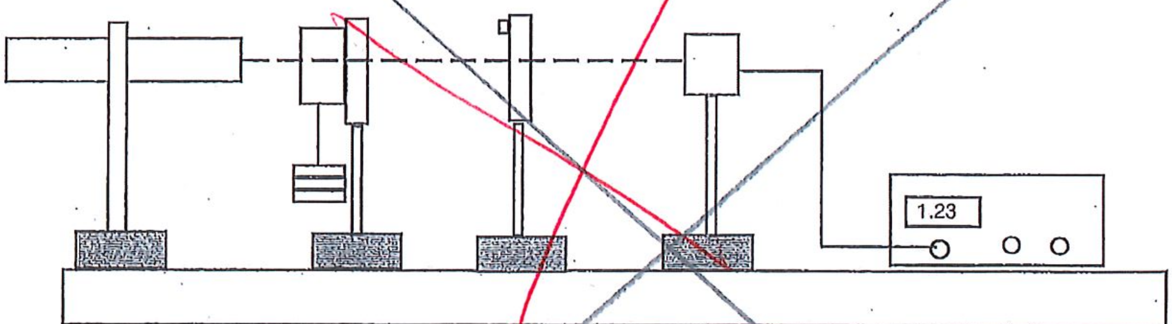
Part 2: Discussion of Results

Law of Malus: $I_{transmitted} = T_{max} I_0 \cos^2\theta$

Power, which is proportional to intensity, was graphed in relation to $\cos^2\theta$. The relationship was linear with an R^2 value of 0.9993. These results are consistent with the theoretical concept that polarized light will lose minimum intensity when passed through a polarized filter with transmission axis parallel (0 degrees) to the polarized light, and will lose maximum intensity when the transmission axis is perpendicular (90 degrees).

Part 3: Stress Analysis using Polarized Light

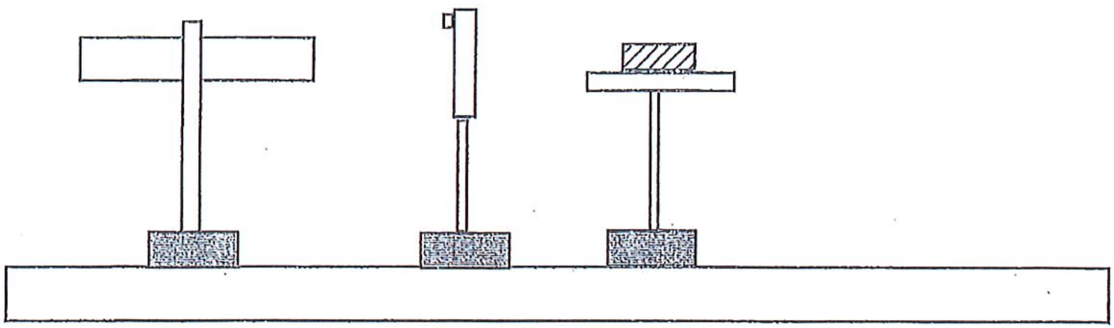
1. Set up the apparatus as shown below. If your laser is unpolarized you will need a second polarizing filter.



2. With no weights on the "hanger" rotate the LP until a minimum signal is detected on the optical power meter (you will probably want the room lights out). Add 100 grams to the hanger and record the transmitted power in the table on the next page. Repeat in steps of 100 grams until a total of 1500 grams is on the hanger.

Part 4: Measuring Index of Refraction by Brewster's Angle

1. Set up the apparatus as shown below, it is best to use an unpolarized laser this time!



2. Being careful not to shine the reflection into anyone's eye, rotate the microscope slide until the laser beam retroreflects (back along its own path). Measure the angle on the microscope slide's rotational stage and enter in the space below.

θ_1= 354 degrees

3. Have your instructor or lab tech help you turn the LP until you are close to TM polarization (some explaination may be needed!). Carefully rotate the slide until the refelcted ray dims. Adjust the LP until it gets dimmer and adjust the slide a bit more. With care ,you should be able to find an angle at which the reflection is almost gone.. Record this angle below≥

θ_2= 294 degrees $\delta\theta = 2°$

4. Brewster's angle is the difference between the two angles you measured above.

θ_B= 60 degrees

Use the expression for relative index given on page one to calculate the index of refraction of the microscope slide. Show your calculations in the box below. Get the results for index from another lab team and calculate a % difference (say which team you compared to).

$n_r = \tan\theta_B$

$n_r = \tan 60°$

$n_r = 1.73$

$$\% \text{ Difference} = \frac{|\text{Value}_1 - \text{Value}_2|}{\text{Value}_1} \times 100$$

$$\% \text{ Difference} = \frac{|1.73 - 1.54|}{1.73} \times 100 = 11\%$$

5. In the box below, discuss any practical applications of Brewster's angle.

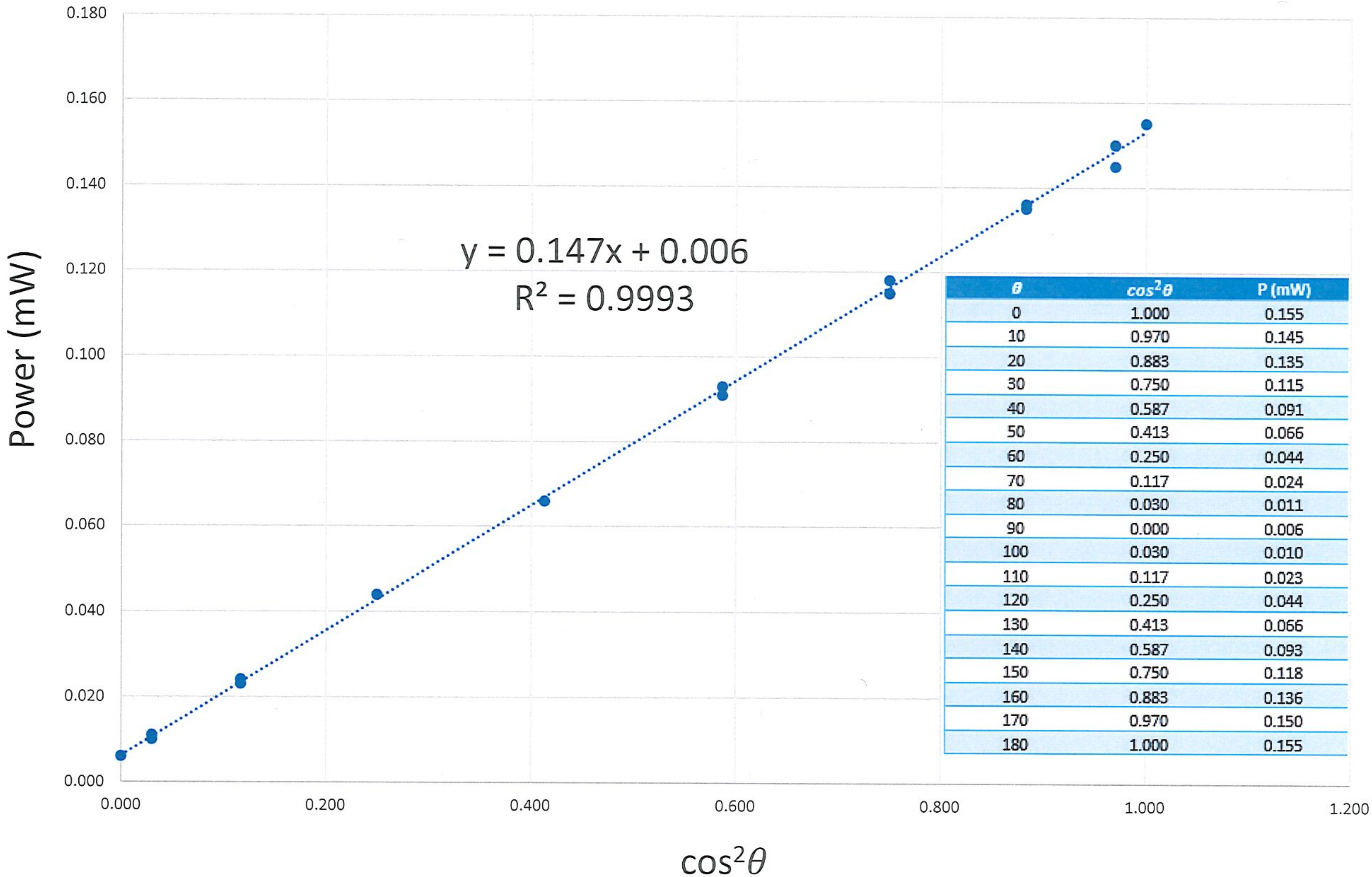
Part 2: Discussion of Results

"Brewsters angle (also known as the polarization angle) is an angle of incidence at which light with a particular polarization is perfectly transmitted through a transparent dielectric surface, with no reflection. When unpolarized light is incident at this angle, the light that is reflected from the surface is therefore perfectly polarized (Wikipedia).

Some of the major practical applications of Brewster's angle include:

1. Brewster angle microscopes - used in imaging layers of particles or molecules at air-liquid interfaces.
2. Hologram Images - Using Brewster's angle in hologram recording reduces/eliminates unwanted interference.
3. Photography & sun glasses - Understanding Brewster's angle helps with the creation of polarizing lenses which can eliminate glare and reflections.

Light Passing Through Polarizing Filter
$\cos^2\theta$ vs Power (mW)
Note: $P \propto I$



θ	$\cos^2\theta$	P (mW)
0	1.000	0.155
10	0.970	0.145
20	0.883	0.135
30	0.750	0.115
40	0.587	0.091
50	0.413	0.066
60	0.250	0.044
70	0.117	0.024
80	0.030	0.011
90	0.000	0.006
100	0.030	0.010
110	0.117	0.023
120	0.250	0.044
130	0.413	0.066
140	0.587	0.093
150	0.750	0.118
160	0.883	0.136
170	0.970	0.150
180	1.000	0.155

Brewster's Angle Derivation

$$Note: \theta_1 = \theta_3 \ by\ the\ law\ of\ reflection$$

$$\theta_2 + 90° + \theta_1 = 180°$$

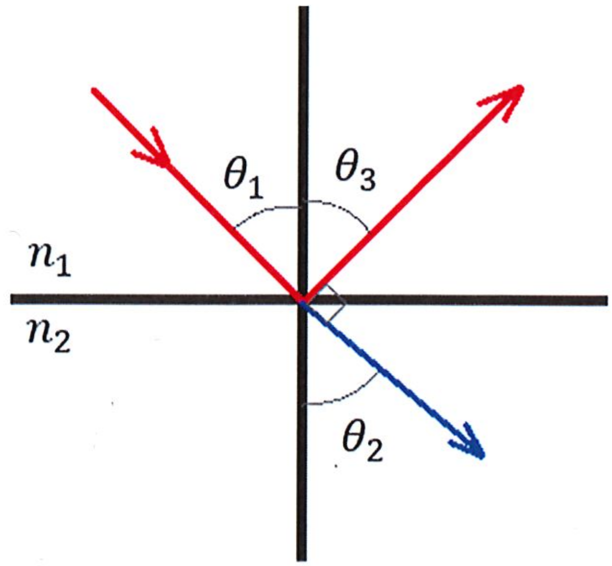
$$\theta_2 = 90° - \theta_1$$

$$sin\theta_2 = \sin(90° - \theta_1) = cos\theta_1$$

$$Snell's\ Law: \quad n_1 sin\theta_1 = n_2 sin\theta_2$$

$$\frac{n_2}{n_1} = n_r = \frac{sin\theta_1}{sin\theta_2} = \frac{sin\theta_1}{cos\theta_1} = tan\theta_1$$

$$\boldsymbol{n_r = tan\theta_1}$$



Error Propagation

$$n = tan\theta_B$$

$$\frac{\partial\theta}{\partial n} = \sec^2\theta = \frac{1}{\cos^2\theta}$$

$$\frac{\delta n}{n} = \left\{\left[\frac{\left(\frac{\partial\theta}{\partial n}\right)\delta\theta}{n}\right]^2\right\}^{\frac{1}{2}}$$

$$\frac{\delta n}{n} = \frac{\delta\theta}{\cos^2\theta\ tan\theta} = \frac{\delta\theta\ cos\theta}{\cos^2\theta\ sin\theta} = \frac{\boldsymbol{\delta\theta}}{\boldsymbol{\cos\theta\ sin\theta}}$$

$$Note: \delta\theta = 2° = \frac{2\pi}{180} = \frac{\pi}{90}$$

$$\frac{\delta n}{n} = \frac{\pi}{90\cos(60°)\sin(60°)} = 0.081 \rightarrow \boldsymbol{9\%\ Uncertainty}$$

Conclusion

Part 1:

The observable intensity of light was decreased, as expected, while looking at the blue sky through a polarizing filter. There were only slight variations in the intensity as the filter was rotated. Because the incoming light was not polarized, the intensity was theoretically cut in half regardless of transmission axis angle.

Reflected polarized rays were observed bouncing off a shiny surface. These reflections were easily eliminated when the polarizing filter's transmission axis was set perpendicular to the polarized light and was seemingly enhanced when set parallel.

Part 2:

The power, which is proportional to intensity, transmitted through a polarizing filter was found to have a linear ($R^2 = 0.9993$) relationship to $\cos^2 \theta$, where θ represents angular difference between the axis of the polarized light and transmission axis of the polarizing filter. It was seen that power was more easily transmitted when the polarizing filter axis was parallel to the polarized light, and the least amount of power was transmitted when the polarizing filter axis was perpendicular to the polarized light. This behavior accurately supports the law of Malus.

Part 3:

Not assigned.

Part 4:

The principle of Brewster's angle was used to find the index of refraction of a microscope slide. The value was experimentally found to be 1.73 with a 9% uncertainty. This value was compared to another lab group's value, 1.54, and found to have a 11% difference. If this other group's value was taken as the accepted value, then the percent difference is not within the margin of error, however, it is very close.

The reflected light never fully disappeared in this portion of the experiment, hence, the value for Brewster's angle was approximated at the point were the light was the dimmest. The experiment could be improved by positioning the surface which captures the reflected beam at a further distance away from the apparatus. By doing so, the captured light would have a longer arc length and a more precise point of maximum dimness could be determined.