**Experiment 4: Lens Aberrations**

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**Abstract**

~~Spherical Aberrations are studied using apertures and colored film. By defining the radial height which light passes through a large diameter lens, focal lengths were found to decrease with increasing heights. The effect of chromatic aberration was observed to be that the focal power of a lens is effectively increased when the wavelength of that light is shorter.~~

**Introduction**

Light can be thought of as a wave, an electromagnetic wave with electric and magnetic field components which are always perpendicular to each other and to the waves direction of travel. These fields are such that the cross product of the two always points in the direction of motion. When a ray of light is described this simply, its polarity is described as the orientation of a line which lies on the plane of the electric field and which is perpendicular to the direction of travel. Most waves are not polarized but are instead comprised of components oriented in all directions.

Polarizers are light filters that discriminate based on the orientation of its electric field components, where only the components aligned with that of the polarizer’s pass through. This filtering can be described very simply as reducing the total field amplitude of the light by a cosine of the angle between the orientations of that light and the polarizer. In practice, most polarizers do not filter out all non-aligned wave components, nor do they truly transmit 100% of what is aligned. Also, polarizing effects are generally wavelength dependent.

Intensity of a light wave is the square of the total electric field at a given location and time. As a polarizer only allows of the wave through, the intensity will go down by a square of that factor; i.e. . For un-polarized light, the effect of a linear polarizer is a convenient factor of ½ of the initial intensity. This is due to the average of cosine over all angles being equal to .

A 3 mW diode laser light source was then studied to determine if it was polarized. The laser, a polarizer, and a power measuring device were attached to clamps and optically aligned by securing their clamps to a long metal rail system in the lab. The power measuring device appeared to be a flat surface and likely utilizes something like a photomultiplier tube with some interface on the back end which generates charge that gets read out as a current. This current is converted to a value for power by a Newport Digital Power Meter 815 Series. By rotating the polarizing film, one can study the polarization of incoming light.

A quarter wave plate is a special type of filter, instead of blocking non-aligned components of incoming light, it selectively shifts these components by pi/2 of the wavelength. The total electric field, and total intensity, can be described with the following equations after having passed through a plate with a component shift of pi/4, and then of the quarter wave (pi/2).

Brewster’s angle is the angle of incidence where incoming light of a certain polarization is completely transmitted through the second media, and none is reflected. However, when the incoming light is un-polarized there is a portion of it that gets reflected and that reflected light will be perfectly polarized. Brewster’s can be described as the arctangent of the ratio of the two medias indices of refraction.

**Analysis & Discussion**

We first set out to determine whether light can be polarized when reflecting off a glass plate. This was done by letting un-polarized light from a lamp reflect off the glass plate, and up through a polarizing film to our naked eye. By rotating the film, the observed intensity of the reflection could be very nearly completely removed. It was noted that the degree to which this effect was possible depended on the light’s angle of incidence with the plate. This observation of angular dependence on polarized reflection supports the idea that what’s being seen is the effect of Brewsters’ angle, as noted in the introduction. The polarization of reflected light is perpendicular to the plane spanned by the incoming, refracted, and reflected rays. It’s oriented in this direction because of the many dipole moments at the surface—which allow the radiation of transmitted light—also uniquely do not transmit light oriented along the direction of their moments. A situation somewhat analogous to how moving electrons along wires in a wire grid polarizer reflect light in that orientation but allow orientations 90 degrees from it pass through. If we had instead observed light reflecting off of a heated road, the orientation of the reflected light would be the same but due to the fact that the indices of refraction are so much closer to each other their ratio would be closer to one and Brewsters angle would be much larger. Meaning that if one were to manufacture sunglasses, they’d want the polarizing media to be oriented in the vertical direction (if it were a grid, the wires oriented horizontally).

A green laser light source was then studied for polarization using the optical set up described in the introduction. It is important to note that the units read out on the meter may not be accurate. Throughout the lab we maintainied range setting of 10 microWatts, and background to be a 0.01 uW. There also appeared to be a capacitive effect in the signal where, with no changes to the system, the power read back would increase for some time in the order of 2 minutes before rapidly decreasing to the initially read value. Effort was made to take our measurements at consistent time periods after having adjusted any system parameter.

When rotating the polarizer, it was clear that the laser light was polarized. Rotating from -85 to +85 degrees, by intervals of 10 ±1 degrees, the power was read out from the meter and logged. This data is tabulated below.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Angle | | -85 | | -75 | | -65 | | -55 | | -45 | | -35 | | -25 | | -15 | | -5 |
| Intensity | | 0.475 | | 0.34 | | 0.215 | | 0.125 | | 0.08 | | 0.09 | | 0.15 | | 0.265 | | 0.415 |
| 5 | 15 | | 25 | | 35 | | 45 | | 55 | | 65 | | 75 | | 85 | |
| 0.525 | 0.71 | | 0.82 | | 0.87 | | 0.96 | | 0.98 | | 0.88 | | 0.78 | | 0.66 | |

Plotting this function, its apparent that this is best fitted with a sinusoidal function. By taking values for max, min, oscillation amplitude, and the function of cosine squared, a very good fit was made with an R-Squared value of 0.9972. This function is . Both functions are plotted here:

This is quite nice, and if you were to remove the background, the function approaches zero, meaning that the theory of rejecting all light with orthogonally oriented polarizations can be observed. Something else that’s good to see is that this cosine squared function matches with the equation of intensity seen in the introduction.

A quarter wave plate and a second polarizer are then introduced for analysis of the effect of the plate. The first polarizer was put into place and rotated until the highest power could be read on the meter, then a second polarizer was put into place and rotated until the least light was transmitted. In this way, the difference in orientation of the two is known to be 90 degrees. Now a quarter wave plate is placed between the two polarizers and rotated until rotationally positioned in a way to produce minimum and maximum power readings at the exit of the second polarizer. These angles were read out from tick marks on the outside of the quarter wave plate holder, and were found to be between -6 to -10 degrees for a minimum power of 0.01 x 10 uW, and between 34 and 40 degrees for a maximum power of 0.4 x 10 uW. Taking the average of angles for each point returns about -8 and 37 degrees for the minimum and maximimum points of transmission, the difference of which is about 45 degrees. This result is again very nice as it fits our theory from the introduction. An angle of 45 degrees results in a maximum for our intensity function after a quarter wave plate. Overall the system decreases the intensity by 36%.

It’s likely that our eyes have a higher resolution when using a lamp than the power meter does when using a laser, but this wasn’t tested in the lab. What would have been interesting is to maintain the orientation of the last polarizer and instead slide it along the optical axis in very small increments. What’s likely to have been observed is that a maximum could be found, as the vector is then rotating, it’s polarization is time dependent and will be aligned in a single direction at distances separated by integer wavelengths. In the same token, there should then also be an orientation of the second polarizer which transmits all of the wave through the system.

**Conclusion**

~~The parabolical longitudinal shift in focal lengths was seen to be negative when light passed through increasing radial displacements of the lens. The fit of the data was very good with R-Squared values of 0.9941 when the planar side of the lens faced the object, and 0.9983 for when the lenses’ orientation was reversed. However, the fitting parameters seemed to be a factor of 1000 off from the calculated value of S, where the second order factor of the fit was -0.0015 and S was about -1.6. It’s curious that the value for S was found to change between each change in height h.~~

~~A linear shift of the same sign was seen when decreasing the wavelength of light that passed through the lens. The fit of this data was poor relative to the other fits in this lab with an R-Squared value of 0.8492. One factor likely plays a large roll in this error: the aperture used was very small and at the center of the lens, this means that the angle at which the focused light met with the optical axis is very small and meaning the change in clarity for the image with longitudinal shifts of the screen was also very small. However, the inverse slope of the fit (0.164) would match very nicely with the radii of curvature calculated from measurements made with the spherometer (16.3cm).~~