Polarization Lab

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Throughout this paper, I will be explaining the theoretical background of light polarization and birefringence, as well as the experiments conducted in testing the properties of light including polarization and phase transitions at $\frac{\lambda}{4}$ and $\frac{\lambda}{2}$. These experiments were performed using univariate analysis of the three filters, as well as bivariate analysis using polarization and one of the phase transitions.

I. INTRODUCTION AND THEORETICAL BACKGROUND

James Clerk Maxwell put together Maxwell's Equations in the 1860s, and ever since then the idea of light as an electromagnetic wave has been the subject of experimentation[5]. Electromagnetic waves have two key components, the electric field carrying most of the energy of the wave, and the magnetic field controlling the direction of the wave. These two fields carry waves of energy perpendicular to each other and the direction of propagation. Faraday's law tells us that a changing magnetic field induces an electric field, while Maxwell's contribution to Ampere's law tells us a changing electric field generates a magnetic field. Together, light can be described as two perpendicular waves propagating itself forward.

We describe waves by the polarization, which is the angle of the electric field. Light bulbs emit light with polarization at every angle. When this light passes through a polarization filter, the filter only allows the electric field at a certain angle to pass through. This is why holding a polarization filter up to a light will reduce the intensity of the light, but never completely block it because some light will always be at the angle of polarization.

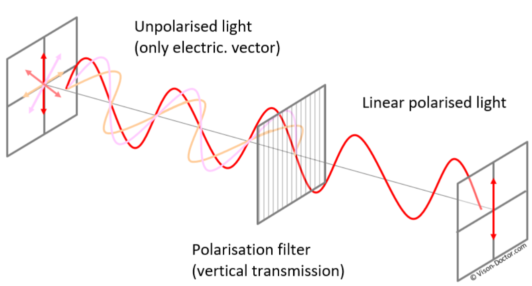


FIG. 1: The effects of a polarizing filter

Our computers emit light that is polarized in one direction. When this light passes through a filter that has a different angle of polarization, the component of the wave in that axis passes through. The strength of the light decreases as the angular difference increases up to 90°, at which point it will completely block light.

As a polarization filter blocks light according to the direction of polarization, a phase transition changes the polarization of the beam. Light passing through is refracted into two beams perpendicular to each other, one in the slow axis and one in the fast axis. The beam in the fast axis moves slightly faster than the beam in the slow axis. This slowness causes the light in the slow axis to be $\frac{\lambda}{4}$ or $\frac{\lambda}{2}$ behind the light in the fast axis.

For $\frac{\lambda}{4}$ phase transition, at the angle where an equal amount is split between the slow and fast axis, light becomes circularly polarized[4]. At every other angle, it is eliptically polarized.

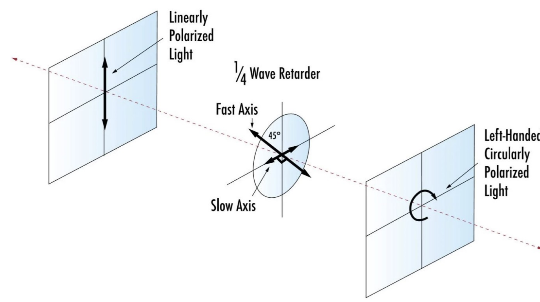


FIG. 2: The effects of a quarter wavelength retarder plate[4]

When orienting the fast axis of $\frac{\lambda}{2}$ phase transition with the polarization of light, it causes the polarization to rotate 90°.

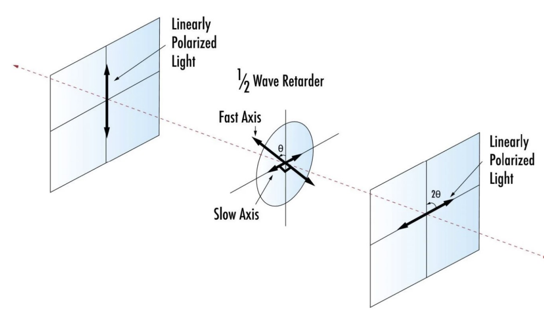


FIG. 3: The effects of a half wavelength retarder plate[4]

II. EXPERIMENTAL METHODS

The experimental setup consisted of a rail aligning four components along the same beam of light. The light source was a vertically polarized laser with wavelength

633nm. The laser would travel through two rotating filters attached to stepper motors connected to the Arduino. For one of the stepper motors, I made the apparatus to fasten it to the rail. Once the beam passes through the filters, the power of the laser is measured by a photodetector at the end.

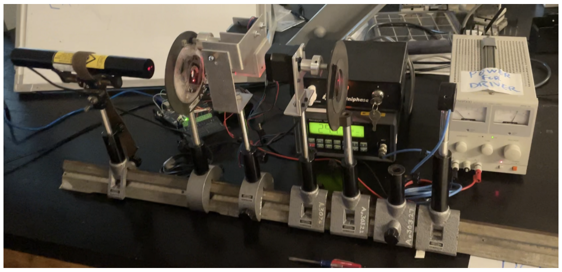


FIG. 4: Experimental Setup

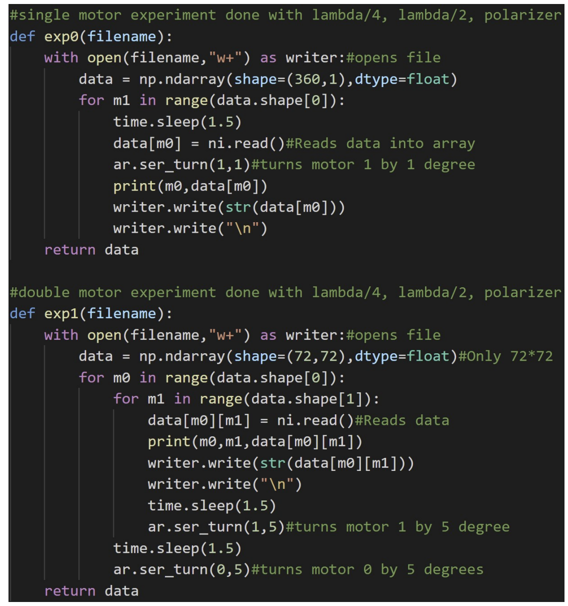
The arduino and photodetector interface with the computer through two drivers, ardriver.py and nidriver.py respectively. For univariate experiments, either the polarization filter, $\frac{\lambda}{4}$, or $\frac{\lambda}{2}$ was put on the rotating apparatus and every 1° was measured. For experiments that had two of the filters, they will be described as A and B to destinguish the order that the beam travelled and for data purposes every 5° was measured. In the experimental setup, a polarization filter with horizontal polarization is at 0°, as well as the fast axis of the phase transitions.

A. Coding Methodology

The first driver used is nidriver.py. It has only one method in which it sends a query "D?" to the photodetector. This reads the data of the photodetector and is recieved by the driver. The second driver used is ardriver.py, which interacts with the arduino running compatible firmware. The primary method used in ardriver.py is turn(motor,angle). This method sends a command to the arduino which will rotate the specified motor by the specified angle.

The main file experiments.py combines the functionality of the two drivers and defines the experiments conducted. There are two functions exp0 and exp1 that can be called when you want to conduct an experiment on 1 or 2 rotating filters respectively.

The data from these experiments are stored into filenames sent in as parameters. It returns the data into a function that graphs the data. The full source code can be found here.



```
#single motor experiment done with lambda/4, lambda/2, polarizer
def exp0(filename):
    with open(filename,"w+") as writer:#opens file
        data = np.ndarray(shape=(360,1),dtype=float)
        for m1 in range(data.shape[0]):
            time.sleep(1.5)
            data[m0] = ni.read()#Reads data into array
            ar.ser_turn(1,1)#turns motor 1 by 1 degree
            print(m0,data[m0])
            writer.write(str(data[m0]))
            writer.write("\n")
    return data

#double motor experiment done with lambda/4, lambda/2, polarizer
def exp1(filename):
    with open(filename,"w+") as writer:#opens file
        data = np.ndarray(shape=(72,72),dtype=float)#Only 72*72
        for m0 in range(data.shape[0]):
            for m1 in range(data.shape[1]):
                data[m0][m1] = ni.read()#Reads data
                print(m0,m1,data[m0][m1])
                writer.write(str(data[m0][m1]))
                writer.write("\n")
                time.sleep(1.5)
                ar.ser_turn(1,5)#turns motor 1 by 5 degree
            time.sleep(1.5)
            ar.ser_turn(0,5)#turns motor 0 by 5 degrees
    return data
```

FIG. 5: From experiments.py, the methods running the experiments

B. Part Sketches and Final Product

The first part created was the adapter to control the angle of the rotating filter using a stepper motor. It was created using a lathe out of aluminum, and there are fitting screws at both holes to lock in the components.

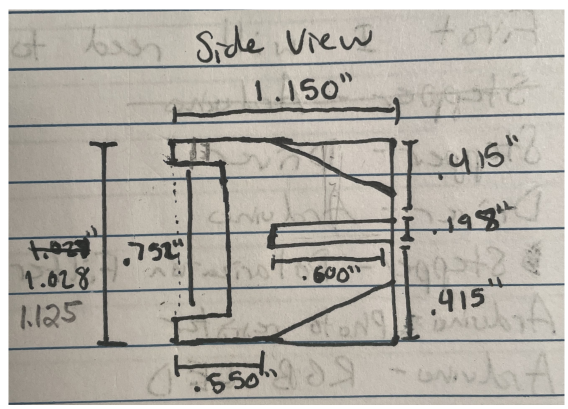


FIG. 6: Sketch of Stepper Motor to Rotating Device Adapter

The holder for the stepper motor is a plate that is cut out in the shape of the sketch along with a piece perpendicular at the bottom of the holder where it is connected to a bar fastened to the rail.

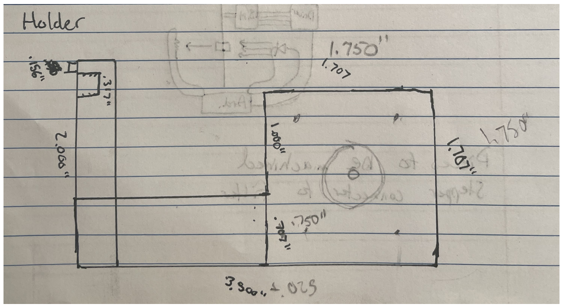


FIG. 7: Sketch of Holder for Stepper Motor

This is the final product once it is put into it's spot in the experiment. The adapter varies slightly from the sketch because it was easier to make and a diagonal in that place of the sketch was purely asthetic.

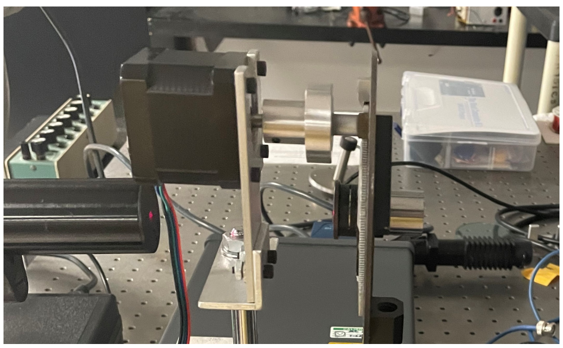


FIG. 8: Side view of the final product

III. EXPERIMENTAL RESULTS

Experiments 1 and 2 were conducted on $\frac{\lambda}{4}$ and $\frac{\lambda}{2}$ phase transitions respectively. In experiment 1, there are 8 countable peaks to the power of the laser. This would correspond to a peak every 45°. In experiment 2, there are 2 peaks indicating a peak every 180°. The power of these two experiments should be compared to that of experiment 3, in that the range of the experiments are .01 and .02 respectively while experiment 3 has a range of .08. This gives the reference to how much power is actually being lost with these filters, only small amounts compared to that of a polarization filter.

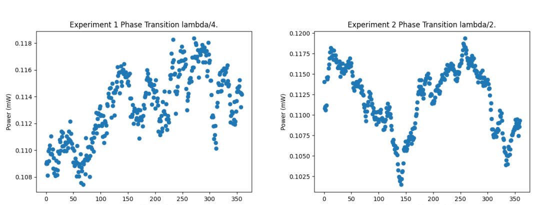


FIG. 9: Results of $\frac{\lambda}{4}$ and $\frac{\lambda}{2}$ phase transitions

Experiments 3 was conducted using vertically polarized light passed through a polarization filter oriented horizontally at 0°. When the polarization of light is parallel to the polarization of the filter, the maximum energy is able to pass through. There are two peaks in the graph because the filter is parallel to the polarization of light at 0 and 180. At 90 and 270, the graph is at it's minimum. This is because the sin of angular difference between the laser and filter is greatest. Experiment 4 is similar to experiment 3, in that a $\frac{\lambda}{4}$ phase transition was placed before the polarization filter, causing the graph to become behind phase by 45°.

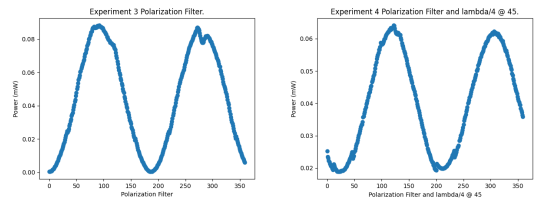


FIG. 10: Results of polarization filter and polarization filter with $\frac{\lambda}{4}$ at 45°

Experiment 5 was conducted using two rotating elements with A being a $\frac{\lambda}{4}$ phase transition and B being a polarization filter oriented horizontally at 0°. The combined effects of the polarization filter and phase transition appear to slice through each other. The top right graph indicates the power as a function of the phase transition. Consistent with experiment 1, there are 8 countable peaks, with noticable valleys every 90°. The bottom left graph shows the power as a function of the polarization filter. The result is consistent to that of the univariate experiment 3. Finally, the bottom left shows a heat map indicating the peaks as lighter areas on a graph of polarization filter and phase transition.

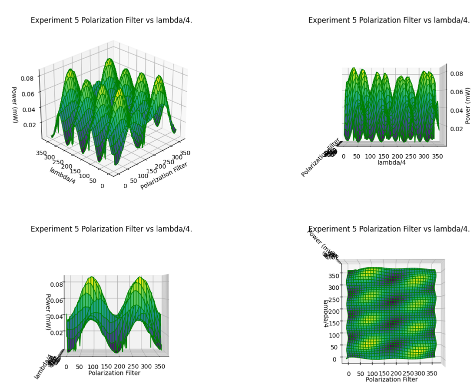


FIG. 11: Results of polarization filter and $\frac{\lambda}{4}$

Experiment 6 consisted of $\frac{\lambda}{2}$ at A and a polarization filter at B. The interesting part about this result is the diagonal lines shown in the right figure. This is the only diagonal feature in this report. The four waves are at an angle of 20° to the axis of the polarization filter. 20° is a strange number in this series of experiments, every other results aligns with a multiple of 45°. I believe this to be an experimental error, and the error analysis can be found below. More experimentation is required to say more about the properties of this experiment.

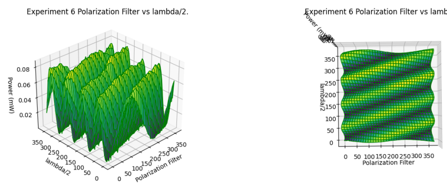


FIG. 12: Results of polarization filter and $\frac{\lambda}{2}$

Experiment 7 and 8 had very similar results. The difference between experiments 5/6 and 7/8 are the order to which the beam passes. In the previous experiments, the phase transition was at A and the polarization filter was at B. For 7 and 8, the beam passes through the polarization filter first at A, followed by phase transition at B. In both experiments, the results can be simplified to that of a polatization filter, the phase transitions did not have any effect if it is the second filter.

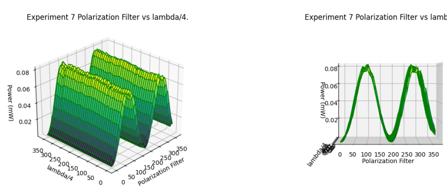


FIG. 13: Results of the reverse of experiment 5

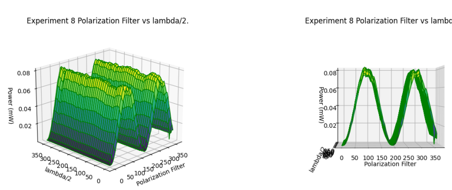


FIG. 14: Results of the reverse of experiment 6

A. Error Analysis

For the last four experiments, the data collection was greater and I let it run overnight. When I came back to check on the results, I consistently found one element to be at 355°, while the other one was at about 30°. This is clear reason for concern because I would expect the experiment to terminate at 355°,355°. The motor found at 30° was the more active motor, it would do a full turn and then the other motor would rotate 5°. Given this evidence, I believe the error is in calibration of the formula that converts angle to the desired step count. Here is a code exerpt. The way I made this equation

```
//3200 steps=35 degrees
int rem = angle%35;
int steps = (((angle-rem)/35)*3200)+map(rem,0,35,0,3200);
```

FIG. 15: From IOArduino, firmware run on the arduino

was testing the angular difference that 3200 steps would make, a full rotation of the stepper motor. This came out to 35°. The first step in the formula is to separate the remainder of the angle and 35°. If the angle was 40°, rem=5, angle-rem=35 and that quantity is divided by 35 to find the number of full motor rotations that should be used. Once the number of full motor rotations is found, it is multiplied by 3200 to get the number of steps required for that many full rotations. The map will find the appropriate extra steps required to move the remainder. The remainder is mapped from the domain [0,35] to [0,3200] to find the number of steps needed to cover the remainder. I believe that I could have spent more time calibrating the stepper motor, instead of calibrating over 35°, I could have calibrated it over a full rotation of the rotating element, or even more for greater precision.

IV. CONCLUSION

The first conclusion to be made is the finality of the polarization filter. In experiment 3 we see the clean sinosoidal nature of the polarization filter as it rotates. In experiments 7 and 8, the polarization filter was the first filter that light passed through and it seems to have ignored the phase transitions. Comparing 7 and 8 to their reversed counterparts, it's interesting that the properties of light depend on the order to which the beam passes through filters. The second coExperiment 5 was interesting in particular because it combined the properties of $\frac{\lambda}{4}$ and polarization filter perpendicularly. Looking at it from one angle, you see the 8 peaks of the phase transition. Looking at it from another angle, you see the 2 peaks of the polarization filter. This tells me that the effects of these two filters combine as a superposition of both waves.

V. REFERENCES

[1] Michael Cyran, Source Code
[2] Douglas Murphy, Principles of Birefringence
[3] Tim Davis, Explainer: what is wave-particle duality
[4] Edmund Optics Understanding Waveplates and Retarders
[5] P. Lucas Maxwell's Equations