**Lab #7: Linear Polarization**

**Goal:**
Explore linear polarization and Malus’ Law

**Equipment:**
Optical bench with incandescent lamp, three Polaroid filters and photometer

1. **physics**

Unpolarized light (of intensity $I_{up}$) can be viewed as a superposition of two linearly polarized, *incoherent* waves (of intensity $I_{up}/2$) with orthogonal $E$-vectors. Polaroid filters (PF) pass only waves which have their $E$-vector in a certain direction, the ‘transmission axis’. After a PF with transmission axis in the y-direction, unpolarized light has become linearly polarized with amplitude $E_0$, since only half the intensity passes the PF. Linearly polarized light can be viewed as a superposition of two linearly polarized, *coherent* waves with orthogonal $E$-vectors, $E_{0,a}$ and $E_{0,b}$. If this light traverses a second PF with its transmission axis at an angle $\theta$, only the $E_{0,b}$ component is passed. Since intensity is proportional to the square of the amplitude, the intensity $I_1$ after the second PF is

$$I_1 = I_0 \cos^2 \theta \quad .$$

This is known as Malus’ Law (Hecht, eq.8.24).

**Question:** Assume that you have arranged two PFs ($PF_1$ and $PF_2$) with orthogonal transmission axes, such that no light passes. Now you introduce a third PF ($PF_3$) *between* the other two. The transmission axis of $PF_3$ is at an angle $\theta$ with respect to that of $PF_1$. What is the transmitted intensity as a function of $\theta$?

2. **measurements**

<table>
<thead>
<tr>
<th>incandescent lamp</th>
<th>$PF_1$</th>
<th>$PF_2$</th>
<th>light sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.1 **Malus’ Law**
- Set up the incandescent lamp and the light sensor but first omit the polarizers. Measure the intensity of the light ($I_{up}$).
- Now put $PF_1$ into place and measure the intensity for several orientations of its transmission axis. Does the intensity depend on the orientation of $PF_1$?
- Orient the transmission axis of $PF_1$ to be vertical. Put $PF_2$ into place and measure the intensity as a function of the angle $\theta$ between transmission axes of $PF_1$ and $PF_2$. 


2.2 Analysis 1
Enter the data in a spreadsheet and plot $I(\theta)$ versus $\theta$. In order to test Malus’ Law, fit the data with the expression

$$I(\theta) = a + b \cos^2 \theta.$$ \hspace{1cm} (2)

Determine the constants $a$ and $b$. What is the physical significance of these constants?

2.3 Three polarizers
Orient PF$_1$ and PF$_2$ such that their transmission axes are orthogonal, i.e., such that no light passes through. Now, introduce a third PF$_3$ between them. Measure the transmitted intensity as a function of the angle $\theta$ of the transmission axis of PF$_3$ with respect to that of PF$_1$.

2.4 Analysis 2
Enter the data in a spreadsheet and plot versus $\theta$. Fit the data with the expression that you were asked to derive in sect.1.

3 Questions
- Estimate the error in measuring the intensity of the light with no polarizers, with one polarizer, with two polarizers.
- The polarizers are calibrated with a scale in degrees. Can you think of a way to check the angle scale?
- Estimate the error of the angle $\theta$ between the transmission axes of two polarizers.
- How would you try to reduce the constant $a$ in analysis 1?
- Would the experiment be improved by using lenses to focus the light path from the lamp to the light sensor?