PHYSICS 202 LAB 12: THE ANGULAR DEPENDENCE OF LIGHT TRANSMISSION THROUGH A POLARIZER

DR. TIMOTHY C. BLACK

SPRING, 2009

THEORETICAL DISCUSSION

The intensity *I* of a light wave is proportional to the square of the amplitude of the electric field amplitude associated with the wave; i.e.,

$$I = \langle S \rangle = \left(\frac{1}{2\mu_0 c} \right) E_0^2$$

Its SI units are W/m^2. The intensity is an important experimental quantity, because, unlike the electric field amplitude, it is directly measurable.

Dichroic polarizers: A dichroic polarizer is one which selectively absorbs one component of the electric field while allowing the other to pass unmolested. There are many varieties of dichroic polarizers, but the most commonly used is the *polaroid film*, the first of which was invented by Edward Land (when he was a 19~year old undergraduate). Polaroids consist of parallel long-chain polymer molecules created by extrusion of the polymer melt. Conduction electrons are relatively free to travel the length of these molecules, but their motion is relatively constrained in the direction perpendicular to the chain. Light waves polarized along the chain direction are freely absorbed by the conduction electrons, whose energy is dissipated traveling up and down the length of the chain. Light along this axis is therefore not re-emitted, but is (almost) completely absorbed. There is a slight frequency dependence across the visible range to this absorption, with the efficiency of blue light absorption somewhat smaller than the efficiency of absorption in the red. (They “leak” in the blue.)

For a generic light wave polarized as shown in figure 1, the component parallel to the pass axis, $E_{\|} = E_0 \cos\theta$, passes through the film, whereas the component perpendicular to this axis, $E_{\perp} = E_0 \sin\theta$, is absorbed.

If the intensity of the initial wave is

$$I_0 = \left(\frac{1}{2\mu_0 c} \right) E_0^2$$

then the intensity of the wave after passing through the polarizer is

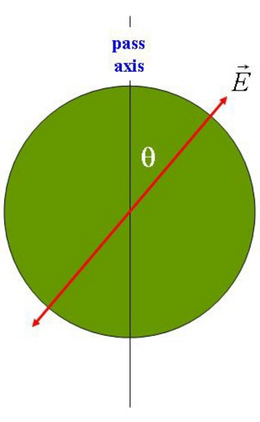

Fig. 1: Geometry of transmission through a polarizer

$$I_1 = \left(\frac{1}{2\mu_0 c}\right) E_{\parallel}^2 = \left(\frac{1}{2\mu_0 c}\right) E_0^2 \cos^2\theta,$$

so that

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

This result is known as Malus' Law. Note that if the initial light wave is unpolarized, so that the polarization axes are randomly distributed, then the intensity is given by the average intensity, integrated over all possible polarization directions, from $\theta = 0$ to 2π. Thus, for initially unpolarized light,

$$I_1 = \frac{I_0}{2\pi}\int_0^{2\pi} d\theta \cos^2\theta = \frac{1}{2} I_0$$

In reality, there is also going to be some loss from reflection at the surface, so that in practice,

$$I_1^{obs} < \frac{1}{2} I_0$$

EXPERIMENTAL PROCEDURE

The object of this lab is to experimentally verify Malus' Law, which states that the intensity of initially polarized light, after passing through a second polarizer, will vary as the square of the cosine of the angle between the two pass axes of the polarizers. Although laser light is generally polarized to some degree, we are not going to assume this. Rather, you will pass the laser light through an initial polarizer and measure its post-polarizer intensity I_1, as shown in figure 2.

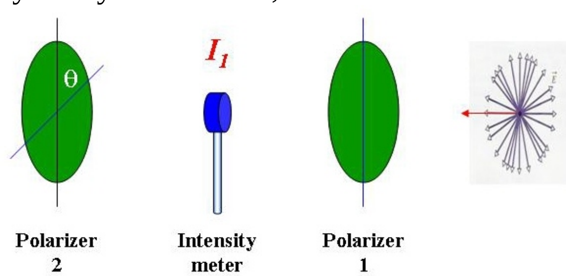

Fig. 2: Experimental setup for measuring the intensity I_1

You will then pass light through a second polarizer and measure its intensity I_2, as shown in figure 3. You will also record the angle θ that this polarizer makes with respect to a nominally 0° angle. The angles shown on

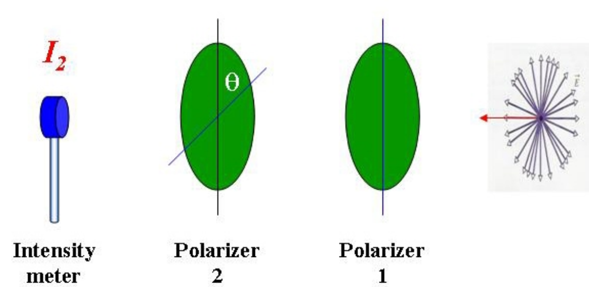

Fig. 3: Experimental setup for measuring the angular dependence of I_2

the polarizer holders are not calibrated, so that they do not necessarily refer to the actual angle of the pass axis. Therefore, there will be an unknown angle offset, which you can, however, determine in the analysis. You will take data at 15° increments, from 0° to 180°. According to Malus' Law, the intensities $I_2(\theta)$ should follow a $\cos^2(\theta+\theta_0)$ distribution, where the angle θ_0 is the unknown offset angle. In other words,

$$I_2(\theta) = I_1 \cos^2(\theta+\theta_0) \qquad \textbf{Equation 1}$$

In order to analyze this data with a program like Excel, we are going to have to linearize it. If we define the variables

$$f(\theta) = \frac{I_2(\theta)}{I_1} \qquad \textbf{Equation 2}$$

and

$$g(\theta) = \cos^{-1}\left(\sqrt{f(\theta)}\right) = \cos^{-1}\left(\sqrt{\frac{I_2(\theta)}{I_1}}\right) \qquad \textbf{Equation 3}$$

then we obtain a linearized version of Malus' Law, namely that

$$\theta = g(\theta) - \theta_0 \qquad \textbf{Equation 4}$$

This procedure is not perfect. In particular, since the transmission of the polarizers is not perfect there will be an additional angle-independent loss term on the RHS of equation 1 which we cannot account for with this linearization procedure. In order to extract this term also, we would need either additional data, or a more sophisticated analysis program. You will be the ones to determine how significant this discrepancy is. The following table should help you to organize your data:

Angle θ	**Intensity** $I_2(\theta)$	$f(\theta)$ **(Equation 2)**	$g(\theta)$ **(Equation 3)**
0°			
15°			
30°			
45°			
60°			
75°			
90°			
105°			
120°			
135°			
150°			
165°			
180°			

After collecting the data, you should generate a linear plot of θ vs. $g(\theta)$. If the plot is not linear, you should discuss why not. Remember to use radian angles in your analysis.