PHYS263 Lab 3

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September 27, 2024

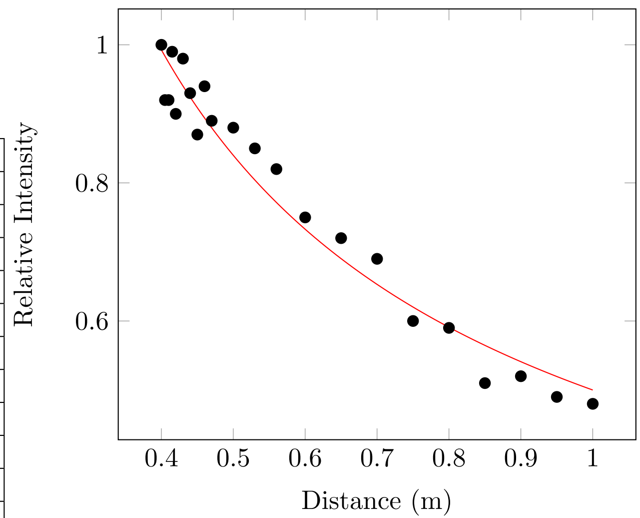
Abstract

Displacement, reflection, refraction, and polarization each have their own transforming effects on the intensity and direction of light. We used a constant monochromatic microwave source, a goniometer, and simple objects to enact these transformations before a detector. We found that intensity decreases with distance, reflection occurs precisely opposite the angle of incidence, refraction varies increasingly with angle of incidence, and polarization is a trigonometric transformation.

1 Data & Analysis

1.1 Intensity

Distance (m)	Intesity
.4	1
.405	0.92
.41	0.92
.415	0.99
.42	0.9
.43	0.98
.44	0.93
.45	0.87
.46	0.94
.47	0.89
.5	0.88
.53	0.85
.56	0.82
.6	0.75
.65	0.72
.7	0.69
.75	0.6
.8	0.59
.85	0.51
.9	0.52
.95	0.49
1	0.48



The curve fitting this data is

$$\frac{0.50}{(d/1\mathrm{m})^{0.748}}$$

which is the optimal case of

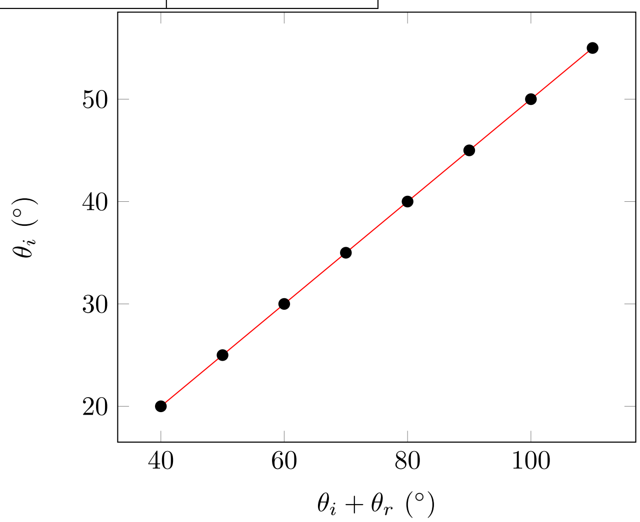
$$\frac{a}{d^p}$$

. Though more complex functions defining power per angular area could put the best-fit function in many other families, this one encompasses the simplest cases of uniform intensity ($p = 2$) and of a plane wave ($p = 0$). The p/θ^2 function of our transmitter is always decreasing as θ moves away from the central angle, making it qualitatively between these two cases, so the use of this equation with an intermediate p stands to reason.

Additionally, it was observed that on top of this inverse power trend, there was a consistent pulsing with peaks about every 1.5 cm. This is exactly half the wavelength of our microwaves, suggesting an interference pattern proportional to $\cos^2(\omega d - \phi)$. Incorporating this into the model would further decrease error.

1.2 Reflection

Arm Angle (°)	Plate Angle (°)
40	20
50	25
60	30
70	35
80	40
90	45
100	50
110	55



This data proves with 0% error that $\theta_i = \theta_r$, regardless of its value.

1.3 Refraction

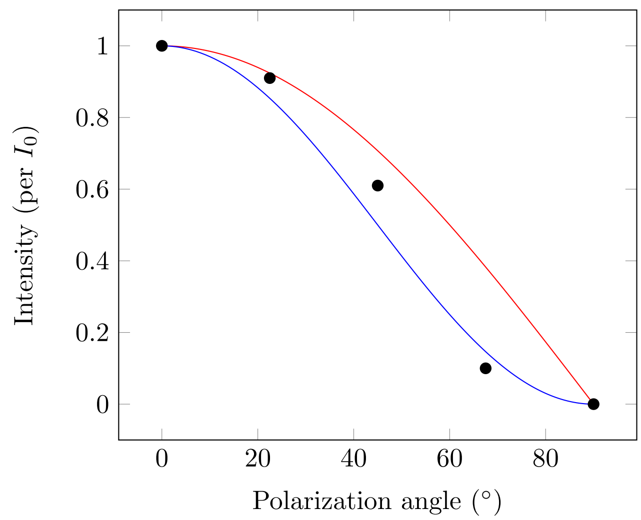
$\theta(°)$	$\theta_1(°)$	$\theta_2(°)$	n_2
15	20	35	1.68

Due to 2.5°measurement uncertainty, n_2 is confirmed only to be from 1.40 to 2.02.

1.4 Polarization

θ	I (per I_0)	$\cos(\theta)$	$\lvert I - \cos(\theta)\rvert$	$\cos^2(\theta)$	$\lvert I - \cos^2(\theta)\rvert$
0	1	1	0	1	0
22.5	0.91	0.92	0.014	0.85	0.056
45	0.61	0.71	0.097	0.50	0.11
67.5	0.1	0.38	0.28	0.14	0.046
90	0	0	0	0	0

Average error: 0.078, 0.024



$\cos^2(\theta)$ is a better fit to the data, corroborating that I is proportional to E^2, as E should intuitively be proportional to $\cos(\theta)$.

2 Questions

2.1 Reflection

- What relationship holds between the angle of incidence and the angle of reflection? Does this relationship hold for all angles of incidence?

  The angle of reflection is always equal to the angle of incidence, regardless of any parameter whatsoever.

- In measuring the angle of reflection, you measured the angle at which a maximum meter reading was found. Can you explain why some of the wave reflected into different angles? How does this affect your answer to question 1?

  The transmitter releases light at a range of angles, with the nominal straight angle only really being its maximum.

- Ideally you would perform this experiment with a perfect plane wave, so that all the Transmitter radiation strikes the Reflector at the same angle of incidence. Is the microwave from the Transmitter a perfect plane wave (Consider how you could test this)? Would you expect different results if it were a perfect plane wave? Explain.

  All microwave rays originate from a source at most a few centimeters wide, and if they were all parallel, they would stay within an area that wide, including after reflection. Radiation was detected on a much wider range than that, so the light from the transmitter is not a perfect plane wave.

  Furthermore, intensity decay in light occurs because fewer rays intercept unit-sized objects at greater distances; rays themselves do not decay. The rays in a perfect plane wave stay together at any distance, so the intensity of a plane wave does not decay.

2.2 Refraction

Would you expect the refraction index of the styrene pellets in the prism mold to be the same as for a solid styrene prism?

The styrene pellets are roughly homogeneously packed in air, so the mass thereof can be understood as a singular material. Solid styrene is not the same material as this, so it would not necessarily have the same index of refraction.

2.3 Polarization

- Based on your data from rotating the polarizer when starting with the horns aligned, how does the Polarizer affect the incident microwave?

- Can you explain the results of the last step of the polarization experiment?

- How can the insertion of an additional polarizer increase the signal level at the detector?

  Let $\mathbf{r} : [0, \pi) \to \mathbf{R}^+$ be the intensity of light polarized at angle θ passing normally through a 2D neighborhood.

  $\{\mathbf{r}\}$ is polarized if and only if

  $$\exists! \theta \in [0, \pi) : \mathbf{r}(\theta) \neq 0 \quad .$$

  Let $\boldsymbol{\theta}$ denote a unit vector, so that $I\boldsymbol{\theta}$ denotes the set $\{\mathbf{r}\}$ polarized at θ with intensity I.

  A polarizing filter at angle θ can be expressed as a function

  $$\mathbf{f}_{\boldsymbol{\theta}}\{\mathbf{r}\} = \int_0^\pi \mathrm{proj}_{\boldsymbol{\theta}} \mathbf{r} d\theta = \boldsymbol{\theta} \int_0^\pi \mathbf{r} \cdot \boldsymbol{\theta} d\theta$$

or if $\{\mathbf{r}\}$ is polarized

$$\mathbf{f}_{\boldsymbol{\theta}_2}(I\boldsymbol{\theta}_1) = (I\boldsymbol{\theta}_1 \cdot \boldsymbol{\theta}_2)\boldsymbol{\theta}_2 = I\cos(\theta_1 - \theta_2)\boldsymbol{\theta}_2 \quad .$$

When filters are placed in sequence, the resulting magnitude is

$$|\mathbf{f}_{\boldsymbol{\theta}_3} \circ \mathbf{f}_{\boldsymbol{\theta}_2}(I\boldsymbol{\theta}_1)| = I\cos(\theta_1 - \theta_2)\cos(\theta_2 - \theta_3)$$

which may be greater than $I\cos(\theta_1 - \theta_2)$.
This is most apparent when $\theta_1 \perp \theta_2$ and $\theta_3 = (\theta_1 + \theta_2)/2$:

$$\mathbf{f}_{\boldsymbol{\theta}_2}(I\boldsymbol{\theta}_1) = 0$$

$$\mathbf{f}_{\boldsymbol{\theta}_2} \circ \mathbf{f}_{\boldsymbol{\theta}_3}(I\boldsymbol{\theta}_1) = \cos^2(45°)I\boldsymbol{\theta}_2 = \frac{1}{2}I\boldsymbol{\theta}_2$$

2.4 Error

Artifacts aside, angle measurement was by far the largest source of error, as there was often no convenient way of connecting objects on the stage to points on the goniometer.