Name
Section Number
Lab Partner's Name

Geometrical Optics

I. Brief description of the experiment

In geometrical optics, refraction is described by Snell's Law. Refraction refers to the bending of light as it passes from one medium to another. Snell's Law will be studied in this lab. It states that

$$n_i \sin\theta_i = n_r \sin\theta_r \qquad (1)$$

where *n* is the index of refraction of the incident or refracted material, and θ is the angle of the incident or refracted light ray measured from the normal to the surface. When the incident index of refraction is greater than the refracted index of refraction, there is a critical angle beyond which refraction can no longer take place and the beam of light is totally internally reflected. This critical angle is given by

$$\theta_c = \sin^{-1}(\frac{n_r}{n_i}) \qquad (2)$$

The index of refraction of a material will be measured using a semi-circular lens and equations 1 and 2.

When light passes through a rectangular piece of material of width, *t*, its lateral displacement, *d*, is given by

$$d = t\frac{\sin(\theta_i - \theta_r)}{\cos(\theta_r)} \qquad (3)$$

Equation 3 presumes that the light emerging from the rectangular plate is parallel to the incident path. This is the "optical micrometer" case. If there is some angle of deviation from the incident path, it can be found using

$$\theta_{dev} = \frac{d_{far} - d_{near}}{L} \qquad (4)$$

where *L* is the distance between the two different locations where the lateral displacement is measured.

In the first part we will use refraction measurements to find the index of refraction n, then compare it to the values obtained by subsequent refraction measurements and the critical angle method. We will then use Eq 3 to predict displacement vs angle of the optical micrometer, and measure the deviation angle for this configuration, which should ideally be 0.

II. <u>Questions and Extra Credit Work</u> (start as a new page).

Q1) It's important that the beam passes over the center of the lens because….

…

Q4) As stated below, our results are consistent with the expected values with no optical elements in place …..

EC1) ….

III. <u>Measurements, Calculations, and Results</u>

A summary of results and calculations can be found on the attached spreadsheets.

	1/9/2014	Geometrical Optics Summary Table							
		f	df	expect	dexpect	D	dD	t value	OK?
	Index of refraction								
	units	no units	no units	no units	no units				
Part I	(1) Flat toward laser (D-config.)	1.472	0.013	1.488		0.02	0.01	1.20	Y
	(2) Curved toward laser (C-config.)	1.307	0.18	1.4880		0.18	0.18	1.00	Y
	(Extra Credit)								
	units	no units	no units	no units	no units				
Part II	Index of refraction from critical angle	1.460	0.007	1.4880	0.00000	0.03	0.007	4.25	N
	units	no units	no units	no units	no units				
Part III	displaced/predicted			1.00	0				N
	L1 (58.5 cm)	1.261	0.044	1.00	0	0.26	0.044	5.90	N
	L2 (129 cm)	1.404	0.074	1.00	0	0.40	0.074	5.44	N
	units	radian	radian	radian	radian				
Part IV	dev angle	0.003	0.0017	0	0	0.00300	0.00170	1.76	Y

For the measurement of n in the "D" configuration, we found we had to subtract angles xxx and yyy to get an angle corresponding to theta_r in formula 1); see sketch on p 23 of lab book for the definitions of the angles. We also translated between – and plus angles in the spreadsheet using 180 – the angle at the indicator for the xxx angle case.

In the "C" configuration, the angles are defined in the sketch below, and theta_i corresponds to xxx xxxxx. The critical angle used the same angle definitions, just setting the angle zzz to 90 degrees, and using Eqn. (2).

The optical micrometer part was analyzed using the index of refraction from the "D" configuration to calculate theta_r in Eqn. (3), where the displacements xnear were calculated by subtracting off the position Xo when the lens was removed. We repeated this again in the near position, where we moved the table as seen on page 24 of the lab book.

You could just put the table here in the page order but as a separate piece of paper.

IV. Conclusion

The two measurements of the index of refraction using the D-lens were compatible. This was actually sort of surprising, since we could see the surface was a little wavy, and the values from the first measurement had significantly larger uncertainties than the second measurement. However, the critical angle measurement of the index of refraction was not compatible with the first n measured. We had a lot of discussions about how to define the critical angle (see the crossed out page in the lab notebook), and it was not so easy to say just when it met our criterion. And we might have picked a criterion that gave a systematically biased version of the critical condition, biasing the index of refraction measurement. The equation predicting the optical micrometer displacement worked well. The deviation angle was pretty small, but its fractional error was large; in the end it was compatible with the expected value of zero. Overall, these three measurements appear to be compatible with what ray optics predicts, and indeed we saw the transmitted beam fading as we got closer to total internal reflection.

There were several possible sources of error in this lab. There were random errors associated with the measurements of angles, and lengths. There were also many possible systematic errors. The laser beam may not have been aligned on the track. The plate at the end of the track or the paper attached to it may not have been perpendicular to the laser. The laser may not have passed directly through the pivot point of the protractor device. Perhaps the most obvious source of error was the fact that the lenses where of low quality, and all of the laser images were fuzzy, making it quite difficult to located the true position of the beam on the graph paper.

Extra material at the end of the report as follows:

Any computer plots number the pages so they are easy to refer to

Then calculation spreadsheets number the pages so they are easy to refer to

Finally, photocopied pages from your lab notebook

Uncertainty calculations example

(Here you describe how did you derive the uncertainties of the key results used to draw your conclusions, e.g. the column df in the summary table.)

Part I: For the measurements of index of refraction:

$$n = \frac{\sin\theta_r}{\sin\theta_i}, \quad \frac{dn}{n} = \sqrt{\left(\frac{d\sin\theta_r}{\sin\theta_r}\right)^2 + \left(\frac{d\sin\theta_i}{\sin\theta_i}\right)^2},$$

$$\frac{d\sin\theta}{\sin\theta} = \frac{\cos\theta d\theta}{\sin\theta} = \cot\theta d\theta$$

We assigned $d\theta_i \sim 0.5$ º based on the resolution of the protractor. $d\theta_r = \sqrt{(d\theta_i)^2 + (d\theta_d)^2}$

Here $\theta_d = \tan^{-1}(x/L) \sim \frac{x}{L}$ (see notebook page xx), so $\frac{d\theta_d}{\theta_d} = \sqrt{\left(\frac{dx}{x}\right)^2 + \left(\frac{dL}{L}\right)^2}$.

We assigned dx=0.5mm and dL=1mm.

We repeated the measurements several times. We reported the mean value, and to compare with the expected value we calculated the standard deviation of the mean

by stdev / sqrt(Nmeasurements)

Part II: For estimating index of refraction based on the critical angle,

$n = 1/\sin\theta_c$, $dn = \frac{\cos\theta_c}{\sin\theta_c^{\,2}} d\theta_c$.

We assigned $d\theta_c = 0.5$ º.

Part III: For the test of the displacement equation, we calculated the ratio measured/predicted for each displacement trial and again reported mean and standard deviation of mean as the value and error. For uncertainty propagation, see below.

Part IV: For the deviation angle, we tried doing the same thing but all the trials gave the same value of deviation angle. So in the end we derived d(angle) from

Dev = (x_f – x_n) / L = diff / L

d(diff) = d(x_f) (+) d(x_n) = sqrt(2) dx = .14 mm (or, instead of (+) use ⊕ from symbol font)

then dDev / Dev = ddiff/diff (+) dL/L = .14mm / .35mm (+) 2mm / 2m = .57