Angle of reflection, index of refraction, Brewster's angle, total internal reflection
Pandemic Edition
New for 2021: Lacroix Optical supplied first surface mirrors and glass slabs. Thanks you all!

In this lab, you will be using lasers. Do not look at the laser light directly and make efforts to be sure that no one else in the lab has your laser light shining in their eyes. The lasers should only be run long enough to acquire data. They tend to get hot after prolonged operation. The clothespin holds the switch on (rotating the clothespin might be necessary here.

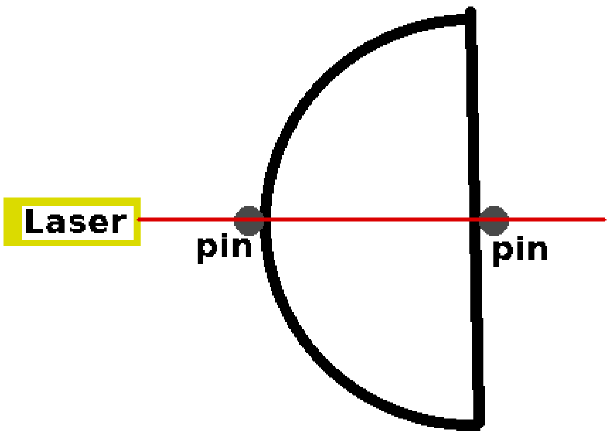
Important: do not touch the surface of the mirror!

Part I: The law of reflection

As you know from class, the law of reflection states that the angle of incidence is equal to the angle of reflection, or

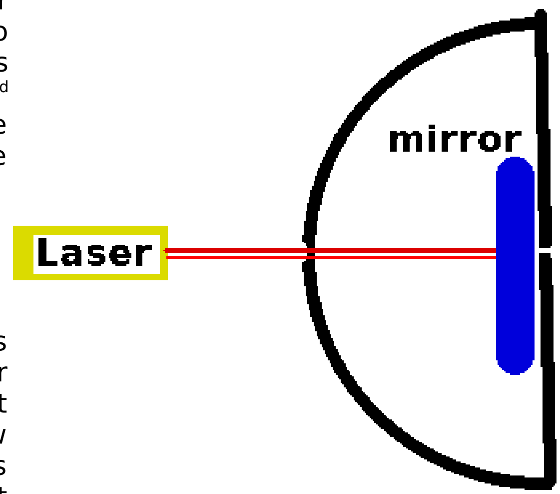
$$\theta_i = \theta_r \quad .$$

One of the easiest things that you will test in today's lab is this law of reflection. In order to do this, I have provided you with a rudimentary optical bench. You will need to place the cork board on top of a larger flat board. In order to elevate the cork board I have placed push pins under the boards.



You will need to optically align your system. The image to the left shows how to do this. Align your system first by putting a pin behind the nail in the protractor and place a second pin in front of the protractor at 90 degrees. Then align your system so that the laser light hits both pins.

Now you can remove the pins (carefully). Place your mirror on the protractor. The mirror will need to be placed so that the front surface is right over the nail. Be aware, the mirror has a 1st surface and a 2nd surface. You want to reflect off of the first surface (silver is on the front). If you are in doubt, shine your laser onto the mirror at an angle and look for either 1 or 2 dots. If you see 2 dots, that is the wrong side.



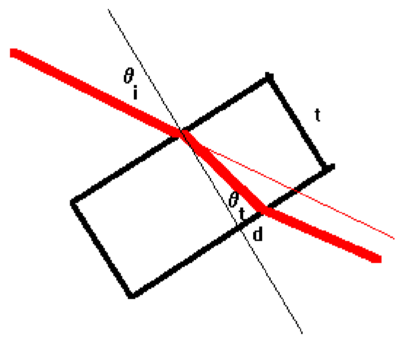
The mirror will tend to fall over at that position. I have supplied a glass slide so you can place one of the mirror holding clams on it for better stability. One is all you need here. What is essential is that the front surface of the mirror is right over the center of the nail. You will now need to rotate the mirror slightly so that the reflected laser light is directed back into the laser as shown to the right. Hopefully your front surface of the mirror will also line up with a black line on the protractor.

Carefully rotate your system so the 140 measurement on the **OUTER** row of the protractor is at the hole for the front pin (which is now removed. In the helper, I call this the "Protractor rotation angle" and read this from the outer row of calibrations. Now use one of the disecting pins to locate the angle of the reflected laser beam. You may find it easier to use the index card to find it. Hold the pin close to the protractor and read the measurement for this from the **INNER** row of calibrations on the protractor. In the helper, this measurement is called "Reflection angle measurement." My helper is going to assume that these are the way the measurements are being made. As you are taking data, enter it into the spreadsheet helper for the angles I have specified in column A. The helper will automatically find the slope and intercept from your data. It will also provide the Perarson Coorelation Coefficient (a value close to 1 shows a linear fit). If you have obtained good data you should have a slope of 1 and an intercept which is nearly zero. Normally error is introduced by not having the front edge of the mirror right over the center of the nail, although alignment difficulties also introduce error.

Part II: Measurement of the index of refraction by beam displacement

Important: do not touch the surface of the glass!

You are now going to measure the index of refraction for a glass slab. You will want to make about 5 measurements of the slabs that I have provided since I had problems with reproducibility in this part of the lab. Also, if the results of your work produce an index of refraction which is less than one, then you know 100% for sure that you're wrong and you need to be a bit more careful. **Don't try to include an index less than one in your report.**



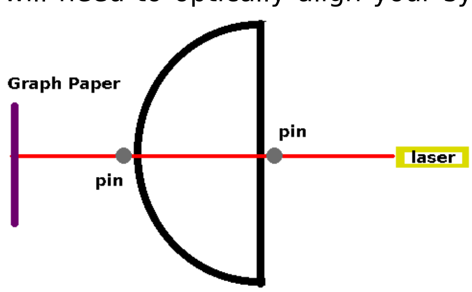
You will want to refer to this figure. What you will recognize is a problem similar to one that we have had in class. Here, however, you want to find the actual displacement of the beam of light through the glass. Snell's law gives us the angle of transmission:

By trigonometry, however, we have:

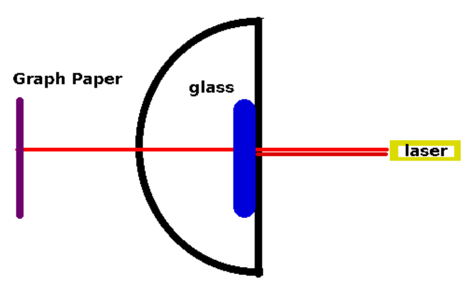
$$\tan(\theta_t)=\frac{d}{t} \quad \text{So} \quad n=\frac{\sin(\theta_i)}{\sin(\theta_t)}=\frac{\sin(\theta_i)}{\sin\left(\tan^{-1}\left(\frac{d}{t}\right)\right)}$$

where n is the index of refraction. You should be able to obtain the index of refraction by measurements of θ_i , d and t. If we have very coplaner surfaces (which we do with the glass slabs) then the beam which would pass through the glass and the displaced beam would be parallel. This realization makes significant modifications and simplifications possible for this part of the lab as compared to previous years.

You will need to optically align your system. This alignment proceedure is slightly different than what we had for the mirror, but just as easy. In addition, the glass slab will stand with only the clamps so the glass slide is not necessary. The image to the left shows the pin arrangement and the orientation of the protractor. I am also showing here the graph paper which will be used a bit later. Align the system so that the laser beam hits both pins. After this alignment, carefully remove the pins. See the two photos below for my setup.



Now carefully place your glass slab so that the face closest to the laser is directly centered over the nail holding the protractor to the cork board. Then rotate the glass slightly so the beam reflected from the glass goes back to the laser. It will probably be over the laser of under the laser. That will not matter. Hopefully your front surface of the mirror will also line up with a black line on the protractor. Now place the piece of graph paper behind as shown. I found it is then best to align the bright dot on a dark line to begin with.



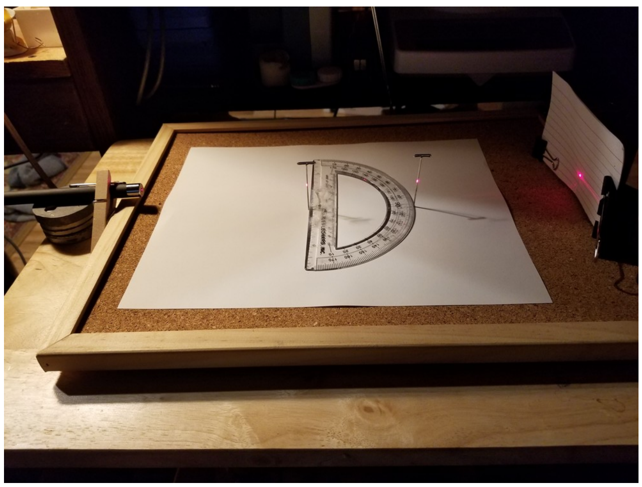
Getting the beam centered on one of the dark lines is surprisingly hard. I may consider cutting a slit on the graph paper on one of the darker lines so that light will pass through. So if you see a cut on the graph paper, you will know what it is for. Now that you have the alignment rotate the protractor until the dot moves through to the neighboring line. If you centered the dot on one of the darker lines then you would center it on the neighboring line. If not, the position in after rotating needs to be similarly placed but one line over.

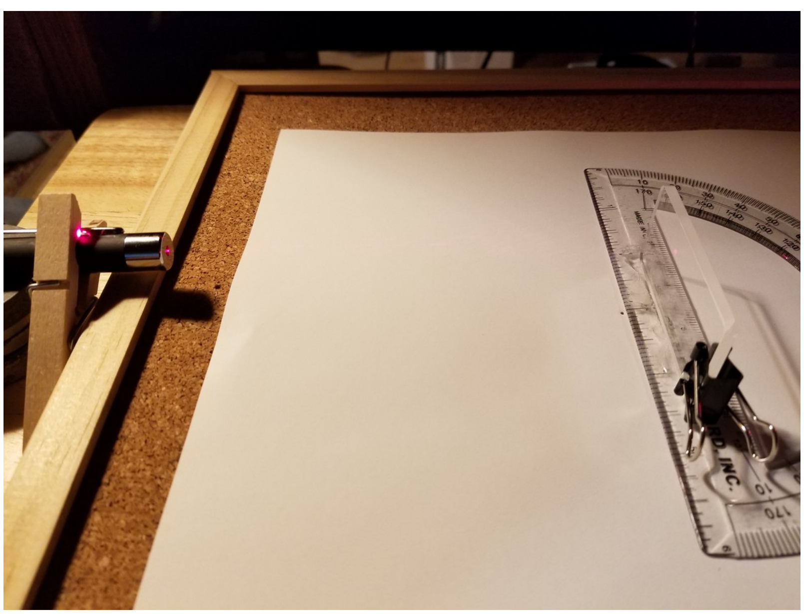
Record this measurement. Rotate your system back, so the dot returns to the original line and repeat this measurement. You will obtain a total of 5 measurements here. The angles you read are here from only the **OUTER** calibrations of the protractor. My spreadsheet helper will take the absolute value of that measurement – 90 degrees. I have also provided the measurement of the glass thickness and the distance between two lines on the graph paper. You may want to verify these, however you should not trust my "incident angle" measurements. If you obtain an index of refraction less than 1, you need to repeat that measurement. Also if you are not careful, you will need to redo the optical alignment of your system. So be very careful when interacting with your system.

After your 5 measurements, provided you have acceptable index of refraction values, you may proceed to Brewster's angle. You should show me your measurements before going on. Do note that the helper calcuates the average index of refraction and the standard deviation of the index measurements.

Do not change the orientation of your glass slab, or the alignment of the system. It makes the next part particularly easy if you can use the existing optical alignment.

My alignment



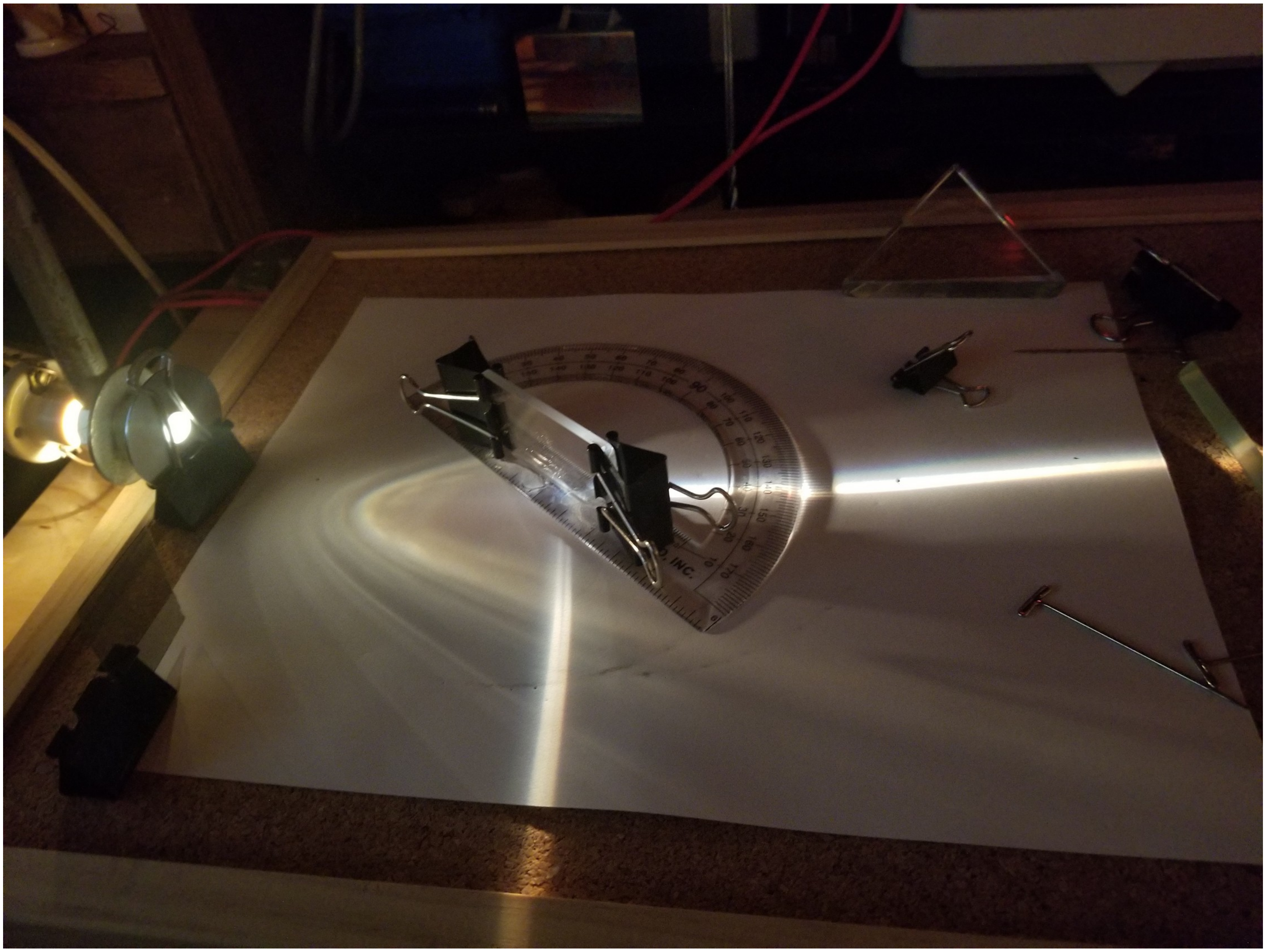


My glass slab. Your slab will have clamps on each side. Note the reflected dot is directed back into the laser.

Measurement of index of refraction with Brewster's angle

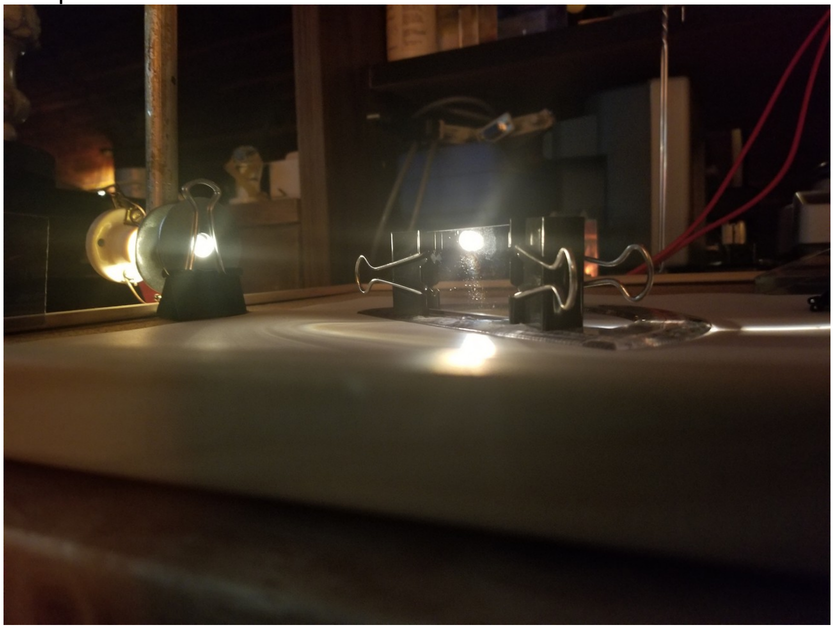
I am going to try to align your lights so that it will provide a light path on the paper. This is surprisingly not an easy thing to do, but it is helpful here.

The alignment for this is based upon the fact that you already have the locations of the two pin positions from the last experiment. I have provided a diaphram here and the light should shine though the hole in it. Your glass slab is already oriented correctly from the previous part of the lab. Place the diaphram close to the laser and the laser beam ought to go through the hole in it. Gently remove your laser and switch it off. Turn on your light from the power supply. I have already set the intensity and do not increase it much because the bulbs will burn out. The light should be shining through the diaphram and striking the glass. I have provided an image of the setup below after rotating.



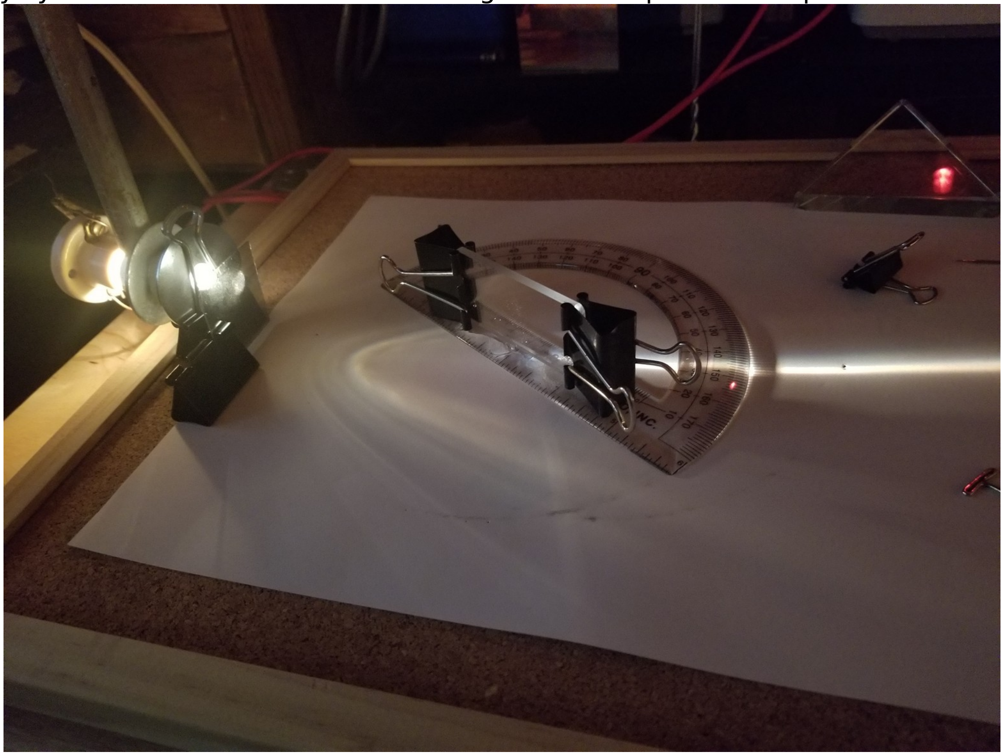
This shows transmission and reflection beams. In fact, this is also close to Brewster's angle. Notice that the beam you see on the paper from transmission and the reflected beam are not at 90 degrees because it is only inside the glass that the transmission beam is at an angle of 90 degrees with the reflected beam. Seeing the beam inside the glass is not easy. However measurement of polarization is doable.

Now you need to orient the polarizer. To do this rotate the protractor to a fairly heafty angle. You can then lower your head, holding the polarizer looking at the circular beam of incoming light. I’ve provided an image of this from my setup below.



To orient your polizer, rotate the polarizer until the beam is at it’s dimmest. The holder clamp for the polarizer should be such that it will hold the polarizer in the orientation when placed in front of the incoming beam.

Place the oriented polarizer in front of the incoming beam. This will result in the reflected component of light not being present in the incoming beam. Then rotate the protractor until the first surface reflection (which is the reflection closer to the ight source) is as dim as possible. Record this measurement and repeat it for a total of 5 measurements. Again, read the **OUTTER** numbers from the protractor. My spreadsheet will automatically subtract 90 degrees from these measurements.
Below is what my system looks like at Brewster’s Angle with the polarizer in place.



My system at Brewster’s Angle. Notice the second surface reflection is not extinguished with the polarizer. However the first surface reflection is.

The physics for obtaining the index of refraction from Brewster's angle is particularly simple:

$$n = \tan(\theta_B)$$

I would like you to repeat this measurement about 5 times (on the same piece of glass) to get a good set of values that can be averaged. The spreadsheet will also calculate the standard deviation of the results for you.

Total Internal reflection and angle of minimum deviation

On the lab website, you should watch the movie regarding total internal reflection

The analysis of the critical angle should allow a measurement of the index of refraction also. The analysis is this: for light emerging from a medium 1 towards air, the critical angle for total internal reflection is given by:

$$\sin(\theta_c) = \frac{1}{n} \ .$$

If you measure the critical angle it is relatively easy to invert this to obtain the index of refraction. For us today, this is only an observation.

On the lab website, you should watch the movie regarding minimum angle of deviation.

There is also a movie regarding the alignment of a prism at the minimum angle of deviation.

Summary of lab 10

(1) Verify the law of reflection
(2) Measure the index of refraction by beam displacement
(3) Measure the index of refraction by Brewster's Angle.
(4) Watch the video for total internal reflection
(5) Watch the video for angle of minimum deviation.
(6) Sample Calculations.