VS 101

Lab 5

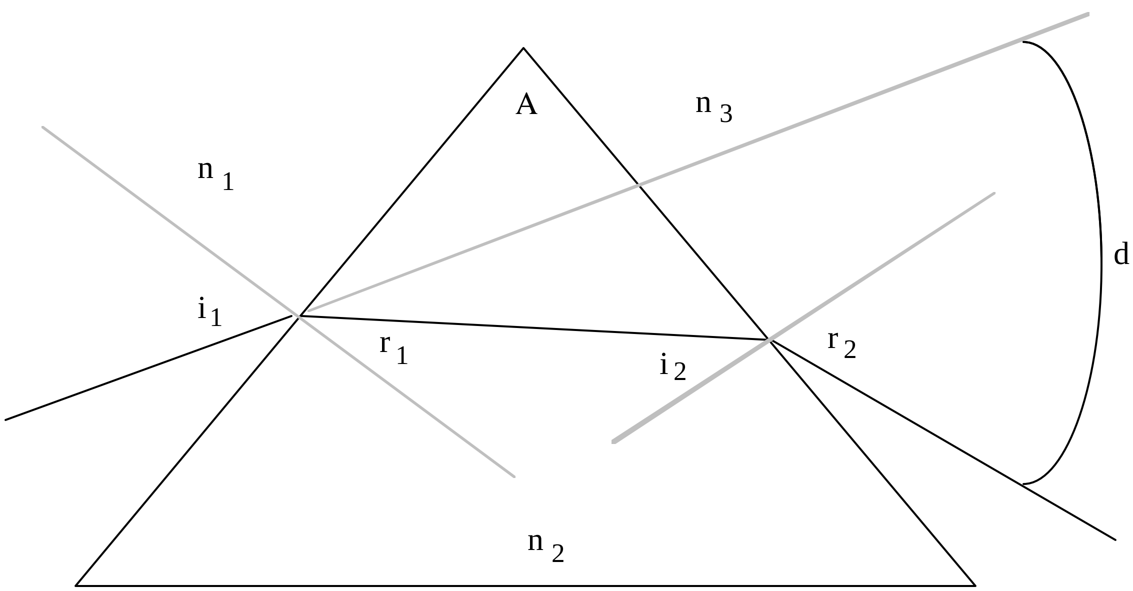
Reflecting and Refracting Prisms

Aim and Background

In this experiment you will be studying the reflection and refraction of light through prisms.

A prism is a piece of transparent material bounded by two plane surfaces which are not parallel. The straight line in which the two surfaces meet is called the refracting edge, or apex, of the prism. The surface parallel to the edge which limits the width of the faces is called the base of the prism. The apical angle (A) of the prism is the angle between the two faces. (See figure below).

When light passes through the prism, it is refracted at both surfaces. Unlike a parallel-sided plate, the emergent ray typically leaves the prism with a direction different from the incident or initial ray. The angle formed by the intersection of the initial and final ray directions is called the angle of deviation (d).



A ray of light, as in the above figure, obeys Snell's Law at both surfaces. Upon entering the prism at the first surface, the light is refracted toward the normal. Emerging into the air from the second surface, the light is refracted away from the normal.

The formulae for the refraction of a ray of light through the prism are:

At the first surface:

$$n_1 \sin i_1 = n_2 \sin r_1 \quad (1)$$

The internal prism angles are related by:

$$A = r_1 + i_2 \quad (2)$$

At the final surface:

$$n_2 \sin i_2 = n_3 \sin r_2 \quad (3)$$

The deviation is:

$$d = i_1 - r_1 + r_2 - i_2 = i_1 + r_2 - A$$

Minimum Deviation:

By rotating a prism relative to the incident ray (and therefore changing the incident angle), one can observe the emergent ray vary direction, producing changes in the angle of deviation. As the incident angle continuously increases from zero, the angle of deviation will be observed to decrease to a minimum and then increase again.

The smallest deviation obtainable is called the angle of minimum deviation (d_{min}), and occurs at that particular angle of incidence where the refracted rays inside the prisms make equal angles with the prism faces. This also means that the incident and emergent angles are equal.

Calculations for minimum deviation can be made by substituting the following relationships into equations (1) and (3):

$$i_2 = r_1 = A/2 \quad (4)$$

$$i_1 = r_2 = (A + d_{min})/2 \quad (5)$$

Critical Angle:

When light passes from a medium of high index (glass, water) into a medium of lower index (air), the angle of refraction is greater than the angle of incidence. Therefore, there exists a given angle of incidence which results in a refracted ray which just grazes along the surface, i.e. the angle of refraction is 90°. This angle is termed the critical angle. Any incident angle greater than the critical angle will result in total internal reflection.

For any surface, the critical angle depends upon the index of refraction of that medium (n_2) and the index of refraction of the second medium (n_3). To calculate the critical angle we can apply Snell's Law. The angle of incidence equals the critical angle (i_2). The angle of refraction (r_2) equals 90°. Therefore:

$$n_2 \sin i_2 = n_3 \sin 90 \quad (\text{where } n_2 > n_3)$$

$$\text{or} \quad \sin i_2 = n_3/n_2 \quad (\text{or generally} = n_2/n_1)$$

Procedure

Laser Safety

The Helium Neon (HeNe) laser emits coherent light in the visible range at 633 nm. Visible lasers, such as the HeNe, and near infrared lasers (such as Nd:YAG lasers) can potentially cause damage to the retina, since these wavelengths are readily transmitted through the eye and focused onto the retina. The most severe situation occurs when looking into the beam, as this allows the near-collimated light to be focused to a point on the retina, giving the highest possible irradiance. **A permanent blind spot can result.** Whether damage does occur depends upon the laser power and exposure time. HeNe lasers with output powers less than 1 milliwatt, such as those used in this laboratory, are considered safe for exposures lasting less than .25 seconds (about the time it takes you to blink). No unusual precautions are considered necessary if common sense is used. You should not stare directly into the beam, but if by carelessness you do, the dazzling brightness is enough to cause you instinctively to blink and look away without damage occurring to the eye. Lasers used in supermarket scanners and surveying, to which the public is exposed, are of this safety class. More powerful lasers (e.g. excimer lasers), pulsed lasers (as opposed to continuous emitting lasers), and lasers producing light invisible to the naked eye require protective measures.

Experiment 1

1. Securely mount the laser on an optical bench.
2. Tape a piece of paper to the wall about 1.1 meter from the output of the laser. Mark the spot where the laser beam hits. Align the paper and laser, if necessary, so that the beam hits in the approximate center of the paper.
3. Place the 4 ? ophthalmic prism, base down, between the laser and the wall. The face of this prism should be perpendicular to the laser beam and around one meter from the wall.
4. Place a mark on the paper where the laser beam hits.
5. Measure the distance between the two marks and note whether the beam has been deviated towards the base or apex. Is this what you expected?
6. Record the deviation in cm, prism diopters and degrees.
7. Repeat the measurements with the prism rotated by 90° and 180° (base up).

Experiment 2

1. Replace the 4 ? prism with a 10 ? ophthalmic prism. With the base down, measure the new deviation.
2. What is the difference between the two prisms?
3. Now, place the two prisms together with their bases touching and pointing down.
4. Measure the size and direction of the deviation.
5. Keep the two prisms attached but rotate the 4 ? prism by 180° so that its base now points up (the base of the 10 ? prism still points down).
6. Measure the size and direction of this deviation.
7. Do the effects of the prisms add algebraically?
8. Now rotate one prism by 90°, while still keeping the two prisms together. Measure the size and direction (in degrees relative to the base of the larger prism) of this *diagonal* deviation.

9. Measure the horizontal and vertical components (or vectors) of this diagonal deviation.
10. Finally, rotate one of the prisms 30° with respect to the other. Measure the size and direction (in degrees relative to the base of the larger prism) of this deviation.

Experiment 3

1. Using a 10 ? prism mounted with the apex horizontal, measure deviation as a function of incident angle by rotating the prism
2. Take measurements for incident angles of +80°, +60°, +40°, +20°, 0°, –20°, –40°, –60° and –80°. Rotate the apex of the prism towards the laser for + incident angles and away from the laser for – incident angles.
3. If a critical angle is reached before you reach the end points, take a measurement just before the critical angle.
4. The “protractor tables” provided are useful for this but the incident angles may still be rough estimates. Try to develop the most accurate technique using the tools available.

Experiment 4

1. Examine each of the following reflecting prisms: right angle, dove, porro, penta and equilateral. Ask the GSI if you are not sure which prism is which.
2. Note that the right angle and porro prisms are similar in shape; it is the orientation in which you use it that makes the difference.
3. Determine what each prism does to the path of a light ray.
   - This is best done with a laser.
   - Aim the laser beam at the face of a prism.
   - Determine where the ray exits the prism and measure the deviation of this ray from the incident ray.
   - To determine if each prism rotates and/or inverts an image, look at the letter “R” through the prism.
4. Look at an object through a dove prism and rotate the prism.
5. What happens to the rotation of the object you see through the prism?

WHAT TO DO THIS WEEK

1. Is light deviated towards the base or apex of a prism? How much does a 4 ? prism deviate light in degrees and prism diopters?

2. For the 10 and 4 ? prisms at 90° to each other what was the size and direction of the deviation (in degrees relative to the base of the larger prism). Calculate the theoretical result and compare.

3. What is the apical angle (A) for the 10 ? prism? Assume $n_{prism} = 1.5$.

4. Plot displacement as a function of incident angle for a 10 ? prism. Can you think of a better way to rotate or measure the rotation of the prism?

5. For a 10 ? prism calculate the theoretical displacement for incident angles of ±20°, ±40°, and the maximum displacement. Plot these points on your graph.

6. Which prisms rotate and/or invert an image?

7. If you used prisms in clinic, did the object move towards the base or apex? Does this agree with your observations in this lab? Explain any difference.