LAB 12 — 04/24/2025

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Introduction: Optics are an essential consequence of electromagnetic waves interacting with matter and allow for many different devices to exist, from telescopes to cameras. Even human eyes have variable lenses to focus light at different focal lengths. One equation core to optics is Snell's Law, which relates the index of refraction of a material and its angle of incidence to another material: $n_A \sin \theta_A = n_B \sin \theta_B$. One consequence of this property is that lightwaves of different wavelengths have different indexes of refraction according to: $n_{21} = \frac{\lambda_1}{\lambda_2}$. Moreover, light passes through different materials at different speeds while maintaining the same frequency (conserving energy according to the Planck–Einstein relation: $E = hf$) which means lights of different frequencies have different angles of refraction, causing rainbows.

Problem 1: Mirrors

Materials: Curved mirror, flat mirror, light source, protractor.

Methods/Procedures: Shine a single light ray at the flat mirror. Measure the angle of refraction at different angles of incidence. Shine three rays at the concave side of the curved mirror and measure the focal length. This is achieved by finding the point where the reflected rays converge and measuring their length to the incident surface. The same process is done with the convex side of the mirror.

Data/Results: When the flat mirror was measured at a 50° angle of incidence, the reflected angle was also 50°. When the incident angle changed, this remained the same. The focal length of the concave mirror was measured at 2.4 cm. The focal length of the convex mirror was -1.5 cm.

Data Analysis: Our findings with the flat mirror confirm that the angle of reflection relative to the normal will always be the same as the angle of incidence. The reason that the convex mirror had a negative focal length was because the focal point was behind the plane of incidence. The rays reflect differently based on where they hit the curved mirror because the normal at each point is different due to the mirror's curvature. A mirror with an infinite radius of curvature would have an infinite focal length due to the direct relationship between radius of curvature and focal length.

Problem 2: Refraction

Materials: Semicircular lens, light source, protractor.

Methods/Procedures: Let one ray of light through the semicircular lens and measure the angle of refraction and reflection. Repeat at multiple angles measured from the normal.

Data/Results: The reflected and refracted light rays were along the normal when the lens was offset 0°. At 30°, the refracted ray was offset from the normal to 15° and the reflected to 60°. At 45°, the refracted ray was offset by 90° and there was total internal reflection. Total internal reflection seemed to occur around 41° (the critical angle). By Snell's law, this means the index of refraction for the lens was around 1.529. For every refracted ray, the light spreads out, since white light is composed of many different wavelengths.

Data Analysis: This experiment was a basic demonstration of Snell's Law and allowed us to calculate the index of refraction of the lens (1.529). This value is very close to the index of refraction of window glass at 1.52 or polycarbonate at 1.58. The index of refraction held true for the different incident ray angles.

Problem 3: Bringing Things into Focus

Materials: Light source, protractor, converging lenses, diverging lens.

Methods/Procedures: Shine the light source through the two converging lenses and the diverging lens. Observe the refraction and measure the focal length of all three lenses.

Data/Results: The thin converging lens had a focal length of 7.2 cm. The wide converging lens had a focal length of 2.9 cm. The diverging lens had a focal length of -6.8 cm.

Data Analysis: The thin and wide lenses focal length differences were due to the difference in their radius of curvature. The radius of curvature correlates directly with the focal length in the lenses as well. The similarity between the magnitude of the focal length of the thin converging lens and the converging lens is due to their radii of curvature being similar. The focal length of the wide lens compares closely with that of the semicircle for the same reason, both had similar curvatures. One could not measure the focal length of the diverging lens by measuring the reflections from the surface where light enters because this is not the incident plane at which the refraction occurs to change the direction of the light to diverge.

Problem 4: I Can See Clearly Now

Materials: Two concave lenses, light source, protractor.

Methods/Procedures: Set the light source to output multiple beams, place the larger lens into the beam, then place the smaller lens into the beam leaving the first lens. Move lens 2 until the light beams appear to be parallel to one another. Measure the focal distances of each lens.

Data/Results: The beams of light are focused down to a point by the larger lens, they then pass the point of convergence before entering the second lens, which re-aligns the light beams to move parallel. As the light source moves around, the beams leave the second lens at an angle, converging a second time.

Data Analysis: The distance between the two lenses is their combined focal lengths. This makes sense as after passing the focal point, the light will spread out again, and then hit the second lens at the perfect angle to realign the light beams. A larger lens is used to a larger amount of fainter light before focusing it down to a brighter combined beam, allowing all the gathered "information" to be funneled down to a manageable scale. While it is tempting to describe what a telescope does as "making distant objects appear closer" a more accurate description would be amplifying light gathered from distant objects.

Problem 5: Raindrop Model

Materials: Cylindrical lens, light source.

Methods/Procedures: Shine a ray of light into the cylindrical lens and note the reflections and refractions and their order (number of internal rays between the original and exit ray).

Data/Results: From what we saw, the light was only totally internally reflected at or beyond a critical angle. As we moved the lens, the incident light ray refracted as it entered the lens and eventually was totally internally reflected. A rainbow appeared to exit the drop at an angle, similar to the other lens, of 40°. Higher order rainbows, caused by repeated internal refraction, were difficult to see, but we managed to see at least two separate rainbows.

Data Analysis: The principle we saw in action is the same that allows raindrops to create larger rainbows from the sun's light. When the sun is low, a rainbow will form opposite to the sun, as the raindrop's act as spherical lenses. From outside to inside, the colors are ordered: red, orange, yellow, green, blue, indigo, violet. This is because the colors each have distinct wavelengths. Rainbows are circular because the spherical raindrops take in parallel rays of light on opposite sides of the sphere to one another, mirroring each rainbow segment from one half of the raindrop to the other.

Conclusion: Within this lab we investigated the way in which light interacts with different lenses and mirrors, Discovering that the angle of incidence will equal the angle of reflection, for our semi-circle lens total internal refraction began at 41 degrees, which we used to calculate the index of refraction to be 1.259. We also took some time to calculate the focal lengths of our thin and wide converging lenses as well as our diverging lenses, those being 7.2cm, 2.9 and -6.8 centimeters respectively. We finally investigated the practical applications and simulated a natural phenomenon involving lenses, wherein we discovered the ways in which multiple lenses can be used to gather and combine light, and that light can be split into a spectrum through natural, round lenses, such as free-falling water droplets. Understanding the way in which light interacts with these lenses is the main focus of optics, alongside its several applications in astronomy, photography and other high tech fields, it is also prevalent in biology where natural lenses are our window into the world. Understanding optics is essential for future endeavors involving lasers, and interpreting how our view of the world is different between people.