REFLECTION AND REFRACTION

Equipment

The ray tracing optics kit is a set of optical components, such as plane, concave and convex mirrors, thick plastic plates, prisms. A ray box is a standard light source for ray tracing optics. Just power the ray box, slide the lens (called collimator) in front of the light source to produce 1, 3 or 5 pencil-thin rays, or a single, wide, beam of light as required for your experiment.

Experimental procedure

1. **Flat mirrors and the law of reflection**
   - Rest a flat mirror at the center of a new sheet of paper. Use a single ray produced by a ray box to visualize both the incident and reflected rays (see Fig. 1).
   - Draw the rays on paper showing all details (the position of the light source, the position of the mirror, the point of incidence, etc.) and attach one sketch to this lab report.
   - Measure the angle of incidence and the angle of reflection for three different angles of incidence and fill out Table 1.

Table 1. Incidence (θ_i) and reflection (θ_r) angles for a flat mirror experiment

Exp.	θ_i (deg.)	θ_r (deg.)	
1			
2			
3			

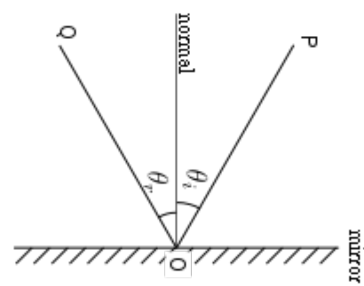

Fig. 1 Incident (PO), and reflected (OQ) rays.

Show one example of error calculations here:

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Conclusion

Based on the experimental data shown in Table 1, is the law of reflection valid? Explain.

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2. **Measure the focal length of a concave/convex mirror based on ray tracing**
   - Rest a concave/convex mirror at the center of a new sheet of paper. Use a 3- or 5-ray splitter to produce **parallel incident rays** (adjust the collimator if necessary).
   - Draw the paths on paper showing all details (the incoming and reflected rays, the position of the mirror, etc.) and attach one sketch to this lab report (see Fig. 2).
   - For a concave mirror, the incoming parallel rays should converge in front of the mirror (real focus). Measure the focal length: $f_{concave}$ = ___________. Estimate the radius of curvature of the mirror $R_{concave}$ = ____________.
   - For a convex mirror, the incoming parallel rays should diverge. By carefully tracing each reflected ray behind the mirror you will find that the prolongations converge to a virtual focus (because no actual rays meet behind the mirror). Measure the focal length: f_{convex} = ___________. Estimate the radius of curvature of the mirror R_{convex} = ____________.
   - What seems to be the relationship between the radius of curvature and the focal distance that you measured experimentally?

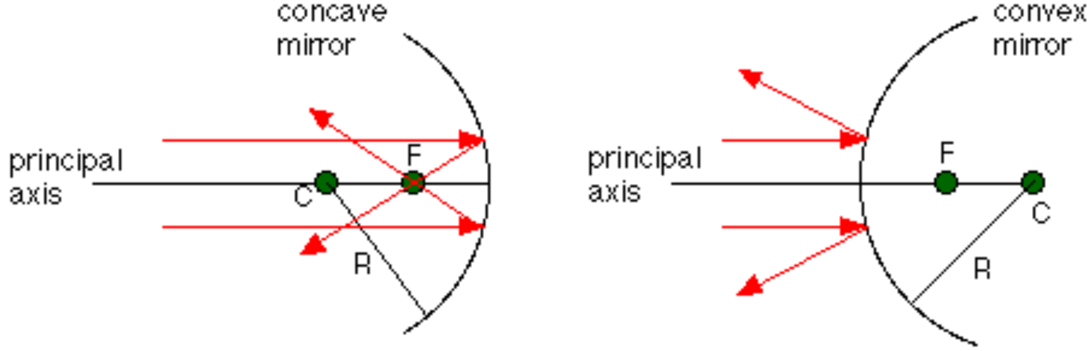


Fig. 2 Ray tracing for spherical mirrors: a concave mirror (left) has a real focus (in front of the mirror), whereas a convex mirror (right) has a virtual focus (behind the mirror).

3. Measuring the index of refraction

a) **Index of refraction of a plastic semi-cylinder**

- Rest a **solid** plastic semi-cylinder at the center of a new sheet of paper. Draw five lines, representing incident rays with angles 10, 25, 40, 50, and 60 degrees so that they all meet **at the center** of the flat surface of the plastic semi-cylinder (Fig. 3).
- Direct a single light beam produced by a ray box **towards the flat side** of the semi-cylinder along the line that makes a 10^o with the normal to the flat side. Mark on paper the point where the light exits the semi-cylinder's curved side. Repeat this process for each incident angle. There will be five dots on the curved side of the semi-cylinder so make sure you distinctly mark which incident ray corresponds to which refracted ray, e.g., use different colors.
- Remove the semi-cylinder and draw continuous lines connecting the point of incidence and each of the five exit points on the curved side of the semi-cylinder. Measure the angle of refraction for each ray and complete table 2.
- Use the law of refraction $n_1 \sin \theta_i = n_2 \sin \theta_r$ with $n_1 = 1$ (air) to determine the index of refraction n_2 of the plastic cylinder from $n_2 = \sin \theta_i / \sin \theta_r$

Table 2 . Angles of incidence and refraction for a plastic semi-cylinder

Exp	θ_i (deg.)	θ_r (deg.)	$n_2 = \sin \theta_i/\sin \theta_r$
1	10		
2	25		
3	40		
4	50		
5	60		

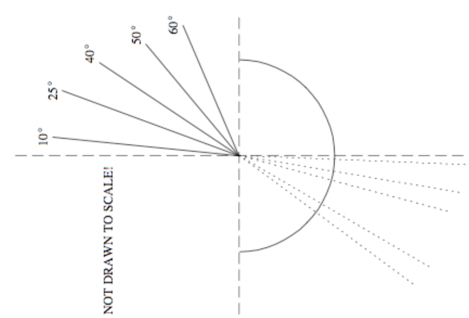


Fig. 3 Refraction through a solid semi-cylinder.

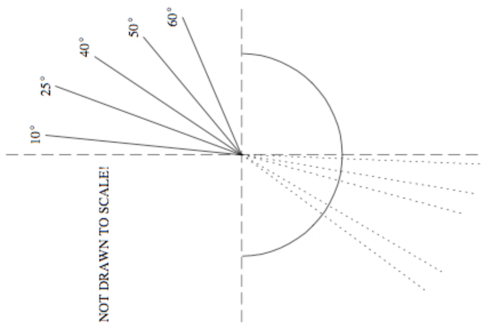
Based on Table 2, compute the average index of refraction of plastic $n_{average}$ = _____________.

b) **Index of refraction of water**

- Rest an **empty** plastic semi-cylinder at the center of a new sheet of paper. Fill the plastic semi-cylinder container with water. Follow the same steps as described in section (a) above in order to fill out table 3.

Table 3 . Angles of incidence and refraction for a semi-cylinder filled with water

Exp	θ_i (deg.)	θ_r (deg.)	n= $\sin\theta_i/\sin\theta_r$
1	10		
2	25		
3	40		
4	50		
5	60		



- Based on Table 3, compute the average index of refraction of water n_{exp} = __________________.
- Knowing that the theoretical index of refraction for water is n_{th} = 1.33, find the percent error of your experiment ____________________.

4. **Determine the critical angle**

a) Critical angle for plastic

- Rest a **solid** semi-cylinder at the center of a new sheet of paper. Send light **through the curved surface** such that the refracted ray exits through the center of the flat surface.
- Start with a small (20°) incidence angle and slowly increase it while carefully notice the incidence angle for which the refracted ray exits parallel to the flat surface of the semi-cylinder ($\theta_r = 90^o$). This incidence angle is the critical angle for plastic (θ_c) (see Fig. 4). Experimental $\theta_{c,\,exp}$ = ____________________.
- Use the index of refraction determined in experiment 3a and the law of refraction $n_1 \sin\theta_i = n_2 \sin\theta_r$ with $n_1 = n$ (plastic), $\theta_1 = \theta_c$, $\theta_2 = 90^o$ to determine the theoretical critical angle: $n*\sin\theta_c = 1*\sin 90^0 \Rightarrow \sin\theta_c = 1/n \Rightarrow \theta_{c,theory} = \sin^{-1}(1/n)$ = _________________.
- Computing the percent error.

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b) **Critical angle for water**

- Rest an empty semi-cylinder at the center of a new sheet of paper and filled with water.
- Follow the steps in Experiment 4a to find the critical angle for water. Experimental θ_c = ____________
- Knowing the theoretical index of refraction for water (n_w = 1.33), find the theoretical critical angle of water $\theta_{c,theory} = \sin^{-1}(1/n_w)$ = _________________.
- Computing the percent error:

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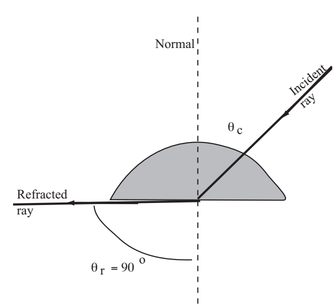

Fig. 4 Total internal reflection and the critical angle.