Geometrical Optics and Refractive Index

TA's signature allowing you to take the quiz or leave ____________

Your Name ______________________________

Partners' Names ______________________________

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Obtained reasonable experimental results?	yes ☐
Answered questions?	yes ☐
Cleaned your table?	yes ☐

Please do not scratch, polish or touch the surface of the mirror.

Introduction

You can find optical phenomena with mirrors, lenses, and the other media, such as water. One of the fundamental laws with a plane mirror is known as the law of reflection. This can be seen when you look yourself into a wall mirror in your daily life, which explains that you find yourself in the mirror as the same size; and even though it is half of your height, you can see entire yourself in the mirror.

Curved types of mirrors are convex and concave mirrors, which are used in various places, such as, in cars, medical or dental purposes, cosmetic mirrors, etc. The important parameters are known as the focal length and radius of curvature, which determines the feature of the mirror. There is a relationship between the focal length and its radius of curvature:

$$R = 2f$$

where R is the radius of curvature and f is the focal length.

You may have an experience when looking in water the depth of the appearance is different from the actual depth. This is caused by the diffraction of light in a different medium. This can be explained by Snell's law. The formula is given as

$$n_1 \sin\theta_i = n_2 \sin\theta_t$$

where n_1 and n_2 are the indices of refraction for each medium and θ_i and θ_t are the angles for the incident and transmitted light.

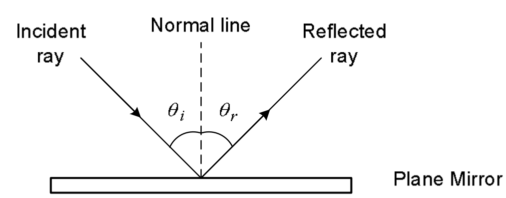
The ray tracing of lenses is fundamentally explained by the Snell's law, but the practical properties of lenses can be illustrated by focal lengths, and other related distances. The basic types of thin lenses are convex and concave lenses. For daily life examples, a convex lens is used as a magnifying glass, and a concave lens is used as a glass for nearsightedness.

Objective:

- To learn the concept of geometrical optics (ray tracing property of light)
- To find the refractive index of acrylic rhombus (Snell's law)
- To see the properties of lenses and mirrors (law of reflection, focal lengths, etc.)

1. Plane mirror (the law of reflection)

If the plane is not a diffuse surface, the trace of light is predictable, which is known as the law of reflection. The angles, θ_i and θ_r, are called incident and reflected angles, respectively. According to the law of reflection, we always have $\theta_i = \theta_r$. Note that the angles are taken from normal line.



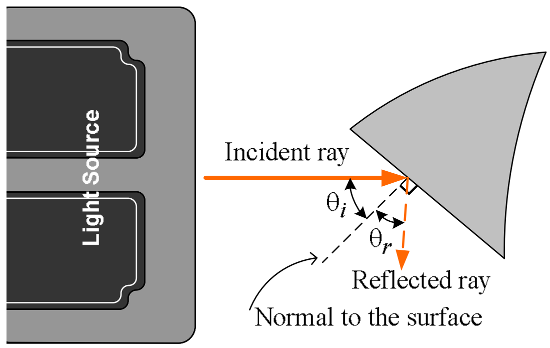
Procedure:

① Place the ray box, label side up, on a white sheet of paper on the table shown below. Adjust the slit so one white ray is coming.

② Use the plane surface of the mirror.
Make an angle as shown below so that both the incident and reflected rays are seen.

③ Mark the position of the surface of the plane mirror. Trace the incident and reflected rays with arrows indicating the incoming and outgoing rays.

④ On the paper, draw the normal to the surface as shown below.
Use a protractor and be precise.



⑤ Measure the angle of incidence (θ_i) and the angle of reflection (θ_r). (Make a large enough angle, θ_i , (more than 30°) to have a proper reflected angle, θ_r.)
Both of these angles must be measured from the normal of the surface.

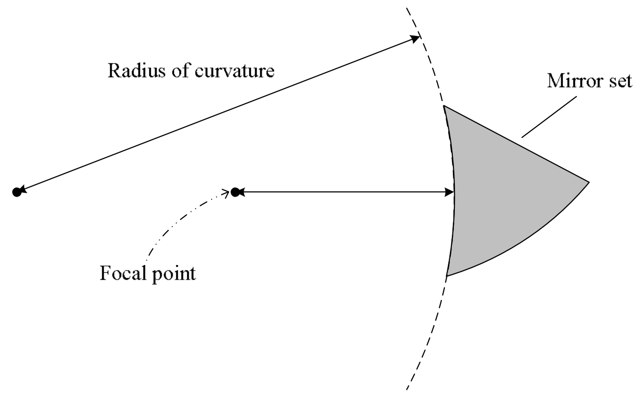
Plane mirrors (The law of reflection) [Measure this by each person in your group. If you are the only person in the group, try at least two measurements.]

	Angle of Incidence, θ_i	**Angle of Reflection, θ_r**	**% difference** $\frac{\lvert\theta_i - \theta_r\rvert}{(\theta_i + \theta_r)/2} \times 100$ (%)
By the 1st person			
By the 2nd person			
By the 3rd person			
By the 4th person			

Question: Are angles of incidence and reflection close to each other?

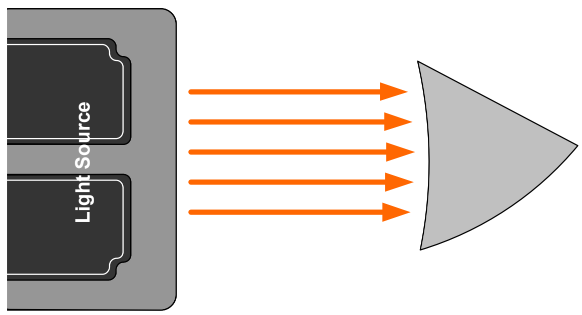
2. Concave and convex mirrors

The surface of the concave mirror consists of part of a circle. The center of the circle called center of curvature, *R*, and the radius is easily obtained. The mirror focuses the incoming parallel rays at the focal point. The distance between the focal point and the surface of the mirror is called focal length, *f*. The relation between *R* and *f* is $R = 2f$.



Procedure:

① Use five white rays from the ray box by adjusting the slit. Shine the rays straight into the concave mirror as shown.
Draw the surface of the mirror and trace the incident and reflected rays with arrows (to show the appropriate directions.)



② The place where the reflected rays cross each other is the focal point of the mirror. Measure the focal length, which is from the center of mirror's surface to the focal point.

③ Use the compass to draw a circle that matches the curvature of the mirror. Measure the radius of the curvature using a ruler. (Hint: Estimate the center of curvature from *R=2f*. Then, check if the curvature fits with the circle you make by the compass.)

[Measure this by each person in your group. If you are the only person in the group, try at least two measurements.]

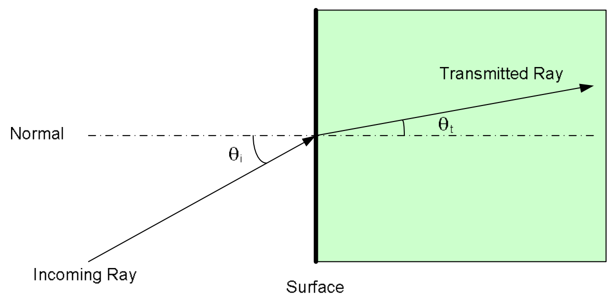
	Focal length, *f*	**Radius of curvature using compass, *R***
By the 1st person		
By the 2nd person		
By the 3rd person		
By the 4th person		

Questions: Does the equation $R=2f$ hold from your experiment?

How about a convex mirror? How do you obtain the focal length? Hypothesize the procedure.

3. Snell's law

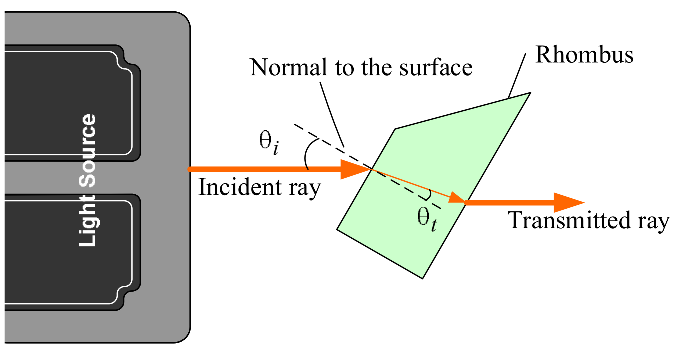
The formula is: $n_1 \sin\theta_i = n_2 \sin\theta_t$, where n is the index of refraction and the θ_i and θ_t are the correspondent angles.



Procedure:

① Place the ray box, label side up, on a white sheet of paper on the table. Use only one white ray by sliding the ray mask.

② Place the rhombus on the paper and position it so the ray passes through the parallel sides as shown below. (Make a large enough angle for θ_i so you can measure θ_t properly.)



③ Mark the position of the parallel surfaces of the rhombus and trace the incident and transmitted rays with arrows in the appropriate directions.

④ Mark carefully where the ray enters and leaves the rhombus.
This is very important because the transmitted ray cannot be seen.

⑤ Remove the rhombus and on the paper draw a line connecting the points where the ray entered and left the rhombus.
Simulate this in your mind to avoid a carefree mistake.

⑥ At the point where the ray enters the rhombus, draw the normal of the surface.

⑦ Measure the angle of incidence θ_i and angle of refraction θ_t with a protractor. Both of these angles must be measured from the normal line. Determine the uncertainties for the measurement.

⑧ Calculate the index of refraction for the rhombus by using the given equation. It should be close to 1.5.
The rhombus is made of Acrylic which has an index of refraction of 1.497.

Reference: for light of wavelength 486 nm in a vacuum (blue), 1.491 for wavelength 589 nm (green), and 1.489 for wavelength 651 nm (red). Notice that in general for visible light, the index of refraction for Acrylic becomes larger with increasing frequency.

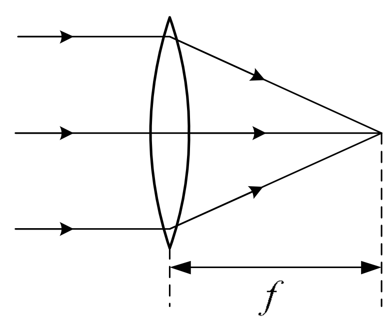
[Measure this by each person in your group. If you are the only person in the group, try at least two measurements.]

	Angle of Incidence (θ_i)	**Angle of Refraction** (θ_t)	**Index of Refraction** (n) For the rhombus
By the 1st person			
By the 2nd person			
By the 3rd person			
By the 4th person			
Average of the index of refraction ⇒			

Question: What is the relationship between the angle of incidence and the angle of refraction?
[When the θ_i increases, will the θ_t be increased or decreased?]

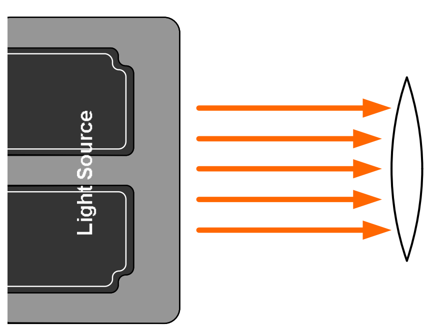
Question: Is the index of refraction for the rhombus close to 1.5?

4. Convex and concave lenses



The convex lens is also called a conversing lens. It depicts that the light rays converge into one place, which is the focal point. The distance between the focal point and the center of the lens is known as focal length, *f*.

Procedure:
① Place the ray box on a white paper. Use the five white rays from the ray box, and then shine the rays straight into the convex lens.



② Trace around the surface of the lens and trace the incident and transmitted rays.

③ With the lens removed, mark the center of the lens.

④ Find the focal point of the lens.
You may see the fuzzy interval around where the focal point should be. Mark the boundaries of this interval to set your limits on the uncertainty and take the center of the interval to be your focal point.

⑤ Measure the focal length, which is from the center of the lens to the focal point. Don't forget to determine its uncertainty.

⑥ Choose a new distance and repeat the above step to see if the focal length changes.

[Measure this by each person in your group. If you are the only person in the group, try at least two measurements.]

	The distance between lens and light source	**Focal length of the convex lens** $(f \pm \Delta f)$
By the 1st person		
By the 2nd person		
By the 3rd person		
By the 4th person		

Questions:

Does the focal length depend on the distance between lens and light source?

Design an experiment where you obtain the focal length of concave lens.
