Reflection and Refraction with Plane Surfaces

I. Discussion

a. Reflection

The laws for the reflection of light at a plane surface, which have been known since ancient times, are: (1) the ray approaching the reflecting surface (incident ray) and the ray leaving the reflecting surface (reflected ray) lie in a plane which is perpendicular to the reflecting surface, and (2) the angle between the incident ray and a normal to the surface (angle of incidence) is equal to the angle between the reflected ray and the normal (angle of reflection). This is shown in Fig. 1 below.

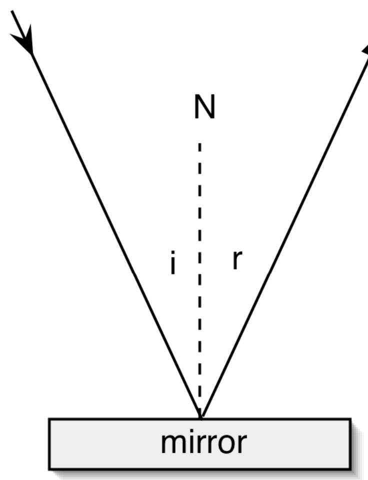

Fig. 1 Reflection

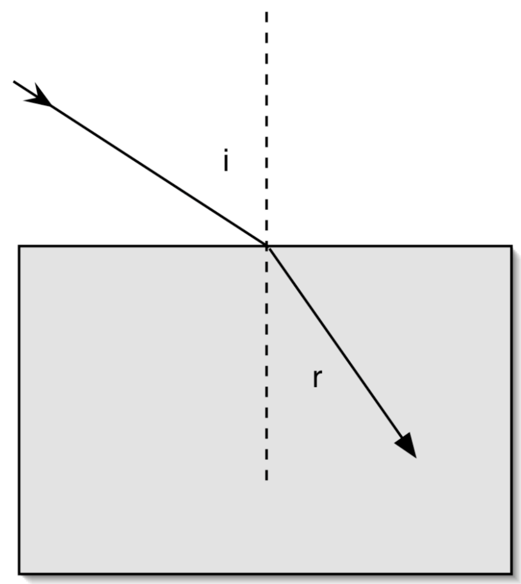

Fig. 2 Refraction

b. Refraction

The laws for the refraction of light at a plane boundary between two media, which were discovered in 1621 by Willebrod Snell of Leiden, are: (1) the ray approaching the boundary in the first medium (incident ray) and the ray leaving the boundary in the second medium (refracted ray) lie in a plane which is perpendicular to the boundary, and (2) the sine of the angle between the incident ray and a normal to the surface (angle of incidence) divided by the sine of the angle between the refracted ray and a normal to the surface (angle of refraction) is equal to a constant for all angles of refraction between 0° and 90°. With respect to Fig. 2 above, Snell's law may be written

$$\frac{\sin i}{\sin r} = n_{2,1}$$

The constant $n_{2,1}$ is called the index of refraction of the second medium relative to the first. More recently, Snell's law is usually written in the form

$$n_i \sin i = n_r \sin r. \qquad \text{(Eqn. 1)}$$

c. Refraction at Successive Parallel Surfaces (Rectangular Plate)

When a ray of light is refracted successively at two parallel plane surfaces, it suffers a lateral displacement, d, as it passes from the first medium into the second and back into the first again. This is shown in Fig.3, below, where the ray of light actually coming from object O appears to come from image I along a line parallel to its original direction of travel. When the separation of the parallel surfaces is t, the displacement, as may be verified by an analysis of Fig. 3, is given by

$$d = t\frac{\sin(i_1 - r_1)}{\cos(r_1)} \qquad \text{(Eqn. 2)}$$

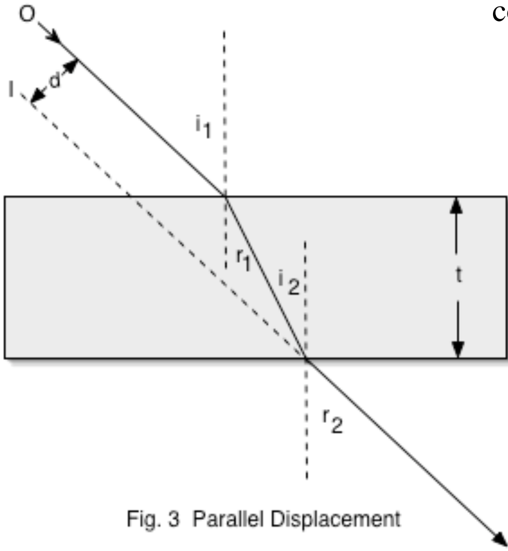

Fig. 3 Parallel Displacement

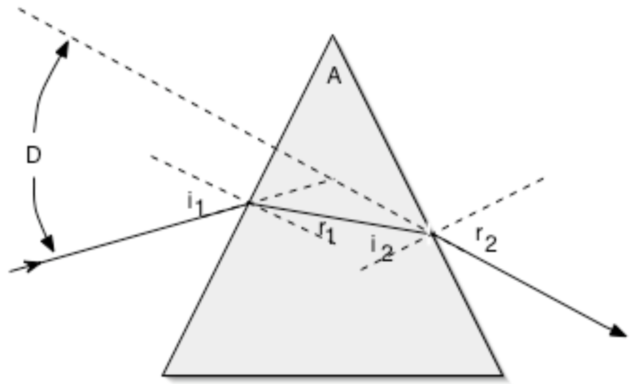

Fig. 4 Non-Parallel Refraction (Prism)

d. Refraction at successive Non-Parallel Plane Surfaces (Prism)

When plane surfaces separating two media are not parallel, a ray of light undergoing successive refractions at the surfaces suffers an angular deviation, D, rather than a lateral displacement. This is shown in Fig. 4, above, where a ray of light actually coming from object O appears to come from image I along a line making an angle with its original direction of travel. When the angle between the two surfaces is A, the angular deviation, as may be derived by analysis of Fig.4, is given by

$$D = i_1 + r_2 - A \qquad \text{(Eqn. 3)}$$

II. Collection of Data

a. Reflection at a Plane Surface (mirror)

Locate a plane mirror vertically on a pencil line drawn across the middle of a sheet of paper, and place a pin, O, to act as an object in front of, and somewhat off to one side of, the mirror, as shown in Fig. 5. The drawing shows a front-surface mirror and not the common back-surface mirror. Place pins #1 and #2 so they line up with the image I. Place pins #3 and #4 so they line up with the image I when viewed from a different position. Draw straight lines through the pin marks #1 and #2, and through #3 and #4. To locate the image I. Label all points and lines in the drawing, indicating the direction of travel of light. Construct normals and use protractors to determine the incident and reflected angles, i and r, for each of the two reflected rays. Also measure and the object and image distances S_o and S_i. Record this data in the table below.

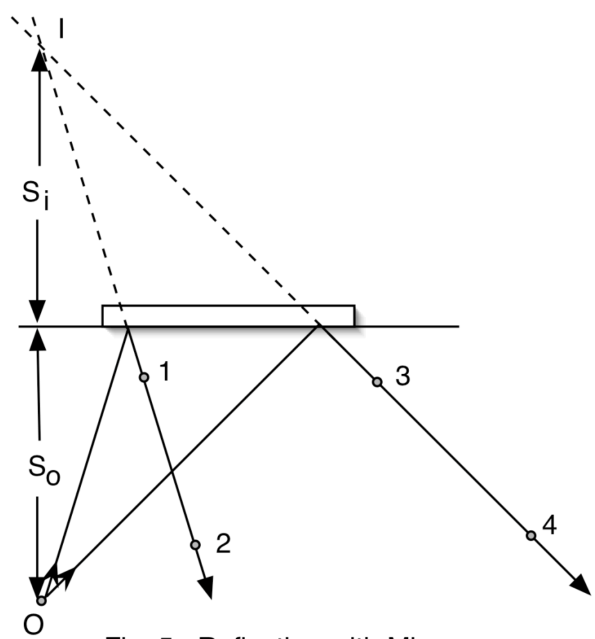

Fig. 5 Reflection with Mirror

b. Refraction through a Plate

Locate the glass plate in the middle of a sheet of paper, and make an outline of it. Place pins #1 and #2 to establish the direction of an approaching ray of light. (Avoid angles of incidence smaller than about 45° or the displacement is small and less accurately measured.) Line up pins #3 and #4 with images of pins #1 and #2 as seen edgewise through the glass plate. Label all points and lines, indicating the direction of travel of light. Determine angles i and r at the first and second surfaces, the thickness t and the displacement d. Record these values in the table.

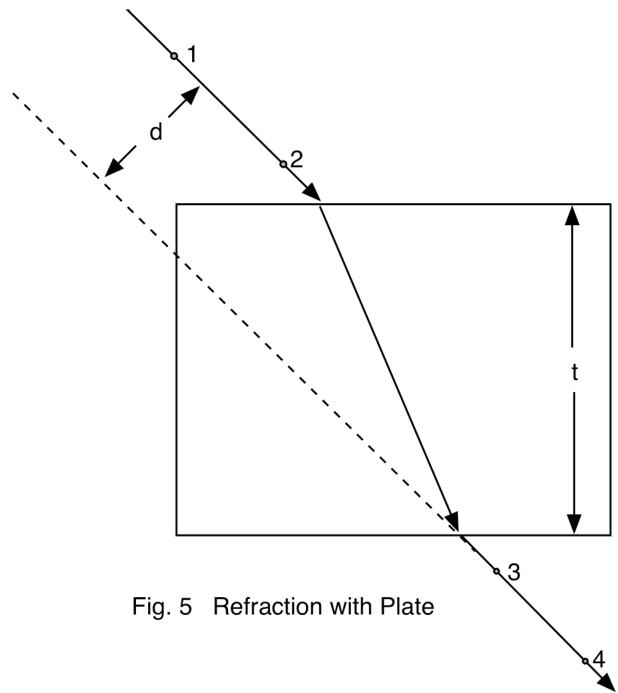

Fig. 5 Refraction with Plate

c. Refraction through a Prism

Locate the glass plate in the middle of a sheet of paper, and make an outline of it. Place pins #1 and #2 to establish the direction of an approaching ray. Let the approaching ray strike the prism closer to the base than the apex Line up pins #3 and #4 with the images of pins #1 and #2 as seen edgewise through the glass prism. Draw circles around all pin holes to mark their locations.
Draw straight lines though pin marks #1 and #2, and through #3 and #4, extending them until they intersect the outline of the glass prism. Label all points and lines, indicating the direction of travel of light. Determine the angles I and r at the first and second surfaces, the prism angle A, and angular displacement D. Record these data in the table.

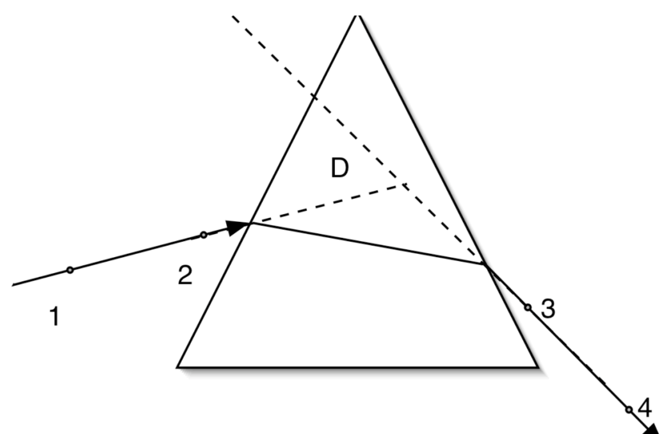

Fig. 5 Refraction with Prism

III. Data

Data Table

Reflection (Mirror)		Refraction (Plate)		Refraction (Prism)	
So (cm)		t (cm)		A (°)	
Si (cm)		d (cm)		D (°)	
i 1 (°)		i 1 (°)		i 1 (°)	
r 1 (°)		r 1 (°)		r 1 (°)	
i 2 (°)		i 2 (°)		i 2 (°)	
r 2 (°)		r 2 (°)		r 2 (°)	

IV. Results and Conclusions

a. Mirror

1. Do your observations support the Law of Reflection? Explain.

2. What is the relationship between the object and image distances, So and Si?

b. Plate

1. Use Snell's Law (Eqn. 1) to compute the index of refraction for the glass plate.

2. Compare the measured displacement, d, to the computed value of d using Eqn. 2.

c. Glass Prism

1. Compare the measured value of the angular displacement, D, to the computed value of D using Eqn. 3. What is the percent difference?

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