Laws of reflection and refraction

I. OBJECTIVES

- To understand and practice optical ray tracing.
- To explore the rules that predict reflection and refraction in optical materials.

II. BACKGROUND

Materials transparent to light are called optical materials. When a light ray moves from one optical material into another its speed will usually be altered causing the ray of light to change its direction (to bend). In Fig. 1 it can be seen that the laser light in the air does not continue in a straight line when moving through a plastic block but bends toward a line drawn perpendicular to the surface where the light entered the block (the normal line). Also note the slight reflection from the front of the block.

As the light leaves on the other side of the plastic block it bends away from the normal line. The amount of refractive bending of the light caused by the plastic block is an intrinsic property of the material making up the block itself. That is, the material in which the block is made can be identified by how much it bends the light.[1] As light enters a more optically dense material (e.g. from air into water or glass) it will always slowdown and thus always bend toward the normal line. If light moves into a less dense material it will always speedup and thus move away from the normal, as we see in Fig. 1.

The angle the incident ray makes with the normal is called the angle of incidence, φ_1. The angle the reflected ray makes with the normal is called the angle of reflection, φ_2. The angle the refracted ray makes with the normal is called the angle of refraction, φ_3. It has been found that the behavior of reflected and refracted rays can each be described by the following laws:

- The law of reflection states that: *(i) the angle of incidence equals the angle of reflection; (ii) the reflected ray is on the opposite side of the normal from the incident ray; (iii) the incident ray, surface normal, and reflected ray all lie in the same plane.*
- The law of refraction states that: *(i) the sine of the angle of incidence and the the sine of the angle of refraction are in constant ratio to each other; (ii) the refracted ray lies on the opposite side of the normal from the incident ray; (iii) the incident ray, surface normal, and refracted ray all lie in the same plane.* The law of refraction is known as Snell's law.

[1] The ultimate test to determine the authenticity of a diamond is for the jeweler to measure its refractive index in an instrument known as a refractometer.

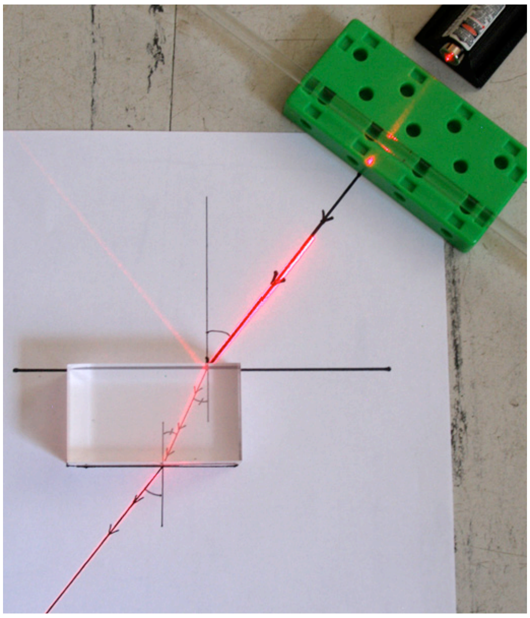

FIG. 1: Reflection and refraction of light rays by a plastic rectangular block.

The index of refraction, or refractive index, of an optical material is defined as the ratio of the speed of light in a vacuum (empty space) to the speed of light in the material. The refractive index of empty space is 1.0, while the refractive indices of all other optical materials are greater than 1.0. The refractive index of air is about 1.0003, and so to a good approximation air can be considered as empty space.

III. MATERIALS

- Plastic rectangular block.
- Light source.
- Pencil.
- Paper sheet.
- Ruler.
- Protractor.

TABLE I: Angles of incidence and reflection.

angle of incidence (φ_1)	angle of reflection (φ_2)

TABLE II: Angles of incidence and refraction.

φ_1	$\sin\varphi_1$	φ_3	$\sin\varphi_3$	$\sin\varphi_1/\sin\varphi_3$

IV. ASSEMBLY AND OPERATION

A. Law of reflection

Shine the light on the reflective surface. On a separate sheet, make a diagram showing the angle of incidence φ_1 and the angle of reflection φ_2. Measure these angles using a protractor and record them in Table I, for three different values of φ_1. Describe in words the relation you found between the angle of incidence and the angle of reflection.

B. Law of refraction

Shine the light on the transparent surface. On a separate sheet, make a diagram showing the angle of incidence φ_1 and the angle of refraction φ_3. Measure these using a protractor and record them in Table II, for three different values of φ_1. Evaluate the sines of the angles and the ratio of the sines. According to Snell's law of refraction $\sin\varphi_1 = n\sin\varphi_3$, where n is the index of refraction of the plastic material and we have assumed that the refractive index of air is 1.0. *(i)* Are your observations consistent with Snell's law? *(ii)* What is the index of refraction of the plastic used in this experiment? *(iii)* The speed of light in a material with refractive index n is $1/n$ times the speed of light in vacuum. What is the speed of light used in this experiment?

Observe the relation between the angle of incidence φ_4 and the angle of refraction φ_5 as the light travels from the plastic into the air. *(iv)* Which angle is larger φ_4 or φ_5? *(v)* As you increase φ_4, at some point the refracted ray disappears. This is called total internal reflection. Find the angle φ_4 at which this occurs.