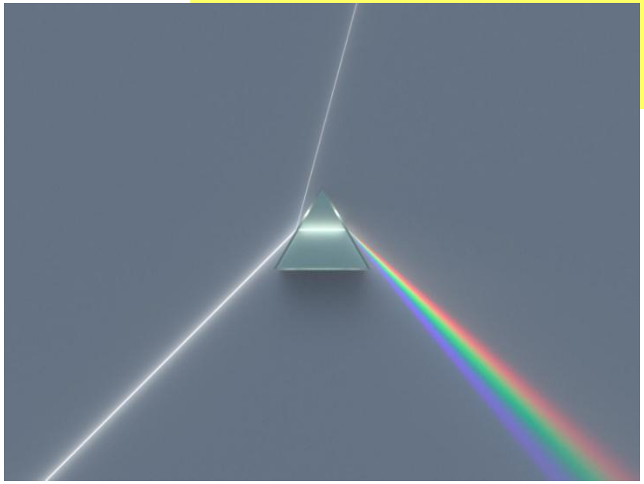
CHAPTER 2

GEOMETRIC OPTICS



Optics is either very simple or else it is very complicated.

Feynman

INTRODUCTION

The treatment of light as wave motion allows for a region of approximation in which the wavelength is considered to be negligible compared with the dimensions of the relevant components of the optical system.

Physical Optics

Geometrical Optics

$$\lim_{\lambda \to 0}\left\{physical\ optics\right\} = \left\{geometrical\ optics\right\}$$

The behavior of a light beam passing through apertures or around obstacles in its path could be handled by geometrical optics.

INTRODUCTION

Within the approximation represented by geometrical optics, light is understood to travel out from its source along straight lines or **rays**.

<u>The ray is:</u>

The path along which energy is transmitted from one point to another in an optical system.

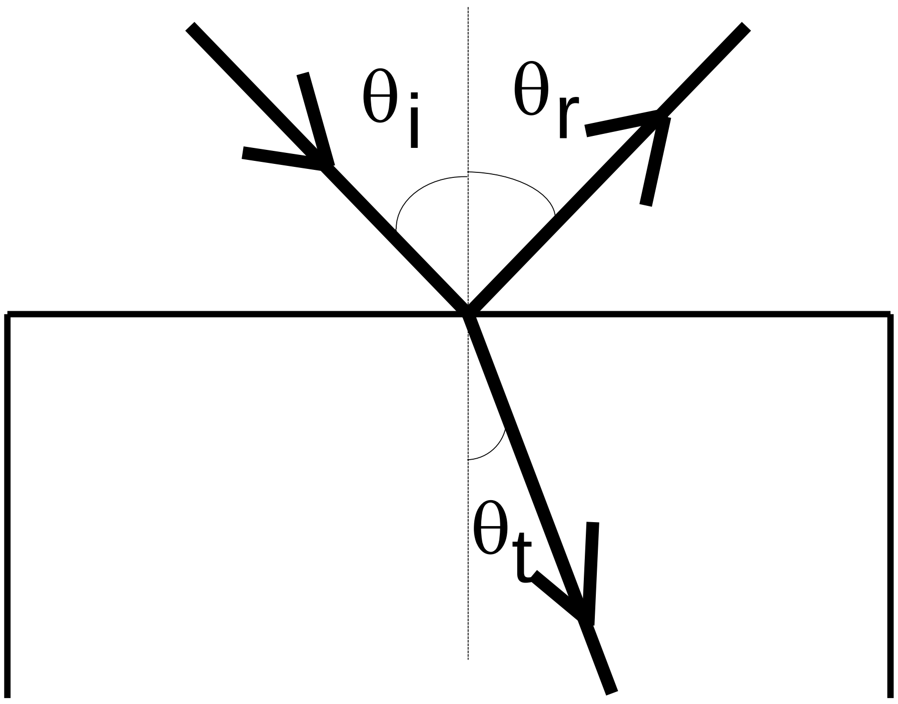
INTRODUCTION

The laws of geometrical optics that describe the subsequent direction of the rays are:

Law of Reflection

Law of Refraction

LAWS OF REFLECTION & REFRACTION



$$\theta_i = \theta_r$$

$$\frac{\sin\theta_i}{\sin\theta_t} = \text{constant}$$

LAW OF REFLECTION

A ray of light is reflected at an interface dividing two uniform media

The plane of incidence includes:

- The incident ray
- The normal to the point of incidence
- The reflected ray

Angle of reflection = Angle of incidence

$$\theta_i = \theta_r$$

LAW OF REFRACTION

A ray of light is refracted at an interface dividing two uniform media

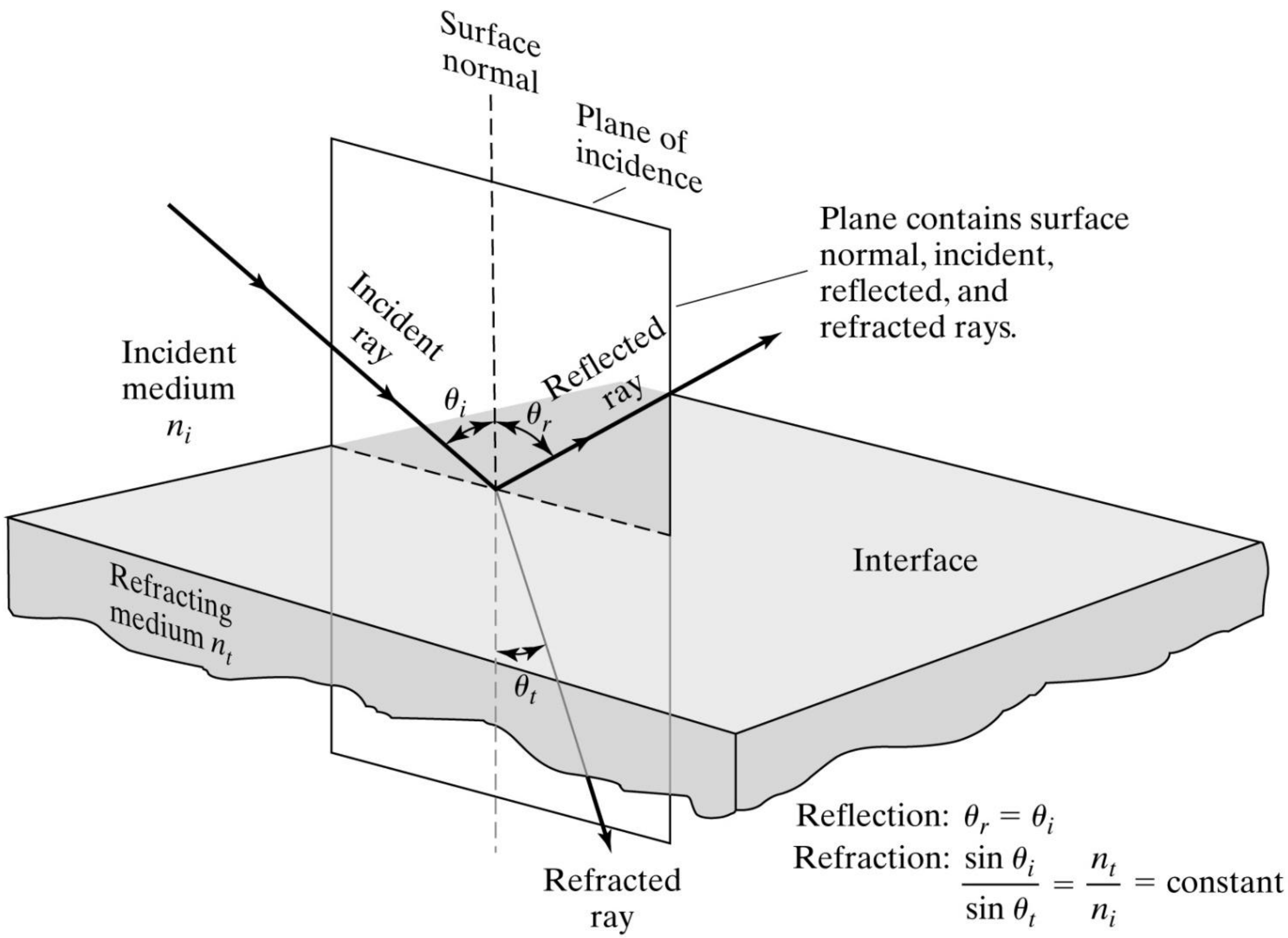
The transmitted ray remains within the plane of incidence

The sine of the angle of refraction is directly proportional to the sine of the angle of incidence.

Snell's Law ←

$$\frac{\sin\theta_i}{\sin\theta_t} = constant$$

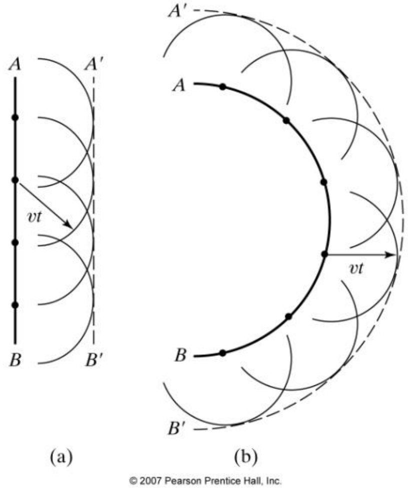
LAWS OF REFLECTION & REFRACTION

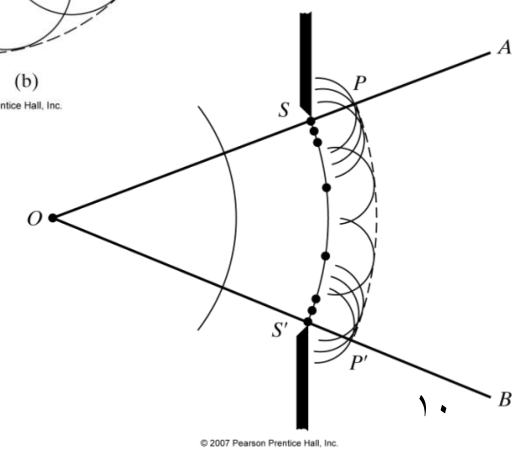


Huygens’ Principle

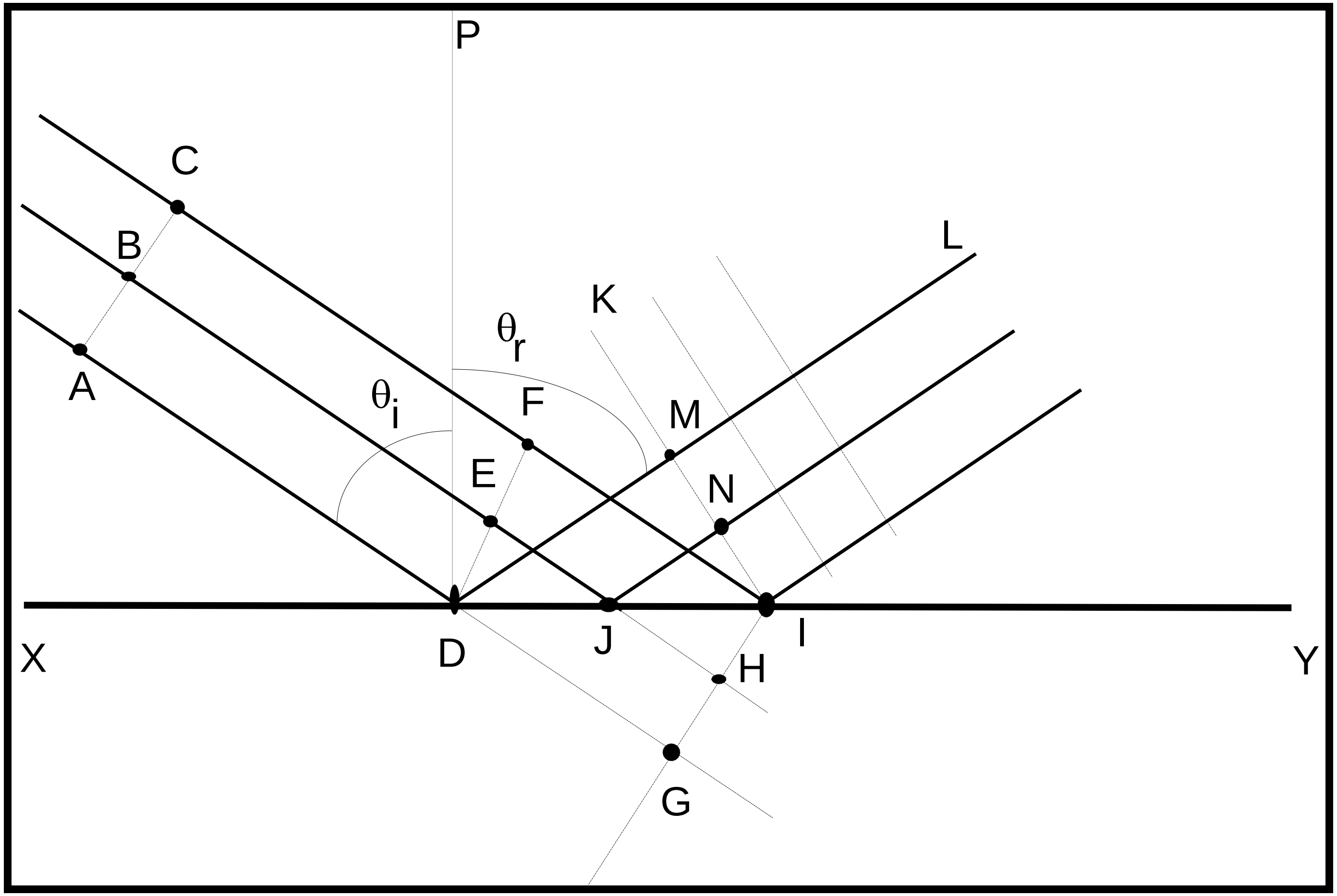
Each point on the leading surface of a wave disturbance may be regarded as a secondary source of spherical waves, which themselves progress with the speed of light in the medium and whose envelope at later times constitutes the new wavefront

- Disregarded the effectiveness of the overlapping wavelets.
- Avoided the possibility of diffraction of the light into the region of geometric shadow.
- Ignored the wavefront formed by the back half of the wavelets.
- *<u>Despite weaknesses in this model</u>*, Huygens was able to prove the laws of refection and refraction.



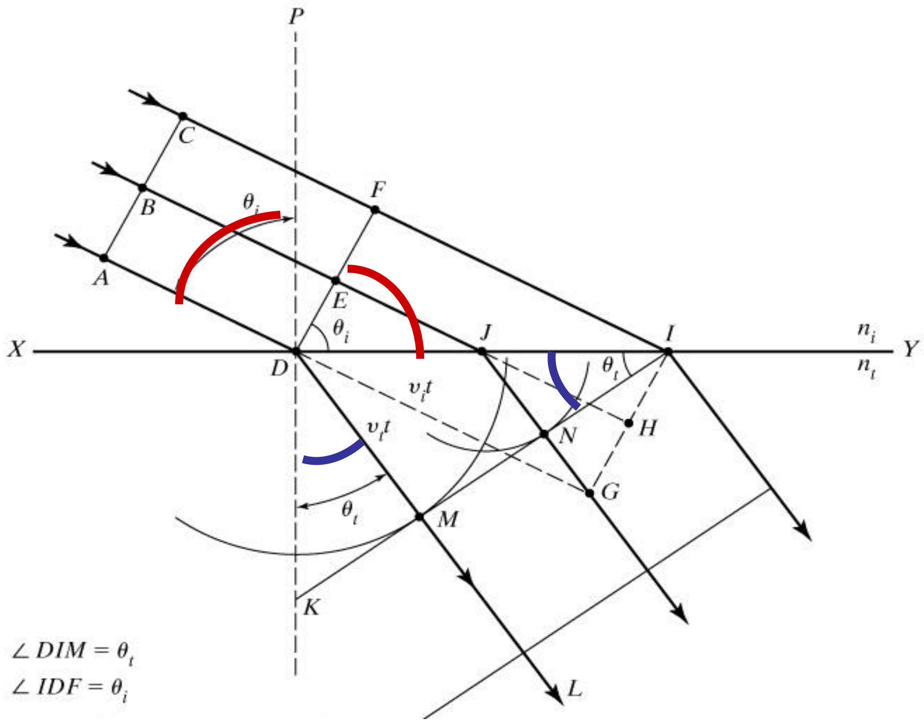


Law of Reflection from Huygen's Principle



$$\theta_i = \theta_r$$

Law of Refraction using Huygen's Principle



$$\upsilon_i = \frac{c}{n_i} \qquad \upsilon_t = \frac{c}{n_t}$$

$$\frac{\sin\theta_i}{FI} = \frac{\sin\theta_t}{DM}$$

$$FI = \upsilon_i t \qquad DM = \upsilon_t t$$

$$n_i \sin\theta_i = n_t \sin\theta_t$$

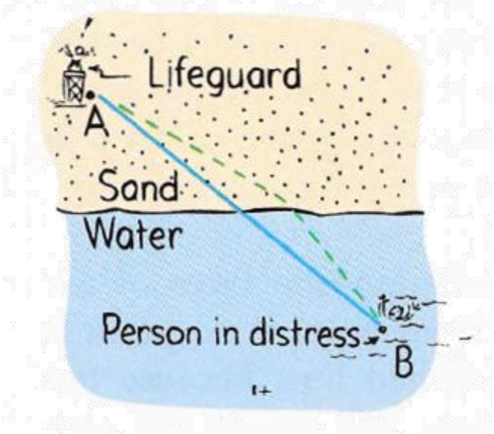
Snell's law

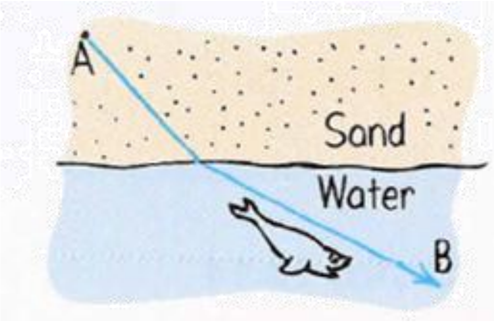
Fermat's Principle

The laws of geometrical optics can also be derived from a different fundamental hypothesis

Let us suppose that nature is economical, and thus requires that the time required for light to travel from point *A* to *B* is the minimum time required

To prove the law of reflection, we use the fact that, for propagation in the same medium, the velocity is a constant and this minimizing the time is the same as minimizing the distance traveled.

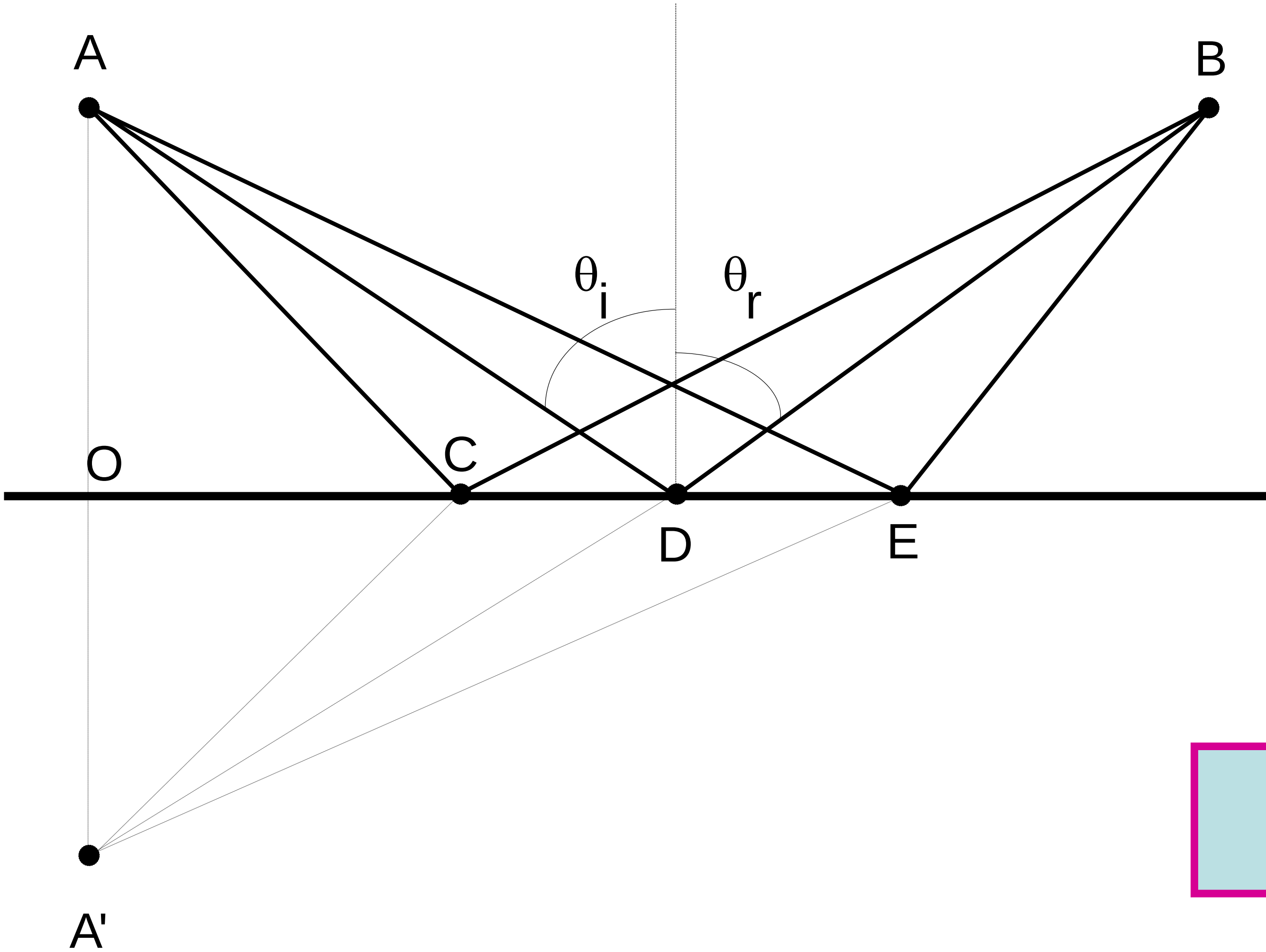




Fermat's Principle

REFLECTION

Three possible paths from *A* to *B* are shown

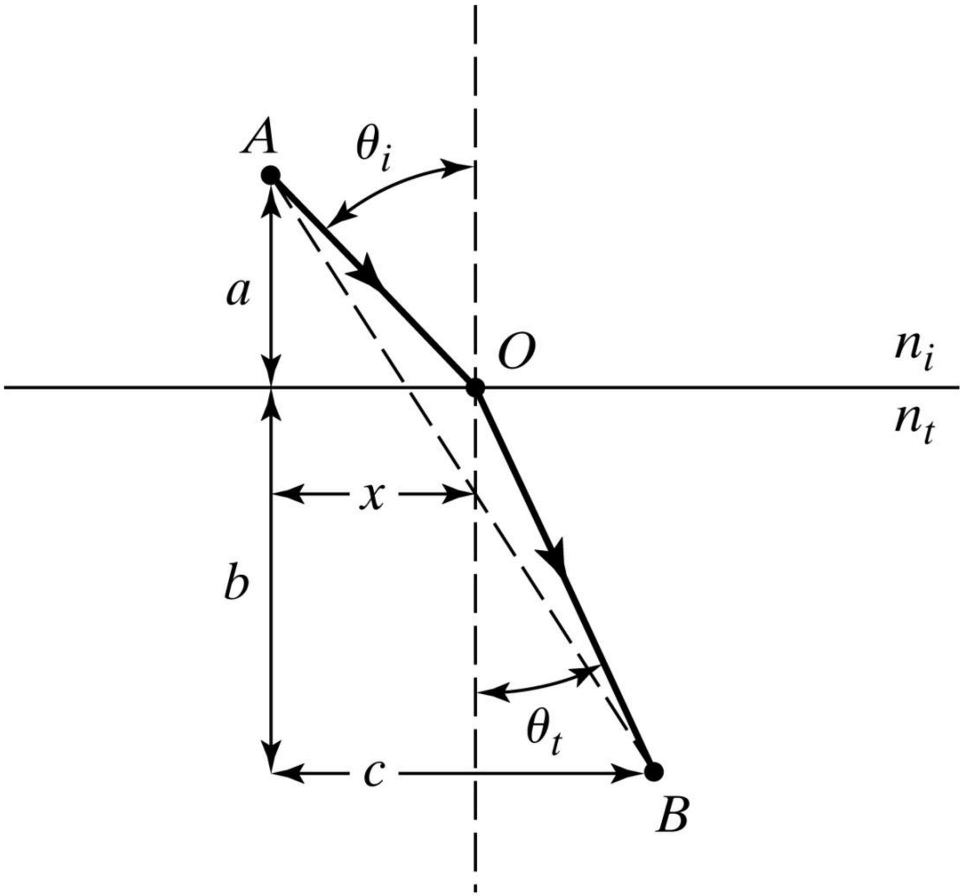


The shortest distance from A' to B is obviously the straight line $A'DB$, so the path ADB is the correct choice taken by the actual light ray.

for this path,
$\theta_i = \theta_r$

Fermat's Principle

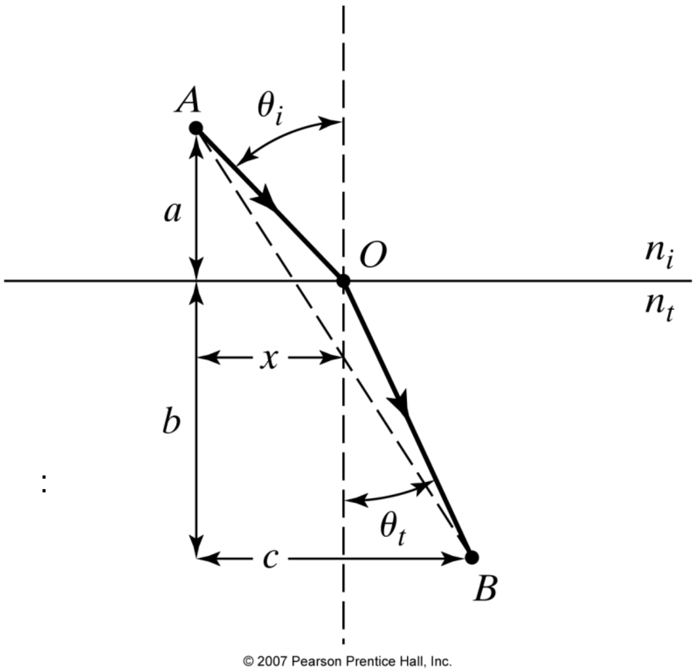
REFRACTION



If the light travels more slowly in the second medium, light bends at the interface so as to take a path that favors a shorter time in the second medium, thereby minimizing the overall transit time from *A* to *B*.

Fermat's Principle

REFRACTION



we are required to minimize the total time

$$t = \frac{AO}{v_i} + \frac{OB}{v_t}$$

$$= \frac{\sqrt{a^2 + x^2}}{v_i} + \frac{\sqrt{b^2 + (c-x)^2}}{v_t}$$

Other choices of path change the position of the point *O* and therefore the distance *x*

we can minimize the time by setting

$$0 = \frac{dt}{dx} = \frac{x}{v_i\sqrt{a^2 + x^2}} - \frac{c-x}{v_t\sqrt{b^2 + (c-x)^2}} = \frac{\sin\theta_i}{v_i} - \frac{\sin\theta_t}{v_t}$$

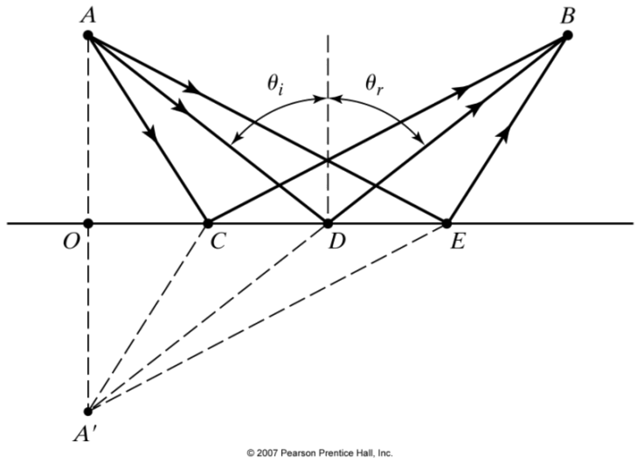
$$n_i \sin\theta_i = n_t \sin\theta_t$$

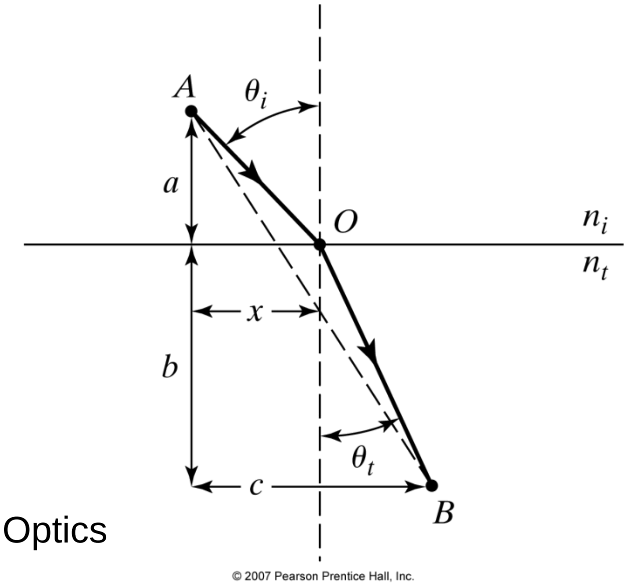
Optical Reversibility

Consider applying Fermat's principle to an optical system.

Since the time must be minimized → the same path is predicted regardless of whether we start at *A* and travel to *B*, or start at *B* and travel to *A*.

Any actual ray of light in an optical system, if reversed in direction, will retrace the same path backward

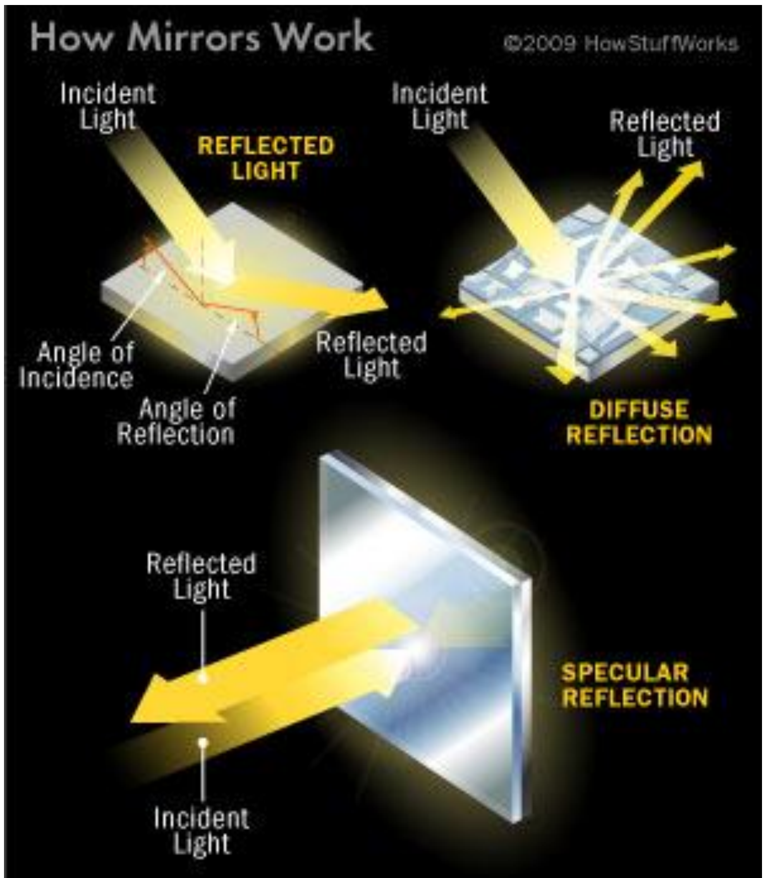


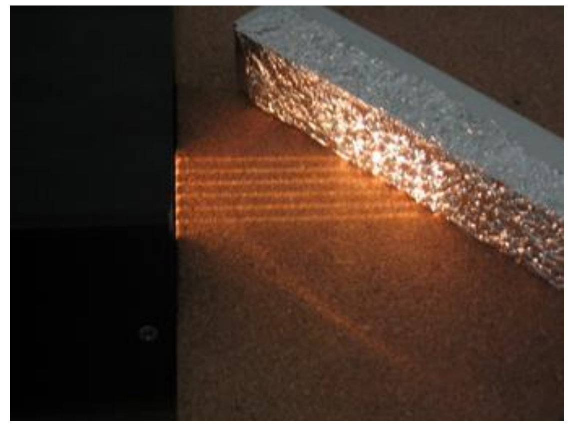


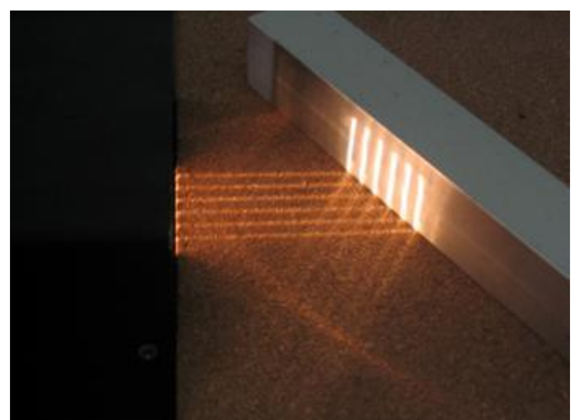
Reflection

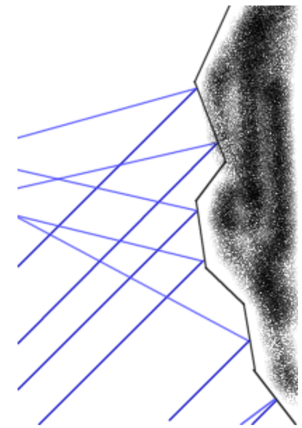
<u>SPECULAR REFLECTION</u>
From a perfectly smooth surface

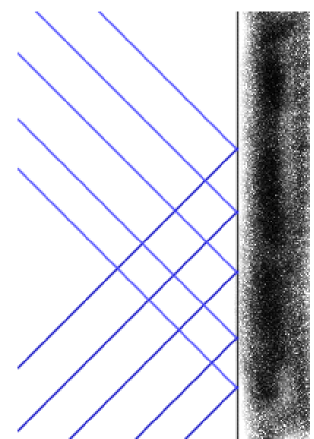
<u>DIFFUSE REFLECTION</u>
From a granular or rough surface











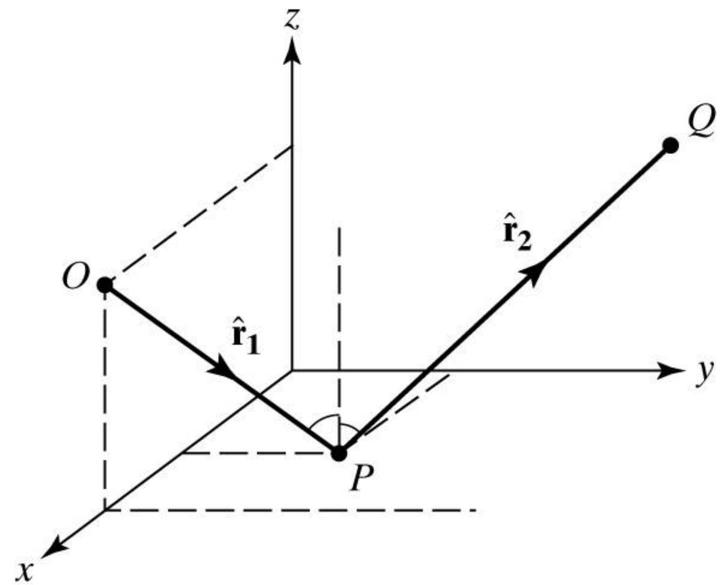
Reflection In Plane Mirrors

Consider the specular reflection of a single light ray from the *x-y* plane.

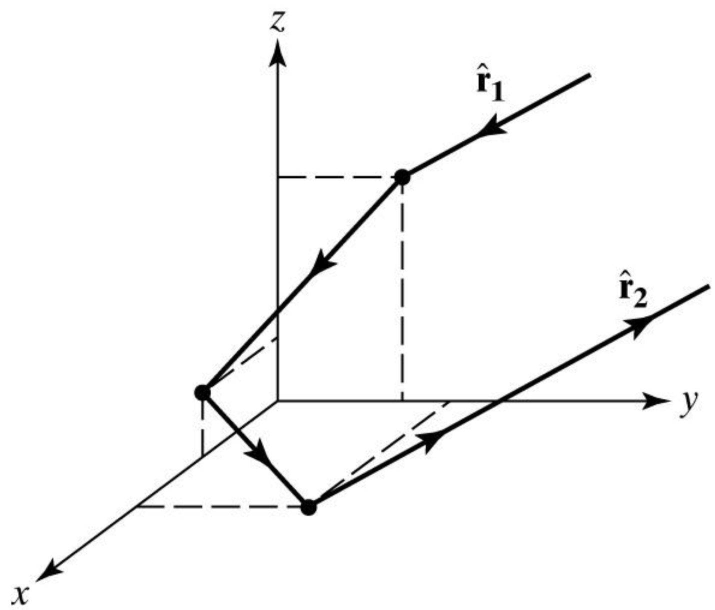
***By the law of reflection*, the reflected ray remains within the plane of incidence, making equal angles with the normal at the point of contact.**

What happens to the z-component of the incident and reflected rays??

$$\hat{r}_1 = (x, y, z) \rightarrow \hat{r}_2(x, y, -z)$$



Reflection In Plane Mirrors



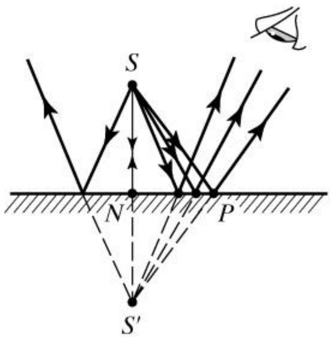
If a ray is incident from such a direction as to reflect sequentially from all three coordinate planes, then

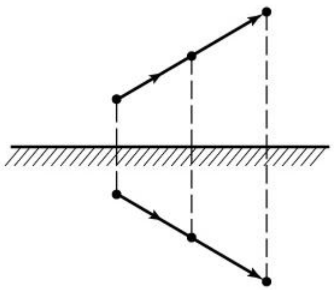
$$\hat{r}_1 = (x, y, z) \rightarrow \hat{r}_2(-x, -y, -z)$$

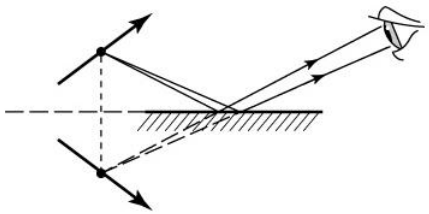
CORNER REFLECTORS

The ray returns precisely parallel to the line of its original approach

Reflection In Plane Mirrors







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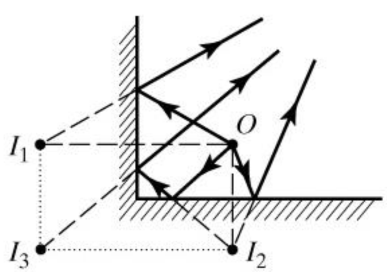
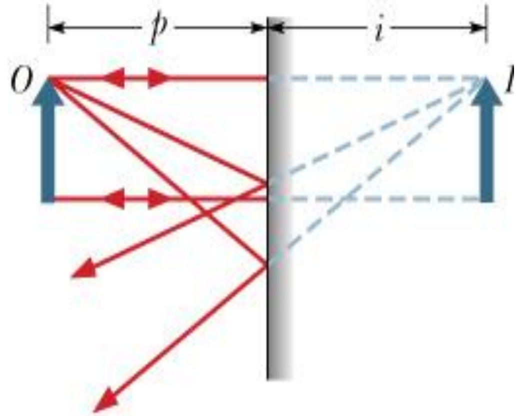
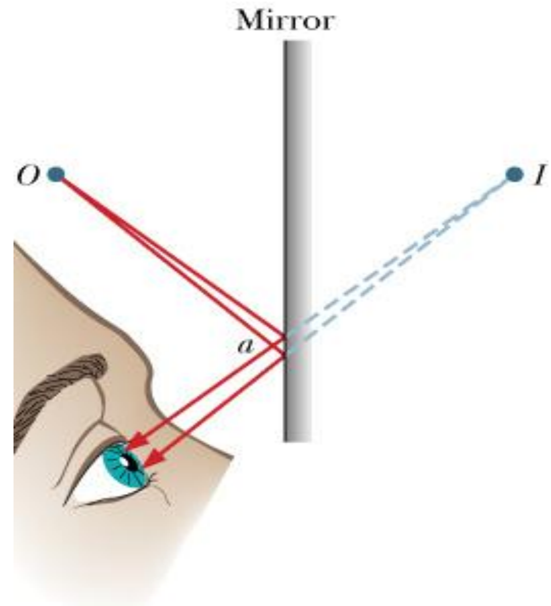




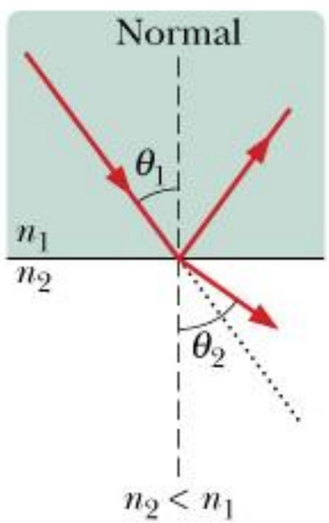
$$i = o$$

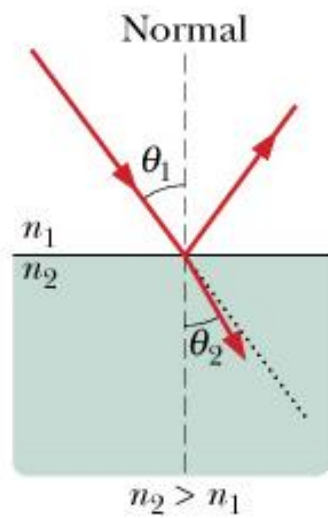
$$m = \frac{-i}{o} = 1$$

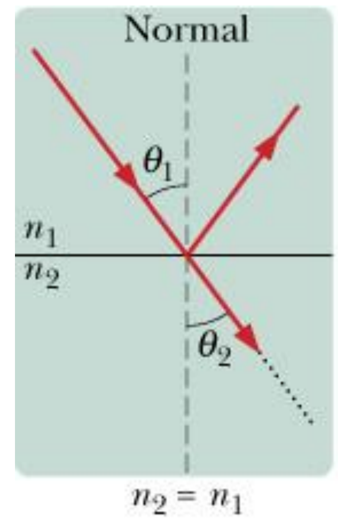


Virtual image

Refraction Through Plane Surfaces







$$n = c / \upsilon$$

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

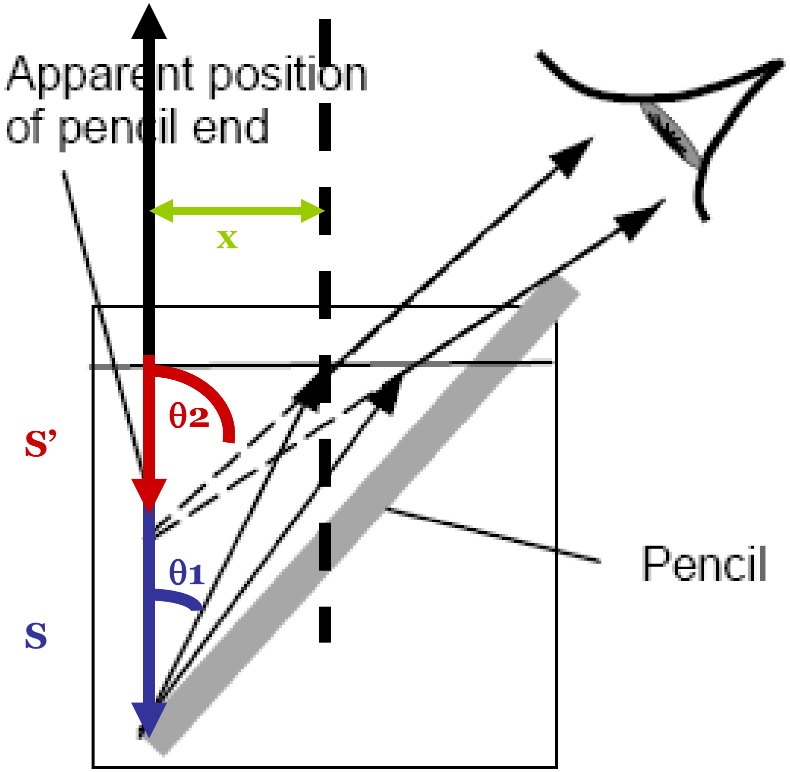
$$\theta_i = \theta_r$$

Refraction Through Plane Surfaces

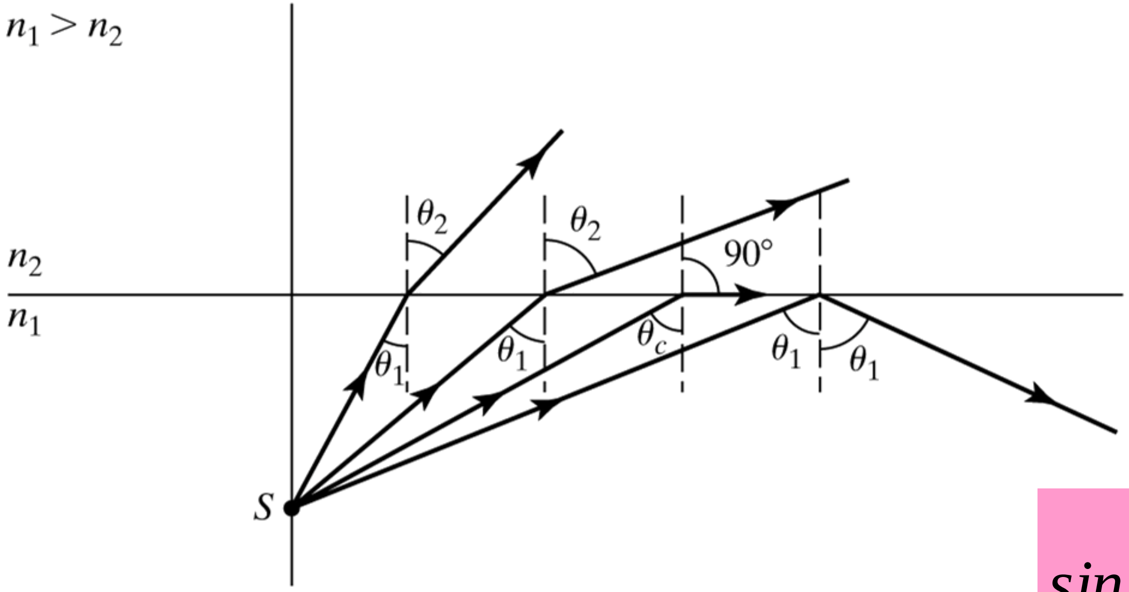
$$n_1\, tan\, \theta_1 \cong n_2\, tan\, \theta_2$$

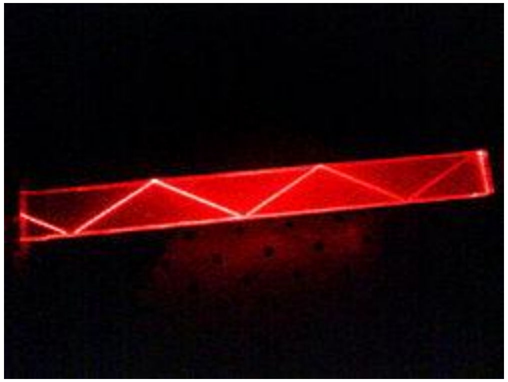
$$n_1\left(\frac{x}{s}\right) = n_2\left(\frac{x}{s'}\right)$$

$$s' = \left(\frac{n_2}{n_1}\right)s$$



Refraction Through Plane Surfaces





Total internal reflection

$$\sin\theta_c = \left(\frac{n_2}{n_1}\right)\sin 90 = \left(\frac{n_2}{n_1}\right)$$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

http://www.opticalres.com/optics_for_kids/kidoptx_p1.html