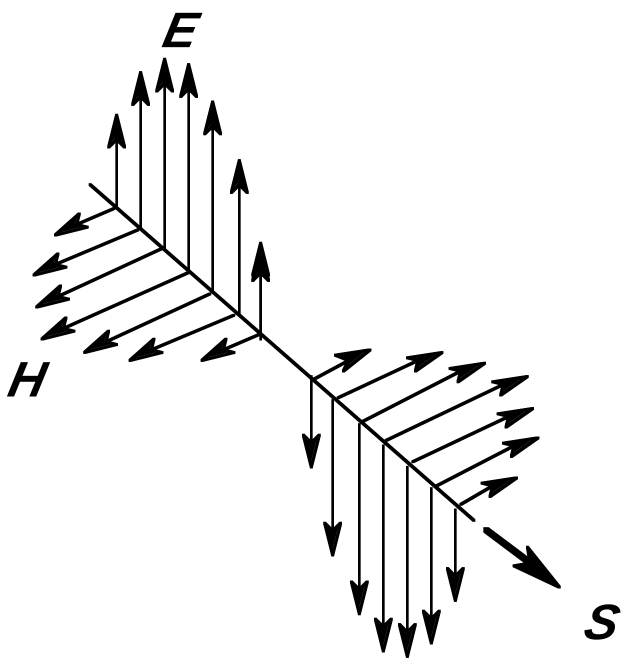
RECTILINEAR PROPAGATION

Electromagnetic Waves

Light is, in fact, an electromagnetic wave and is produced whenever a charged particle is accelerated. In three dimensions the appearance of an electromagnetic wave (if we could see it) would be 2 perpendicular waves, one of electric field ***E*** and one of magnetic field ***H***, in phase, rippling along in a straight line.



The vector ***S*** is the Poynting Vector. Its magnitude is the amount of energy carried by the wave and its direction is the direction of propagation of the wave.

The wave properties of light produce a number of phenomena which are important in a number of clinical phenomena including the physical reasons for the subjectively reported appearances of entoptic phenomena like Haidinger's brushes and vitreous floaters; the reasons truckers and boaters like polaroid sunglasses; why anti-reflection coated lenses and polaroid lenses are used in spectacles and optometric equipment; the special properties of laser light which permit applications in surgery, ocular refraction, and determination of retinal function in cataract patients; what visual acuity is and why none of your patients will have much better than

20/20; how the fluorescing compounds used in fluorography, angiography, and contact lens fitting work.

But you don't need to know about waves to understand how most ordinary light works. To understand lenses, mirrors, and the other stuff of geometric optics, it is sufficient to understand what happens to the Poynting vector when light moves from one medium to another. In geometric optics parlance, that Poynting vector is called a ray. We can think of a light source as an object that kicks out light rays.

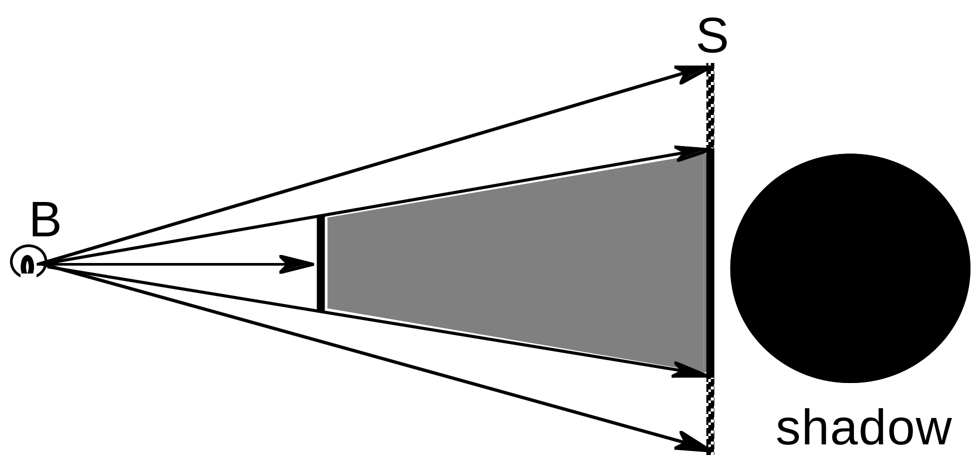
There are two laws of kinematics for rays:

- ☞ Left alone, rays don't change direction. This is called rectilinear propagation.

- ☞ Rays change direction when they encounter a new medium according to Snell's Law or the law of reflection.

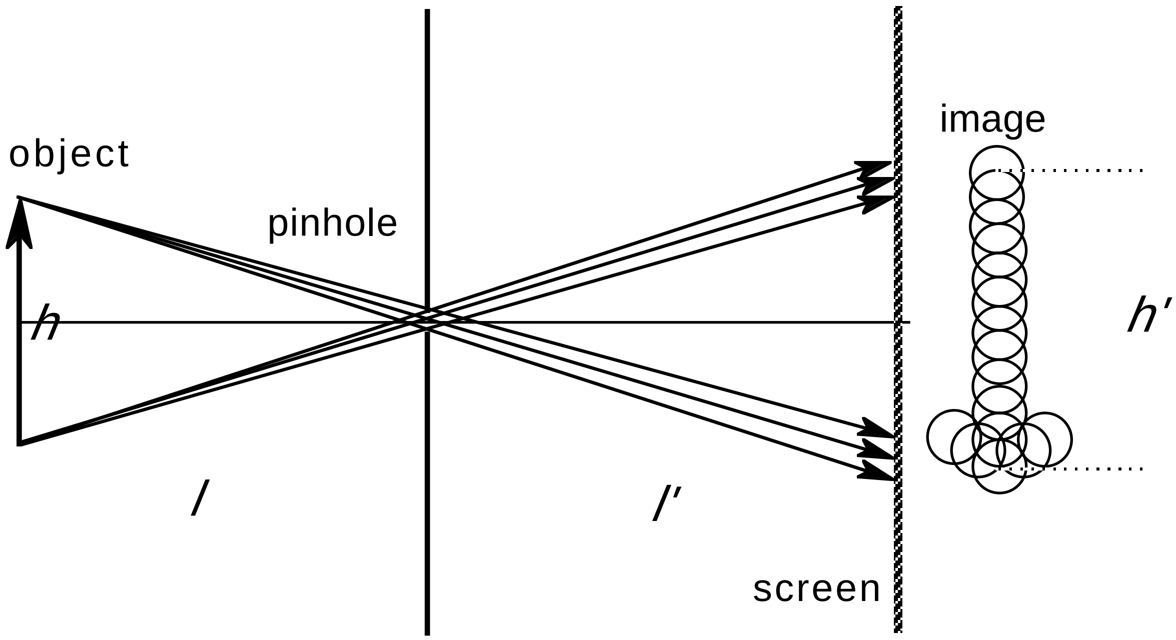
Shadows and Pinhole Cameras

We can use the first of these laws to understand shadows. Suppose we have a point light source B sending light to a screen S and a circular obstruction is placed along the line connecting B to S. The size and shape of the shadow on the screen may be calculated from simple geometry.



The diameter of the shadow can be calculated in straightforward manner from plane geometry.

The pinhole camera is a primitive imaging device in which an aperture, usually circular, is placed between a luminous object and a screen. Miraculuously, an image of the object appears on the screen. The principal is illustrated in the diagram below:

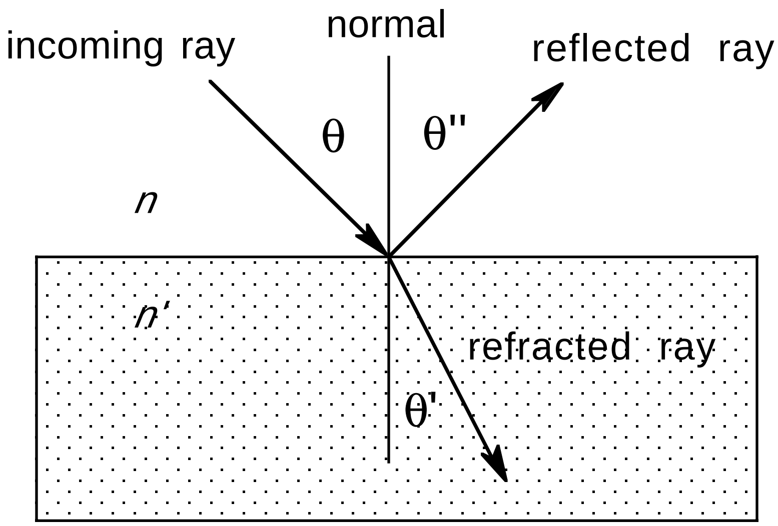


Each point on the object is imaged as a small circle, and these circles combine to form a somewhat fuzzy image of the object. The smaller the pinhole, the sharper--and dimmer--the image. The size of object and image are related to the pinhole position by the equation

$$h/l=h'/l'.$$

Snell's Law

When a ray of light strikes a new medium it may be reflected or it may traverse the boundary with a change of direction. The latter is called refraction. Usually both things happen.



The law of reflection is easy, the angle of incidence equals the angle of reflection, or

$$\theta=\theta''.$$

The refracted ray obeys Snell's law,

$$n\sin\theta=n'\sin\theta',$$

where n and n' are the <u>indices of refraction</u> of the two media. Here are some typical indices of refraction:

material	index
vacuum	1.00
water	1.33
ophthalmic plastic	1.49
crown glass	1.52
flint glass	1.62
diamond	2.42

It turns out that the index of refraction of a material is inversely proportional to the speed of light in that material. If $c \cong 3\times10^8$ m/sec is the speed of light in a vacuum and v is the speed of light within a material, the index of refraction of the material is

$$n=c/v.$$

When light crosses an interface, the medium of greater index is called the dense medium and the index of lessor index is called the rare medium. Snell's law says that light will be bent toward the surface normal ingoing from rare to dense media and will be bent away from the surface normal in going from dense to rare media.

Snell's law may be obtained several different ways; from Fermat's Principle which states that rays take minimum time to traverse between two points, from Maxwell's equations governing electro-magnetic fields, or from Huygen's Principle governing the propagation of waves. It's just as well, however, to regard it as a fundamental experimental fact.

Note that both the law of reflection and the law of refraction are reversible, that is, a ray incident at angle θ' will be reflected at angle θ and a ray in the second medium incident at angle θ'' will be refracted at angle θ. In other words, if you turn all the rays around you will still have a valid ray diagram.

