



**Empedocles**  
490 - 430 CE

Emission Theory of Vision

Light is emitted from the eye and travels to the object, thereby illuminating it.



**Euclid**  
330 - 260 BCE



**Ptolemy**  
83 - 161 CE

Emission (extramission) Theory of Vision

Light is emitted from the eye and travels to the object, thereby illuminating it.

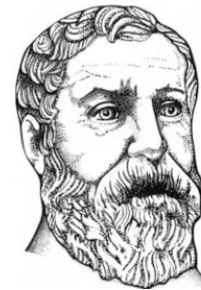
[Am Psychol.](#) 2002 Jun-Jul;57(6-7):417-24.

Fundamentally misunderstanding visual perception. Adults' belief in visual emissions.

Winer GA, Cottrell JE, Gregg V, Fournier JS, Bica LA.

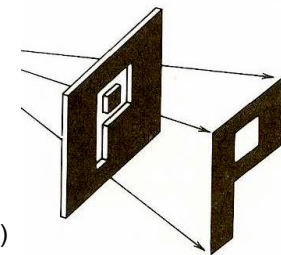
Department of Psychology, Ohio State University, 142 Townshend Hall, Columbus, OH 43210-1222, USA.

The authors reviewed research about a profound misconception that is present among college students, namely, the belief that the process of vision includes emanations from the eyes, an idea that is consistent with the extramission theory of perception, which was originally professed by early Greek philosophers and which persisted in scholarly circles for centuries. The authors document the strength and breadth of this phenomenon and the object failure of traditional educational techniques to overcome this belief, and they reveal that students are leaving psychology courses with a flawed understanding of one of the most studied processes in the history of psychology--visual perception. Some suggestions are offered for overcoming this misconception in traditional college classroom settings.



**Hero(n) of Alexandria**  
(10 - 70 CE)  
"Mechanics & Optics" (~55 CE)

Hero's Principle  
Light rays traveling through homogeneous media in straight lines



"Principle of Reflection"



The “Father of Optics”  
“Book of Optics” (1021)

Ibn al-Haytham  
(965 - 1039)  
Born in Basra

Intromission Theory of Vision  
Light transmits “physical forms” to the eye

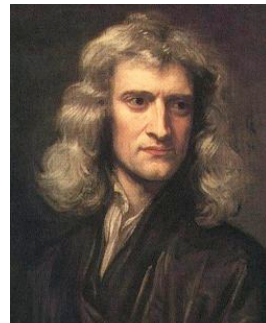
### Glass Production

- ~ 3000 BCE First evidence of glass production
- ~ 700 BCE First lenses appear (crystal)
- ~ 250 BCE Glass blowpipe appears
- ~ 1000 CE Commercial glass production
- ~ 1050 “Reading Stones”
- ~ 1250 Glass lenses manufactured

### Ray Optics



Pierre de Fermat  
(1601 - 1665)

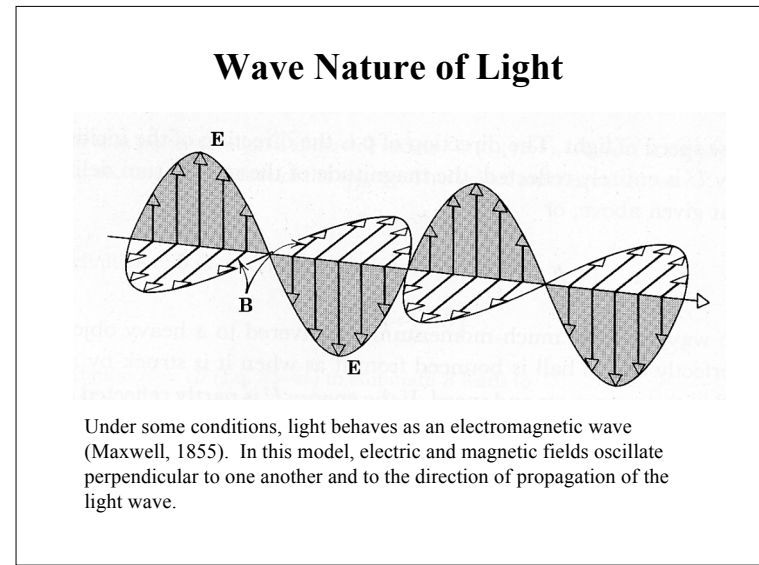
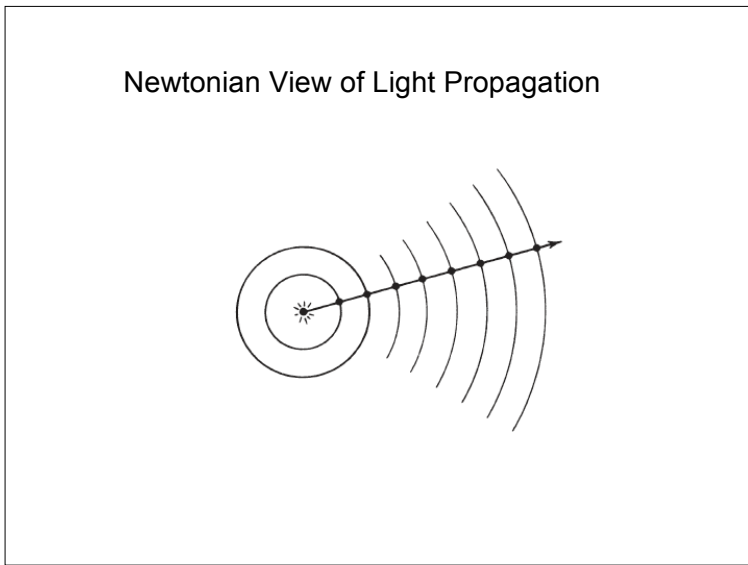
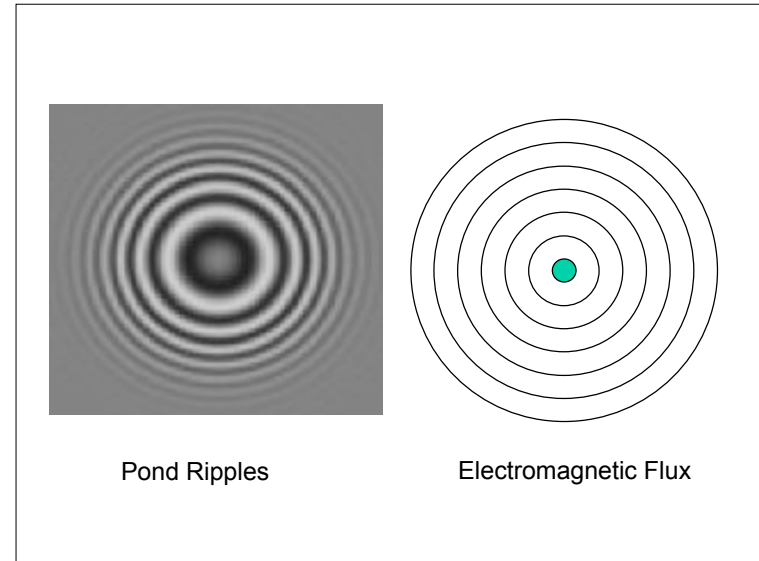


Issac Newton  
(1643 - 1727)

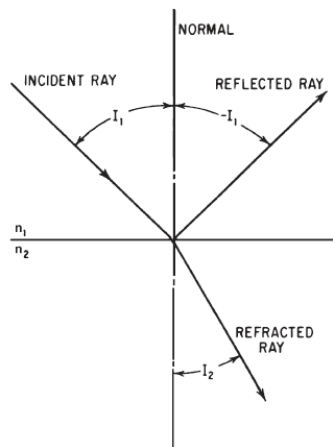
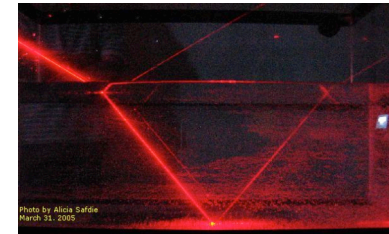
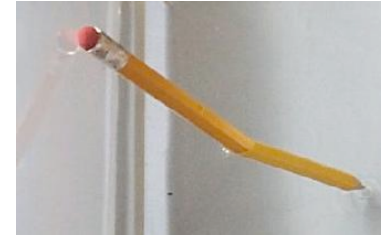
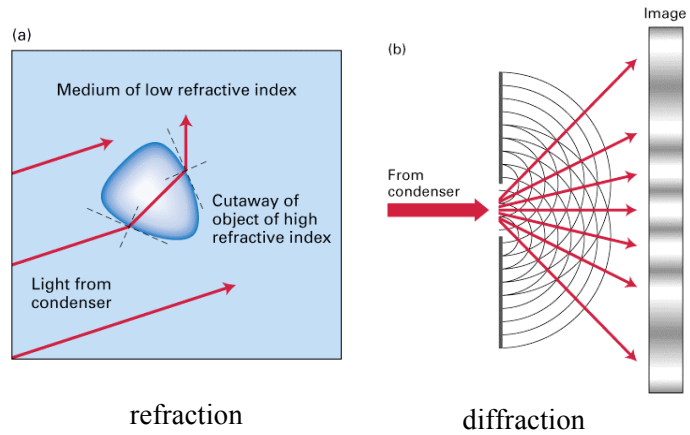


Pierre de Fermat  
(1601 - 1665)

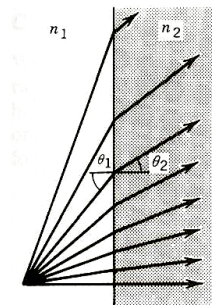
Fermat’s Principle  
In an inhomogeneous medium, light always travels the path of least time.



## Some Properties of Light

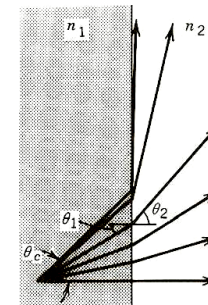


$n_1 < n_2$   
external  
refraction



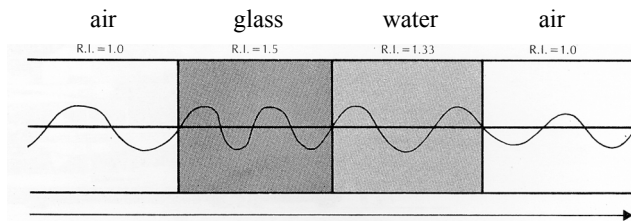
rays bend toward  
the "normal"

$n_1 > n_2$   
internal  
refraction

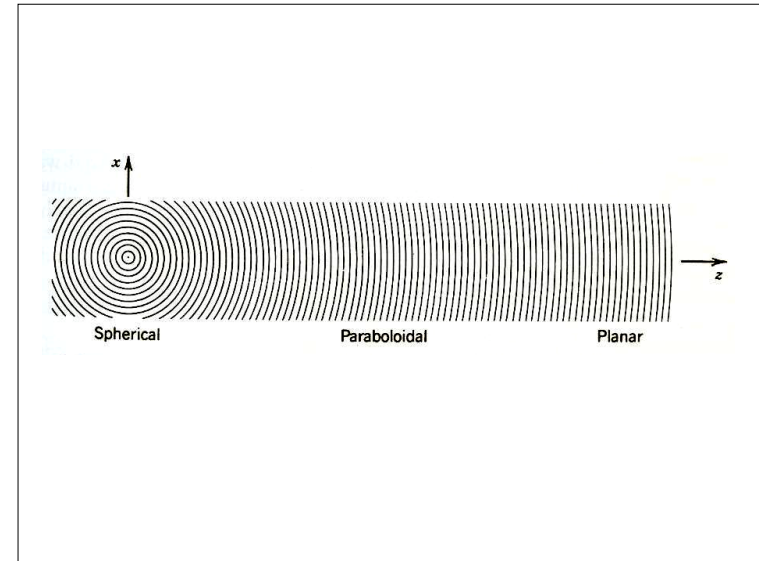


rays bend away  
from the "normal"

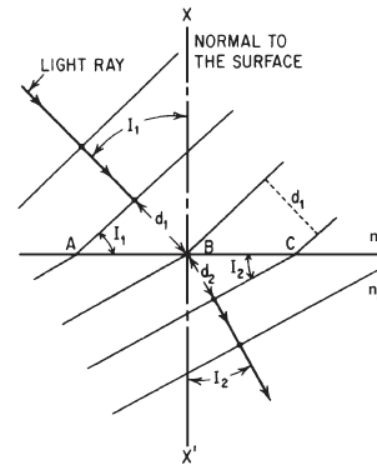
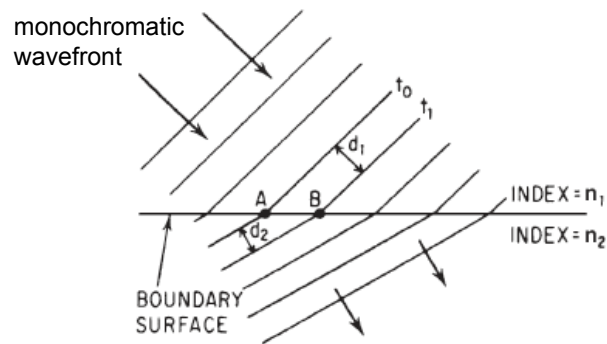
Refraction occurs at the interface between media of different densities due to variations in the speed of light in these media



Refractive index (n) =  $\frac{\text{speed of light in medium}}{\text{speed of light in air}}$



Refraction at a boundary between two media of different refractive indices, where  $n_2 > n_1$



$$d_1 = v_1 \Delta t = \frac{c}{n_1} \Delta t$$

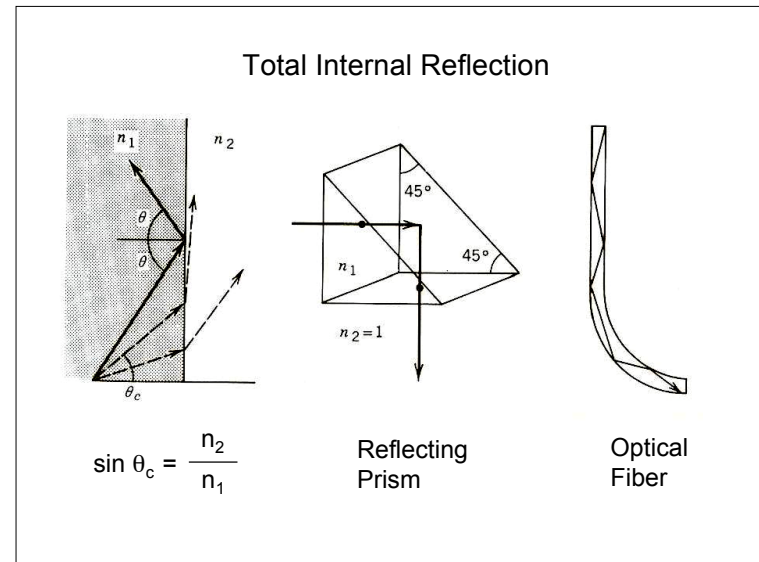
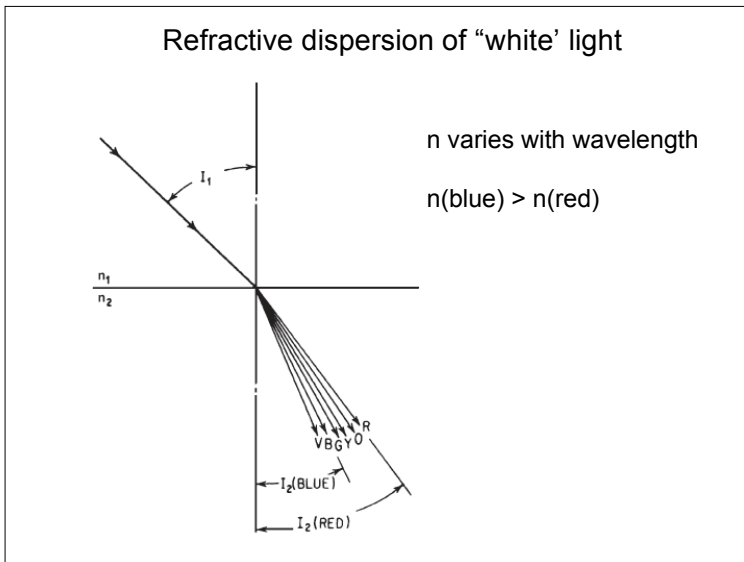
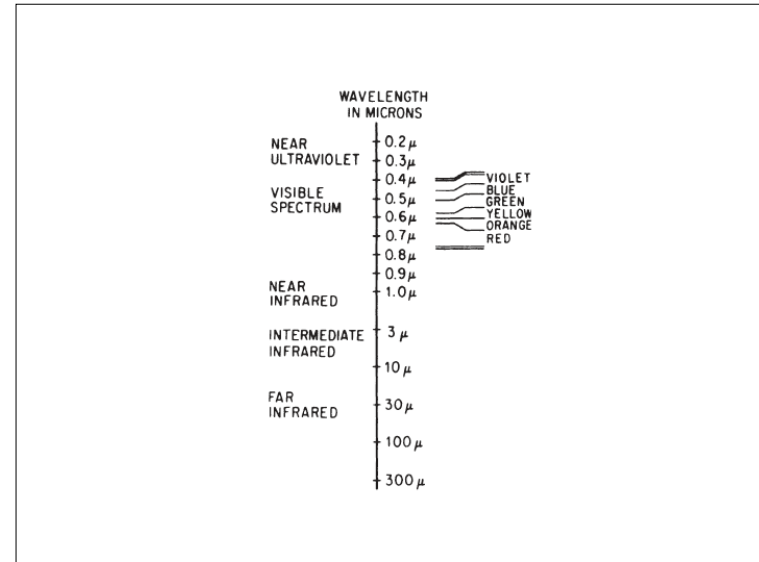
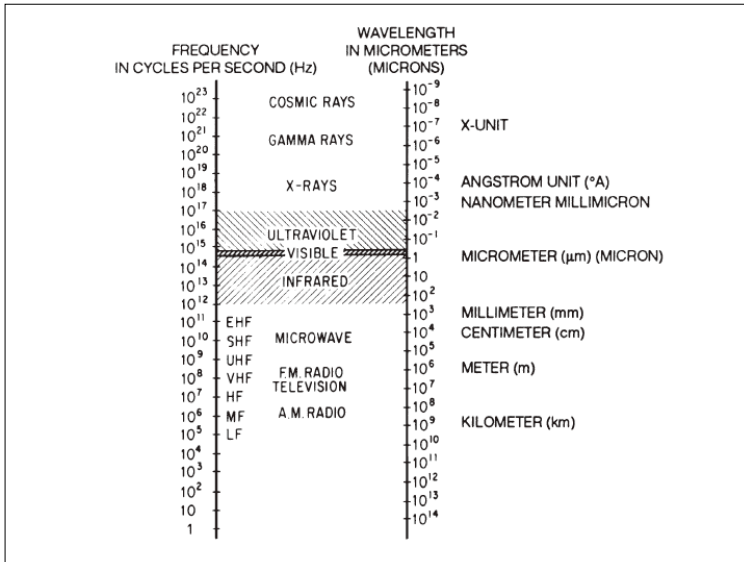
$$d_2 = v_2 \Delta t = \frac{c}{n_2} \Delta t$$

$$AB = \frac{d_1}{\sin I_1} = BC = \frac{d_2}{\sin I_2}$$

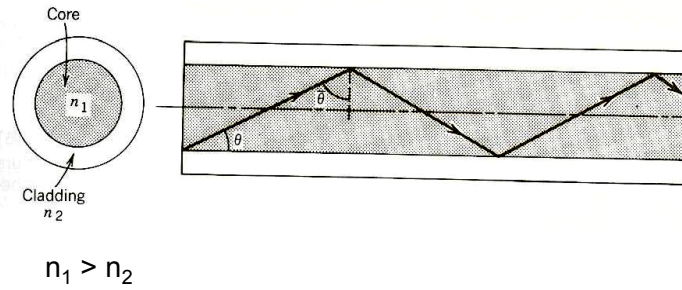
$$\frac{c \Delta t}{n_1 \sin I_1} = \frac{c \Delta t}{n_2 \sin I_2}$$

$$n_1 \sin I_1 = n_2 \sin I_2$$

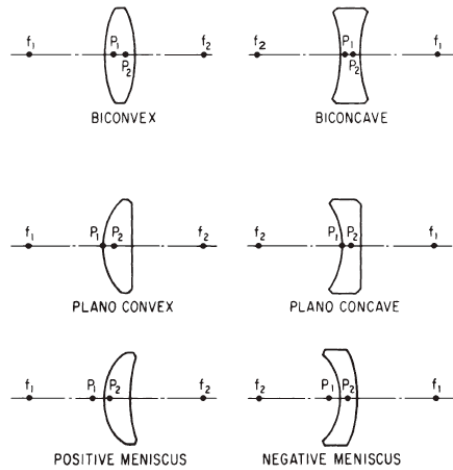
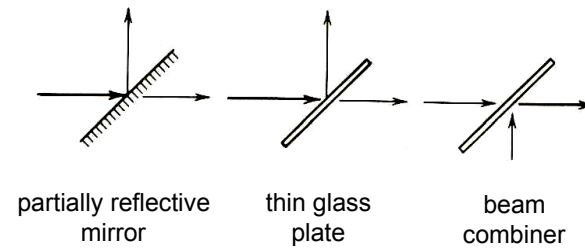
“Snell’s Law”



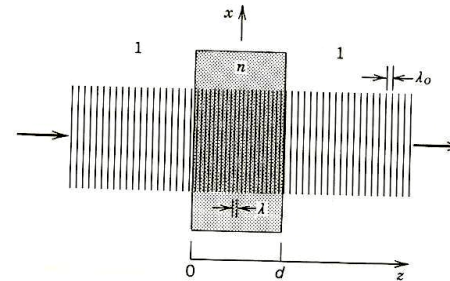
### Total Internal Reflection in an Optical Fiber



### Beam Splitters

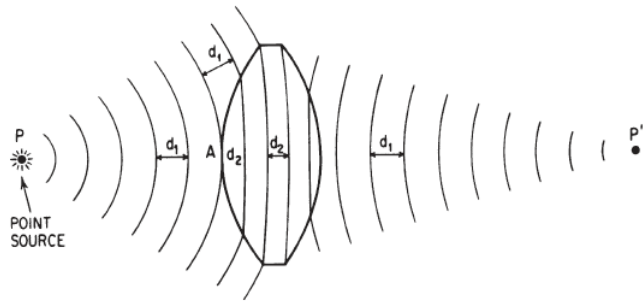


### Compression of a wave front in a medium of high refractive index



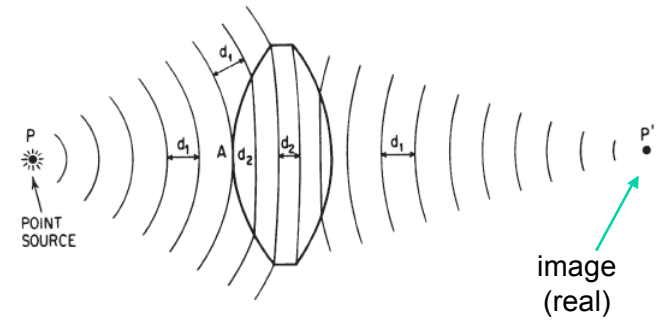


Refraction of a planar wave front by a thin lens



(bi) convex lens

Refraction of a planar wave front by a thin lens



Convergence happens at **positive** lens elements

Divergence happens at **negative** lens elements

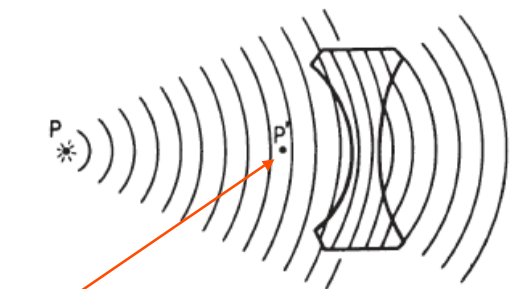


image  
(virtual)

(bi) concave lens

## Real and Virtual Images

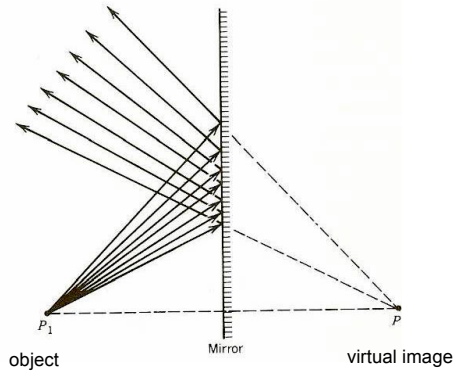
A “real image” is formed on the retina by light that actually passes through the image point.

e.g., an image observed through a window

A “virtual” image is formed by light that behaves as though it diverges from a image point through which it does not actually pass.

e.g., a mirror image

Reflection of light at a mirrored surface  
angle of reflection = angle of incidence



**A mirror projects a virtual image**

