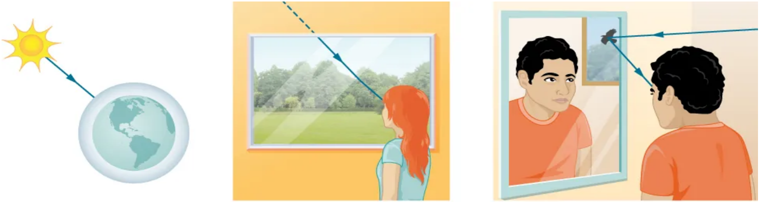
Ray Model of Light

3 ways light can travel from a source to another location



(a) (b) (c)

a directly from source through vaccum . Sun to Earth

b light can travel through various media like Air, glass, water to the observer

c light can also arrive after being reflected such as mirrors

Ray of Light

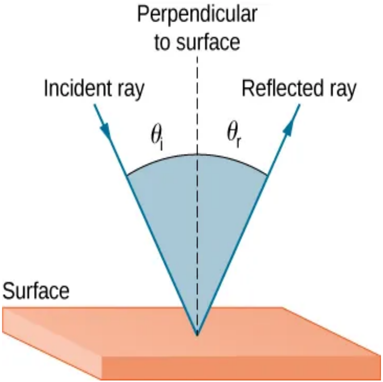
We model path of light as a straight line called ray

- Light behaves both as a particle and a wave
- When light interacts with an object several times larger than its wavelength($\approx 10^{-6}$), it travels in a straight line and acts like a ray.
- Light may change direction when it
  - reflection : encounters objects (such as a mirror)
  - refraction: passing from one material to another (such as in passing from air to glass)

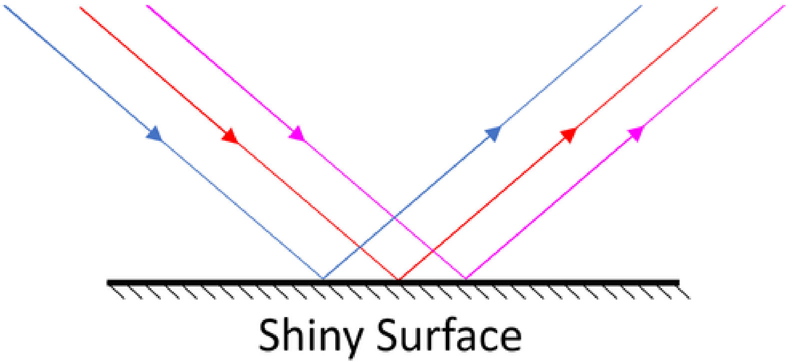
Law of Reflection

the law states that agle of reflection is equal to angle of incidence

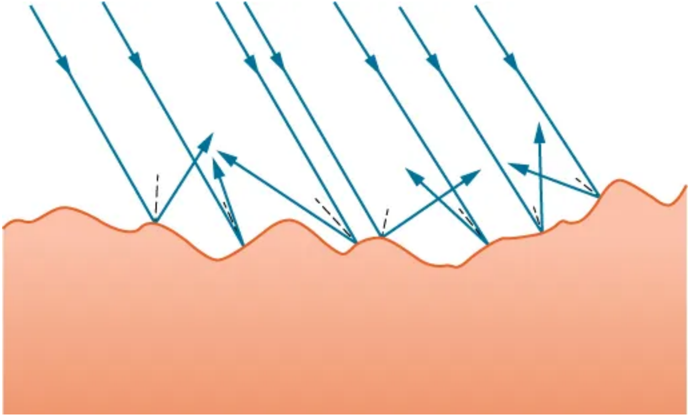
$$\theta_r = \theta_i$$

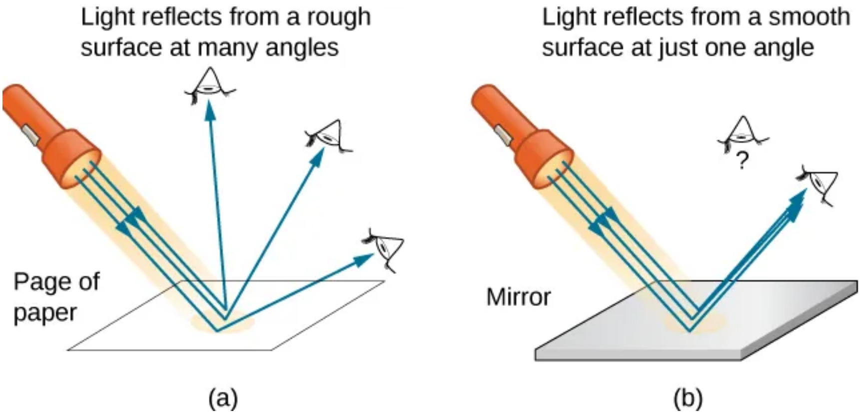


Specular Reflection

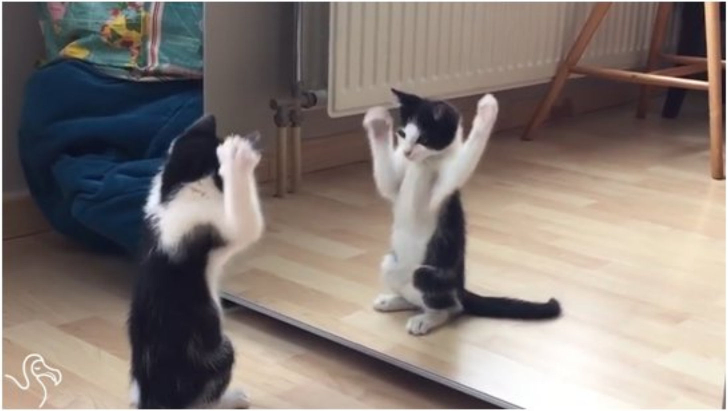


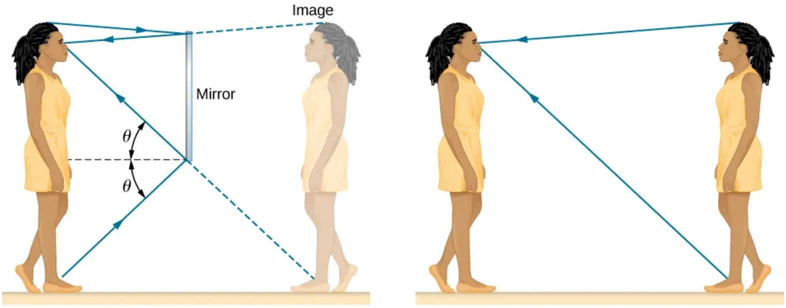
Diffused Reflection




Light reflects from a rough surface at many angles
Page of paper
(a)
Light reflects from a smooth surface at just one angle
?
Mirror
(b)

Reflections: Mirror





(a)
(b)

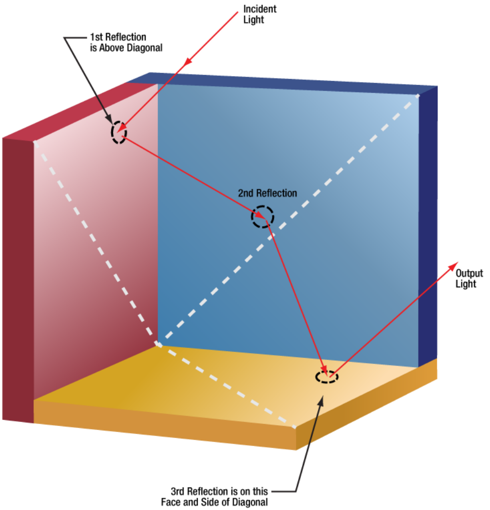
Reflections: Retroreflector

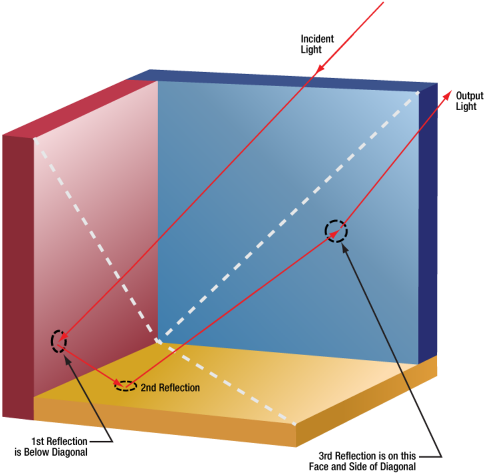
Defenition

A **retroreflector** is a device or surface that reflects radiation (usually light) back to its source with minimum scattering

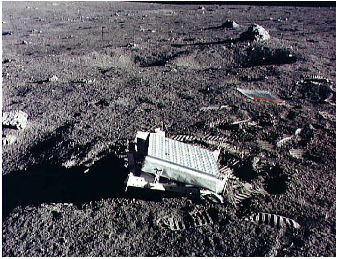
What is the difference from a **planar mirror** ?
This works in wide range of angle of incidence while mirror needs to be perpendicular to the wave front

Retroreflector: Corner Cube Reflector

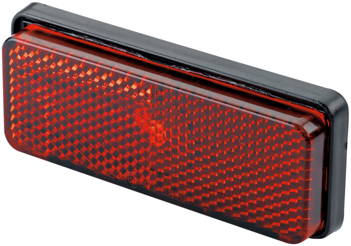



Incident
Light
Output
Light
2nd Reflection
1st Reflection
is Below Diagonal
3rd Reflection is on this
Face and Side of Diagonal

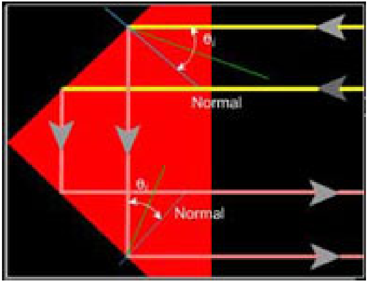
Retroreflector : Uses



- Astronauts placed a corner reflector on the Moon to measure its gradually increasing orbital distance. Laser signals from Earth can be bounced from that corner reflector to measure the gradually increasing distance to the Moon of a few centimeters per year.



(a) cycle reflectors



(b) working principle

- Retroreflection ensures high visibility if the driver and the light source are located together in case of cycle reflectors

Retroreflector : Radar

- Small boats made of fiberglass or wood do not strongly reflect radio waves emitted by radar systems. To make these boats visible to radar (to avoid collisions, for example), radar reflectors are attached to boats, usually in high places

The actual location of Mug ?

The actual location of Mug ?

Both are not the actual location !!!

Why two mugs ?

Refraction

The changing of a light ray's direction (loosely called bending) when it passes through substances of different refractive indices is called **refraction**

Why two mugs ?

Refraction

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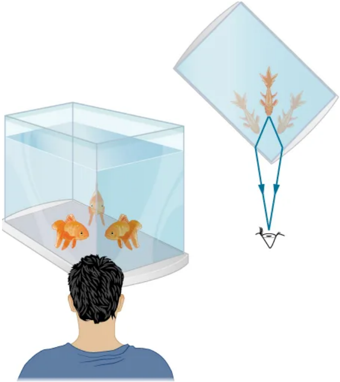
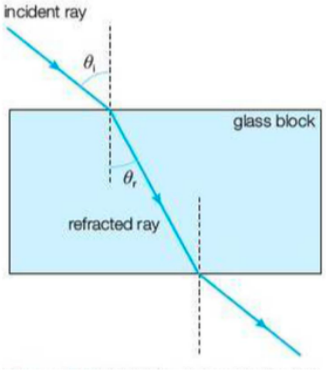
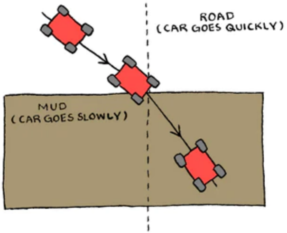


Velocity of Light

$$v = c/\eta$$



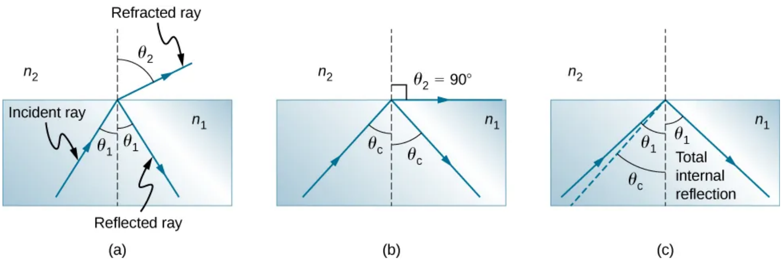
(a) Refraction through a glass block



(b) Direction of Bending

Snell's Law

$$\eta_1 \sin\theta_1 = \eta_2 \sin\theta_2$$



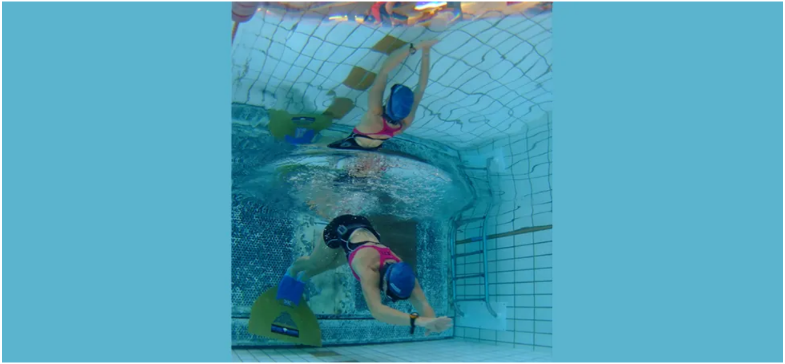
a. $\eta_1 > \eta_2 \implies \theta_2 < \theta_1$

b. $\theta_1 \uparrow \implies \theta_2 \uparrow$. At $\theta_1 = \theta_c, \theta_2 = 90°$

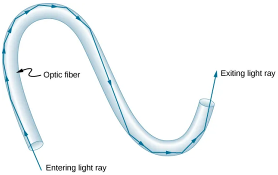
c. At $\theta_1 > \theta_c$, all of the light is reflected back in to medium = **total internal reflection**

$$\theta_c = \sin^{-1}\left(\frac{\eta_1}{\eta_2}\right) \text{ for } \eta_1 > \eta_2$$

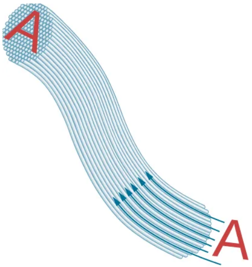
What is happening here?



Fiber Optical Cables and Endoscopes



(a) Total internal reflection in fiber optic cable



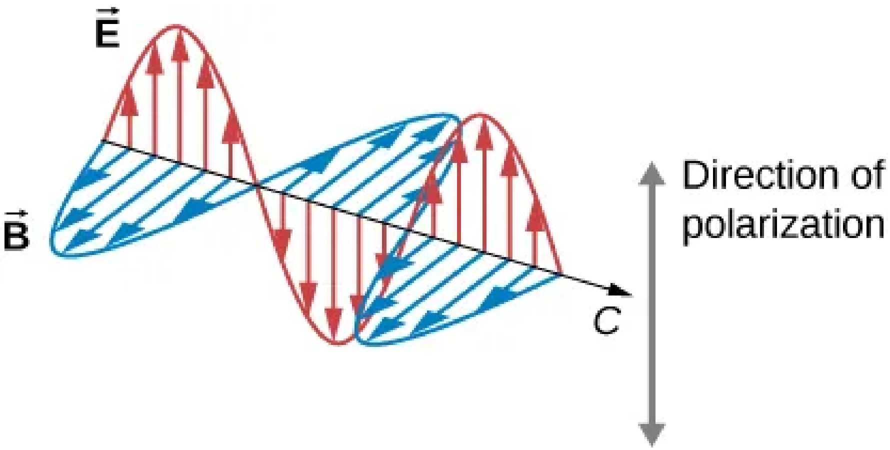
(b) Bundle of Fiber optic cables

(c) Endoscospic Camera

Premise

- Light behaves as both wave and particle
- Some optical phenomena require analysis based on wave characteristics of light when the wavelength is not negligible compared to dimension of optical device e.g. slit in case of diffraction

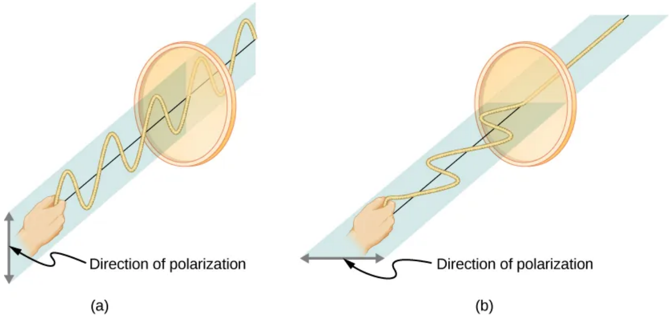
a. glare effect
b. using polarizing filter . this reduces the glare


$\vec{E}$
$\vec{B}$
C
Direction of polarization

EM wave propagation

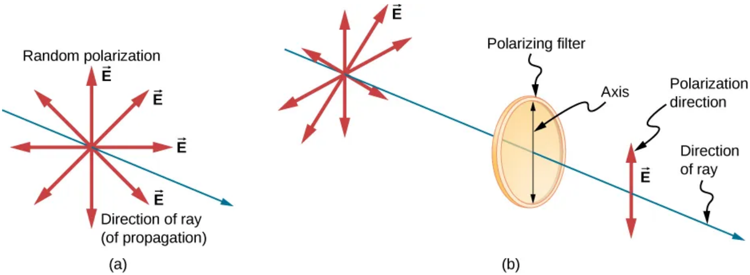
- EM waves are transverse waves consisting of varying Electric and Magnetic fields that oscillate perpendicular to the direction of propagation
- Polarization is the attribute that a wave's oscillations do have a definite direction relative to the direction of propagation of the wave
- For an EM wave, the direction of polarization is the direction parallel to the electric field.

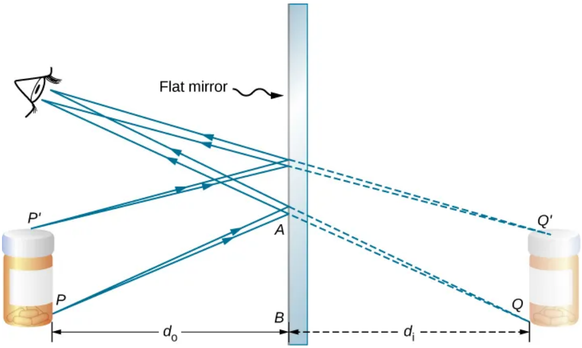
Vertical vs Horizontal Polarization



a. Vertical polarization . Effect of vertical slit placed on the rope and the waves will pass through
b. Horizontal polarization. Effect of horizontal slit where the wave propagation got blocked

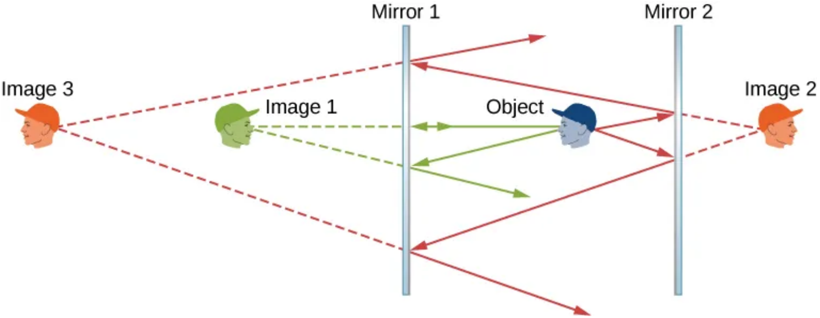
Polarizing filter



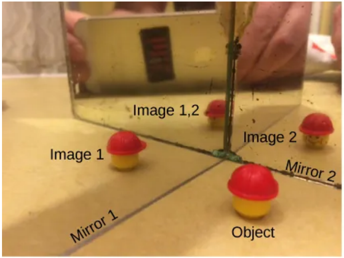


$$d_o = -d_i$$

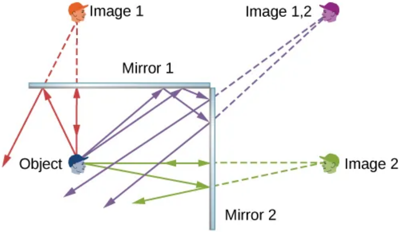
Multiple Images: infinite



Multiple Images: finite



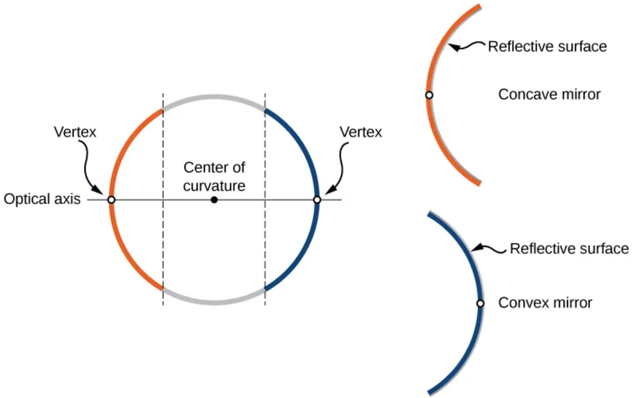
(a)



(b)

Curved Mirrors

- A **curved mirror** can form images that may be larger or smaller than the object and may form either in front of the mirror or behind it.

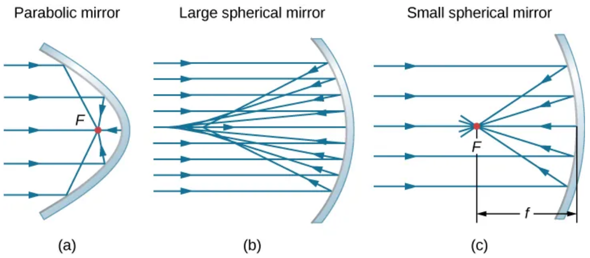


Curved Mirrors

a Rays parallel to the optical axis of a parabolic mirror converges at the point called **focal point**

b If the mirror is large compared to radius of curvature then rays will not converge

c If the mirror is small compared to radius of curvature, then it can be approximated to parabolic mirrors

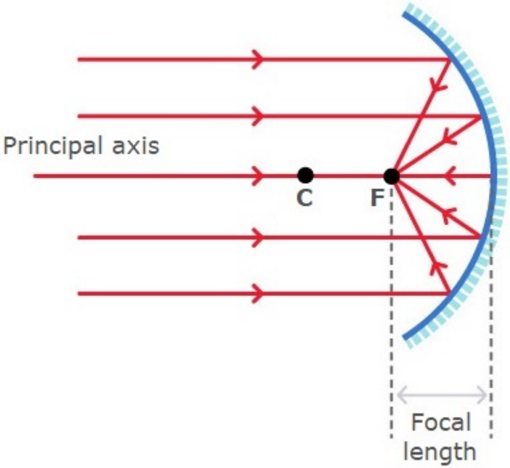


Walkie Talkie Building

(a) Walkie Talkie Building

(b) Egg Fry

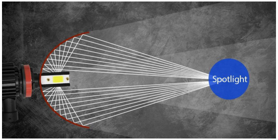
Reflection of light on a concave mirror



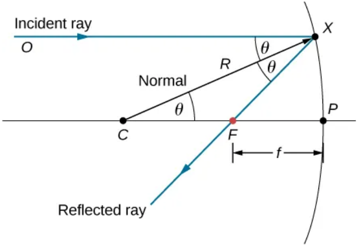
Concave Mirror Applications

(a) Microscope

(b) Dish TV



(c) Reflector Headlight



$$R = CF + FP$$

$$\triangle XCF, CF = XF$$

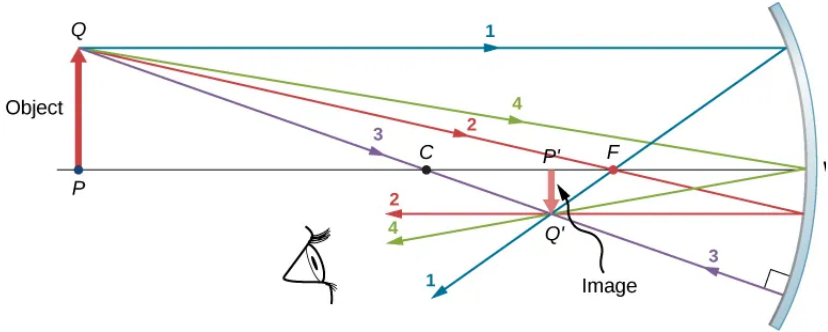
$$\triangle XFP, \cos 2\theta = \frac{FP}{FX}$$

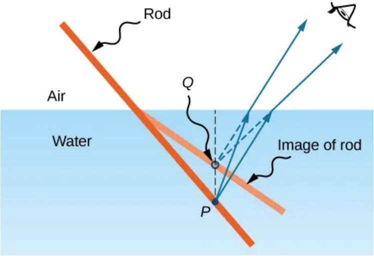
$$\text{for small angles, } FP = FX$$

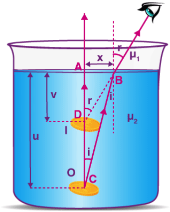
$$R = 2 \times FP$$

$$R = 2f$$

Image Formation in Concave Mirror




Rod
Air
Water
Q
P
Image of rod



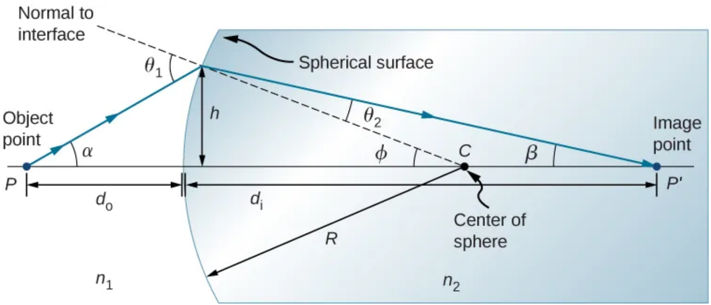
$$\mu_1 \sin i = \mu_2 \sin r$$

For paralaxial rays, $\sin i = \tan i$

$$\triangle ACB, \tan i = \frac{x}{u}$$

$$\triangle ADB, \tan r = \frac{x}{v}$$

$$\frac{\mu_2}{\mu_1} = \frac{u}{v}$$



For paralaxial rays,

$$\eta_1\theta_1 = \eta_2\theta_2$$

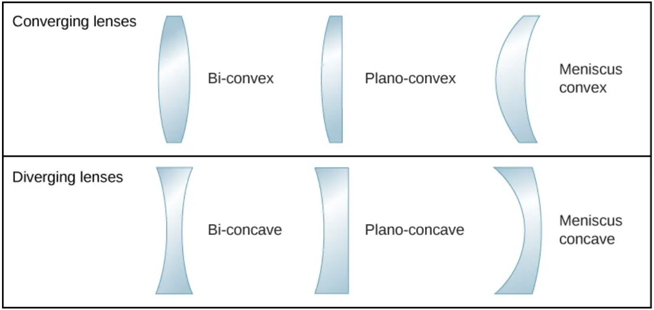
$$\theta_1 = \alpha + \phi, \theta_2 = \phi - \beta$$

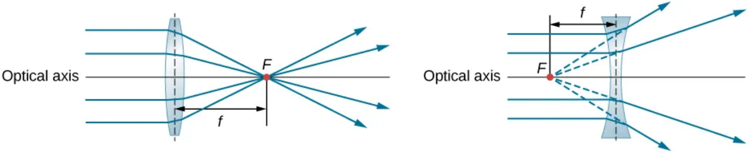
$$\tan\alpha \approx \frac{h}{d_0}, \tan\beta \approx \frac{h}{d_i}, \tan\phi = \frac{h}{R}$$

$$\alpha \approx \frac{h}{d_o}, \beta \approx \frac{h}{d_i}, \phi = \frac{h}{R}$$

title

$$\frac{\eta_1}{d_o} + \frac{\eta_2}{d_i} = \frac{n_2 - n_1}{R}$$

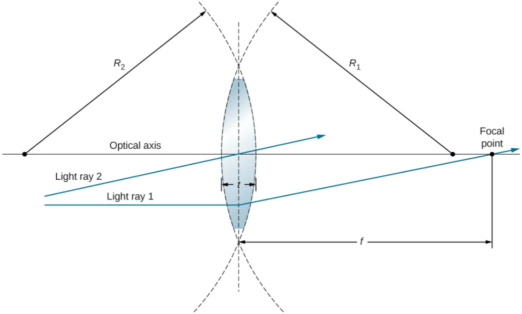




Converging lens
(a)

Diverging lens
(b)

Thin Lens



- If thickness t is much less than radius of curvature of both surfaces
- In this case parallel rays will bent only once at the centre of the lens and go through the focal point
- rays passes through the centre of the lens undeviated

Ray Tracing and Thin Lenses

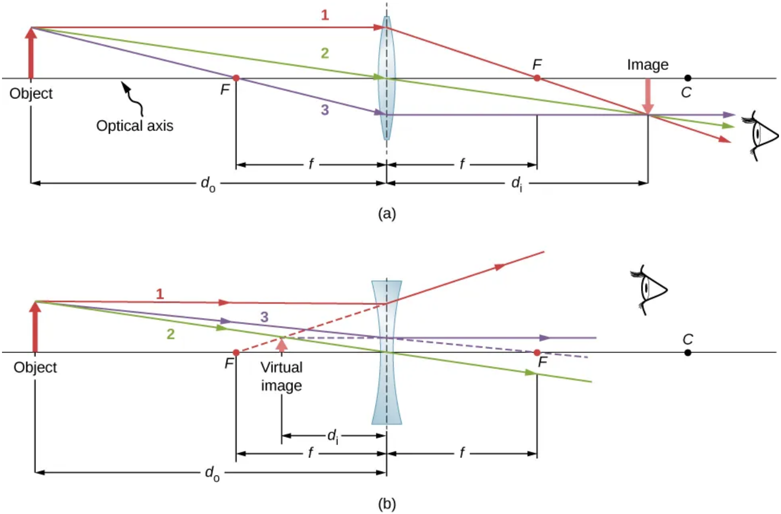
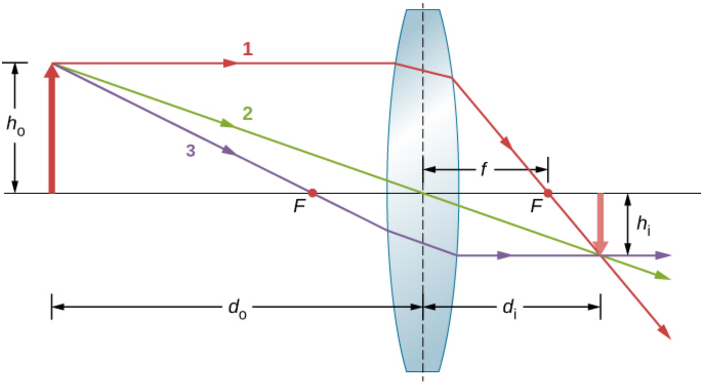
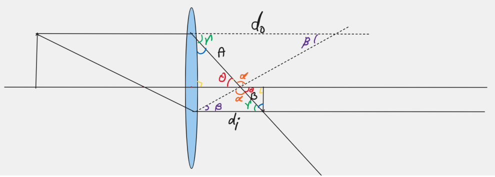


Image formation by Lenses





from similar triangles

$$\frac{d_o}{d_i} = \frac{A}{B} = \frac{f}{d_i - f}$$

Thin-Lens Equation

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

Camera Obscura: Ibn Al-Haytham 1500

- A camera obscura (from Latin 'dark chamber') is a darkened room with a small hole or lens at one side through which an image is projected onto a wall opposite the hole
- A camera obscura without a lens but with a very small hole is referred to as a pinhole camera