Optics (2 hrs)

Harry Tom

Waves (EM vs Mechanical)

Geometric Optics

Physical Optics

OSA Discovery Optics Kits

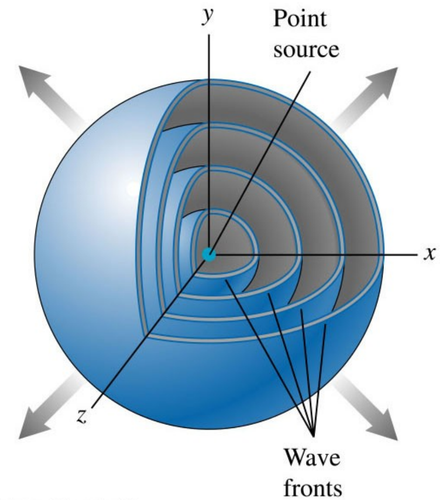
Hands-on Activities

Nature and Propagation of Light

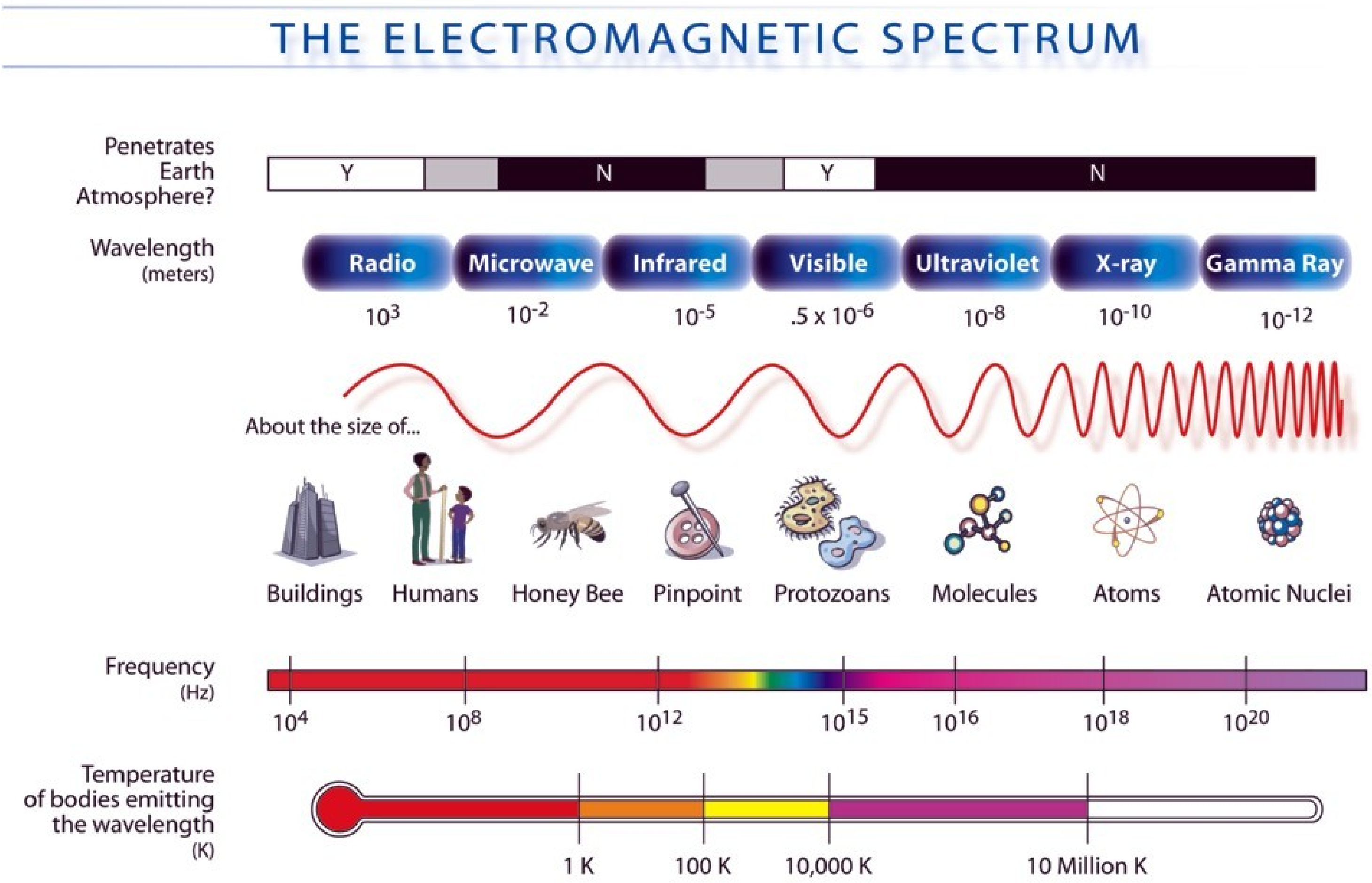
- Wave-particle nature of Light
  - Particle-like (pre-Newton, particles deliver energy from sun, travels in straight lines)
  - Wave-like for propagation (as predicted by Maxwell, light is just another EM wave)
  - Particle-like energy exchange (MODERN: now explained by quantum mechanics) only discrete quanta of energy can be absorbed or emitted, therefore it must exist in only discrete energy units.
- Sources:
  - Thermal (moving charges radiate EM wave, high T, high v, high f->red hot, white, blue)
  - Fluorescence (energy is absorbed by atom/molecule and reemitted at discrete energies corresponding to excited states of atom/molecule)
  - Laser (coherent addition of radiation from each electron)
- $c=2.99792458X10^8$ m/s set as standard, meter is measured relative to c and t from Cesium clock.

EM Waves

- All EM waves behave alike
  - Wavefronts propagate outward at v=c/n
  - Energy travels perpendicular to wavefronts—outward from source at constant speed
  - Intensity (power per unit area) falls as $1/r^2$
  - Waves are polarized
  - Interacts with matter in 4 ways



Spectrum of EM radiation

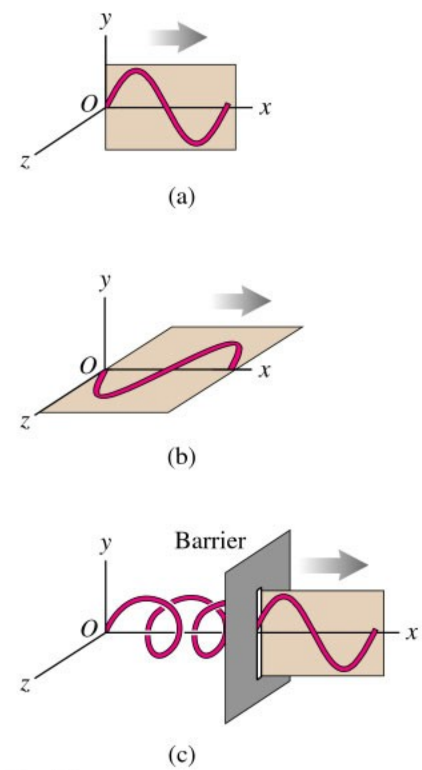


EM waves are transverse waves

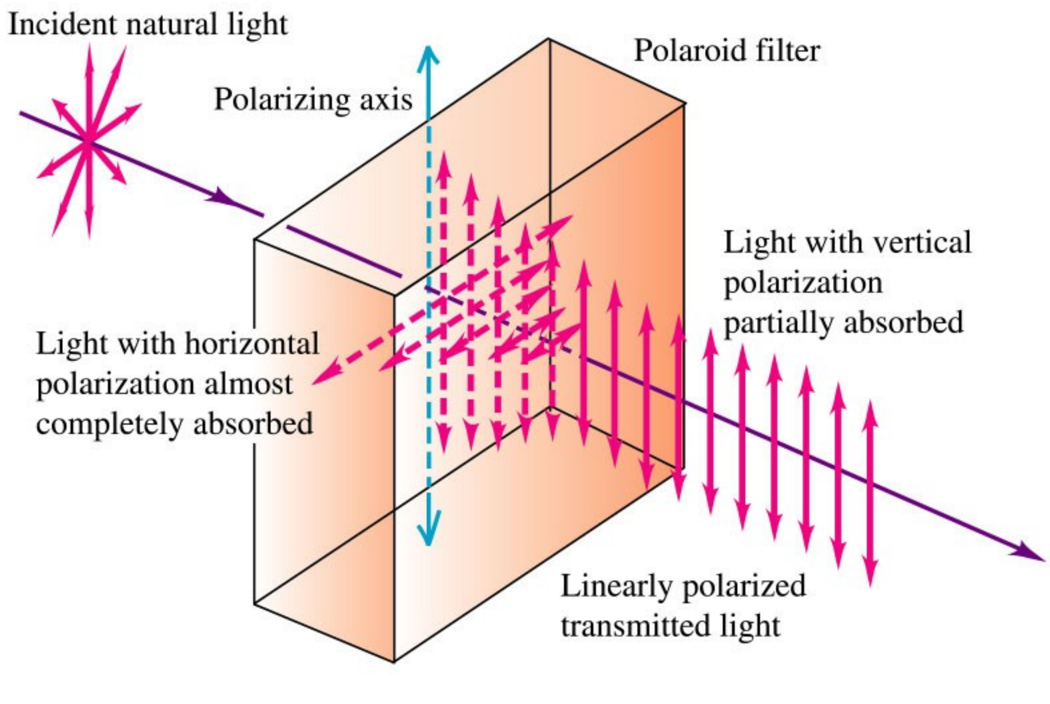
- EM waves must be polarized perpendicular to propagation direction

Polarized Waves and Polarizers

- Unpolarized (equal probability of waves with all allowed polarizations)
- Polarized—well defined E field direction.



Polaroid Film Polarizer



Polarizers

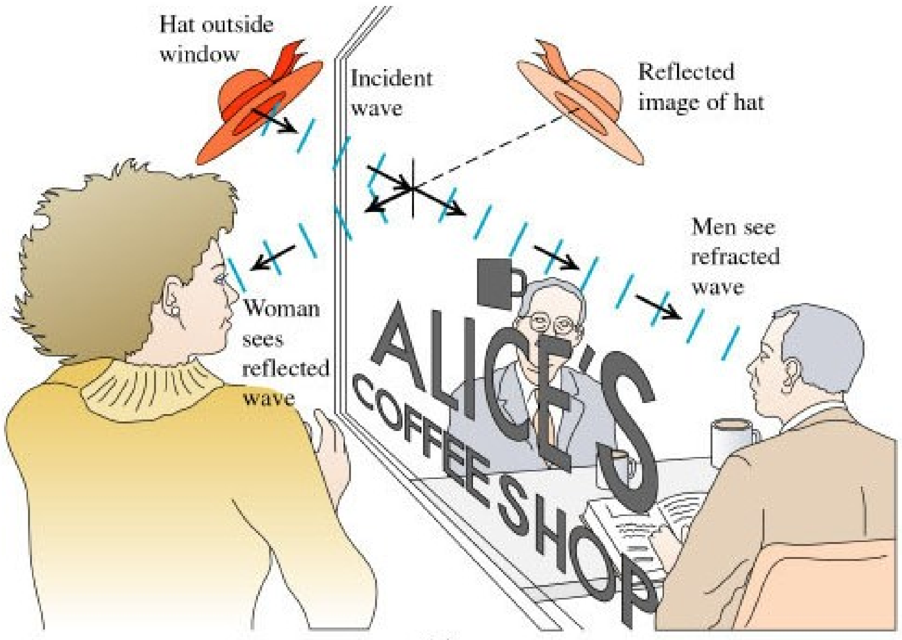
- Crossed Polarizers
- Is light from flashlight polarized?
- Is light from laser polarized?
- Can SaranWrap be a polarizer?

Four ways light interacts with matter

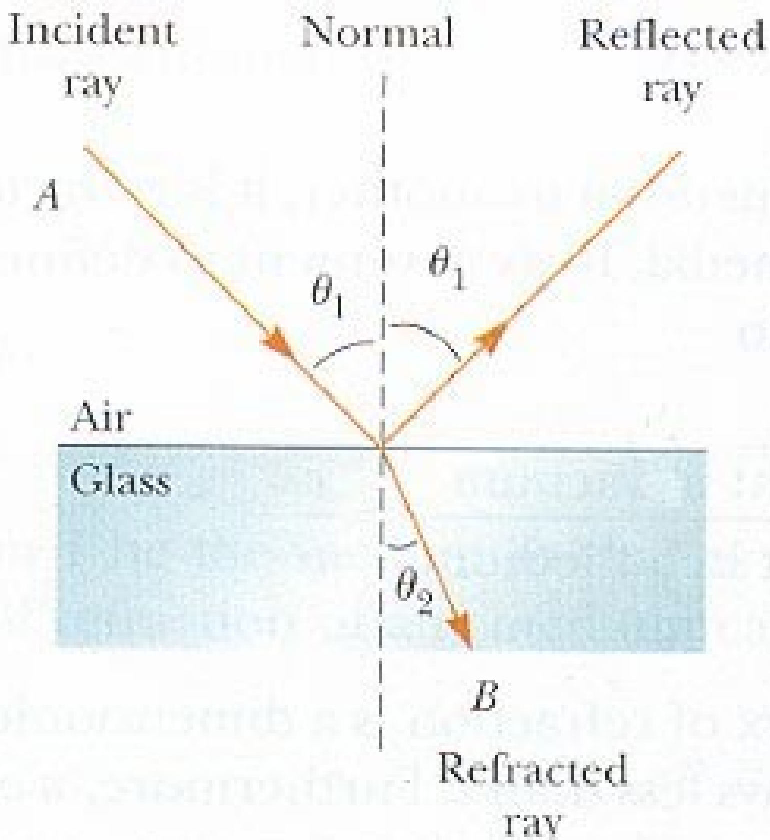
- Reflection
- Refraction (transmission into another medium)
- Scatter
- Absorption

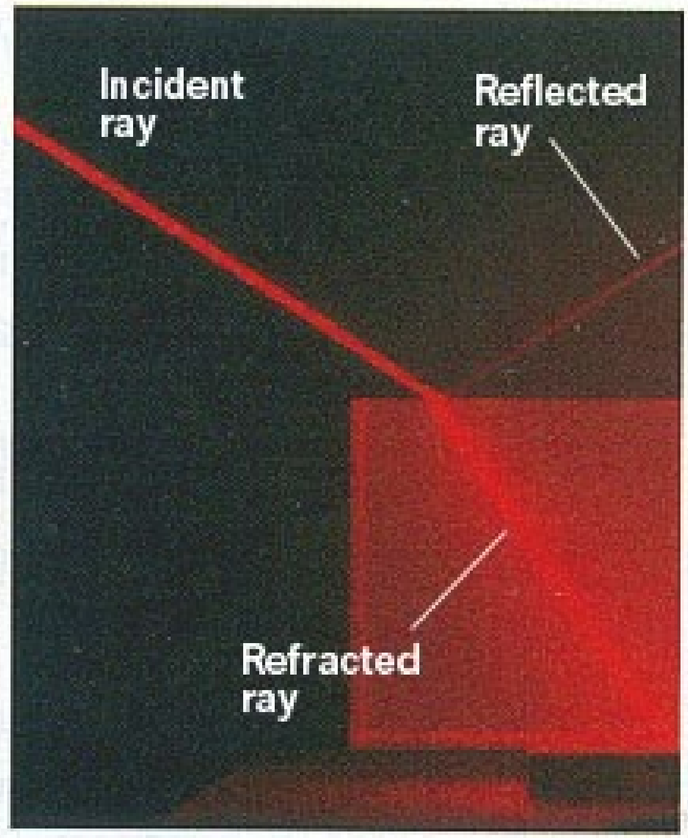
Reflection and Refraction

- Both observers see the hat.
- Rays reflected from hat are transmitted through glass/refracted through glass to man
- Rays are reflected from hat and then reflected from glass to woman



Reflection and Refraction





Flattened sun at sunset

Total Internal Reflection

- Snell's Law of refraction:

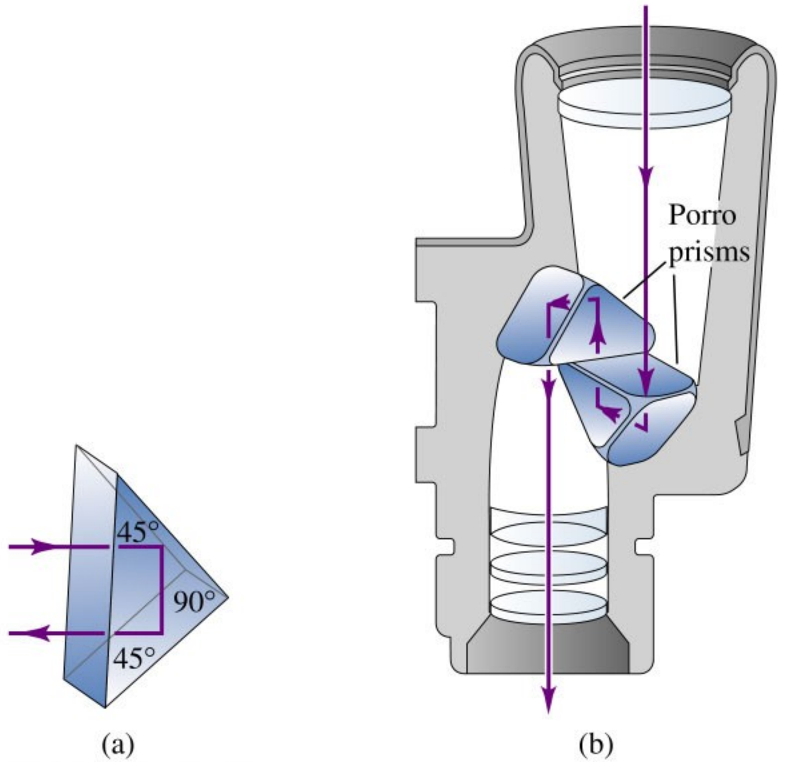
$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \Rightarrow \sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$$

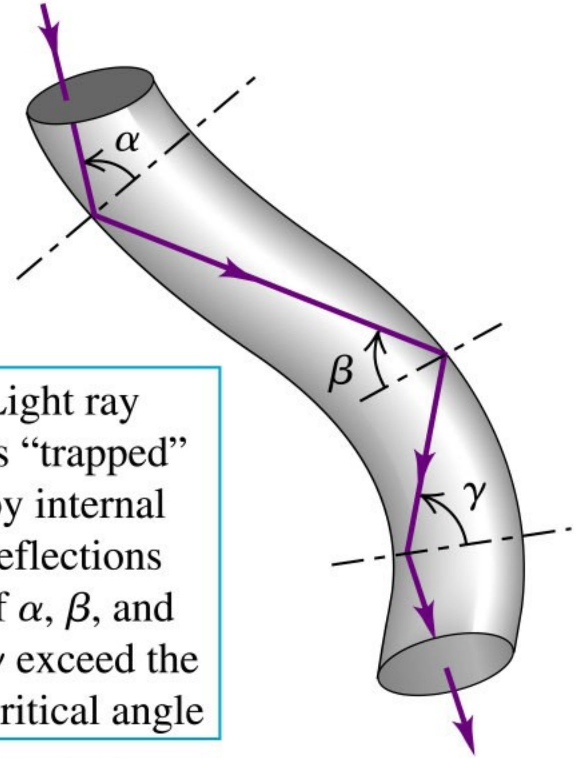
If n1 (water) >> n2 (air),

$$\text{refraction occurs for } \frac{n_1}{n_2}\sin\theta_1 < 1 \Rightarrow \sin\theta_1 < \frac{n_2}{n_1}$$

$$\text{total internal reflection occurs for } \frac{n_1}{n_2}\sin\theta_1 > 1 \Rightarrow \sin\theta_1 > \frac{n_1}{n_2}$$

Prism are used as mirrors using Total Internal Reflection



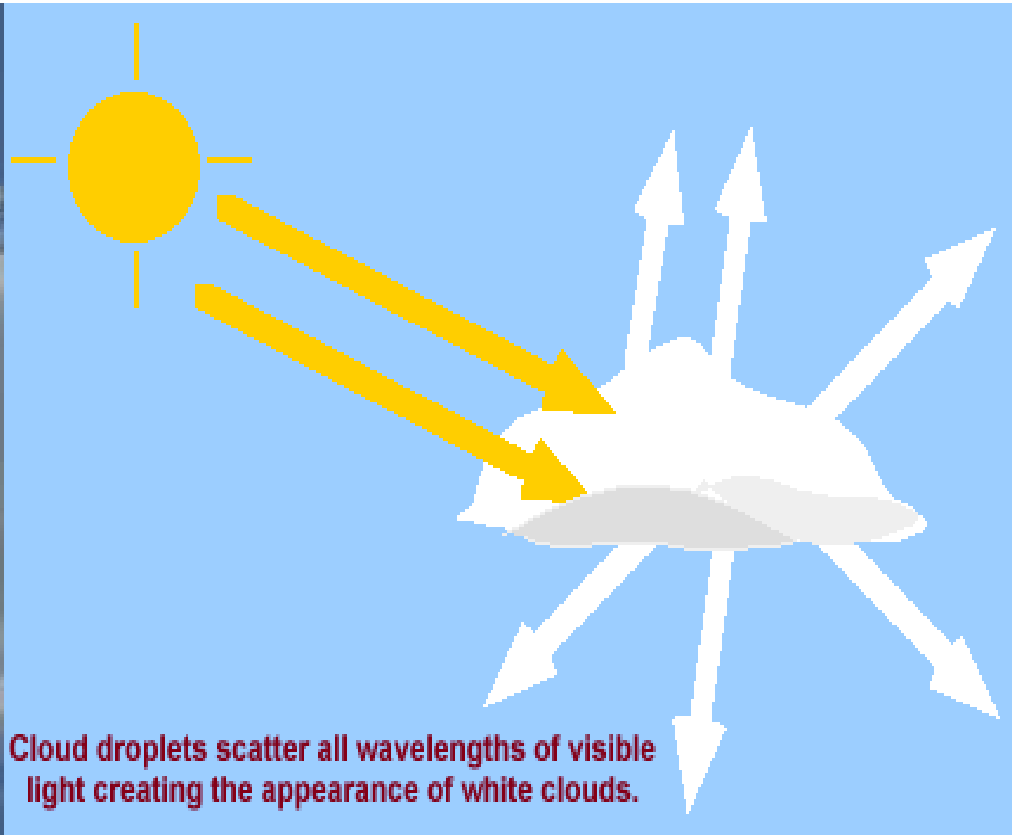


Light ray
is "trapped"
by internal
reflections
if α, β, and
γ exceed the
critical angle

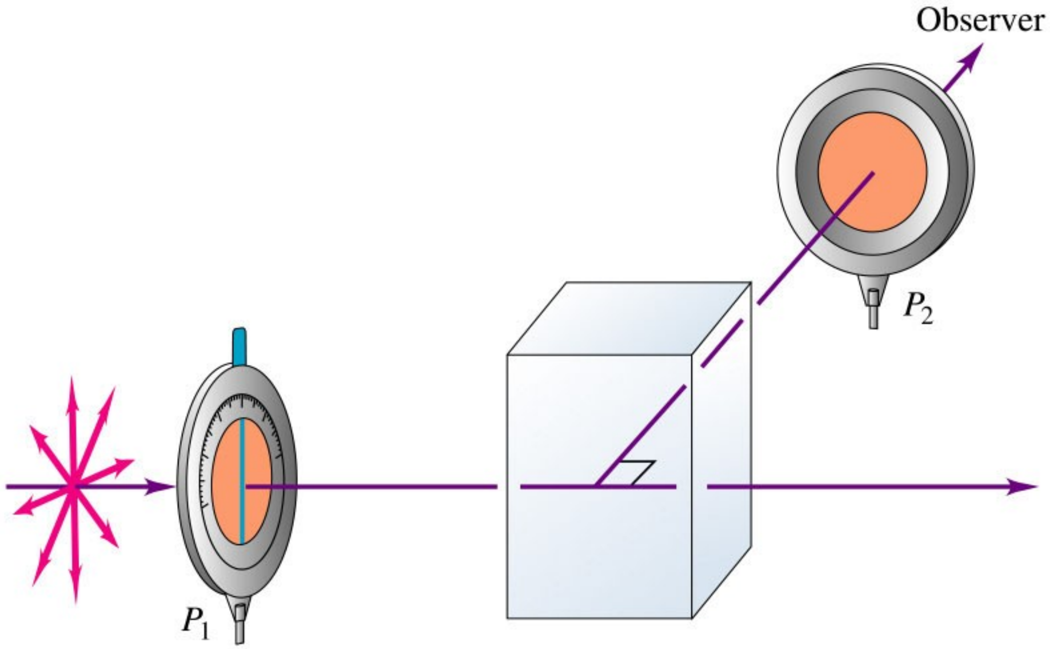
Scatter(Rayleigh)
Blue horizon vs. Red sunset

Clouds


Cloud droplets scatter all wavelengths of visible
light creating the appearance of white clouds.

Polarization from Scatter

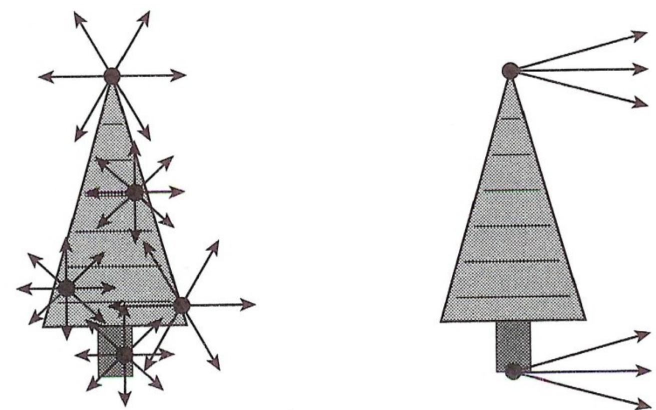


Ray Model
Properties of Light Rays

- Light travels through a transparent medium in straight lines (called light rays) at speed $v=c/n$, n is index of refraction
- Light rays do not interact with each other (they pass through each other)
- A light ray continues in straight line unless it has an interaction with MATTER that causes the ray to change direction or to be absorbed (energy lost)

Ray Model
Objects and Ray Diagrams

- An object is a source of light rays
- Two types of objects: self-luminous and reflective
- Rays originate from every point on object, sending rays in every direction
- A ray diagram is a simplified picture. Ray diagram only shows a few important rays, but these are not the only rays in the physical situation.

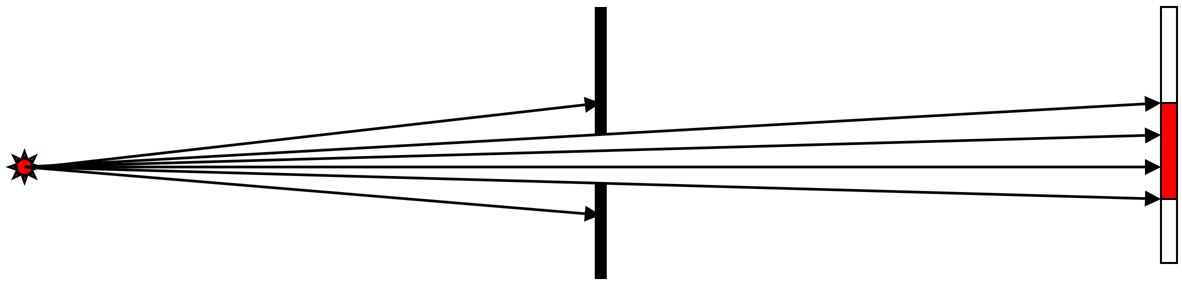


a) Reality b) Ray diagram

a) An object emits light rays in all directions from all points. b) A ray diagram is a simplified view.

Light from a point source through an aperture (shadow)

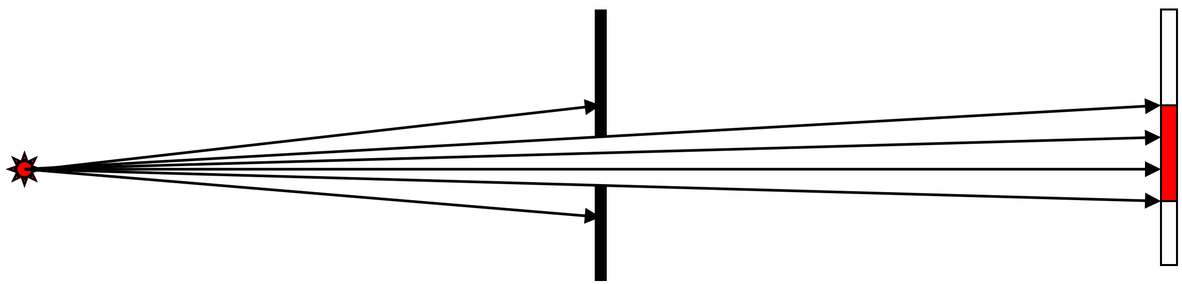
Light from a point source through an aperture (shadow)



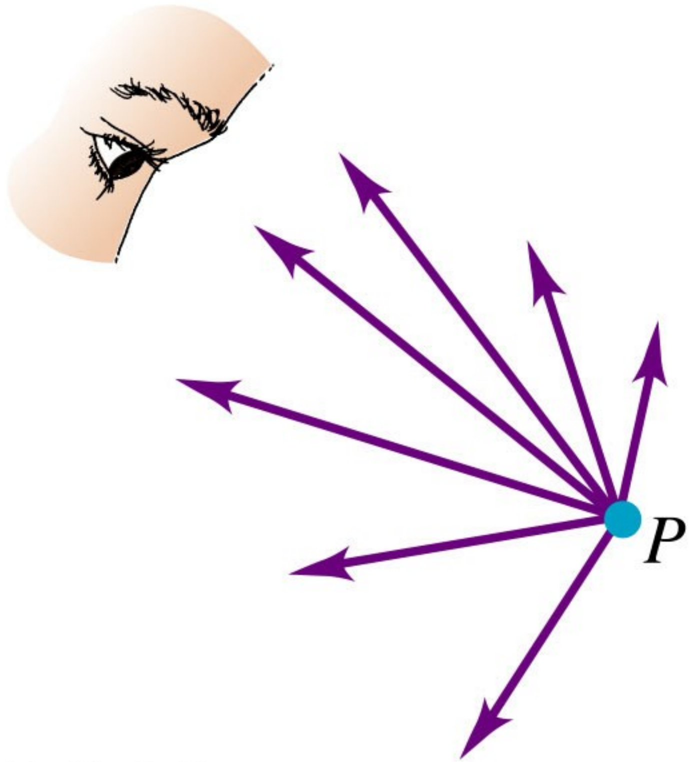
- Many light rays come from source
- Only those that can get through aperture make it to the screen
- We see an “image” of the aperture (and not of the source—this is equivalent to the “shadow” of the mask.

Pinhole Camera

Pinhole Camera



- Pinhole aperture restricts the bundle of rays from each point to a single ray.
- An image is formed of the object, not of the aperture
- Image can form at any distance
- Size of image is proportional to ratio of distance to object
- If pinhole is too large, the object is blurry, why?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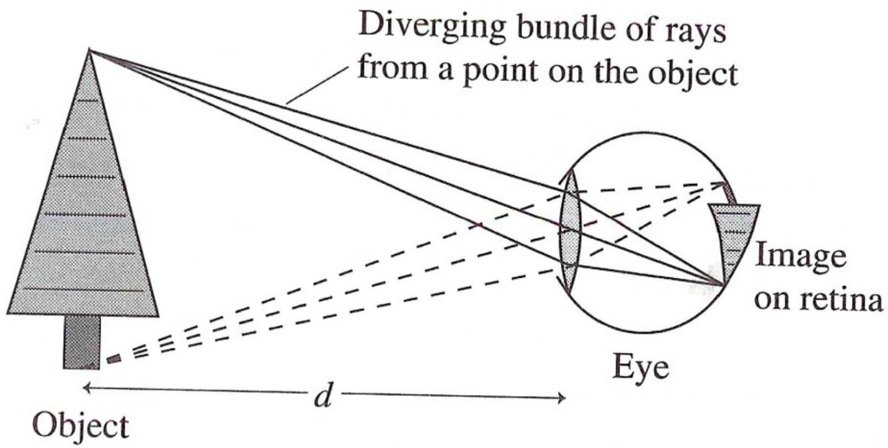
How the eye "sees"



- A bundle of *diverging* rays from a point on the *object* enters the pupil of the eye
- The lens in the eye focuses the bundle of rays to converge or focus on a point on the retina
- A "real image" is formed when rays from an object converge—is sensed at the retina.
- The extended object forms an extended image

How the eye “sees” distance

- http://micro.magnet.fsu.edu/primer/java/scienceopticsu/eyeball/index.html

Reflection from Plane Mirrors

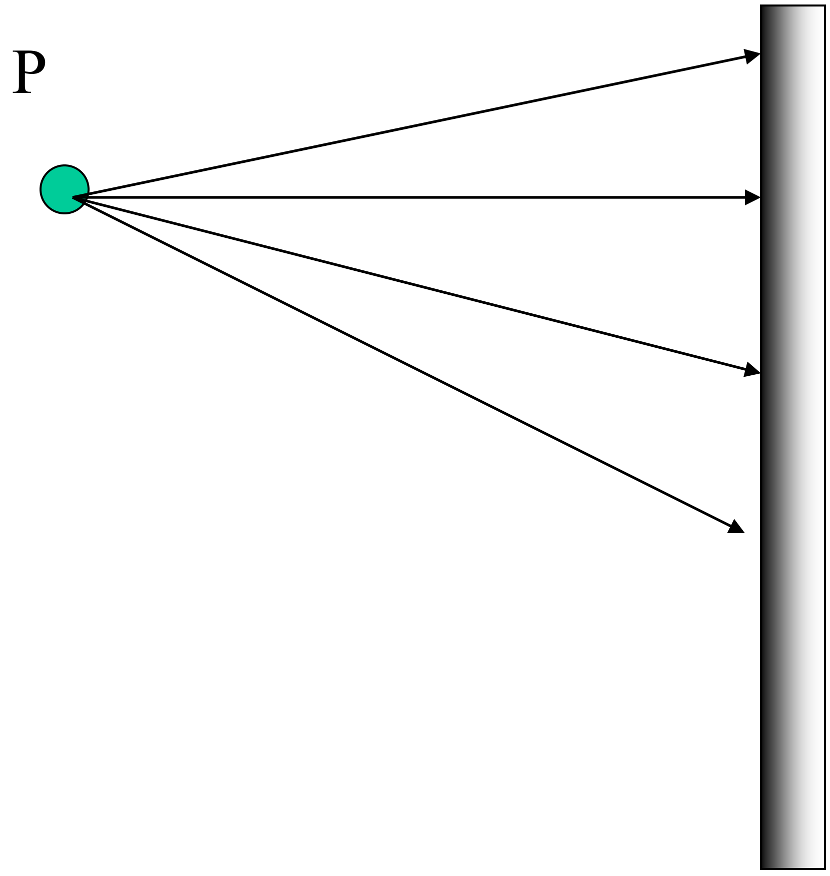
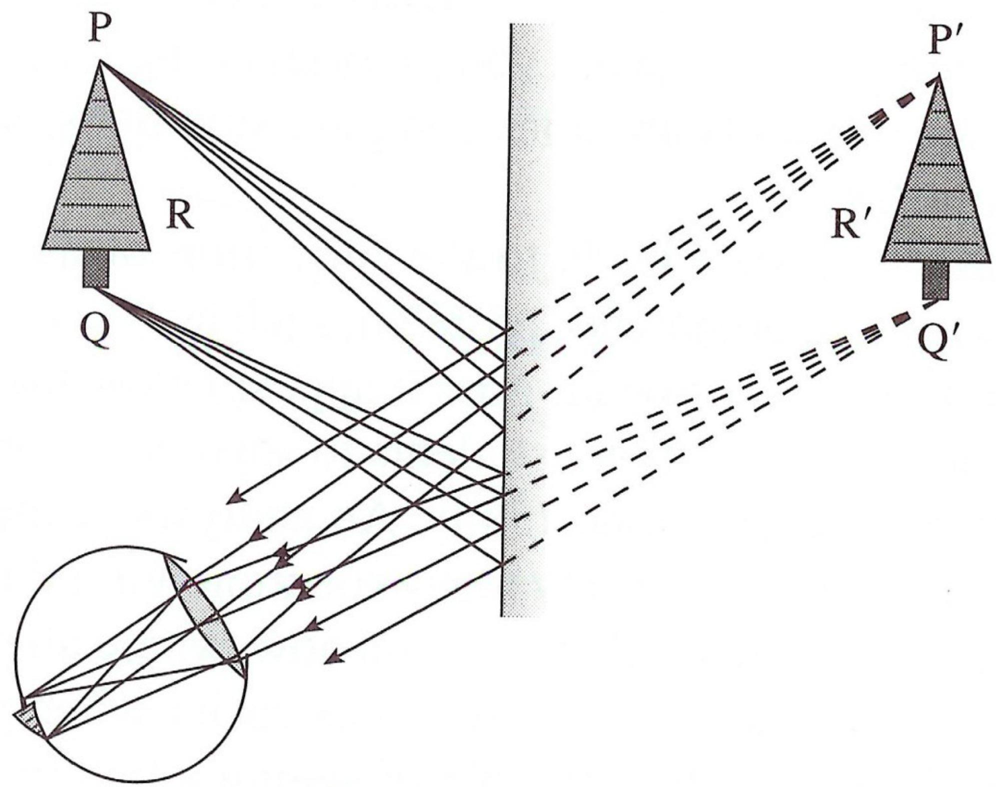


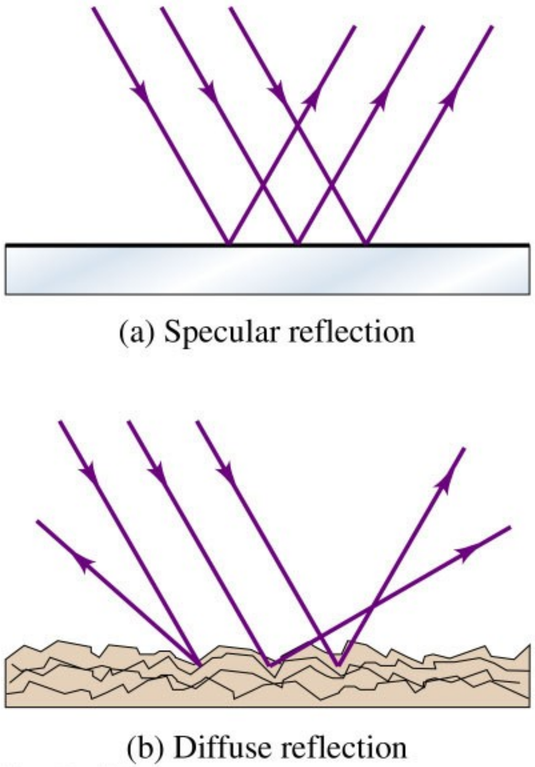
Image from plane mirrors

- Eye sees a *virtual image* at P'Q'

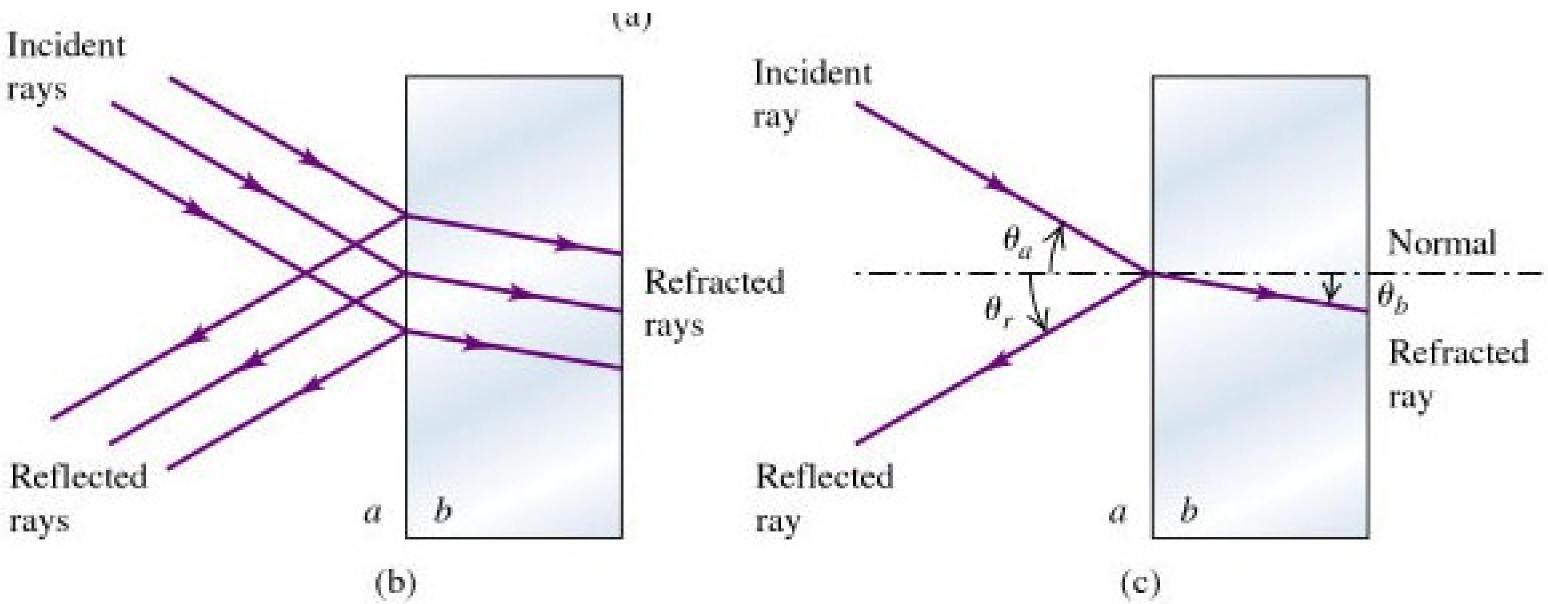


Specular vs Diffuse Reflection

- We "see" most objec[t] because of diffuse reflection which are illuminated by other sources

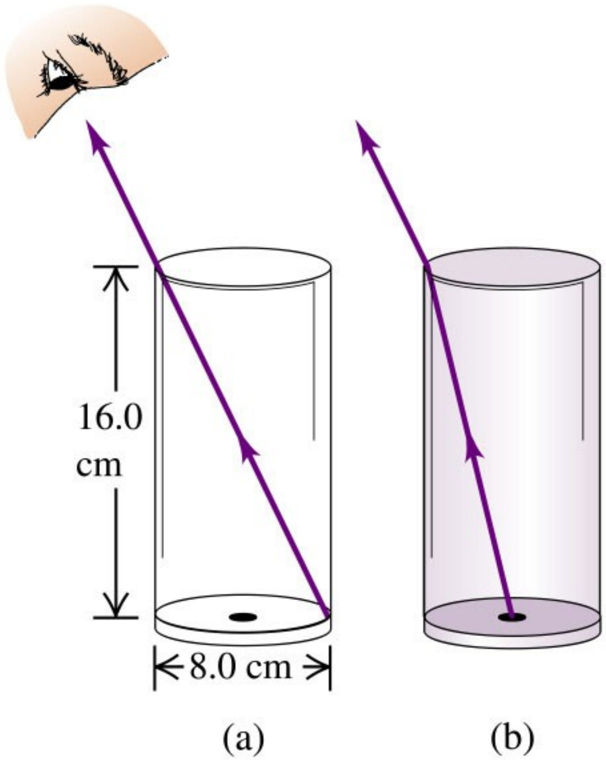


Laws of Reflection and Refraction



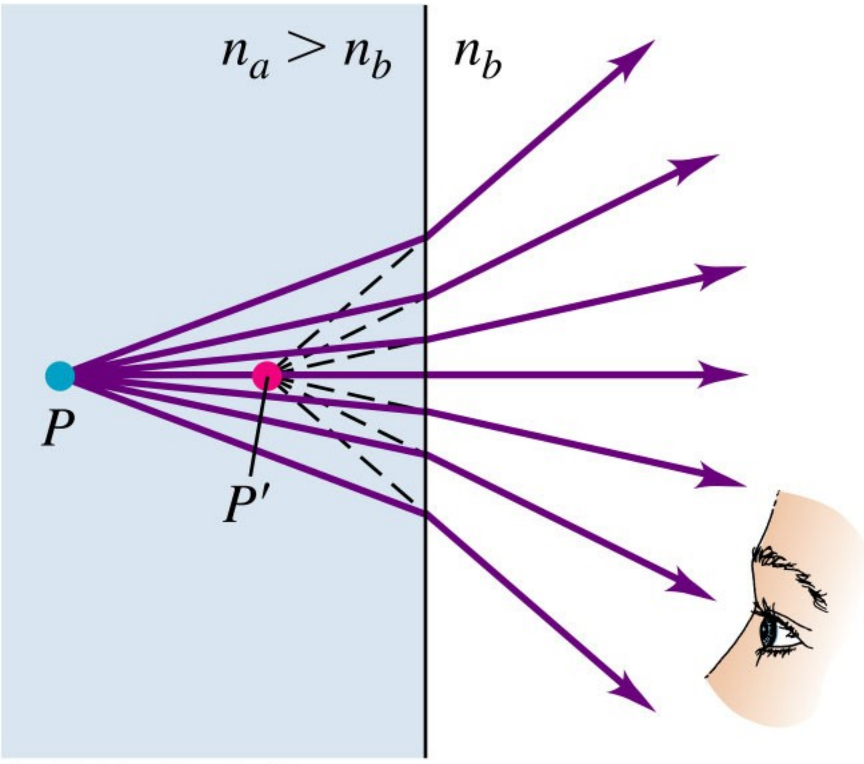
- Each wave is both reflected and transmitted through the interface
- Law of reflection, incident=reflected angle
- Law of refraction, Snell's Law relates

Penny Underwater



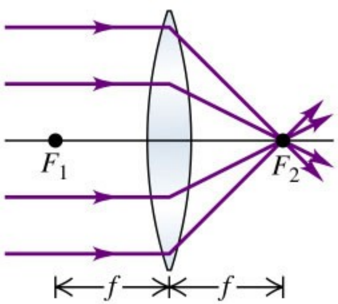
Fish in an aquarium

- Fish looks bigger in aquarium than it is, why?,
- Is it magnified?

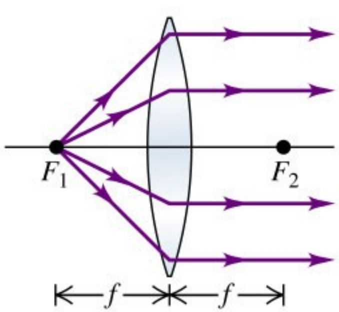


Lenses

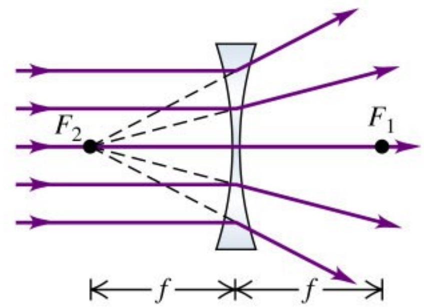
- Converging (positive focal length)
- Diverging (negative focal length)



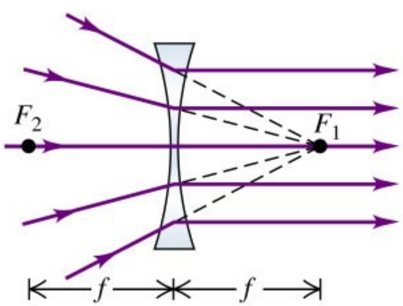
(a)



(b)

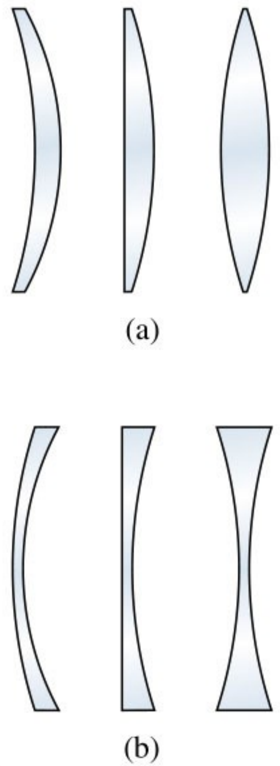


(a)



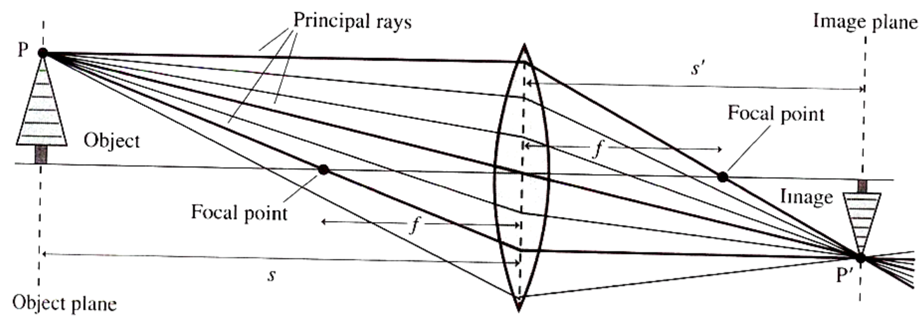
(b)

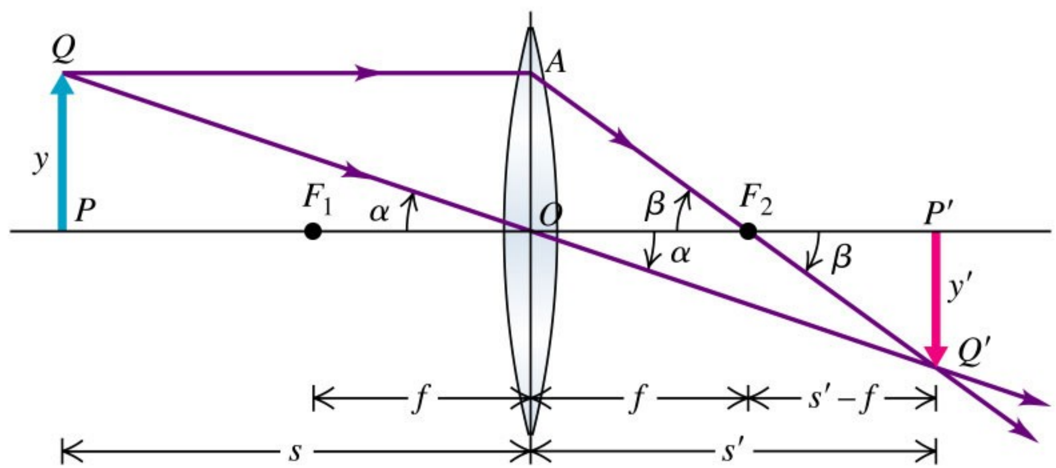
Which of these are positive and negative?



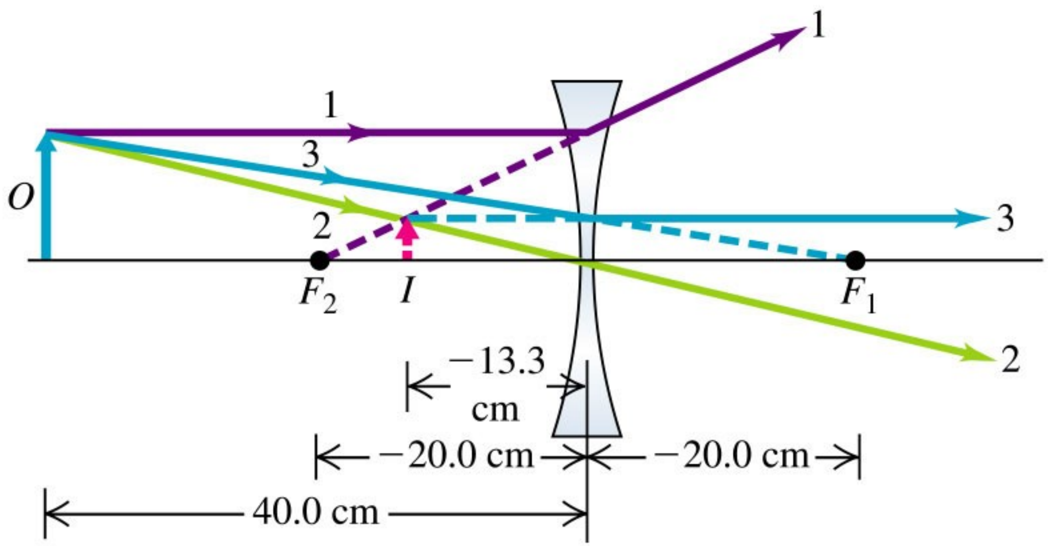
Use 2 of 3 principal rays to locate image plane and image size

- Center
- Through far focus
- Through near focus
- What happens to the image if you block half the lens?

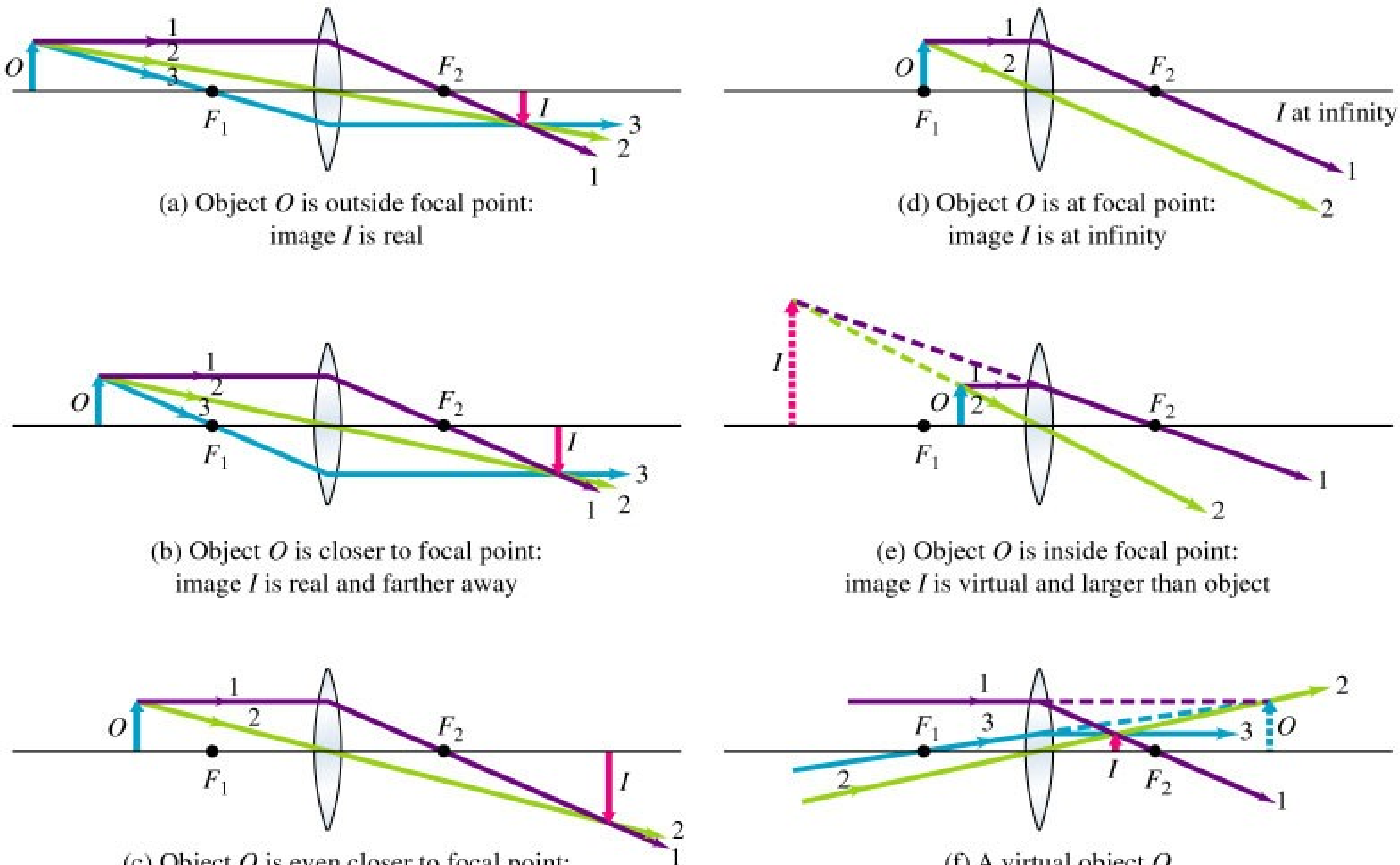




Negative Lens



Ray tracing: using only 3 principal rays as shorthand



(a) Object O is outside focal point: image I is real

(b) Object O is closer to focal point: image I is real and farther away

(c) Object O is even closer to focal point: image I is real and even farther away

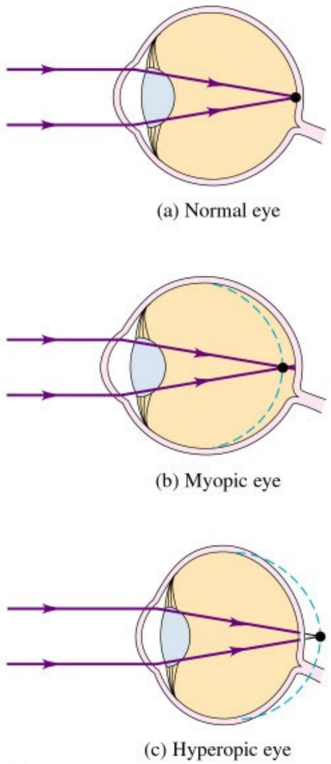
(d) Object O is at focal point: image I is at infinity

(e) Object O is inside focal point: image I is virtual and larger than object

(f) A virtual object O (light rays are *converging* on lens)

Far-sighted and Near-sighted are corrected with spherical lenses

- Which picture is farsighted and nearsighted?
- Which kind of corrective lens do you need in these cases?



Far Sighted

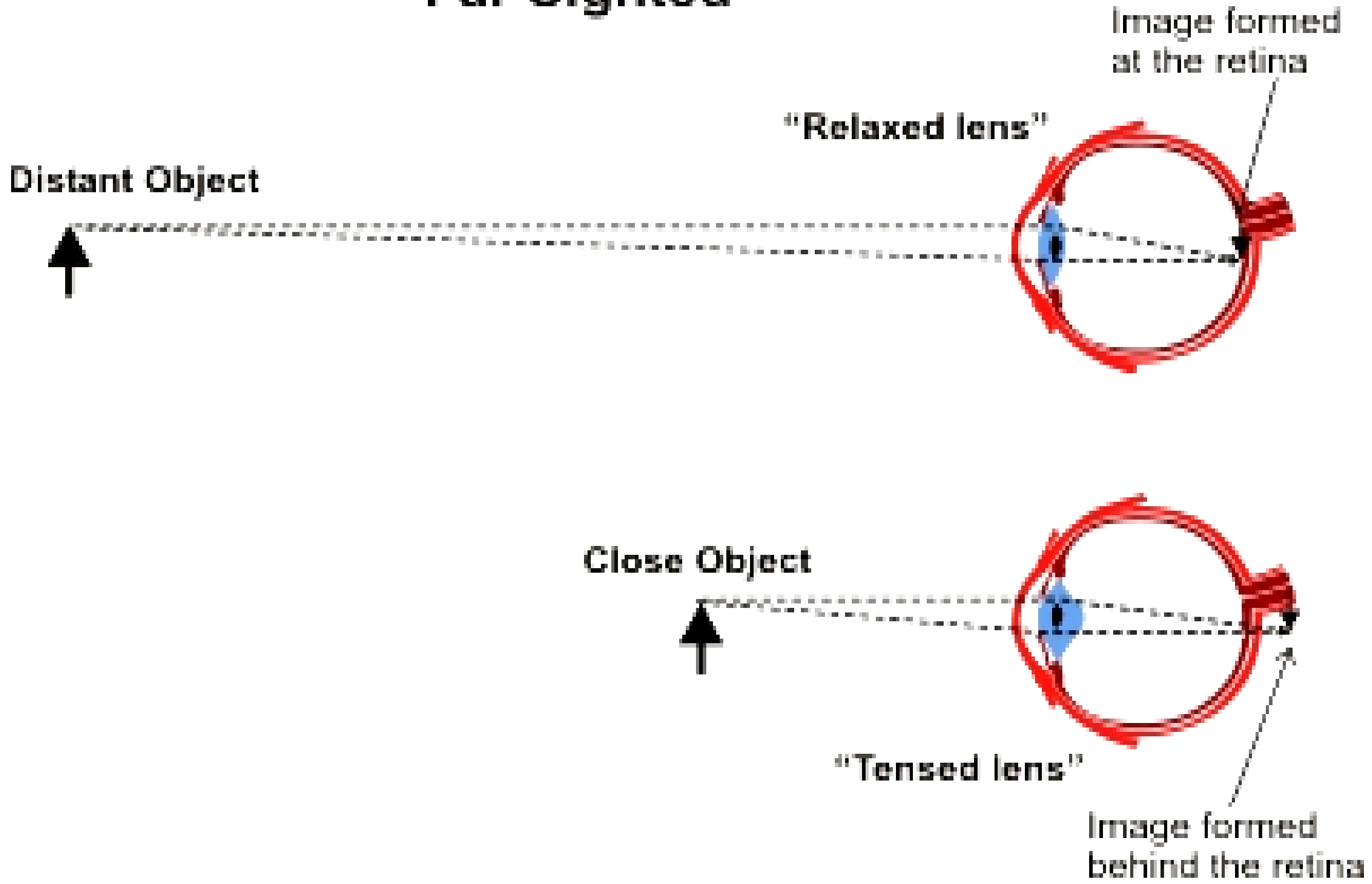
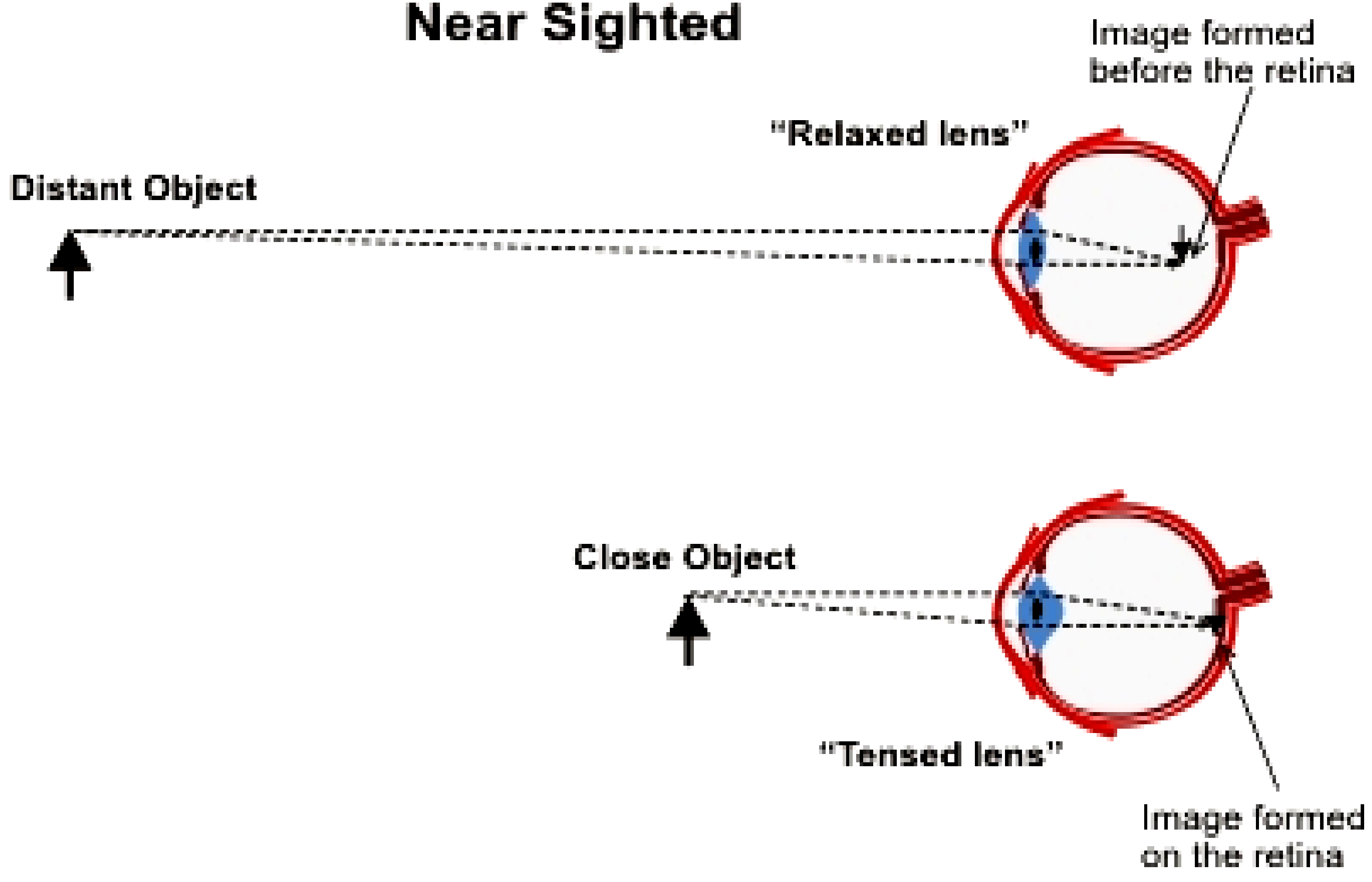
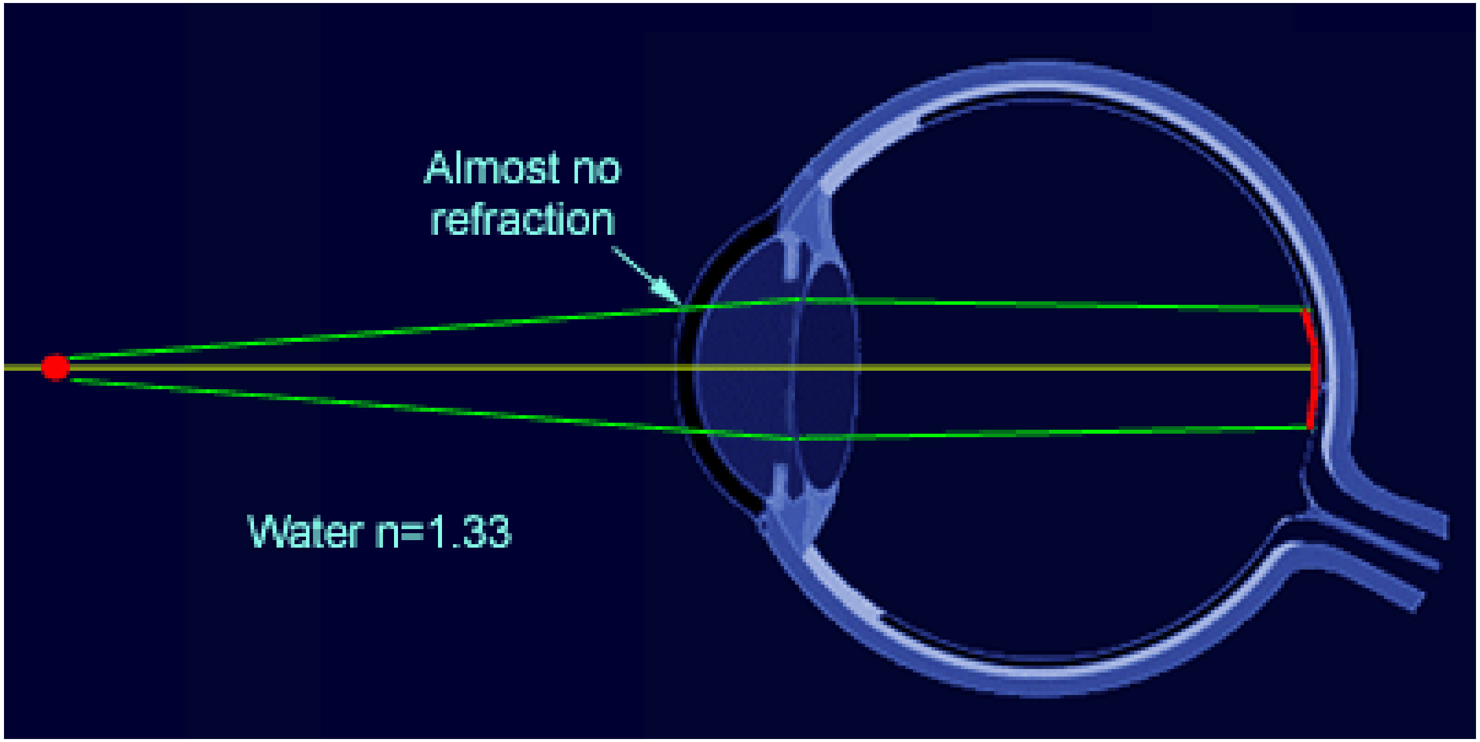


Image formed
at the retina
"Relaxed lens"
Distant Object
Close Object
"Tensed lens"
Image formed
behind the retina

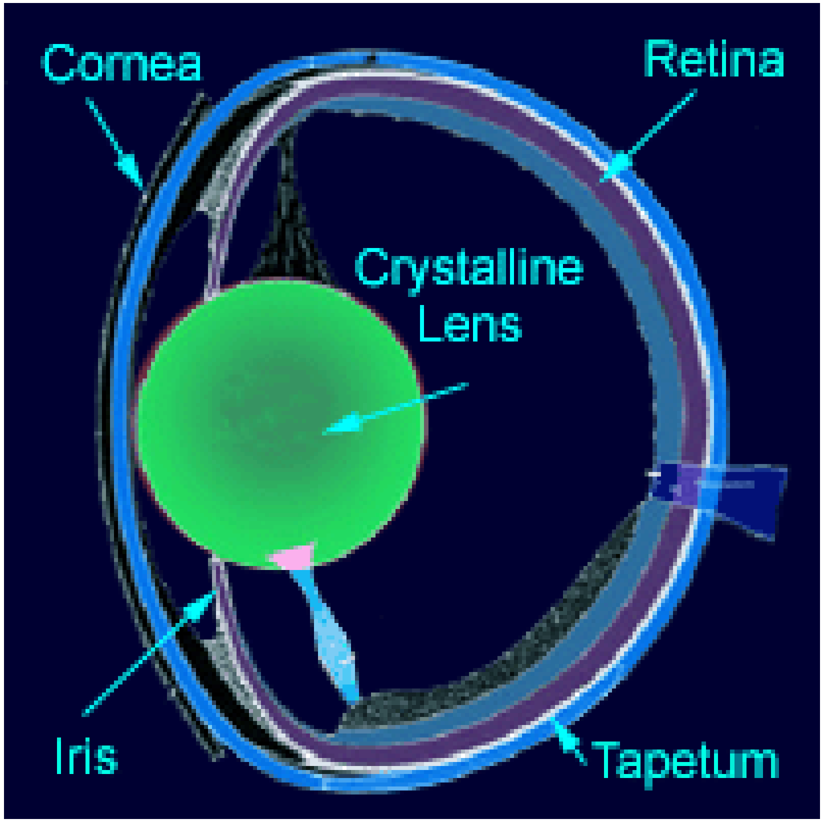
Near Sighted



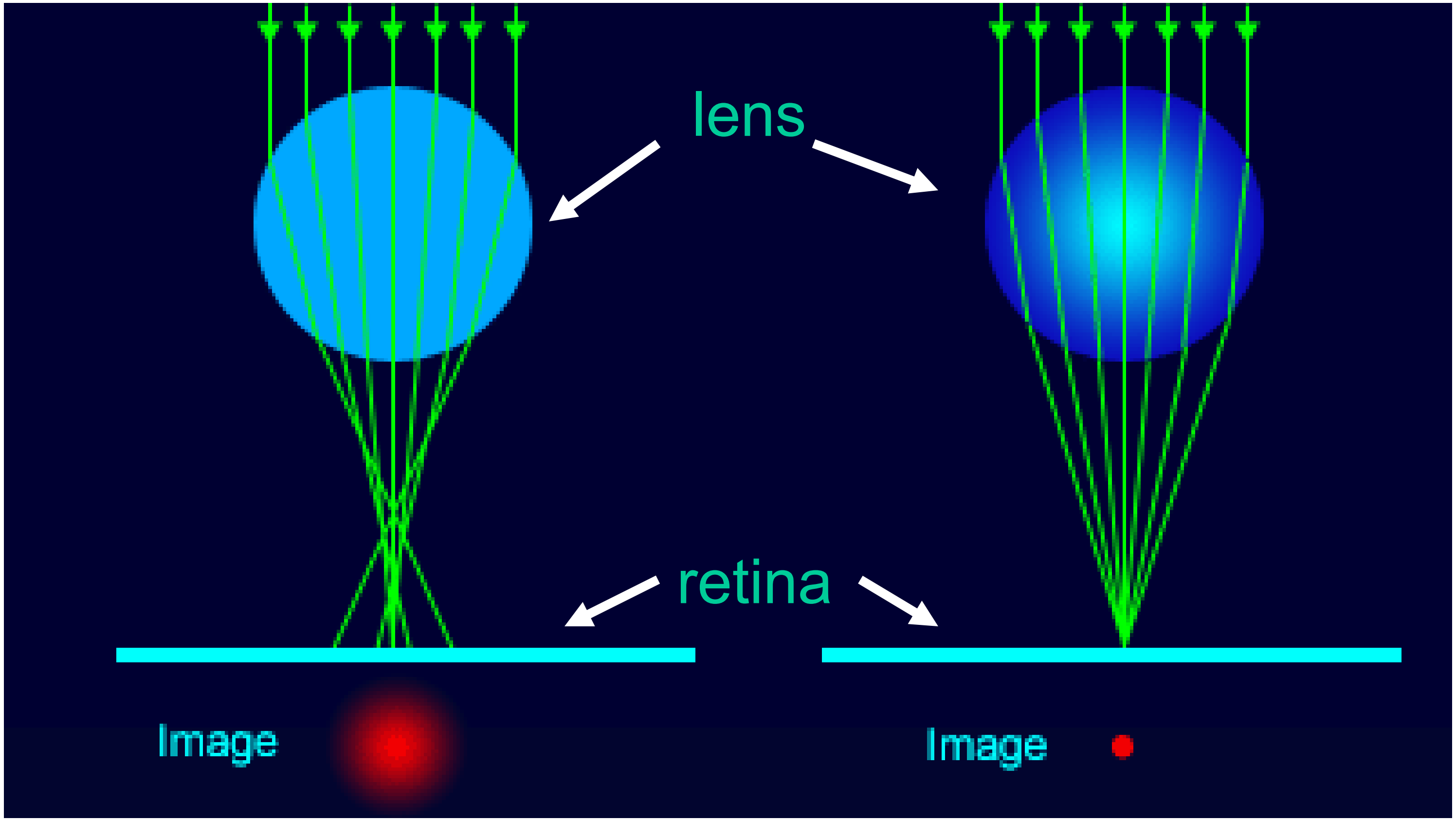
Under water



Fish eyeball



Fish eye

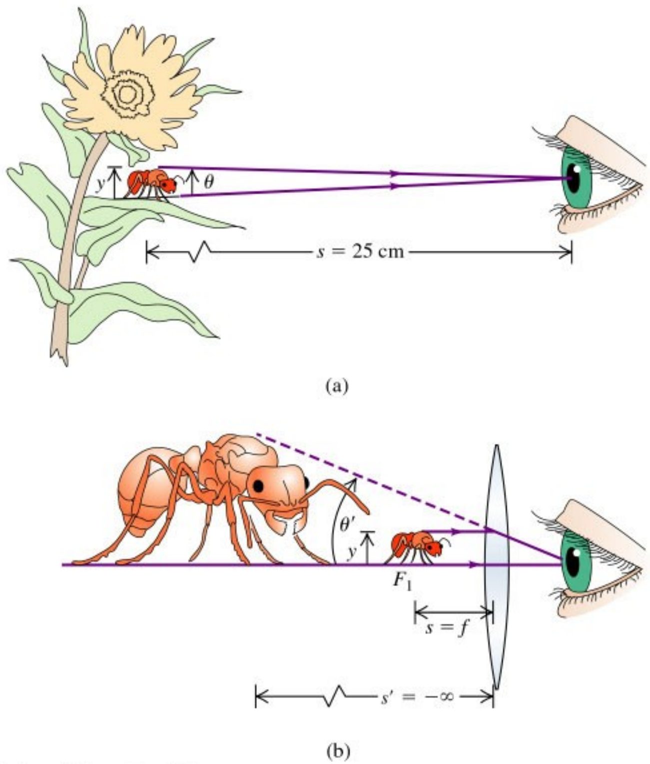


air

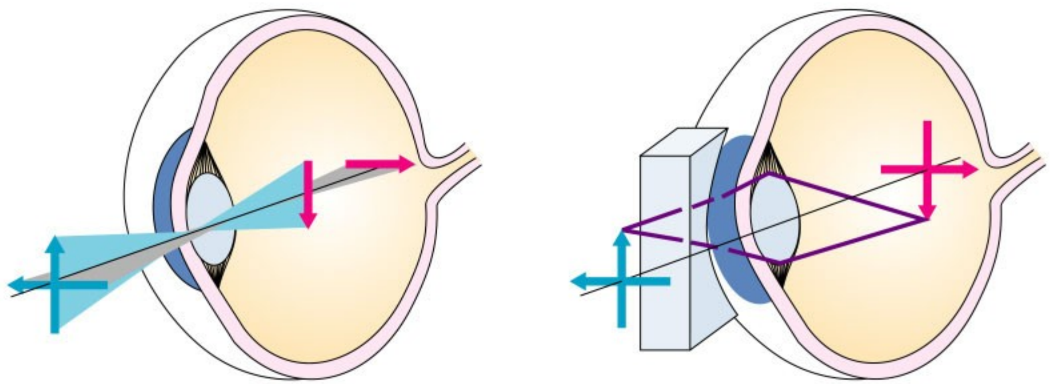
water

Magnifiers

- *Near Point* is 25 cm



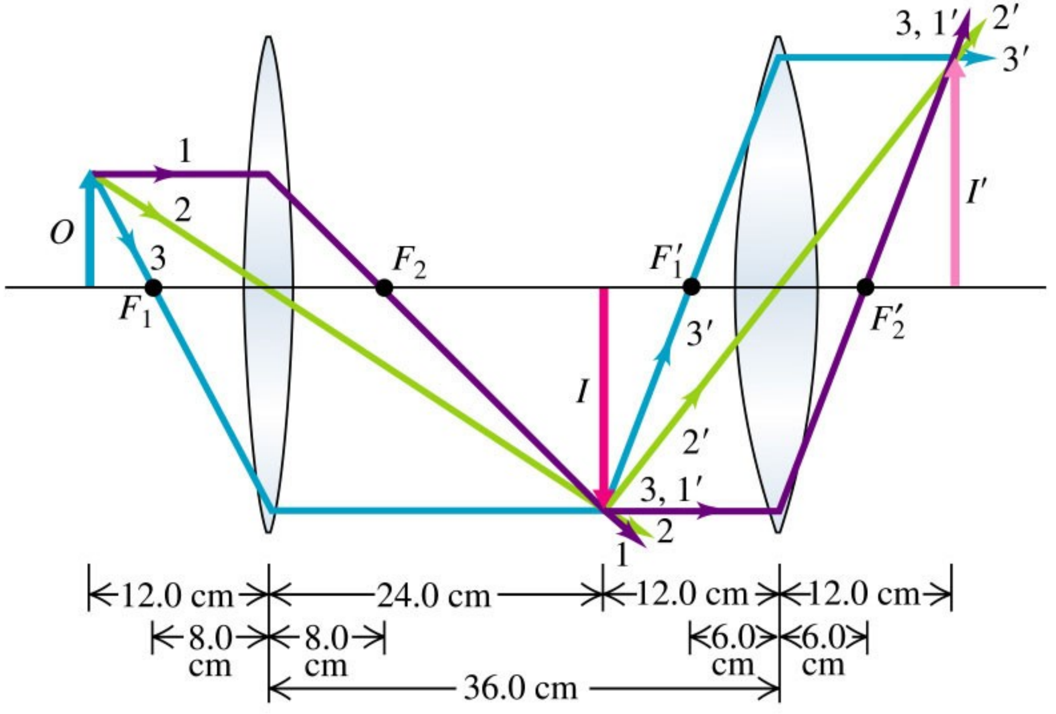
Astigmatism corrected with cylindrical lens



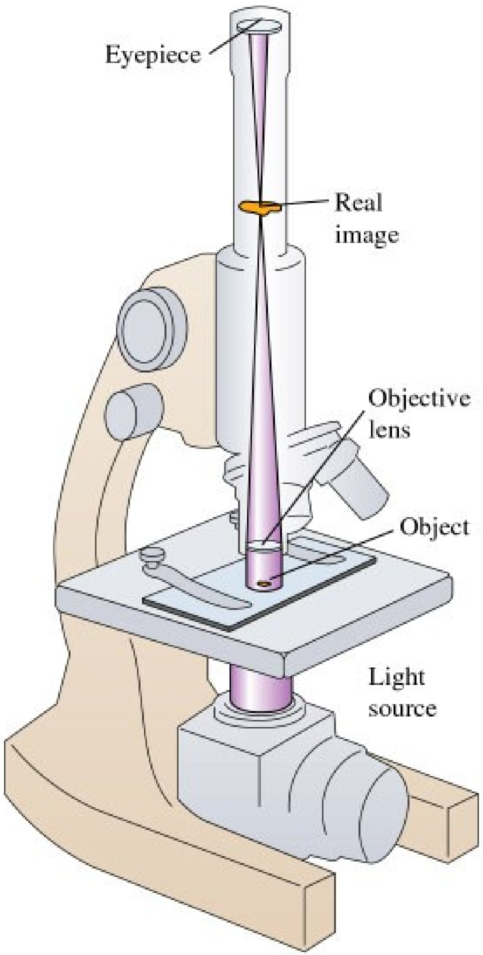
(a) Vertical lines are imaged in front of the retina

(b) A cylindrical lens corrects for astigmatism

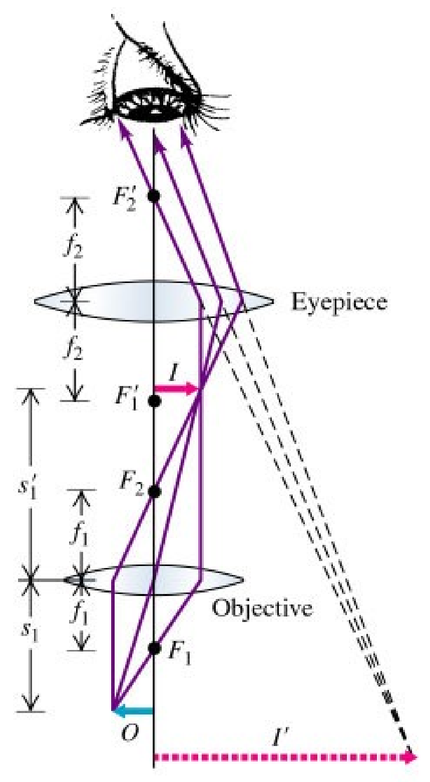
Compound Lens Systems



Compound Microscope



(a)



(b)

Telescope

- Keplerian (positive positive)
- Galilean (negative, positive)

Physical Optics

- Misconceptions: confuse geometric and wave models of light
  - Students treat all apertures as narrow slits
  - Don’t understand location of minima in single slit vs slit width
  - Use incorrect hybrid model, geometric for maxima/center of slit and “edge effect” interference for sides of slit

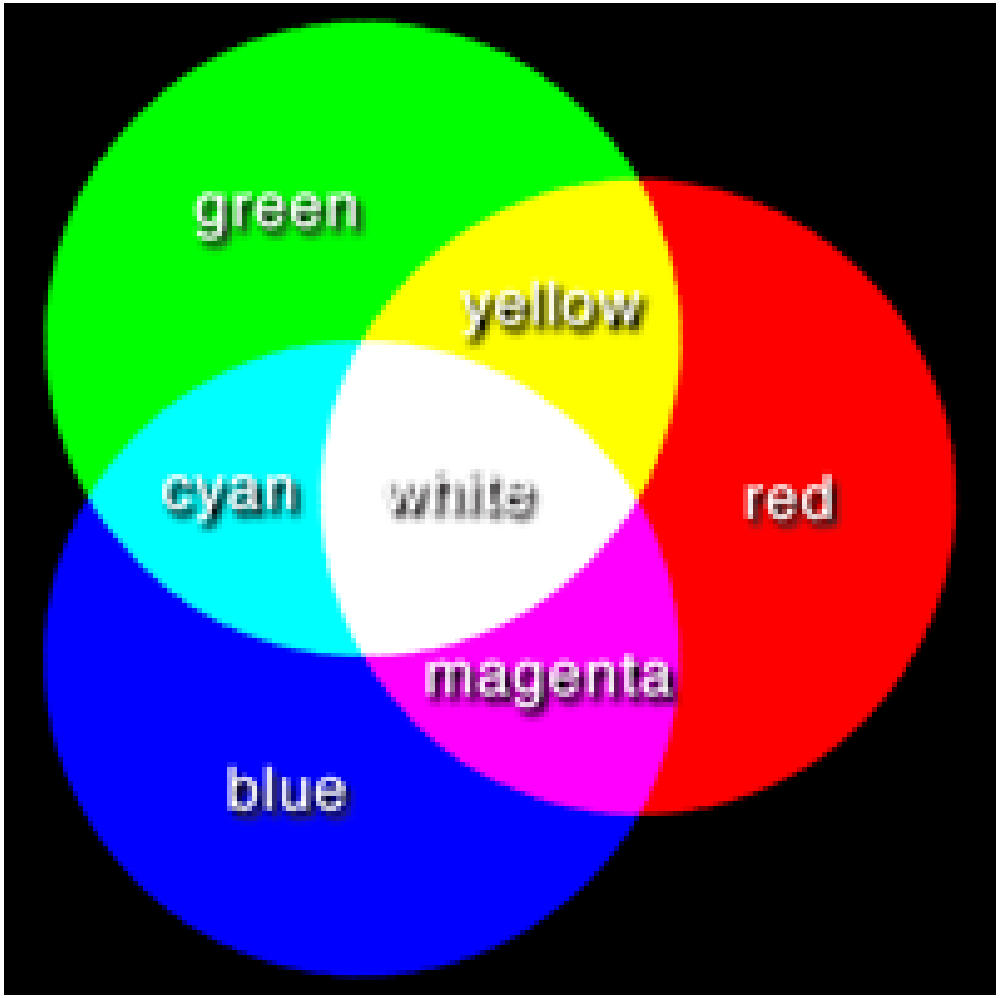
More Misconceptions

- “No light will pass through slit a<lambda”
- “Diffraction occurs for a<lambda, geometric for a>lambda”
- Don’t understand 2 slit interference pattern/ what happens when 1 slit is covered?
- Misinterpret the standard drawing of a wave—literal diagram vs abstract representation
- Misunderstand the standard drawing of 2 slit interference pattern (top view/side view/intensity vs distance are confused)

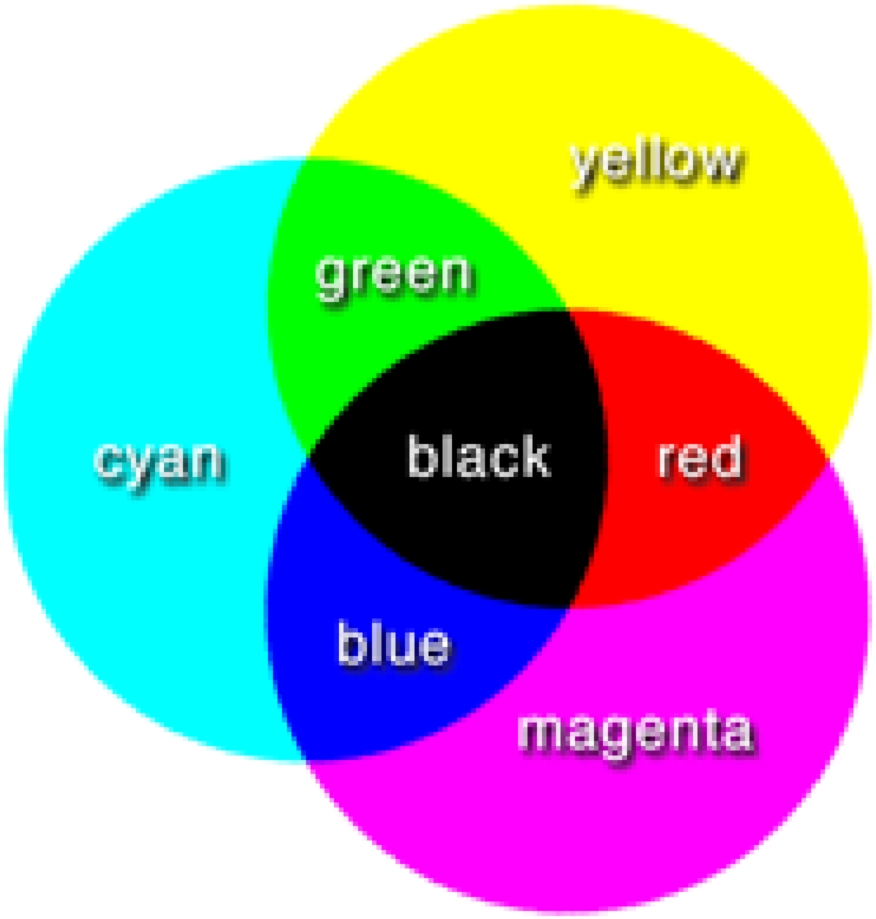
Color

- Wavelength X frequency = velocity
- V=c/n
- Frequency is fixed by source
- We are more comfortable with wavelength but refer to “in vacuum”
- Wavelength changes: wavelength= wavelength_vacuum/n
- Red has long wavelength ~630 nm Red, 520 nm green, 480 nm blue

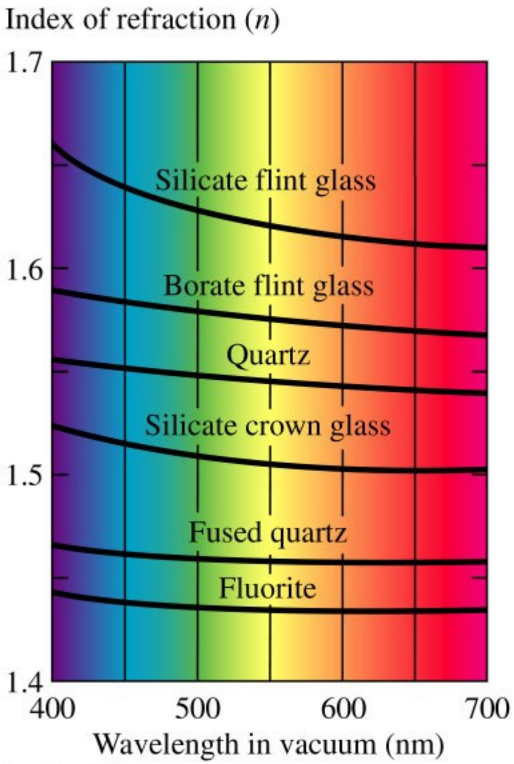
Additive Color Mixing

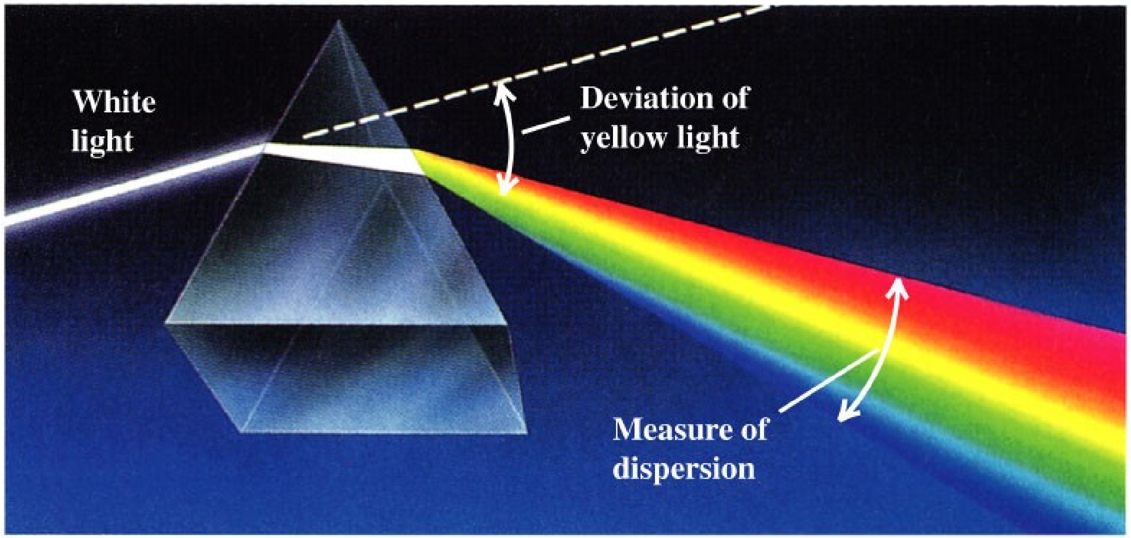


Subtractive Color Mixing

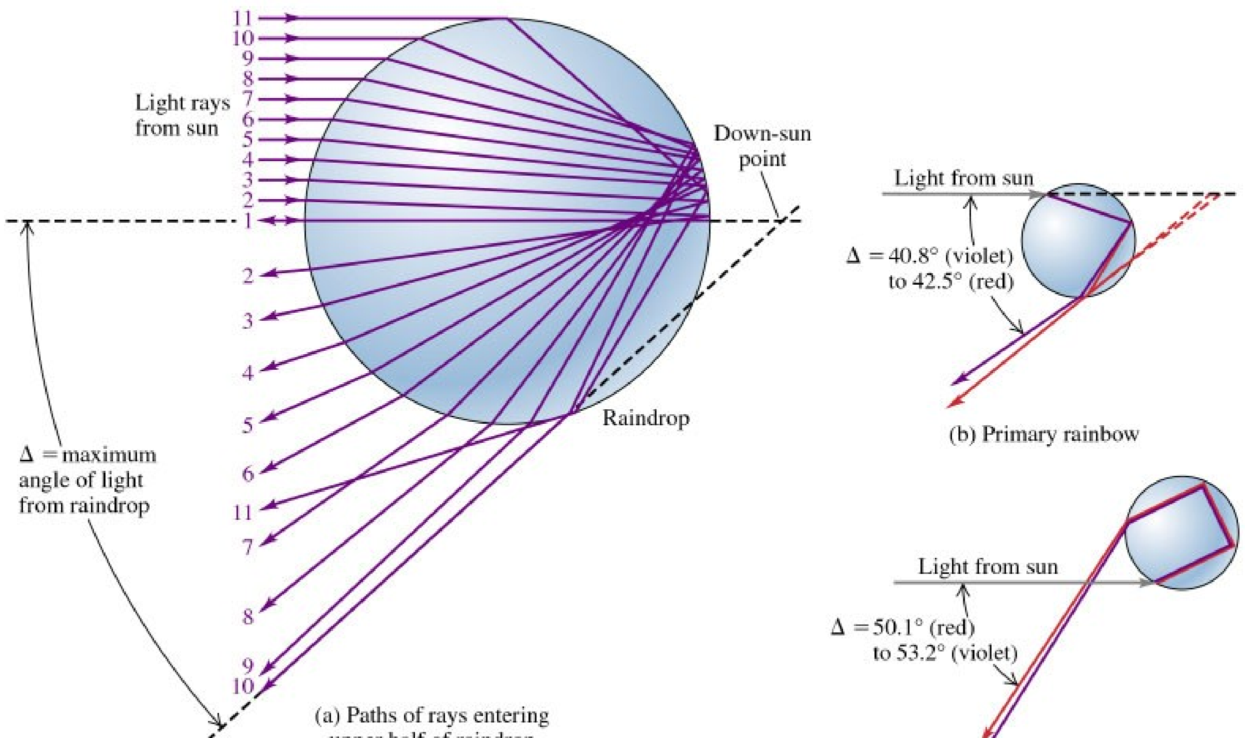


Color Dispersion by Refraction





Two (or more) refractive paths

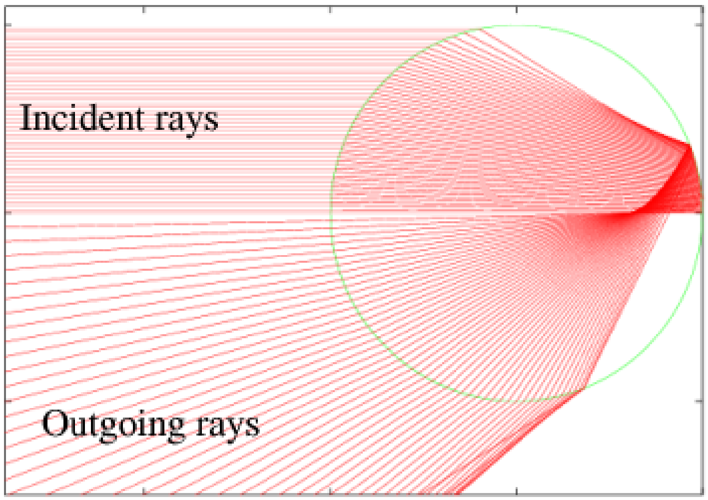


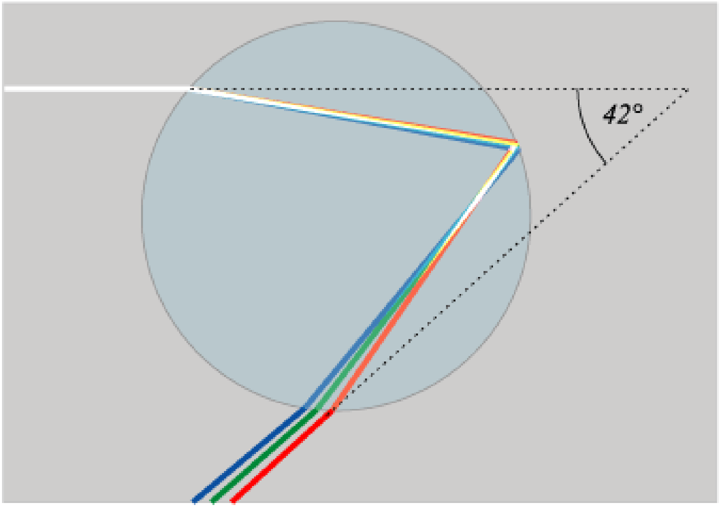
(a) Paths of rays entering upper half of raindrop (for clarity, rays entering lower half are not shown)

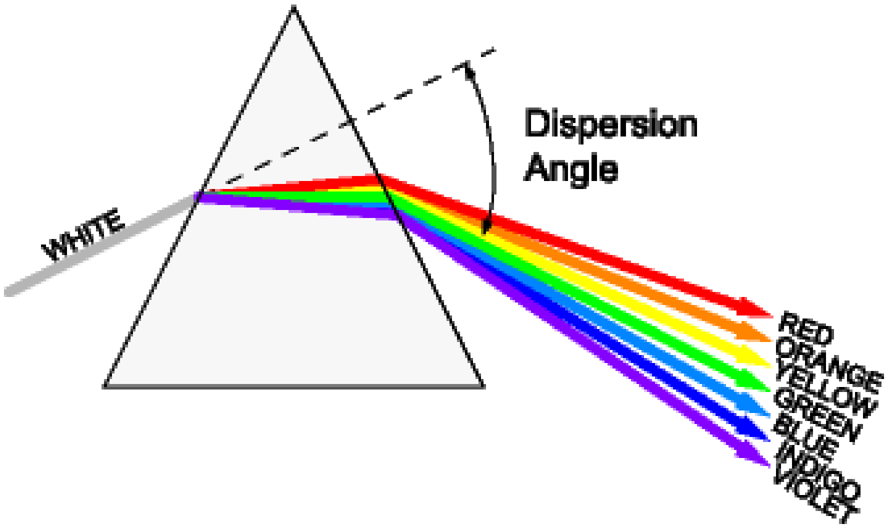
(b) Primary rainbow

(c) Secondary rainbow

Dispersion in water







Rainbows