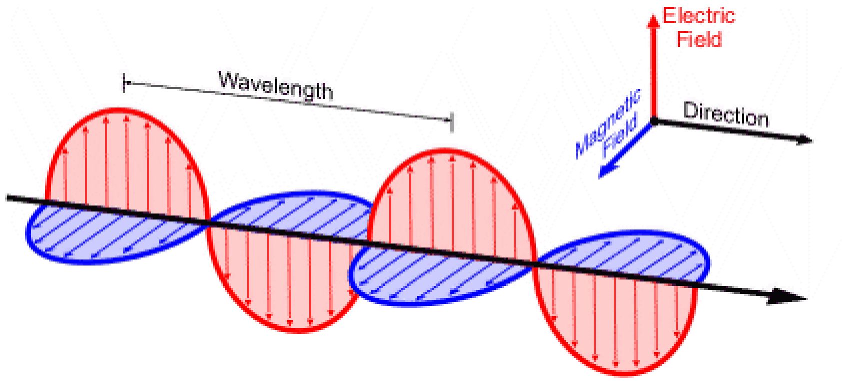
EM waves and refraction

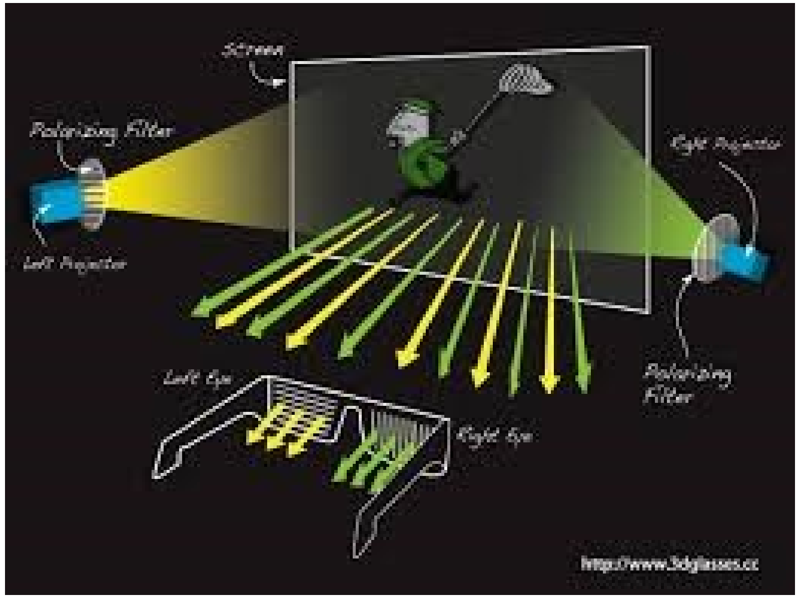
Homeworks

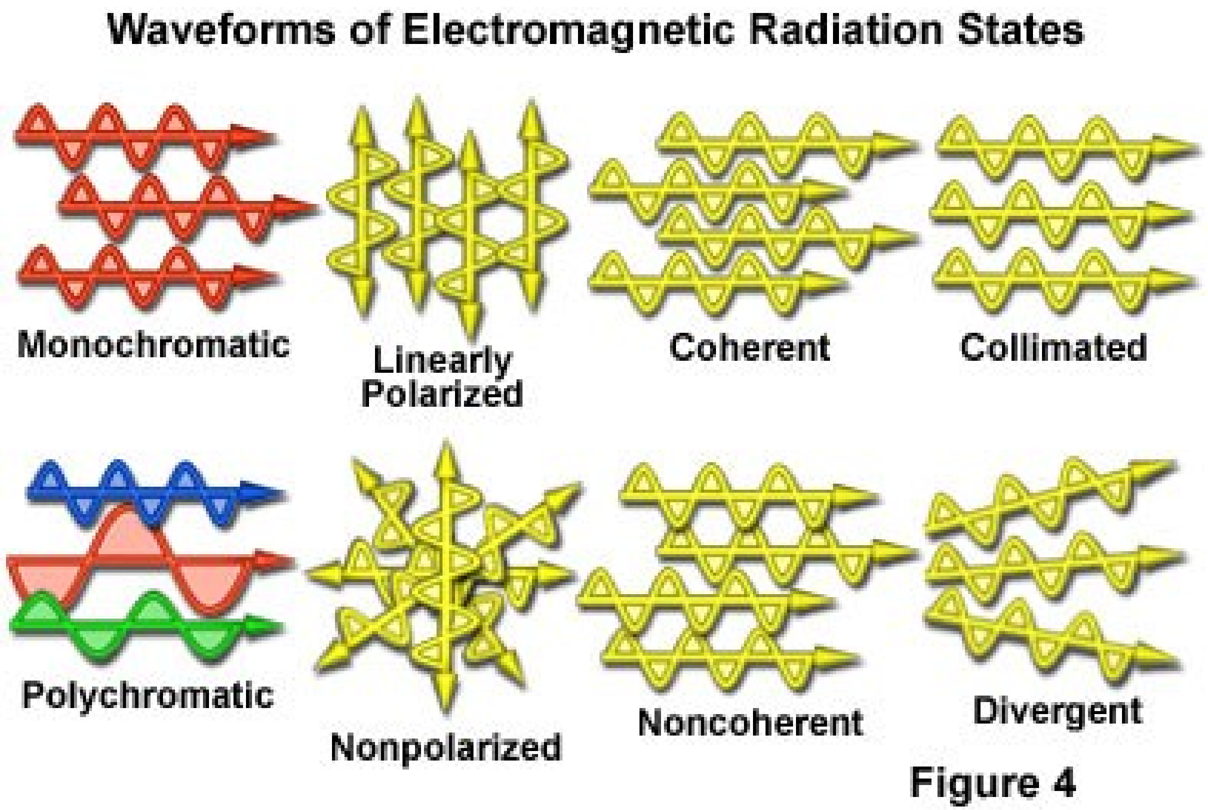
- HW 1 will be posted today, (9/1/2017)
- HW 1 will be due next Fri (9/8/2017)
  - Analytic problems must be turned in at class (or before)
  - Matlab scripts must be emailed to Quant.Optics@Colorado.edu before 11:30
- Office hours are:
  - Mon 1-2 PM
  - Thur 10-11 AM
  - JSCBB 3rd floor, A-wing common area

- Last class
  - What is light
  - Detection of light
  - Properties of EM waves
- This class
  - More about waves
  - Refraction
  - Lenses

Properties of light – propagating EM wave





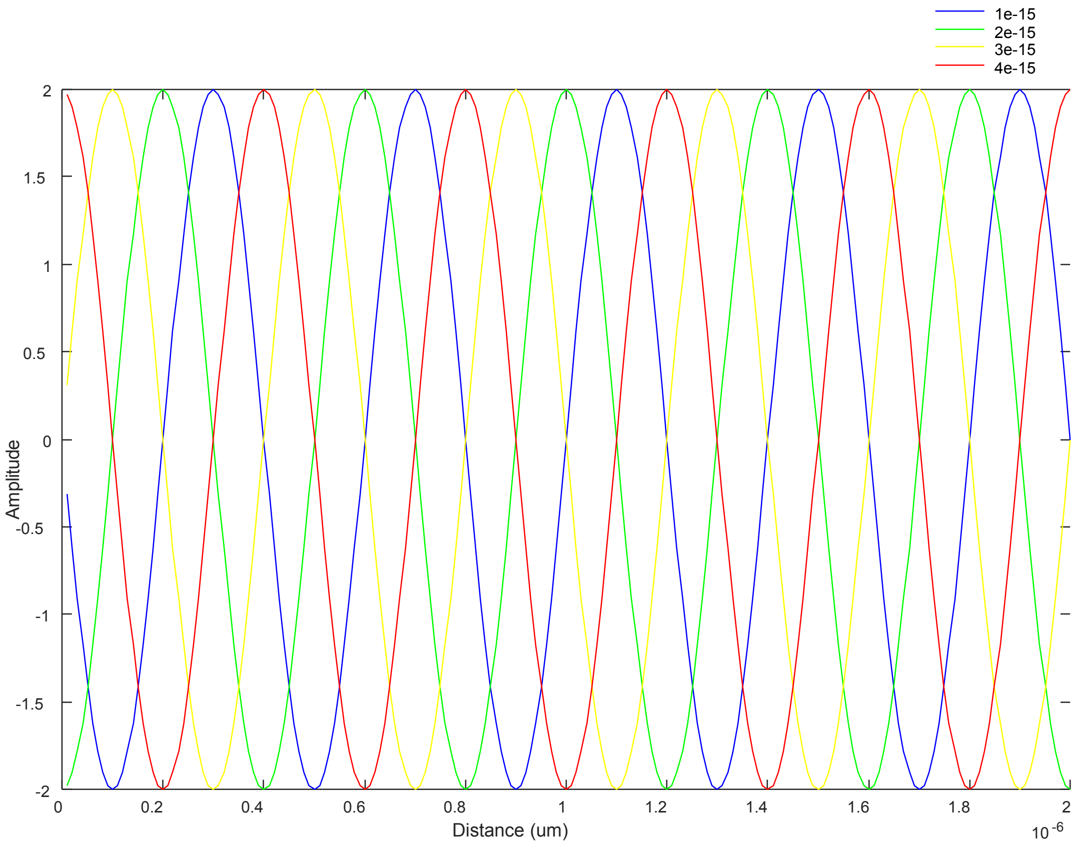


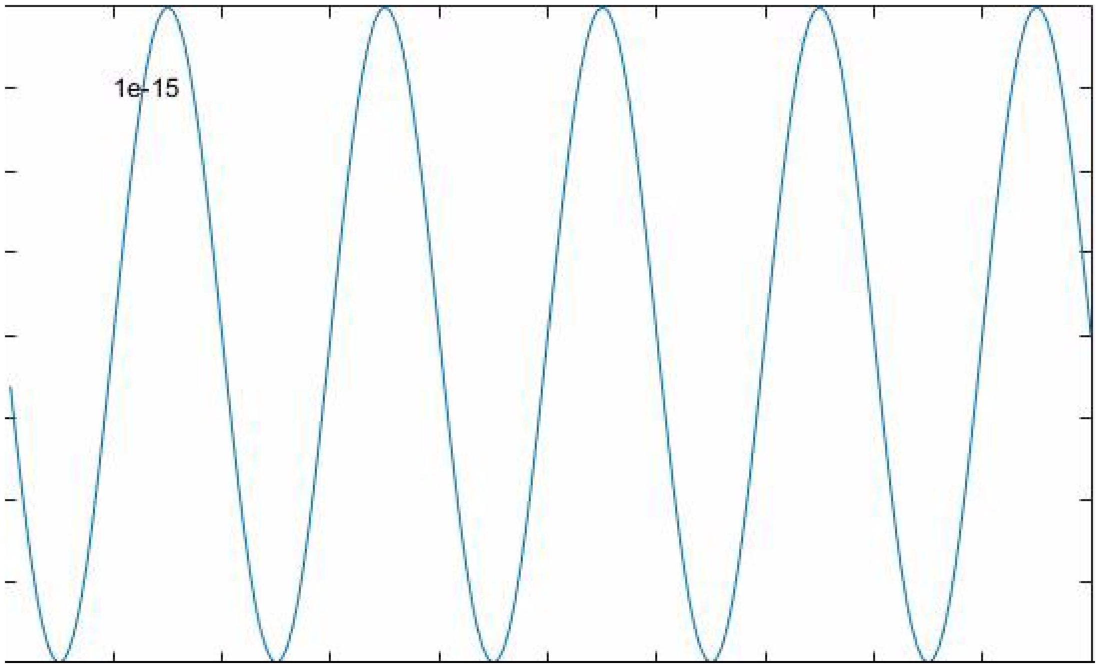
Plane wave properties

A = amplitude
k = wave number = 2*pi/λ
ω = frequency = 2*pi*f

$$y(x,t) = A\cos(kx - \omega t + \varphi)$$

Vary t

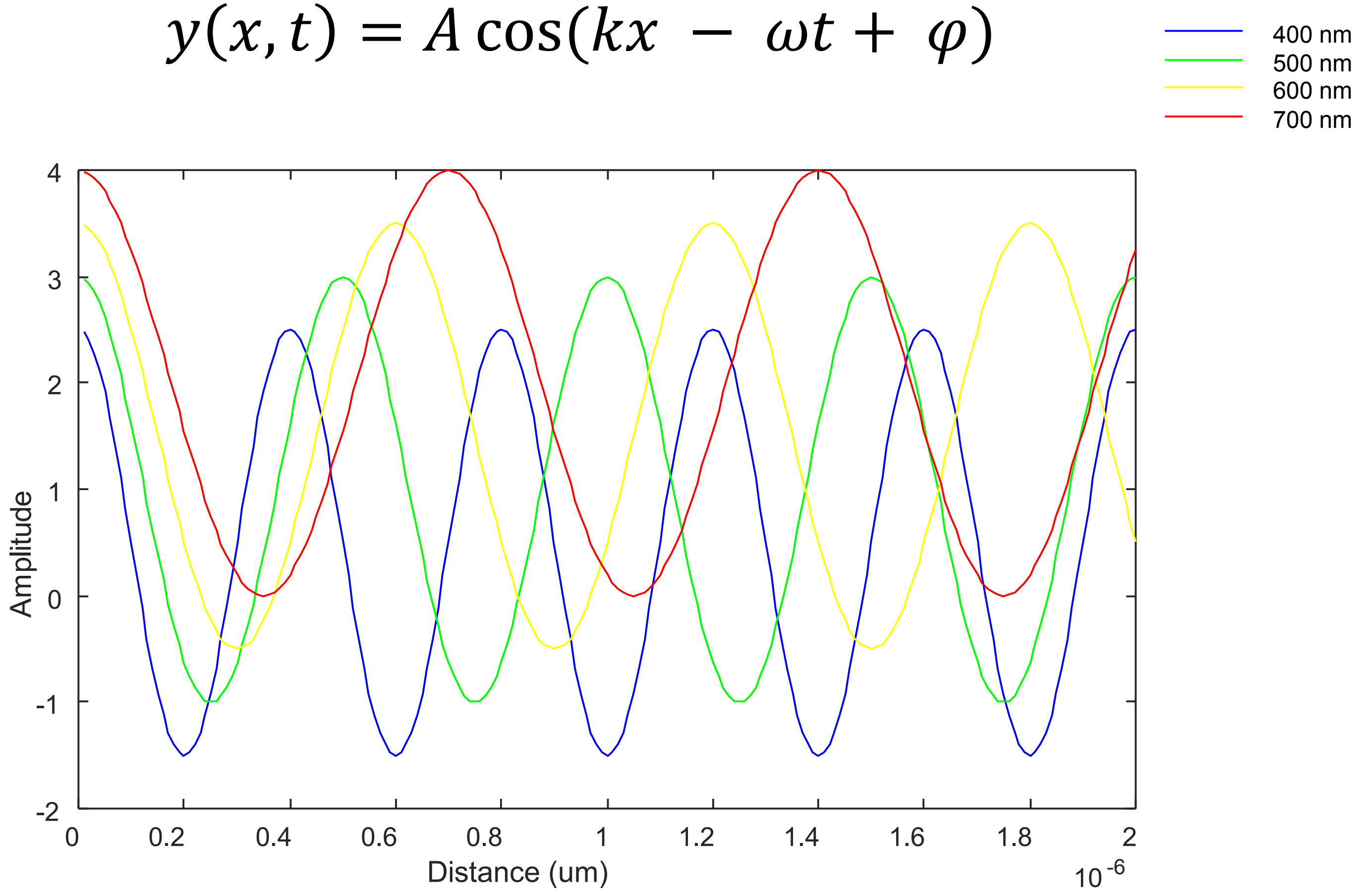




Plane wave properties

$$y(x,t) = A\cos(kx\ -\ \omega t +\ \varphi)$$

Vary λ

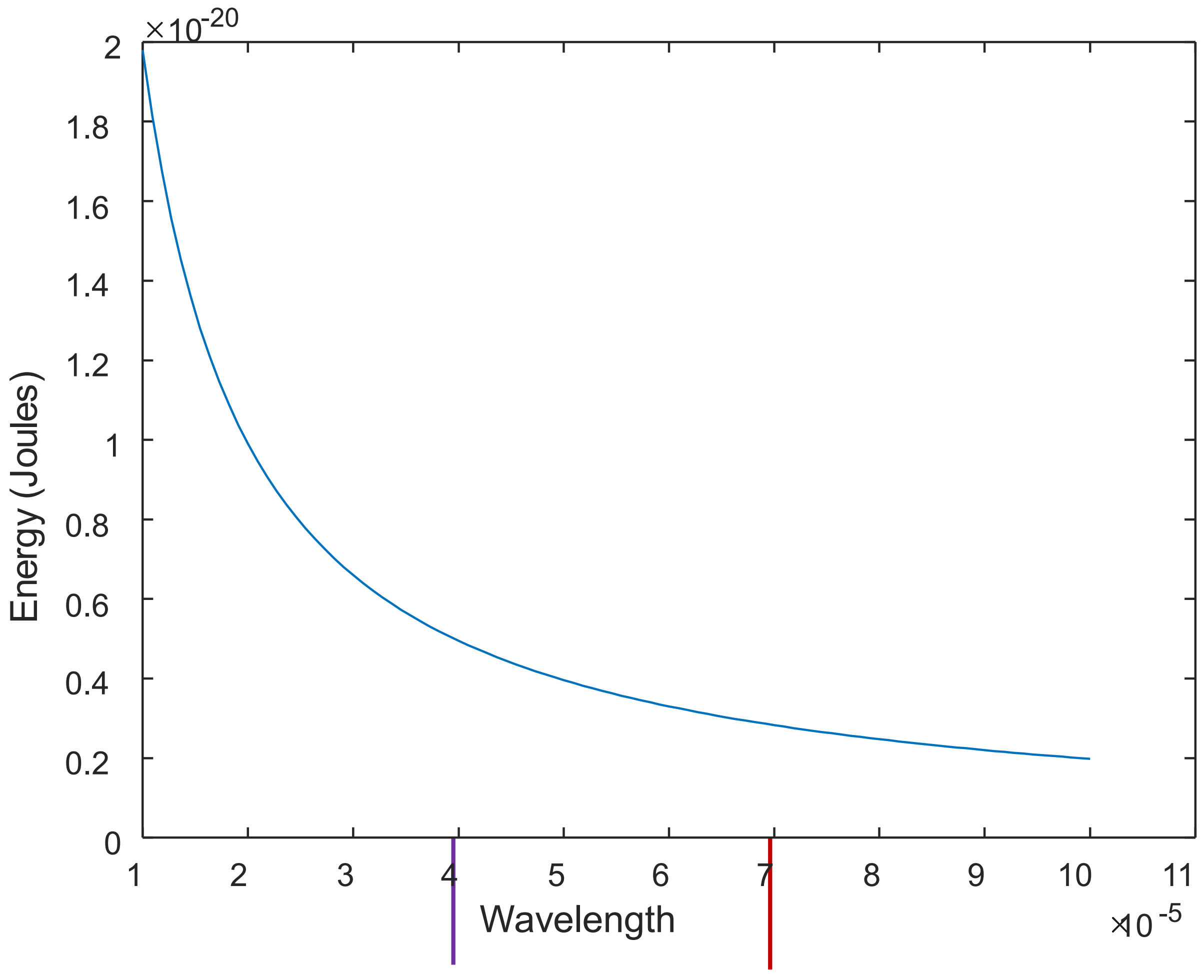


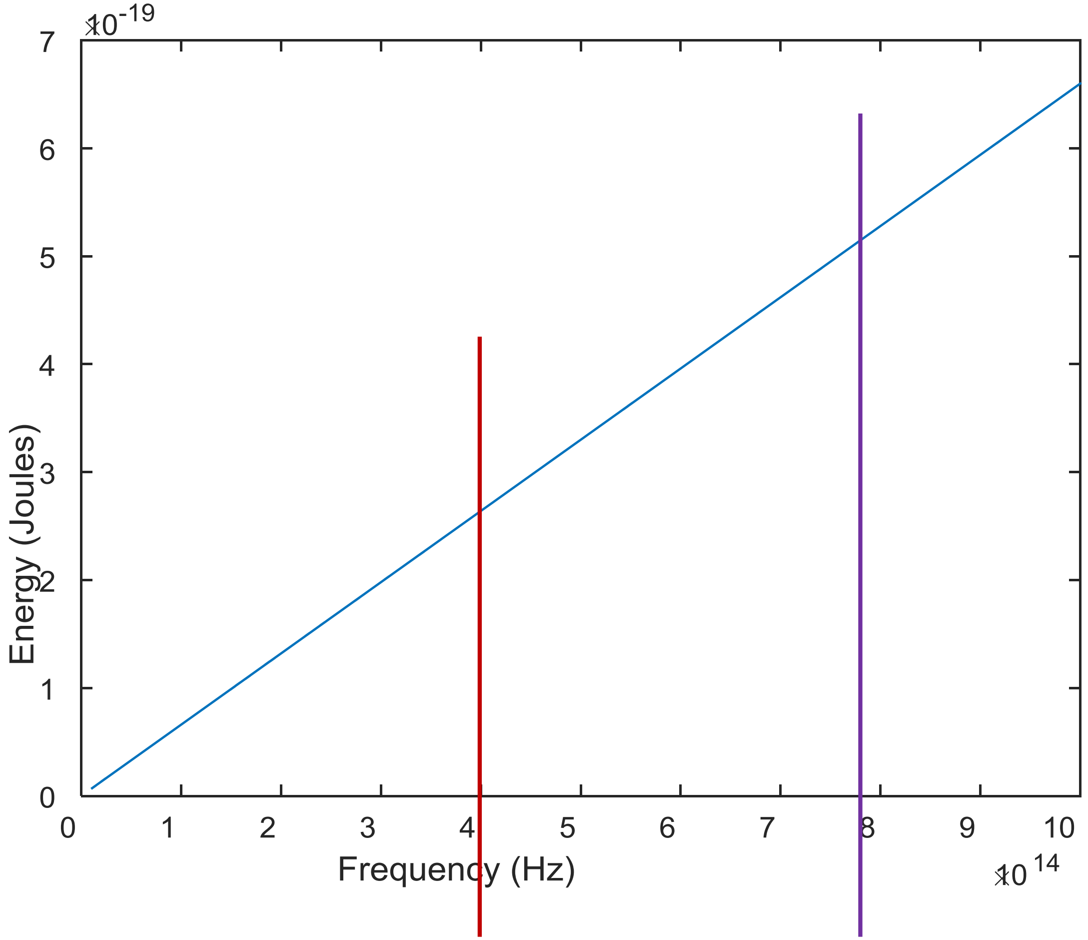
Energy of light

$$E = hf$$
$$= hc/\lambda$$

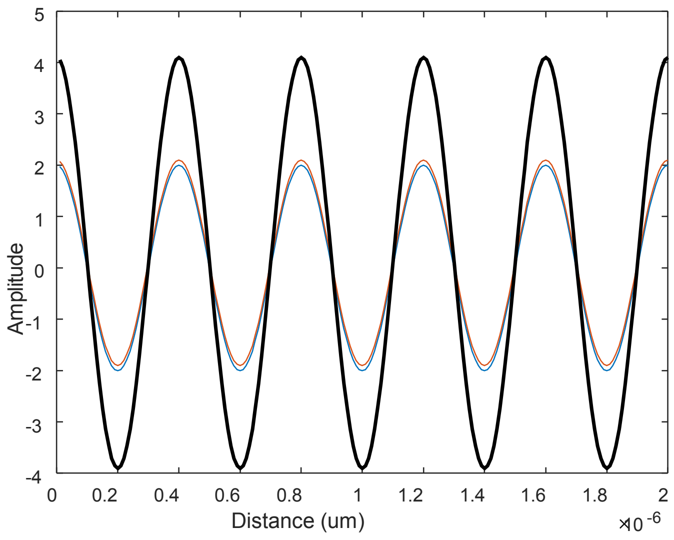
$$u_E = \frac{1}{2}\varepsilon_0 E^2$$

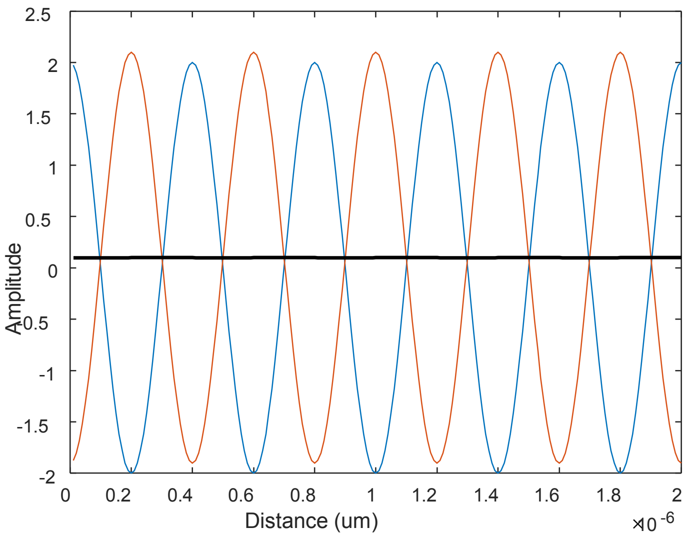
$$u_B = \frac{1}{2\mu_0} B^2$$

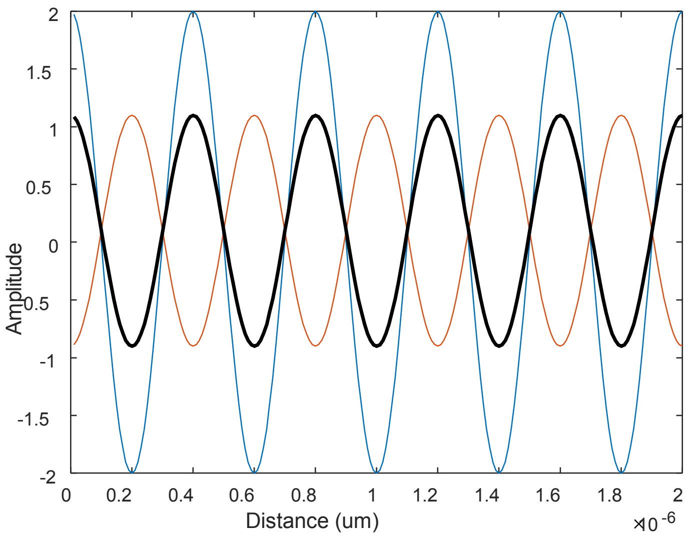




Wave Interference



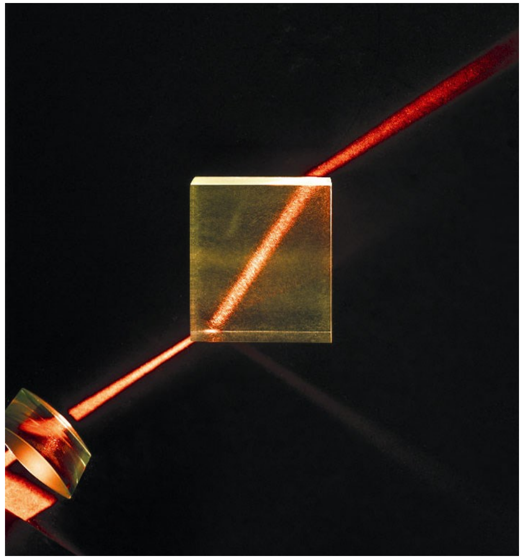


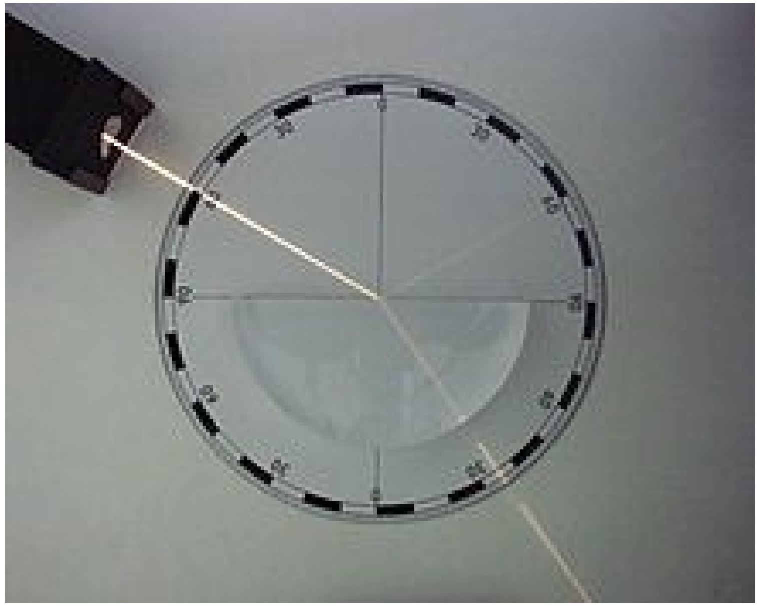


Refraction

http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/refr.html

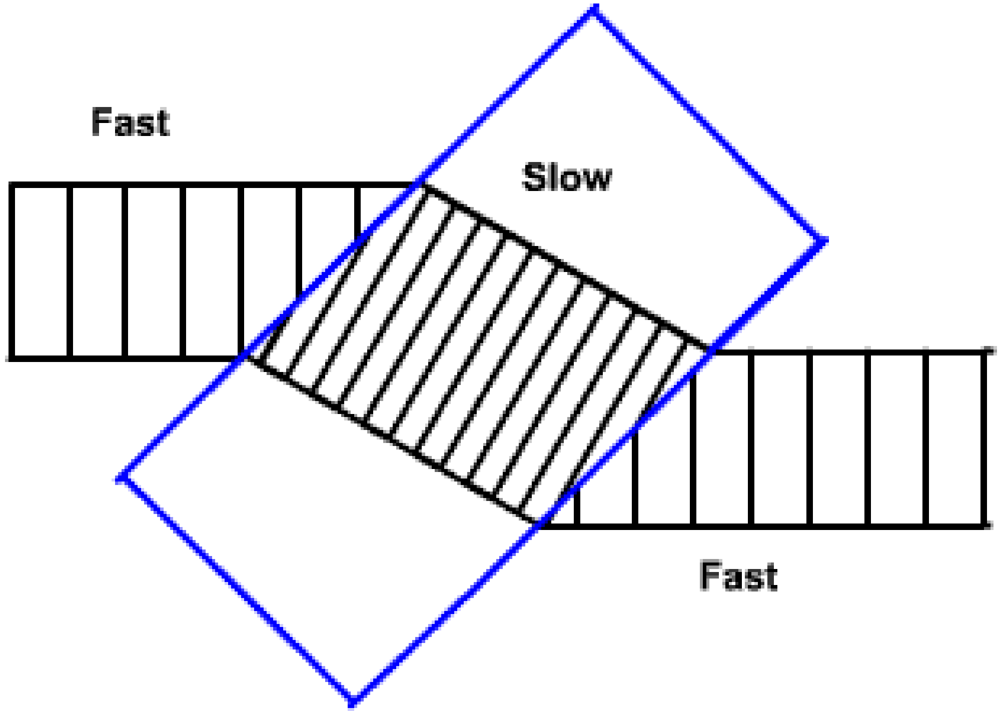
- Wave propagates between 2 different media
- Conservation of momentum and conservation of energy
- Amount light slowed is referred to as index of refraction (n)

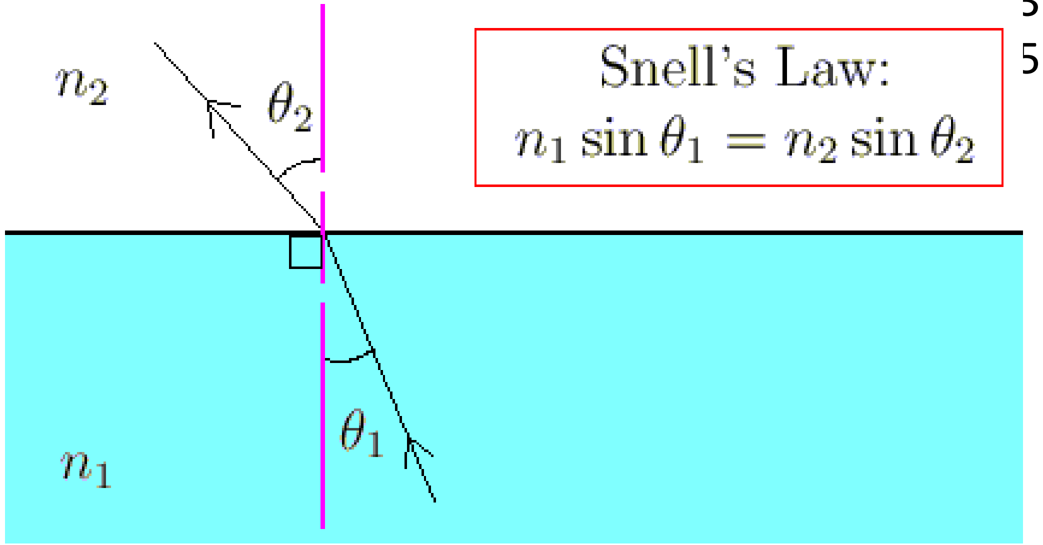




Snell’s law

Velocity is slowed in new medium





Vacuum	1
Air	1.000293
Helium	1.000036
	32
	5
Crown glass	1.52
Flint glass (typical)	1.62
Cubic zirconia	2.15
Diamond	2.42

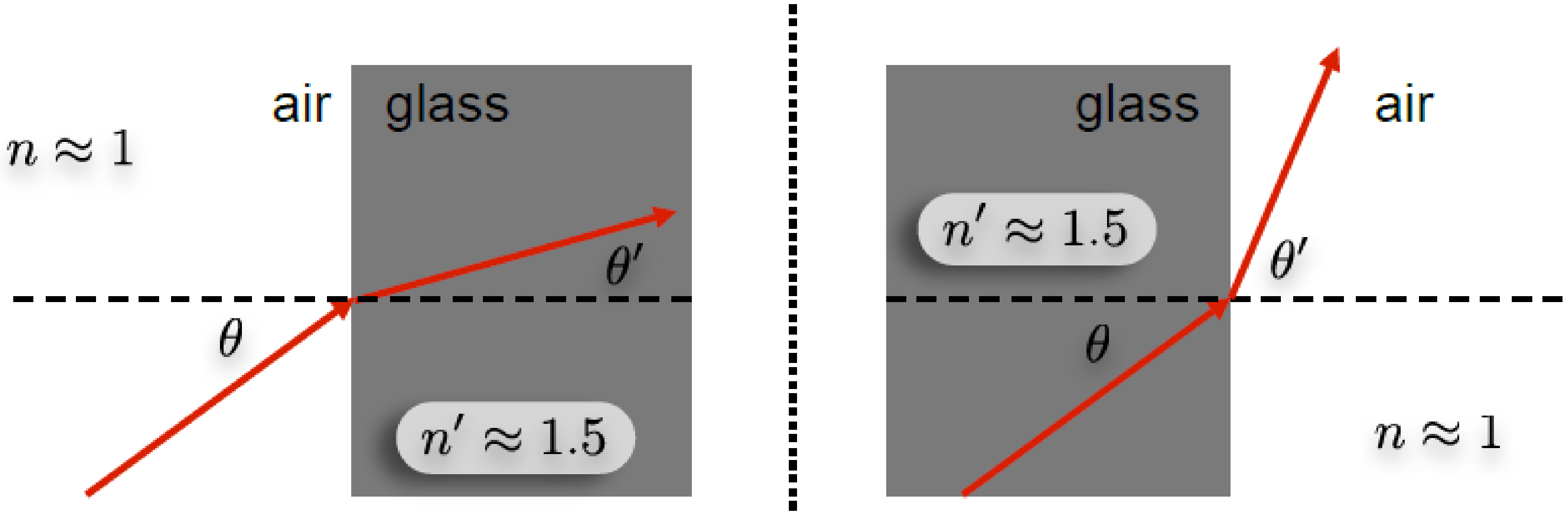
$v = c/n$

$\nu = v/\lambda$

$\lambda = c/\nu n$

$\lambda = \lambda_o/n$

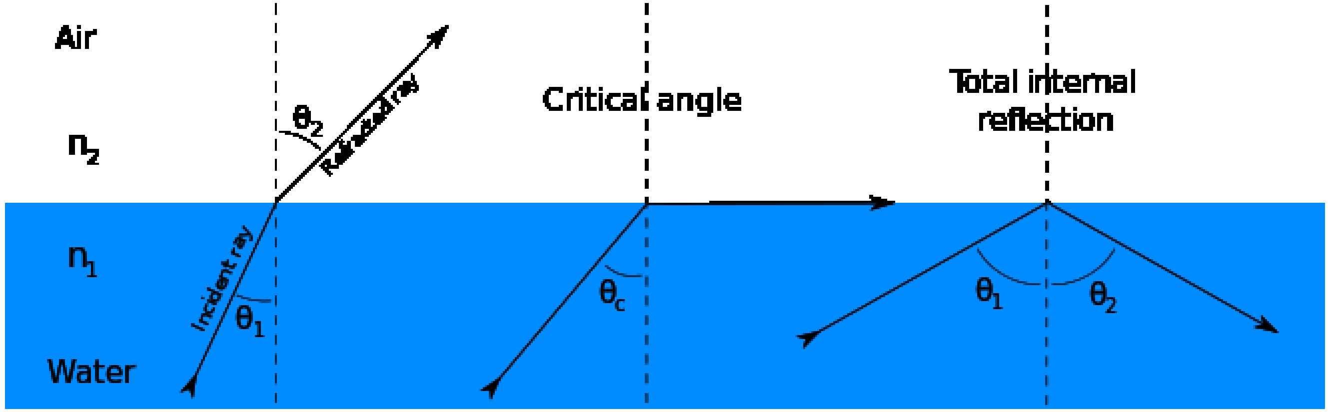
Back and forth…



$$\mathrm{n} \sin\theta = n' \sin\theta'$$

Total internal reflection

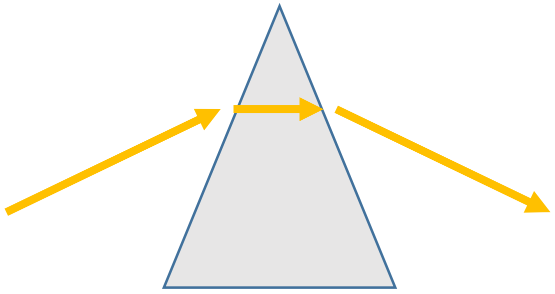
- Consider moving from dense to less dense material

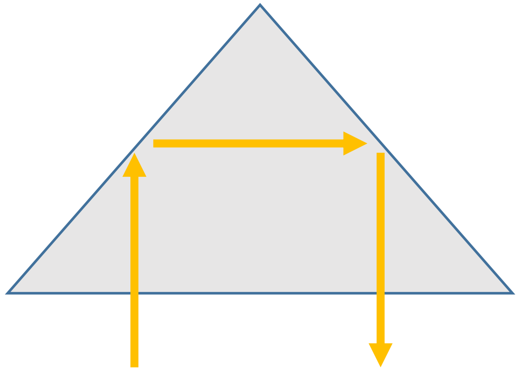


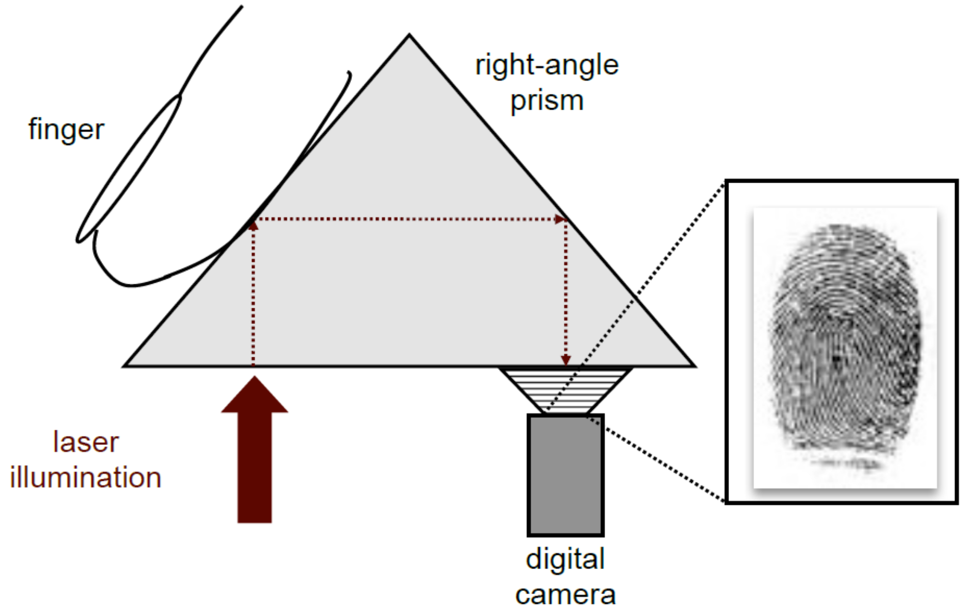
At critical angle, an evanescent wave exists but rapidly decays

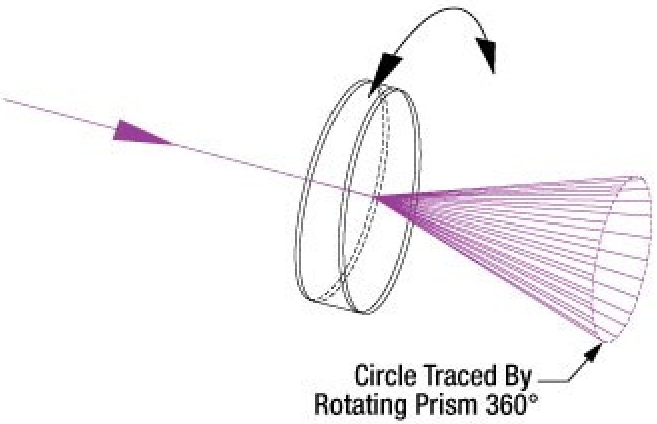
What can you do with refraction?

- Prisms:

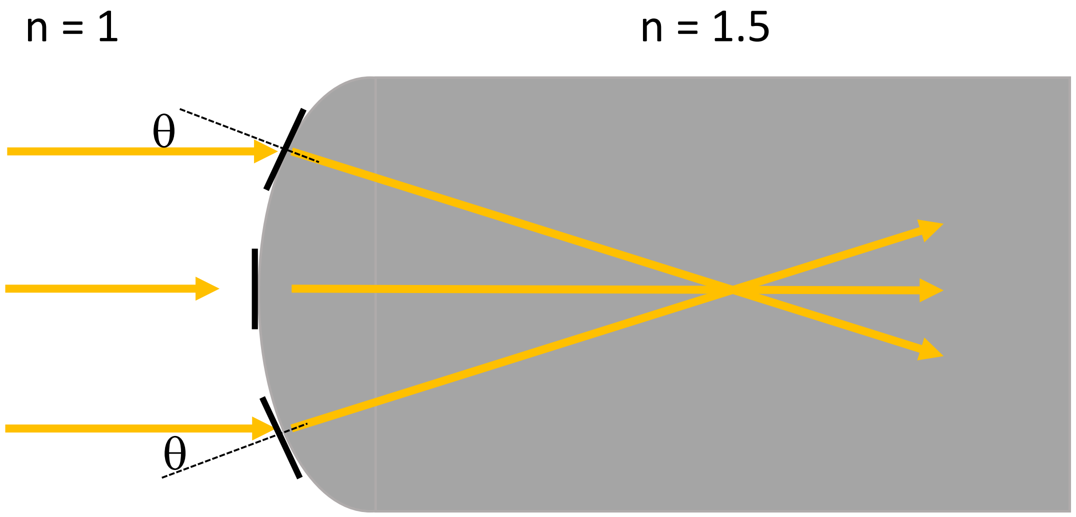


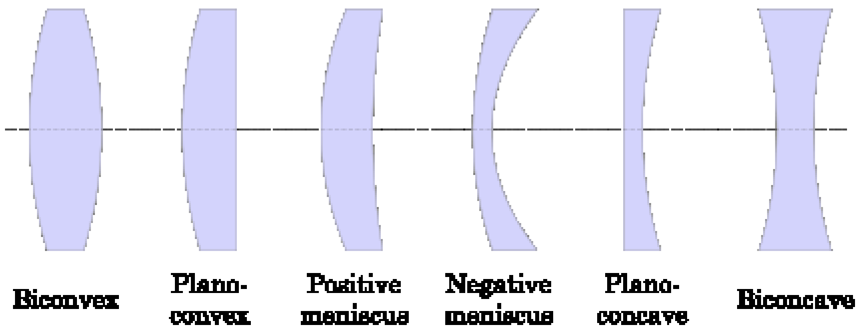






Incident light on a curved surface (Otherwise known as a lens)

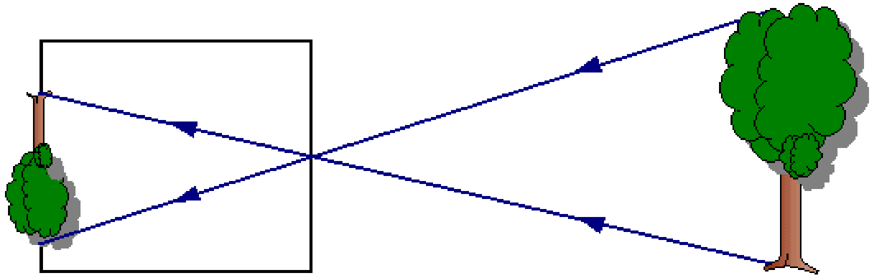




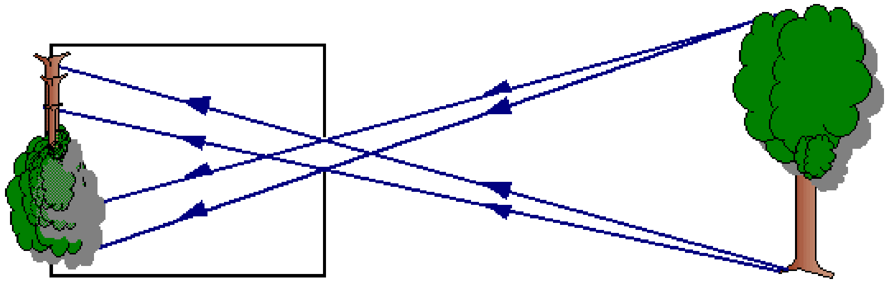
Spherical lenses are the easiest to make – grind with a lathe

Lenses vs pinhole

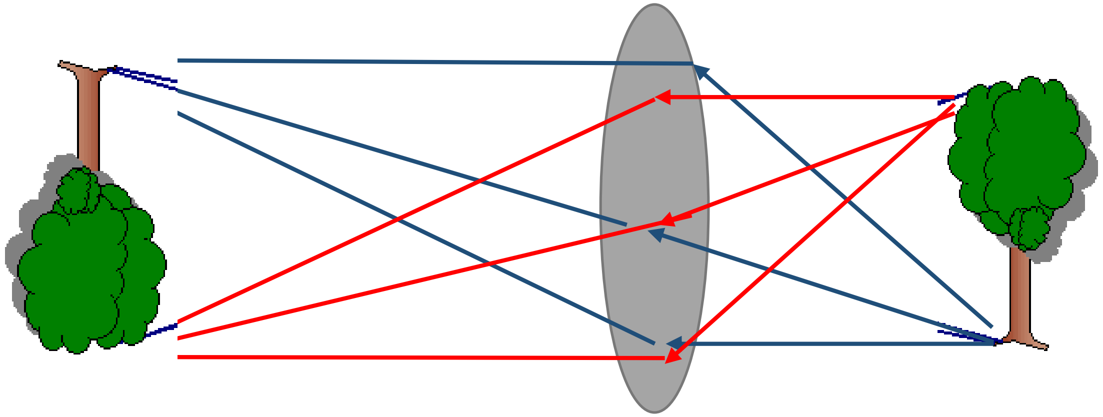
- With pinhole cameras, there was always a trade off between sharpness and brightness set by the size of the aperture
- What we want is to collect all the rays emanating from a single spot, and put them all on the same place
- Have to change the light somehow, since light (in the absence of matter) travels in a straight line
- Lenses enable us both bright and sharp images



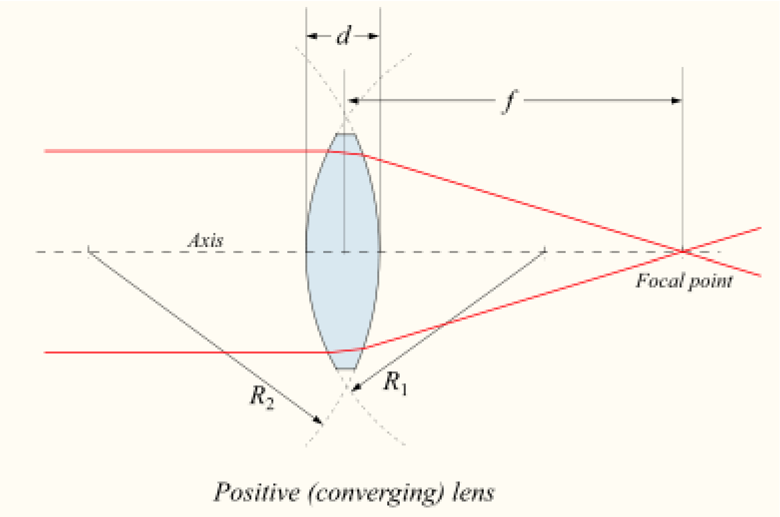
Clear upside down (inverted) image with a small pinhole

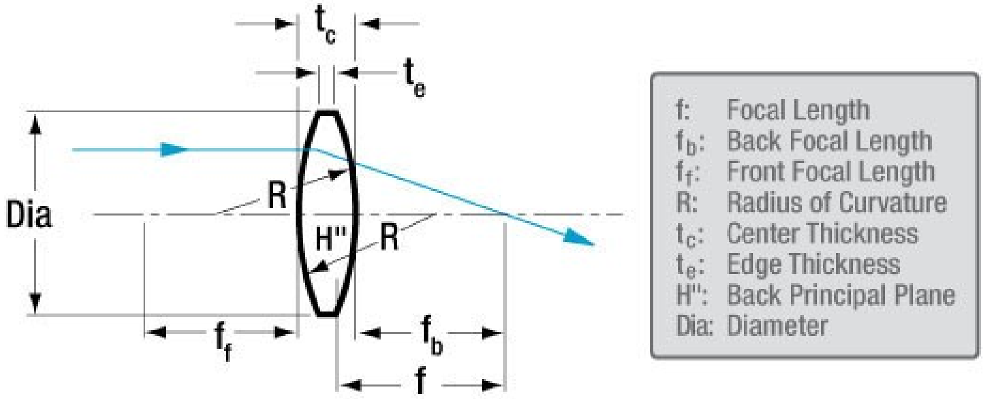


Fuzzy out of focus image with a large pinhole



Lens makers equation

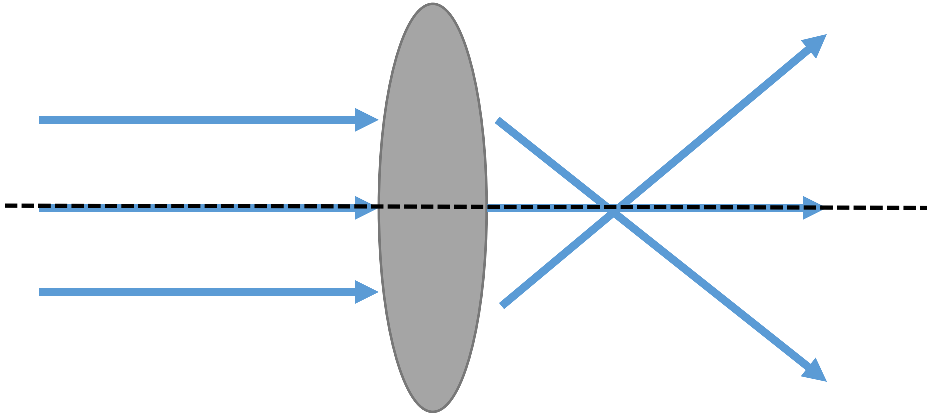


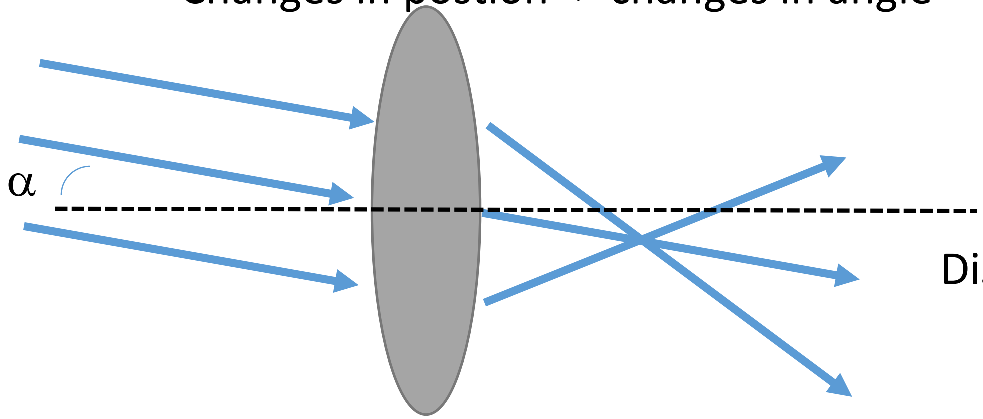


$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right],$$

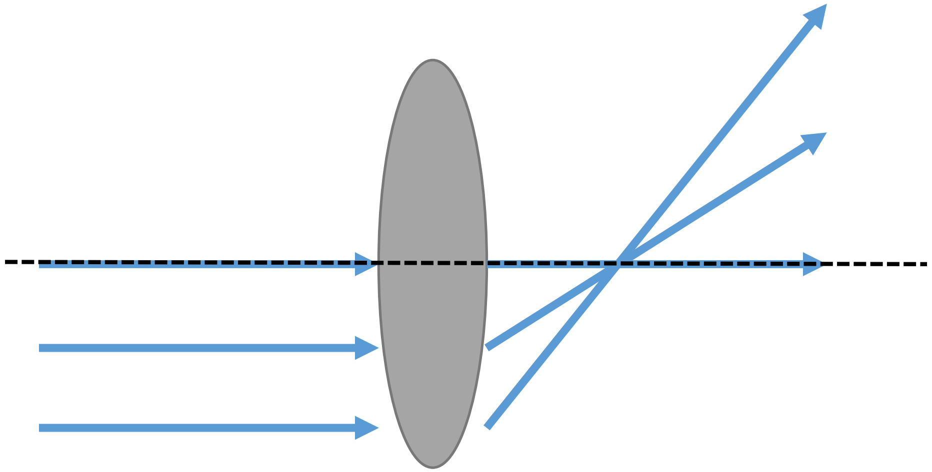
Ray optics – convex lens

Changes in angle -> changes in position
Changes in postion -> changes in angle

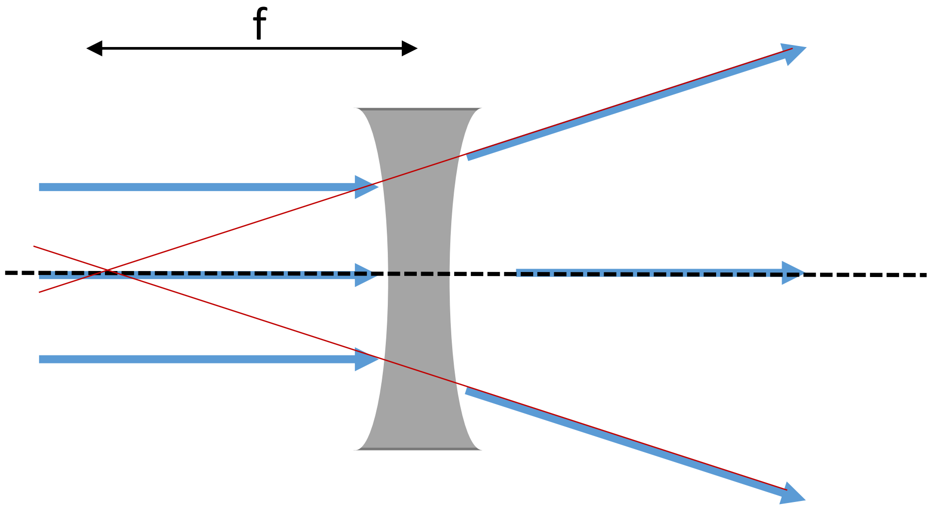


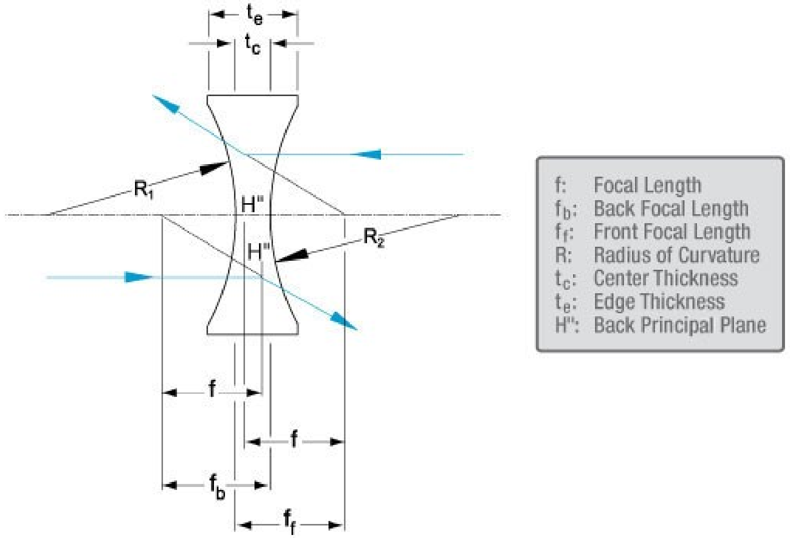


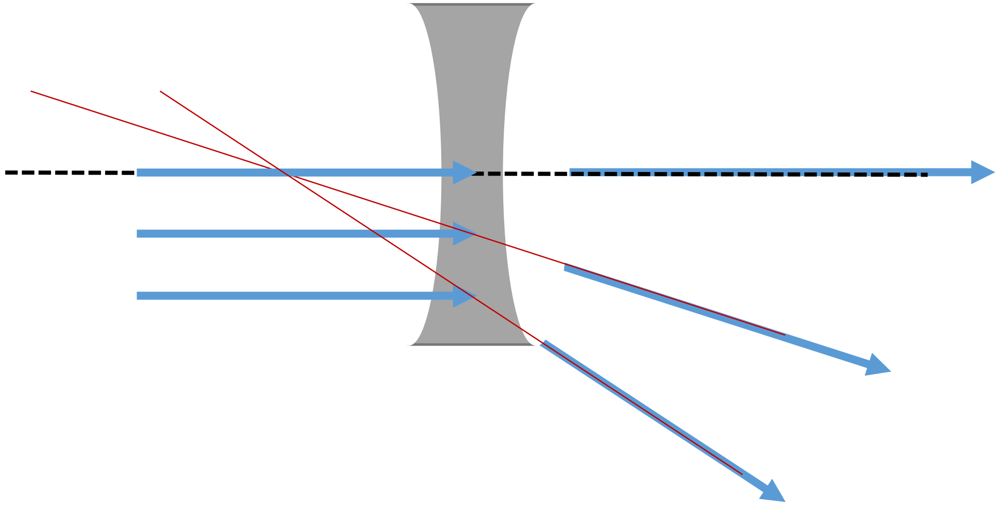
Displacement = αf



Ray optics – concave lens







Ray optics rules

Simple Thin Lens Geometrical Optics

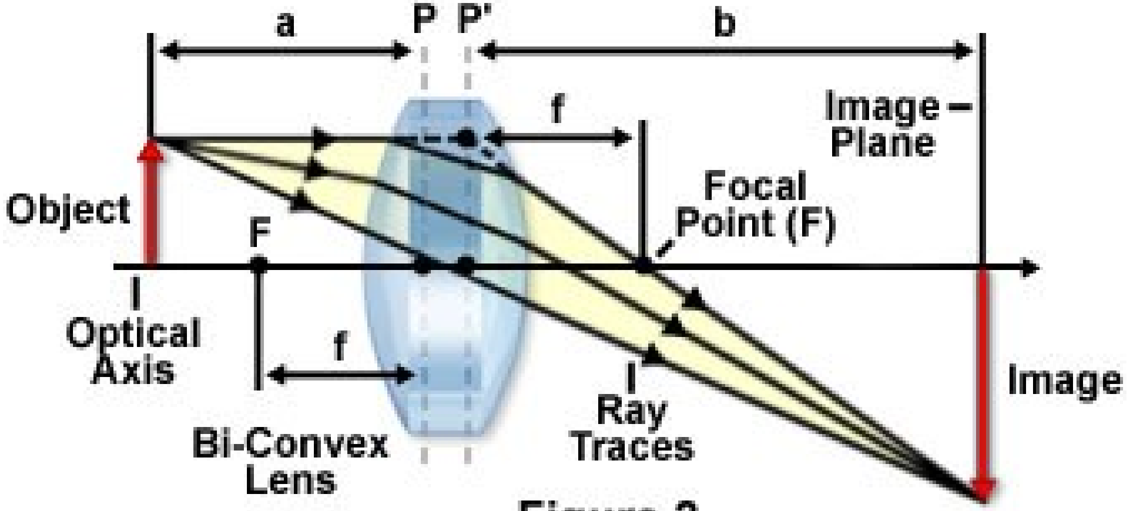


Figure 2

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right],$$

1. Draw a line to the center of the lens, it continues
2. Draw a line perpendicular to the lens axis, it goes through the focal point
3. Draw a line through the focal point, it goes straight

Light is reversible (time invariant)

If it's before the focal plane, draw as if it came from the focal point, forms a virtual image

On to Matlab…