Imaging, absorption, mirrors

- HW 1 due today
- HW 2 will be posted today

- Last class
  - Ray diagrams
  - Imaging with lenses
  - Beam expanders
- This class
  - More on lenses
  - Absorption
  - Reflection

Simple Thin Lens Geometrical Optics

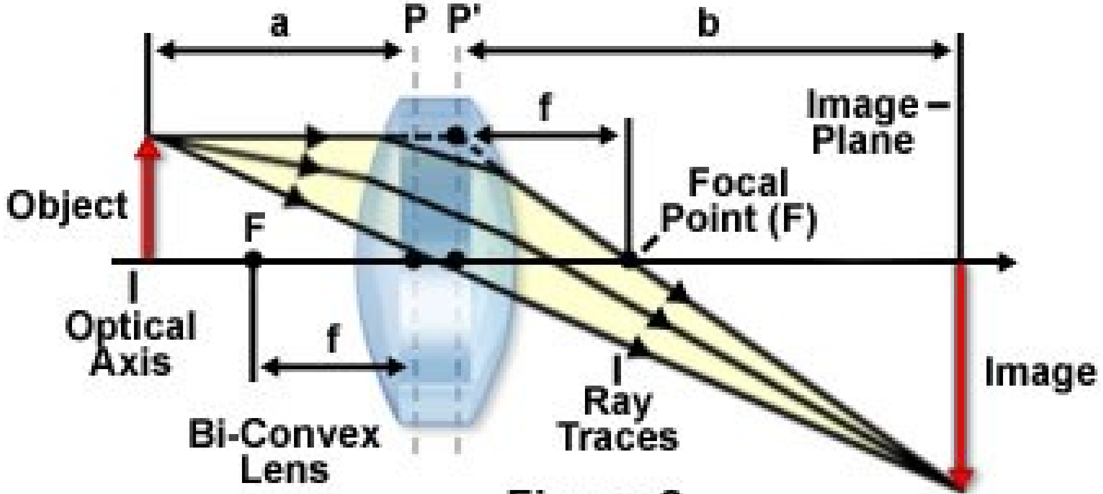
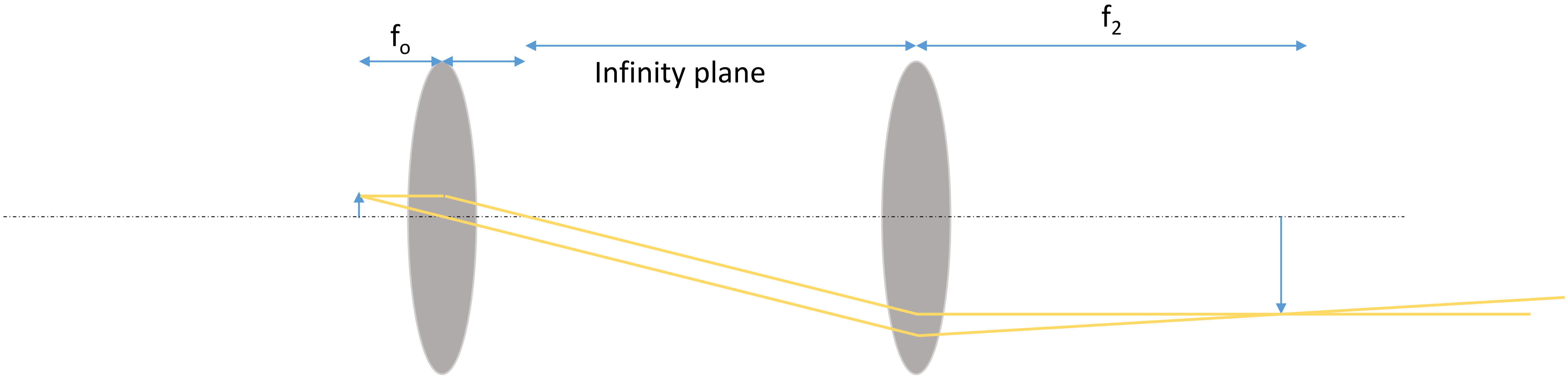
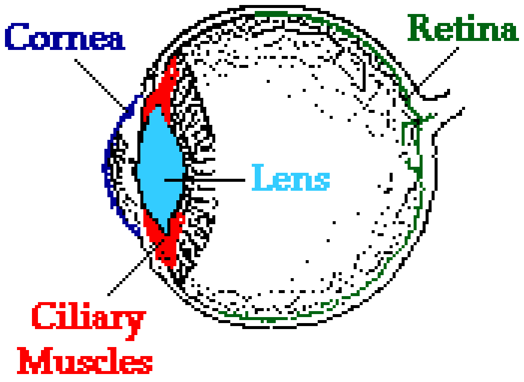


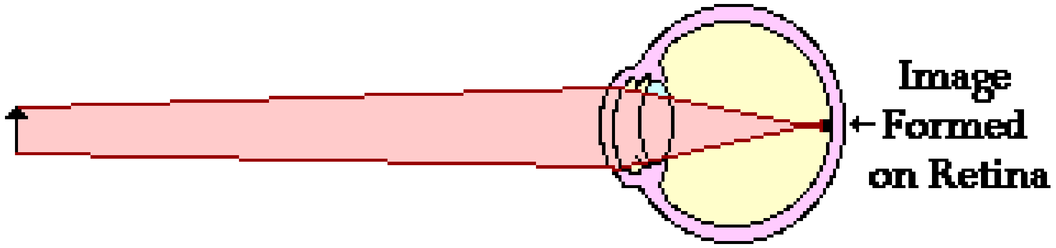
Figure 2



$M = f_2/f_1$

Your eye has a lens





The cornea and lens serve to refract light and focus an image of the object upon the retinal surface.

$$\frac{1}{o}+\frac{1}{i}=\frac{1}{f}$$

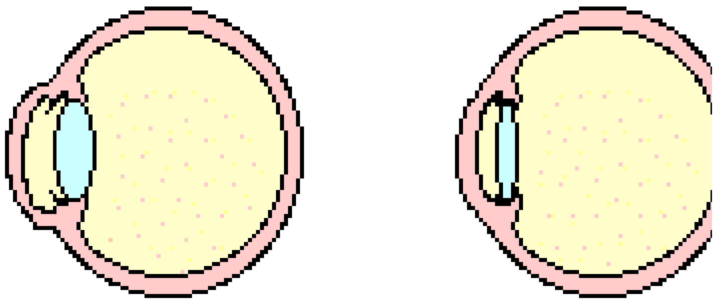
Eye can change focal distance

Accommodation

Object Distance	Focal Length
0.25 m	1.68 cm
1 m	1.77 cm
3 m	1.79 cm
100 m	1.80 cm
Infinity	1.80 cm

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$$

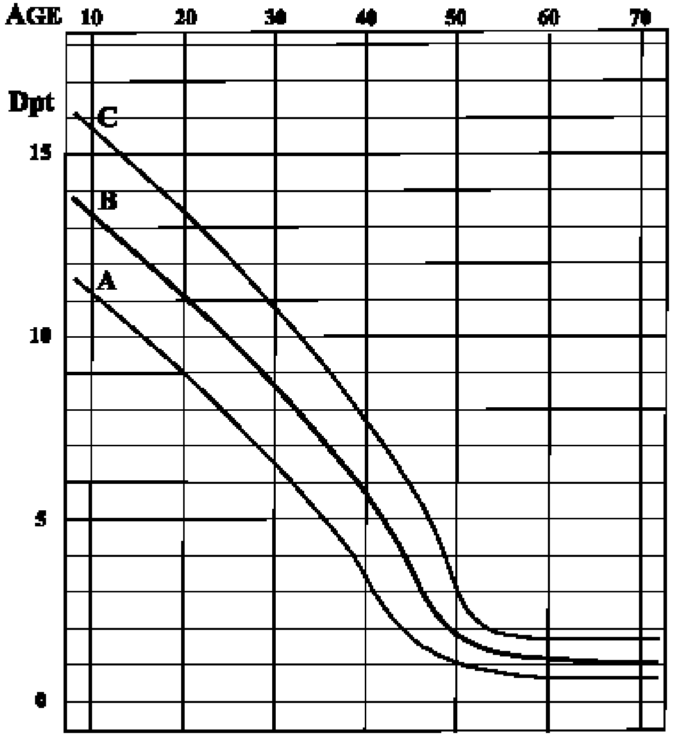
Accomodation



Short focal length for nearby objects

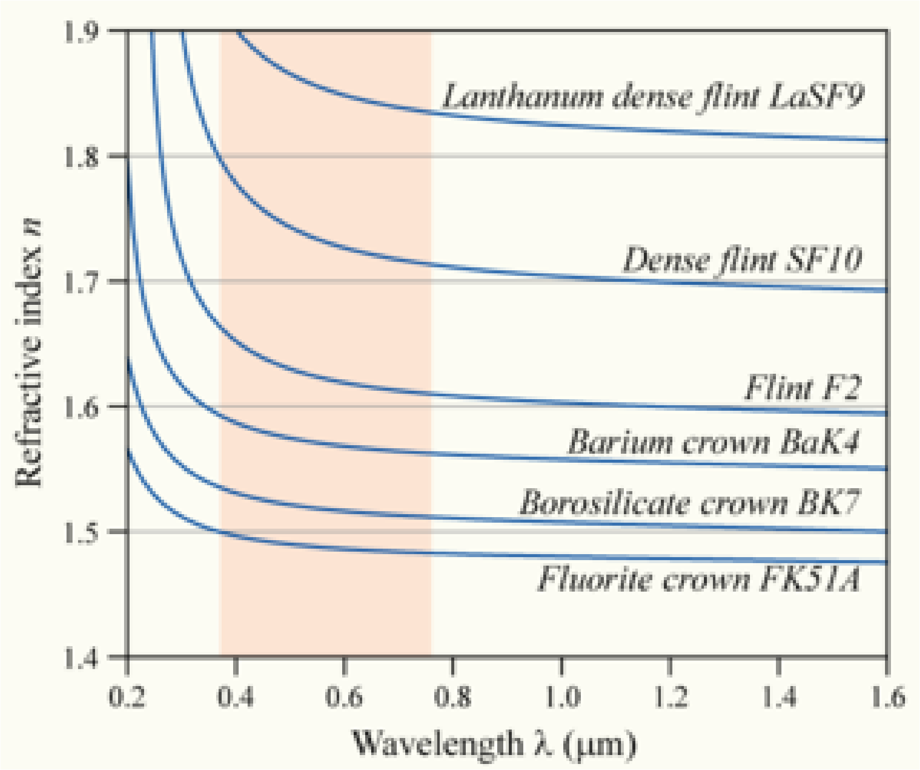
Long focal length for distant objects

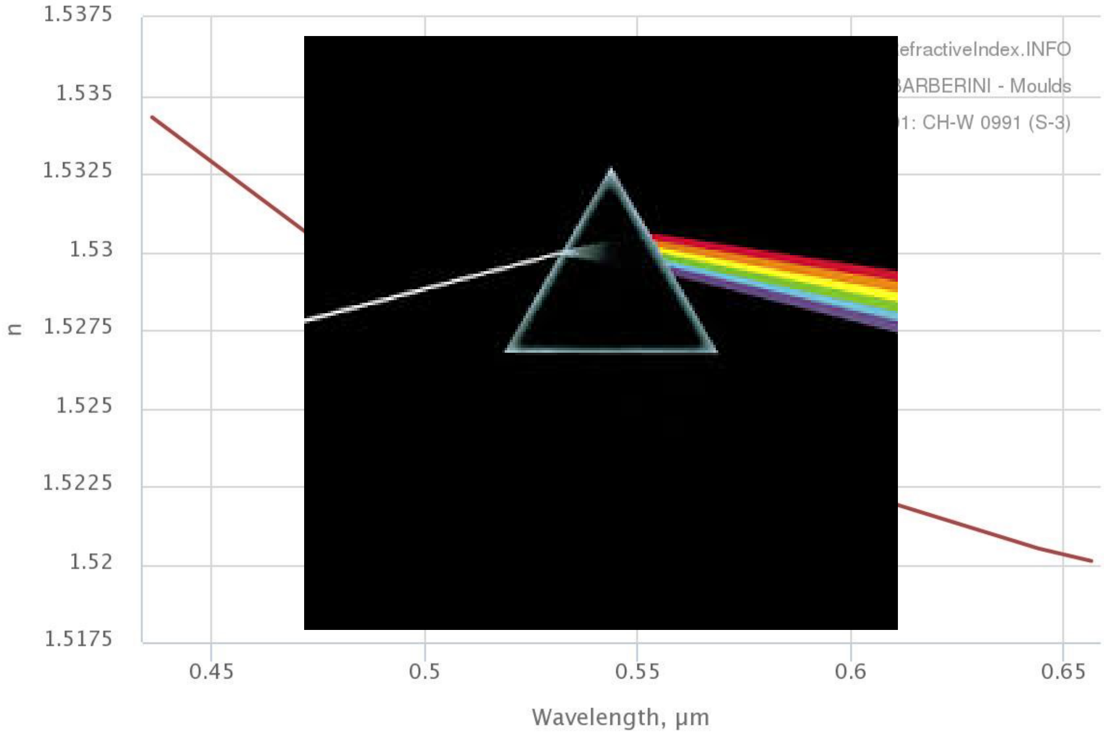
Accommodation Amplitude (Dpt) vs. Age



Dispersion

- n actually n(λ) – different colors see different index of refraction





Dispersion through lenses

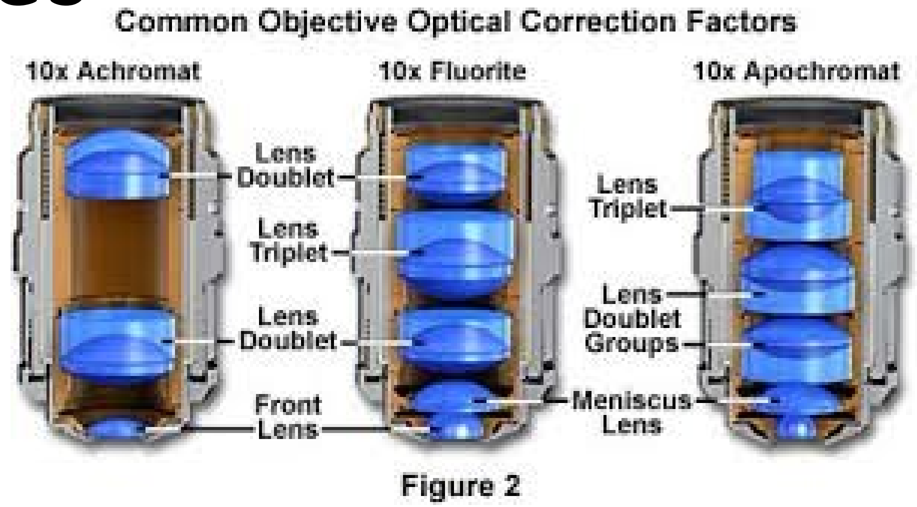
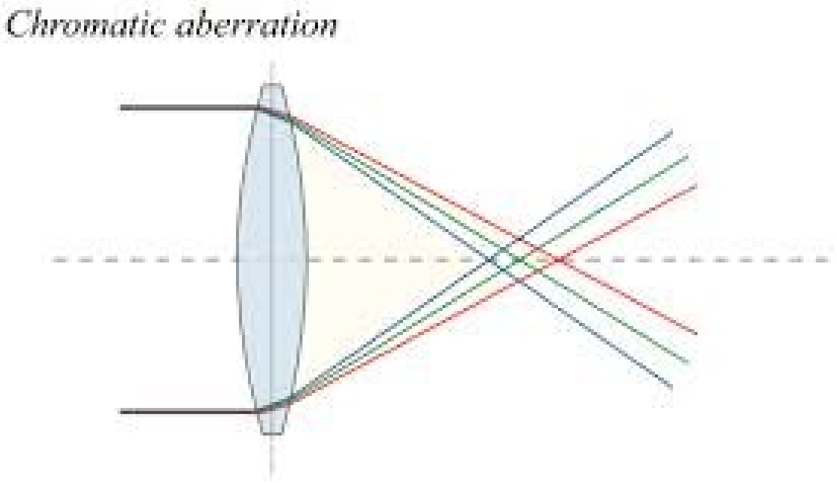
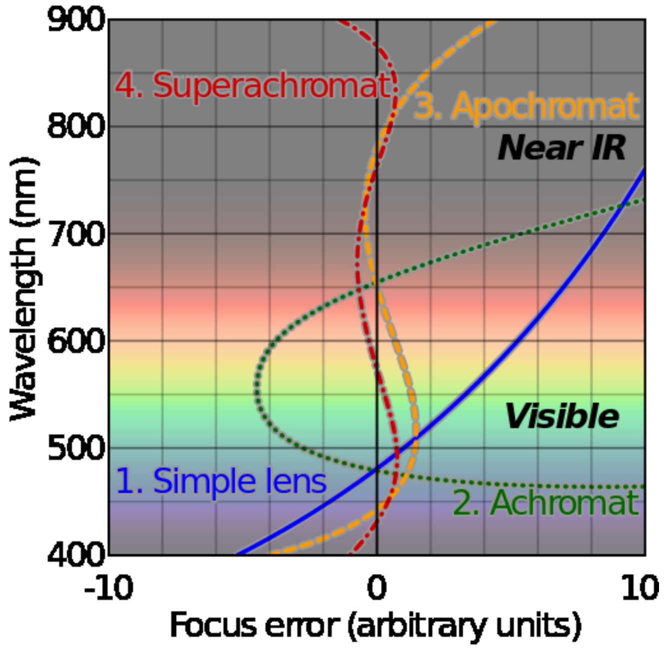


Figure 2



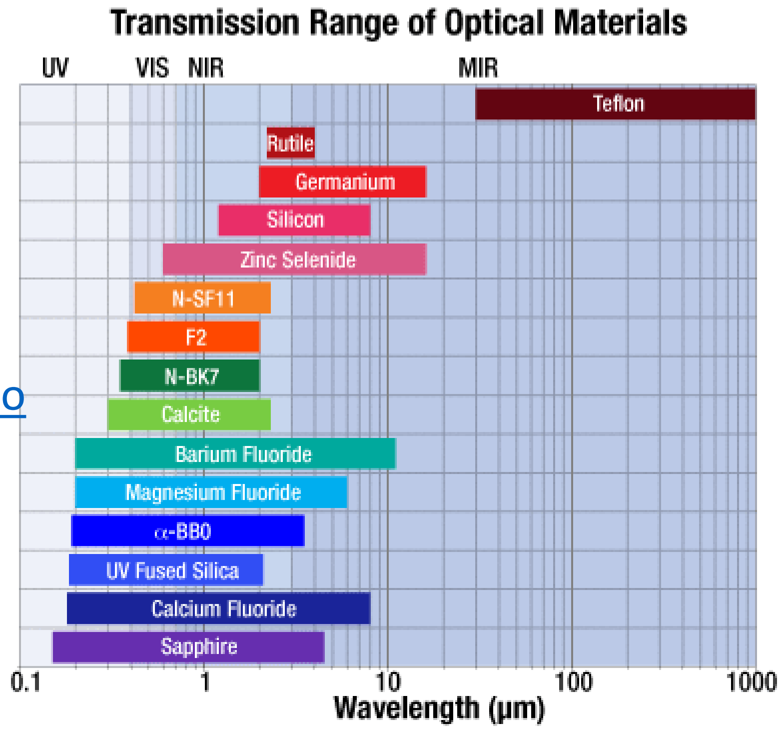


Low dispersion glass – thorium dioxide
Lanthanum oxide

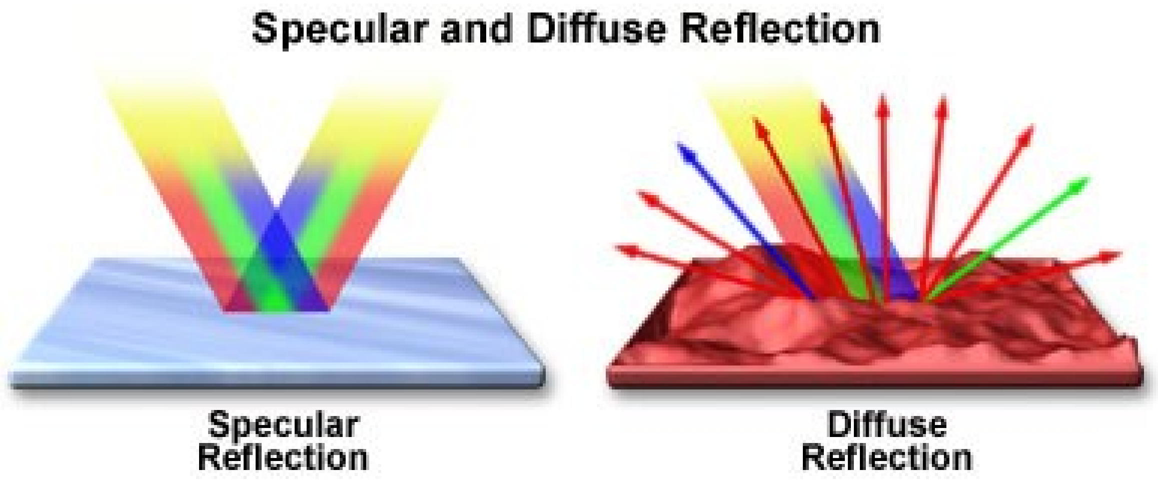
Different types of glass

- **Substrates**
  - α-BBO
  - Barium Fluoride (BaF_2)
  - Calcite ($CaCO_3$)
  - Calcium Fluoride (CaF_2)
  - F2
  - Germanium (Ge)
  - Magnesium Fluoride (MgF_2)
  - N-BK7
  - N-SF11
  - Rutile (TiO_2)
  - Sapphire (Al_2O_3)
  - Silicon (Si)
  - Teflon®
  - UV Fused Silica (UVFS)
  - Zinc Selenide (ZnSe)

- Physical Properties
  - Knoop Hardness
  - Moduli Introduction
  - Young's Modulus
  - Shear Modulus
  - Bulk Modulus
  - Poisson's Ratio
  - Relationship of Moduli and Poisson's Ratio

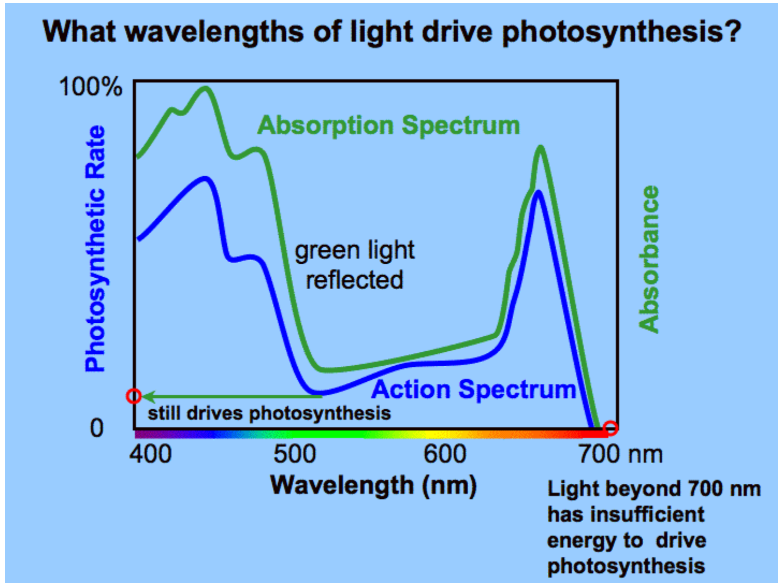


Absorption and reflection

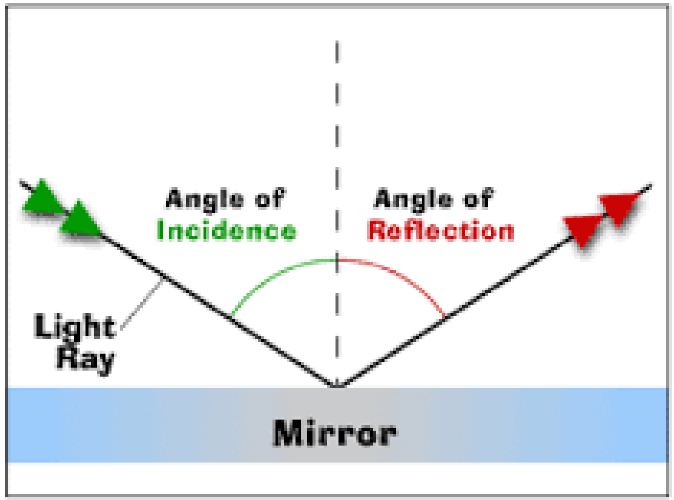


Absorption is inversely correlated with the color we actually see

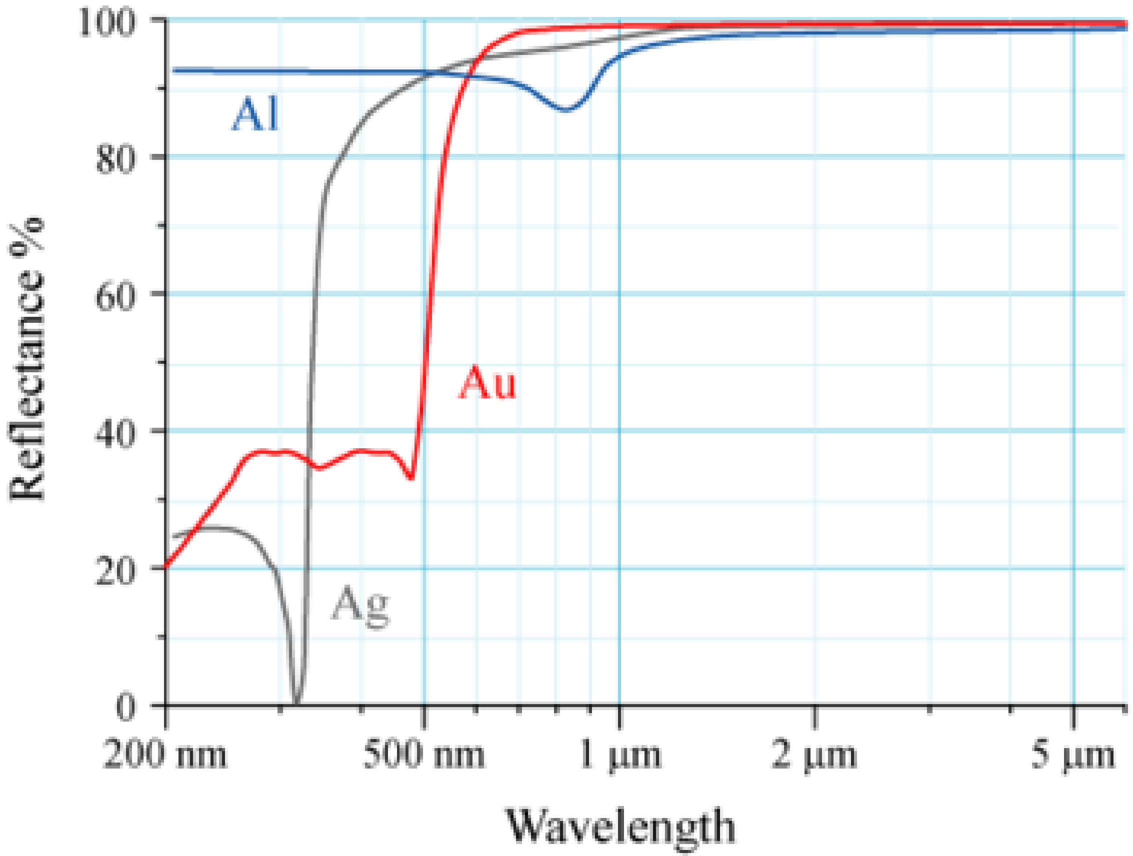
Energy (hc/λ) is converted to electronic excitations, which are then lost to vibrations and heat



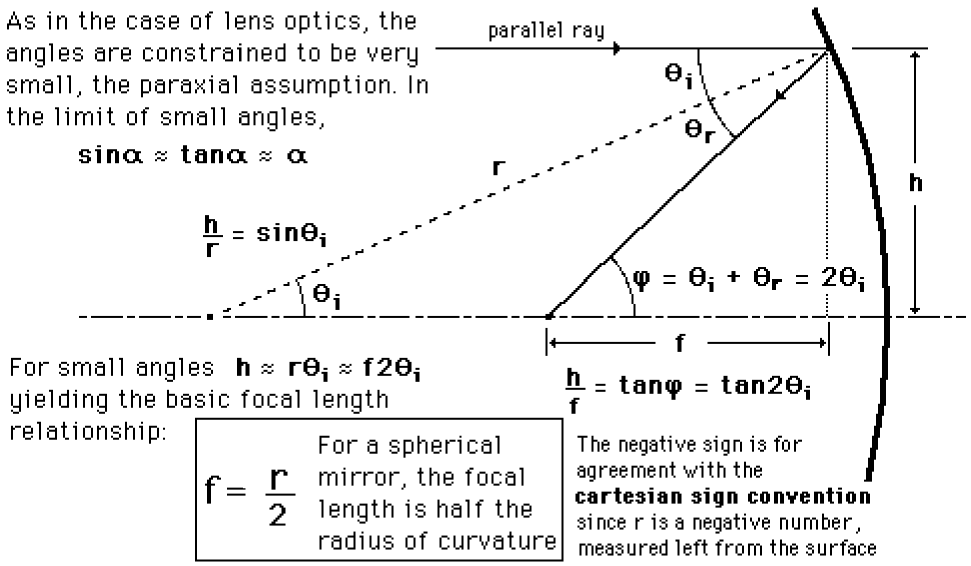
Reflection



$\sin(\theta_1) = \sin(\theta_2)$



Curved mirrors can form images



As in the case of lens optics, the angles are constrained to be very small, the paraxial assumption. In the limit of small angles,

$$\sin\alpha \approx \tan\alpha \approx \alpha$$

$$\frac{h}{r} = \sin\theta_i$$

For small angles $h \approx r\theta_i \approx f2\theta_i$ yielding the basic focal length relationship:

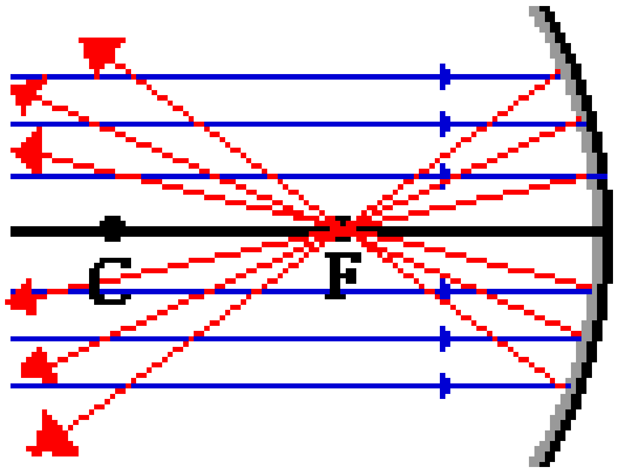
$$f = \frac{r}{2}$$

For a spherical mirror, the focal length is half the radius of curvature

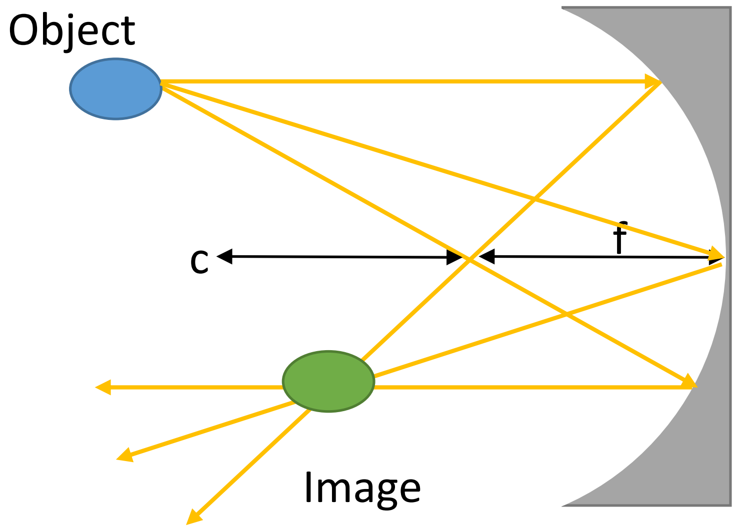
$$\frac{h}{f} = \tan\varphi = \tan 2\theta_i$$

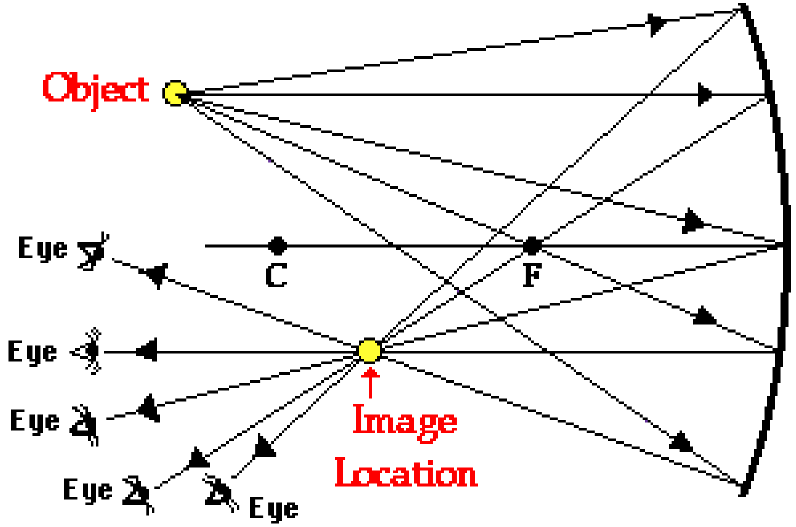
The negative sign is for agreement with the **cartesian sign convention** since r is a negative number, measured left from the surface

All rays of collimated beam pass through focal point



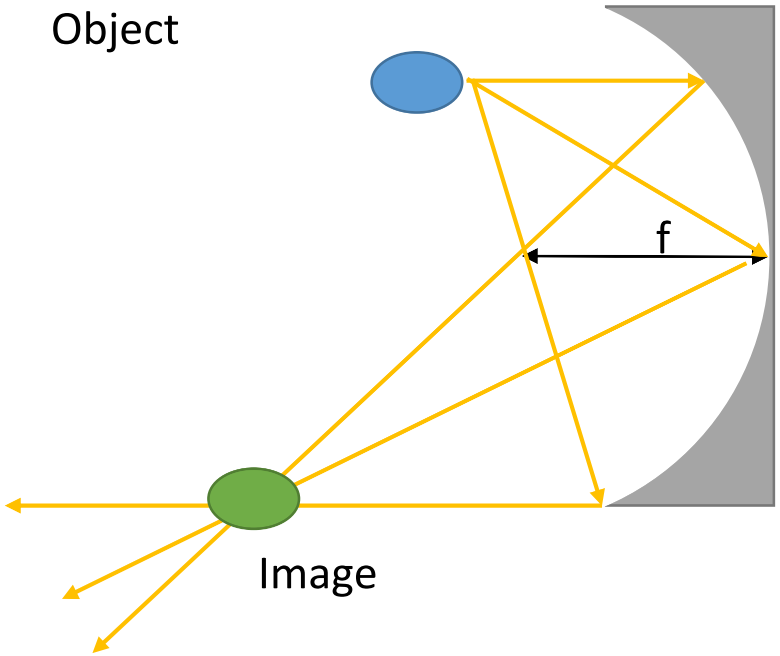
Ray tracing with mirrors

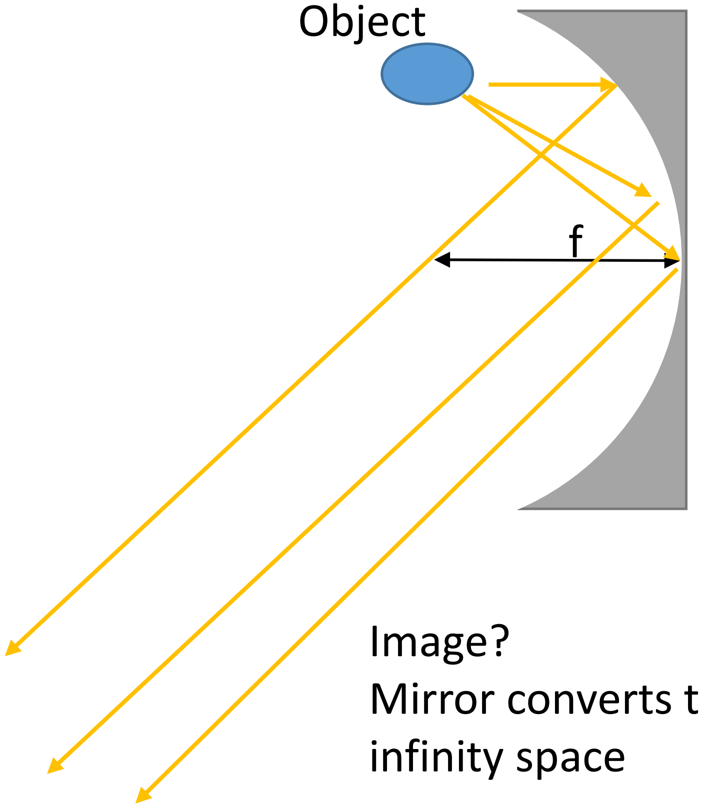




To see the image, have to line up your eye with one of the diverging rays

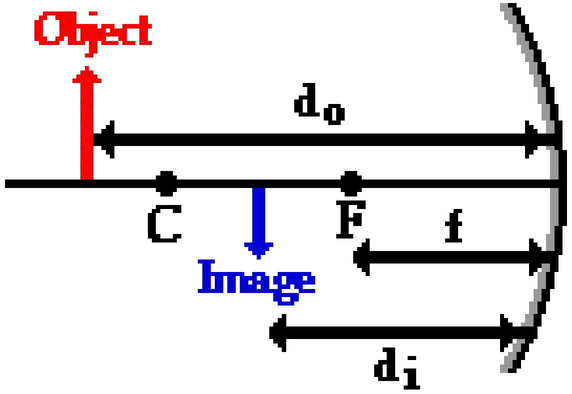
Moving object towards mirror





Image?
Mirror converts to
infinity space

Mirror equation

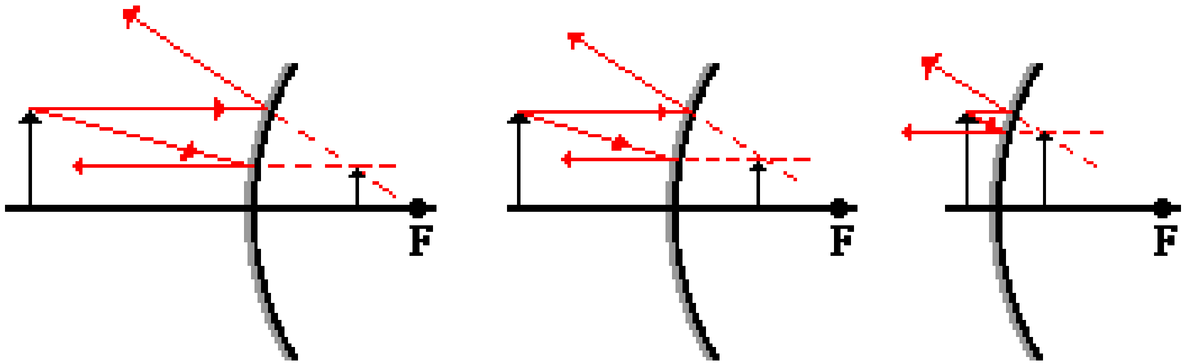


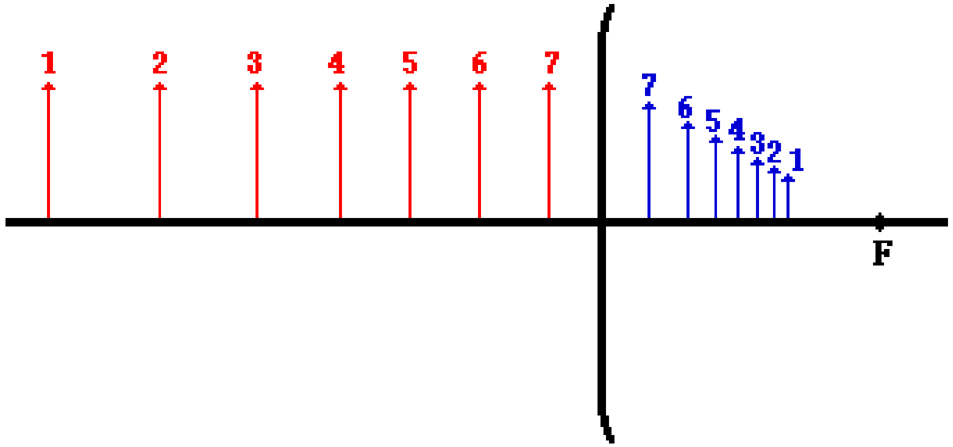
$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

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

- f is + if the mirror is a concave mirror
- f is - if the mirror is a convex mirror
- d_i is + if the image is a real image and located on the object's side of the mirror.
- d_i is - if the image is a virtual image and located behind the mirror.
- h_i is + if the image is an upright image (and therefore, also virtual)
- h_i is - if the image an inverted image (and therefore, also real)

Convex mirrors





It does not matter where you put the object, it will always be upright and virtual

This is unlike imaging with the diverging lens

Benefits of imaging with mirrors:

- No diffraction means no chromatic aberrations
- Reflections can be much larger than transmissions

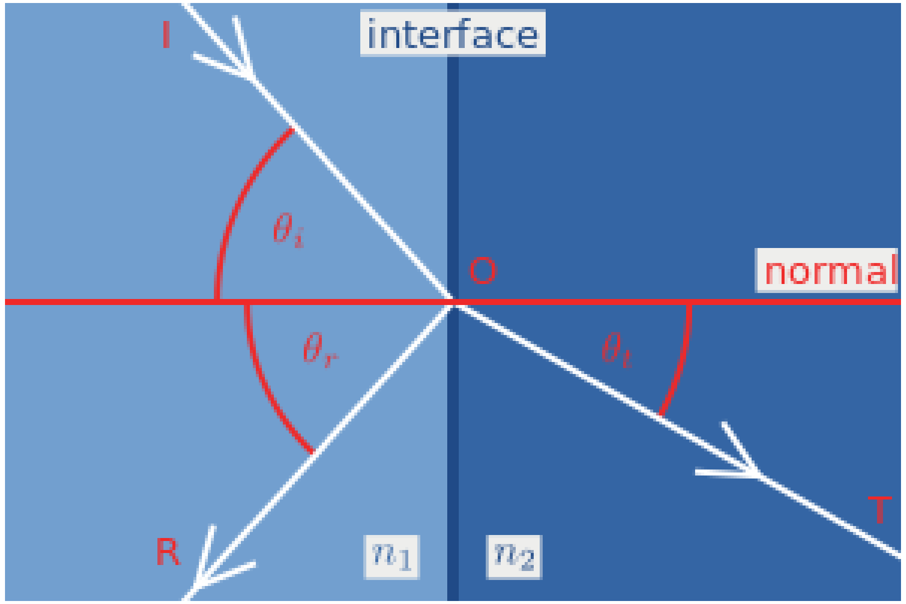
Reflection from glass

Refraction

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$$

Reflection

$\sin\theta_i = \sin\theta_r$

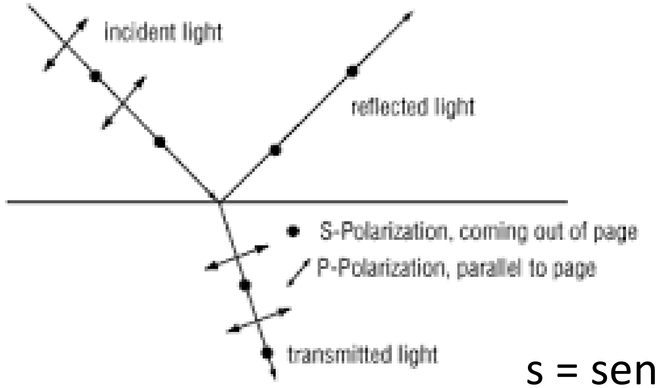


Amount reflected given by Fresnel equations

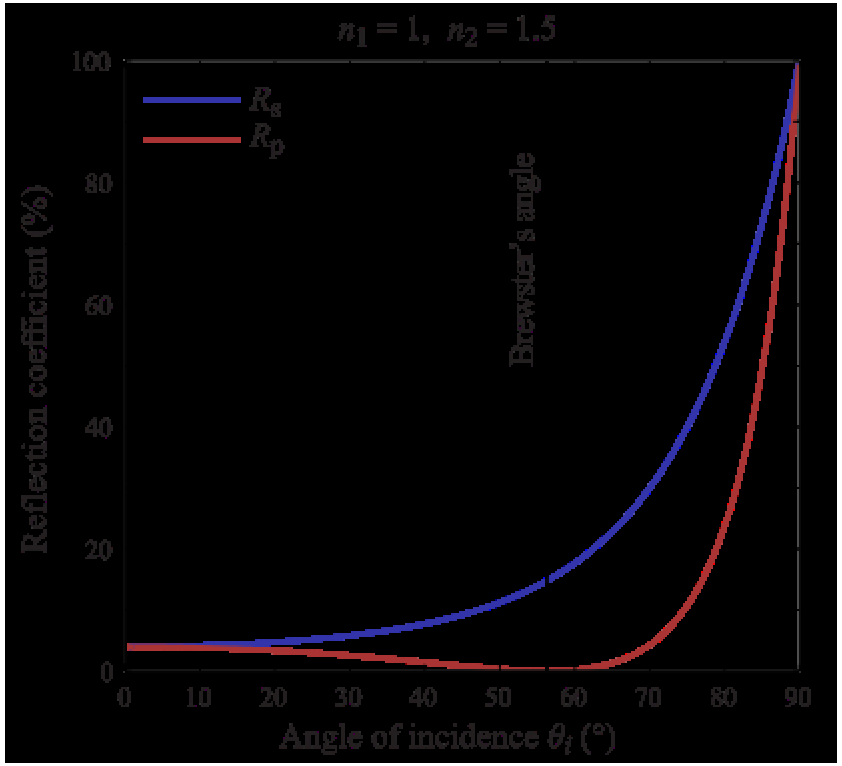
p = parallel to plane of incidence

$$R_{\mathrm{p}} = \left|\frac{n_1\cos\theta_{\mathrm{t}} - n_2\cos\theta_{\mathrm{i}}}{n_1\cos\theta_{\mathrm{t}} + n_2\cos\theta_{\mathrm{i}}}\right|^2 = \left|\frac{n_1\sqrt{1-\left(\frac{n_1}{n_2}\sin\theta_{\mathrm{i}}\right)^2} - n_2\cos\theta_{\mathrm{i}}}{n_1\sqrt{1-\left(\frac{n_1}{n_2}\sin\theta_{\mathrm{i}}\right)^2} + n_2\cos\theta_{\mathrm{i}}}\right|^2.$$

$$R_{\mathrm{s}} = \left|\frac{n_1\cos\theta_{\mathrm{i}} - n_2\cos\theta_{\mathrm{t}}}{n_1\cos\theta_{\mathrm{i}} + n_2\cos\theta_{\mathrm{t}}}\right|^2 = \left|\frac{n_1\cos\theta_{\mathrm{i}} - n_2\sqrt{1-\left(\frac{n_1}{n_2}\sin\theta_{\mathrm{i}}\right)^2}}{n_1\cos\theta_{\mathrm{i}} + n_2\sqrt{1-\left(\frac{n_1}{n_2}\sin\theta_{\mathrm{i}}\right)^2}}\right|^2,$$

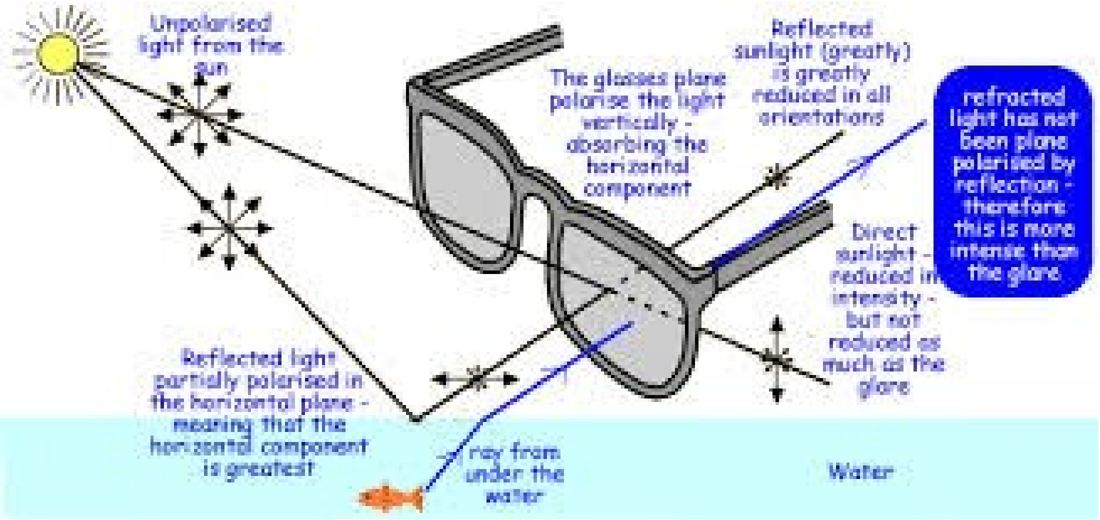


s = senkrecht to plane of incidence



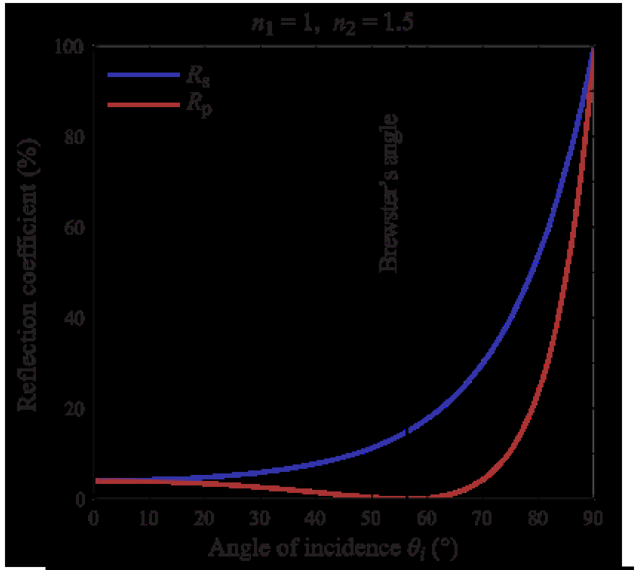
Brewster angle = 100% transmission of p-polar light

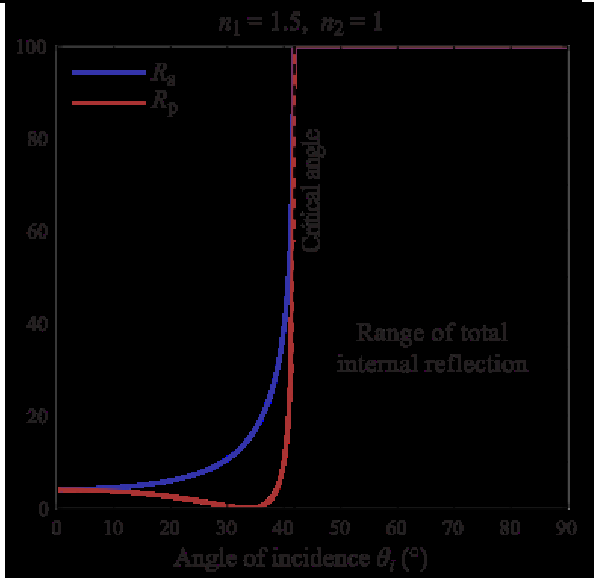
Reflected light is mostly s-polar



Polarizer allows light of only 1 polarization to get through

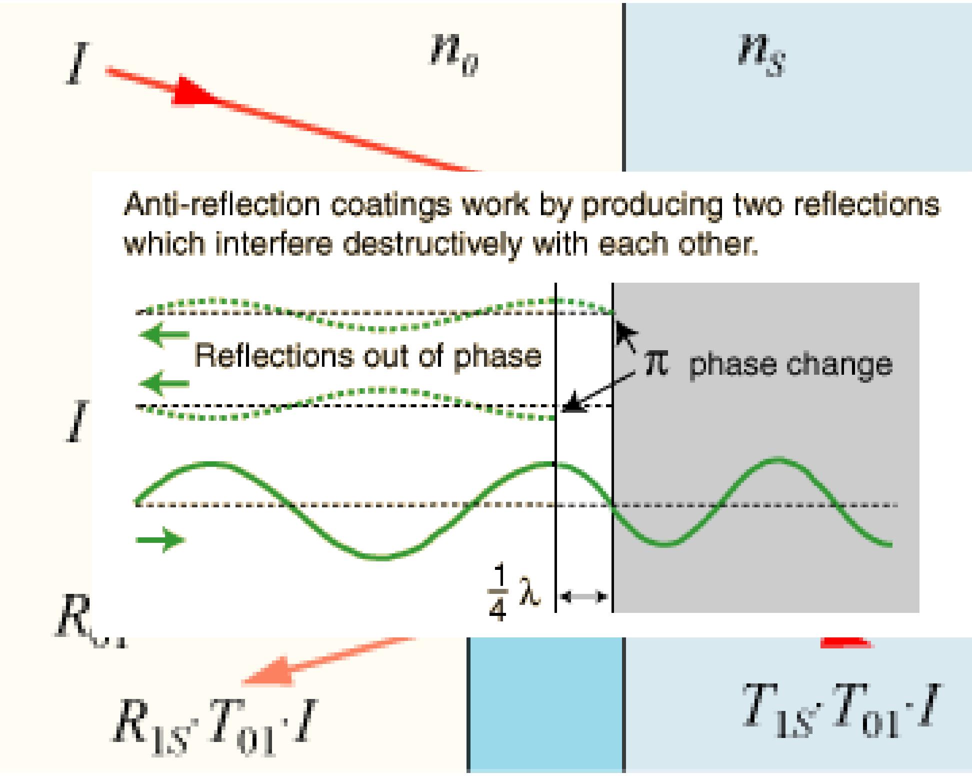
Anti-reflection coatings





Even at normal incidence, glass reflects ~4% of light

Apply coating with n in between air and glass



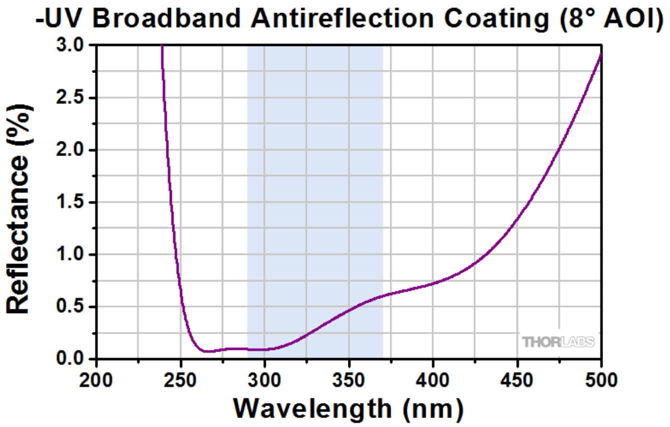
Anti-reflection coatings work by producing two reflections which interfere destructively with each other.

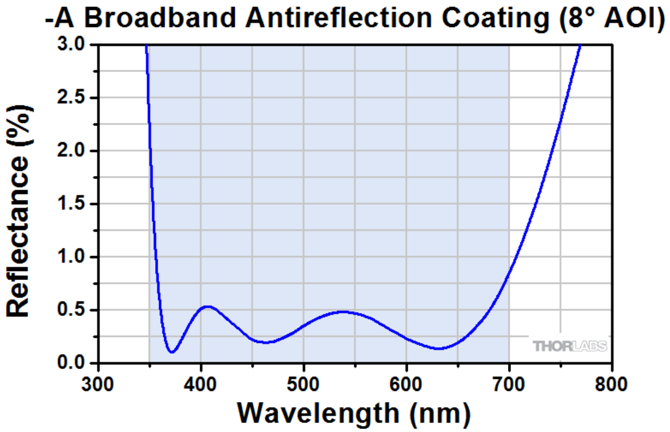
$$n_1 = \sqrt{n_0 n_S}$$

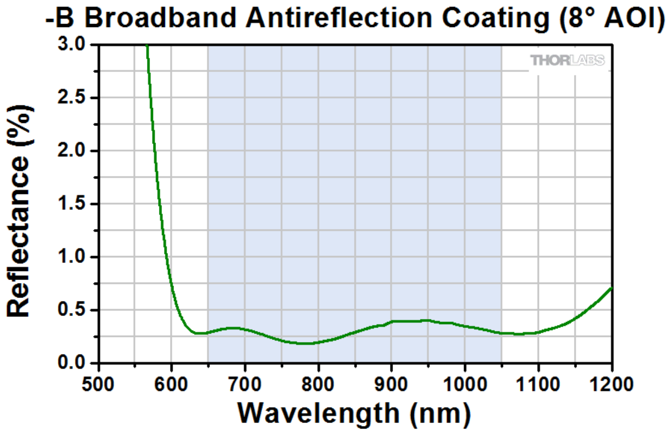
One coat of proper index takes reflection 4% -> 2%

Set thickness = $\lambda/4$

Real world anti-reflective coatings


-UV Broadband Antireflection Coating (8° AOI)


-A Broadband Antireflection Coating (8° AOI)


-B Broadband Antireflection Coating (8° AOI)

On to Matlab…