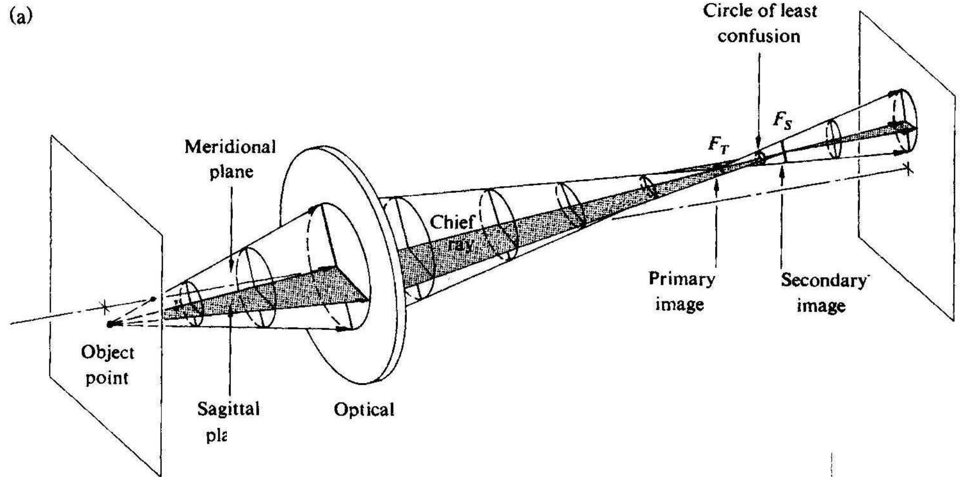
Phys 2310 Mon. Oct. 27, 2017
Today's Topics

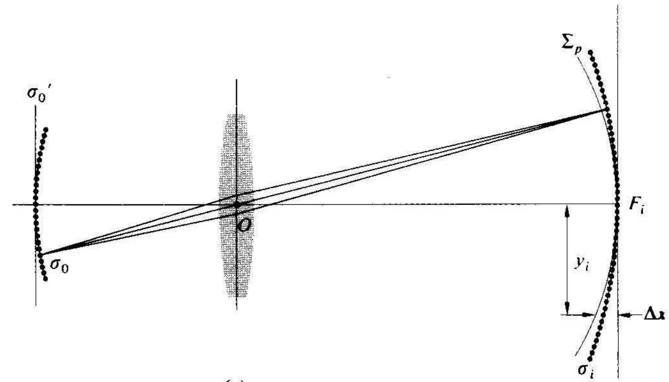
- **Finish Third-Order Optical Aberrations**

Supplemental: Optical Aberrations

- **Astigmatism**
  - Broken symmetry of off-axis objects results in different focal planes.
  - Tangential Plane cuts through the lens in the off-axis direction of an object.
  - Sagittal Plane cuts through the lens perpendicular to the off-axis direction.
  - The two focal planes are curved but by differing amounts (see diagrams)

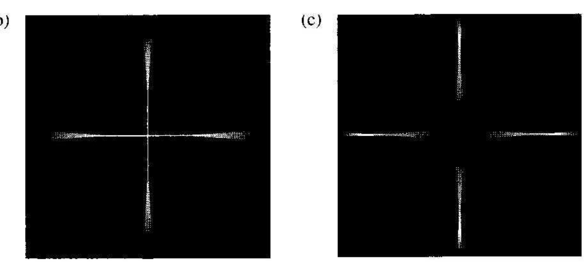
(a)





(a)

(b) (c)



Supplemental: Optical Aberrations

- **Astigmatism**
  - **Third-order theory for a single refracting surface gives:**

$$\frac{n\cos^2\varphi}{s} + \frac{n'\cos^2\varphi'}{s_T'} = \frac{n'\cos\varphi' - n\cos\varphi}{r}$$

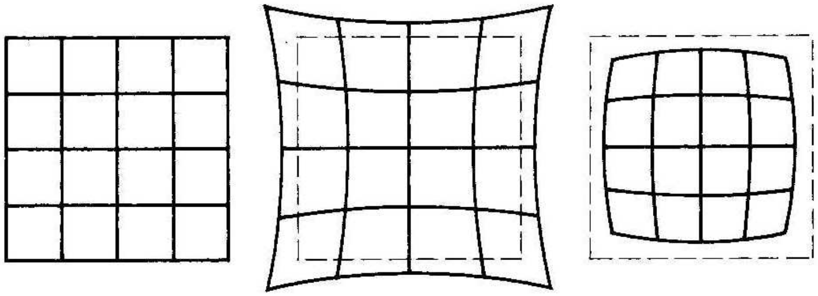
$$\frac{n}{s} + \frac{n'}{s_s'} = \frac{n'\cos\varphi' - n\cos\varphi}{r} \quad \text{vs.} \quad \frac{n}{s} + \frac{n'}{s_s'} = \frac{n' - n}{r} \quad \text{for 1-st order}$$

- **The effects of multiple surfaces can be computed by summing over each surface.**

Supplemental: Optical Aberrations

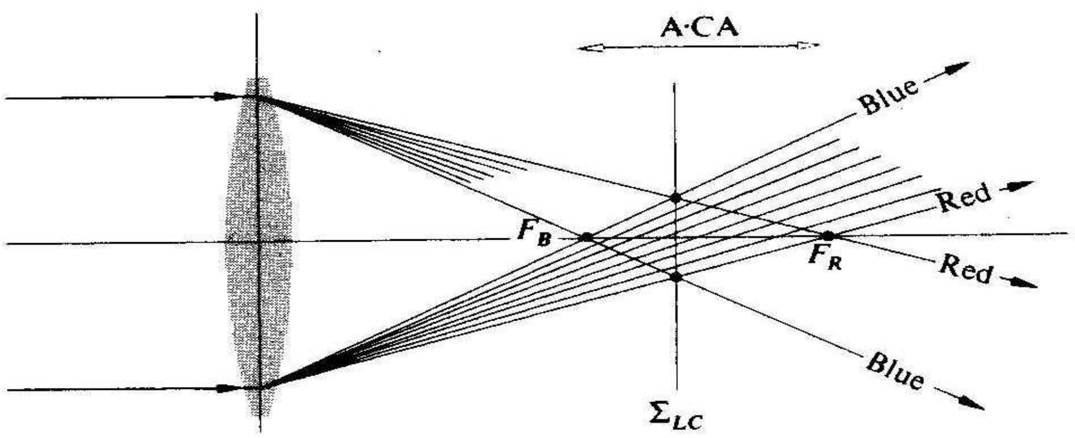
- **Field Curvature**
  - In general, images of off-axis objects will be formed on a spherical (Petzval) surface.
  - There is always a Tangential and Sagittal surface
  - Shape can be controlled via stops and higher-order effects

- **Distortion**
  - Results from non-uniform magnification for off-axis objects
    - Pincoushion distortion (mag increases with off-axis angle)
    - Barell distortion (mag decreases with off-axis angle)



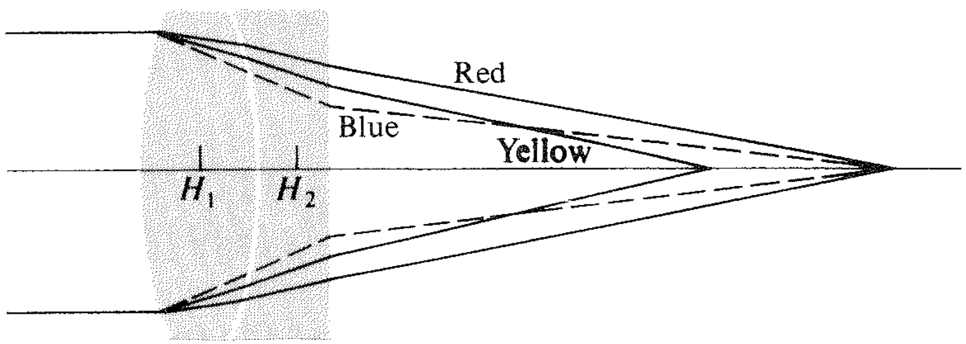
Supplemental: Optical Aberrations

- **Chromatic Aberration**
  - Dispersion of optical material (change in index with λ) results in lenses with chromatic aberration
  - Positive lenses have positive chromatic aberration
  - Negative lenses have negative chromatic aberration
  - A combination of positive and negative lenses with differing index and dispersions can be used to minimize chromatic aberration (achromatic doublet)



Supplemental: Designing an Achromat

- **Consider an Achromatic Doublet**
  - **Choose positive and negative lens focal lengths so combo has a non-zero focal length.**
  - **Choose dispersions of glasses to cancel at two wavelengths, e.g. blue and red.**



$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2} \text{ and since:}$$

$$\frac{1}{f_1} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (n-1)\rho_1 \text{ we have:}$$

$$\frac{1}{f} = (n_1 - 1)\rho_1 + (n_2 - 1)\rho_2 \text{ (d} \sim 0\text{, thin lens)}$$

If we require equality for Blue and Red light:

$$(n_{1B} - 1)\rho_1 + (n_{2B} - 1)\rho_2 = (n_{1R} - 1)\rho_1 + (n_{2R} - 1)\rho_2$$

or:

$$\frac{\rho_1}{\rho_2} = -\left(\frac{n_{2B} - n_{2R}}{n_{1B} - n_{1R}}\right)$$

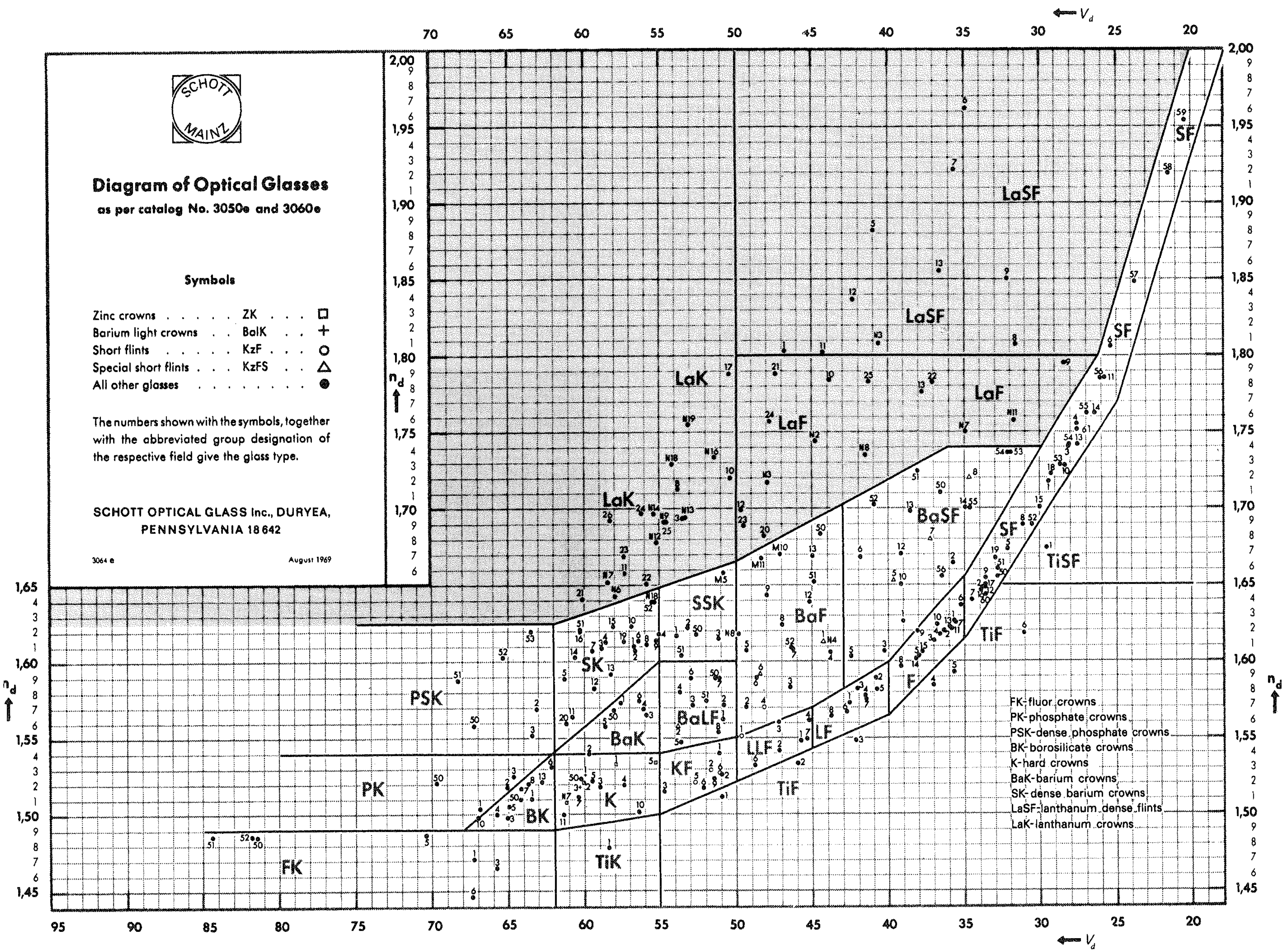
For intermediate wavelengths (yellow):

$$\frac{1}{\mathrm{f}_{1y}} = (n_{1y} - 1)\rho_1 \text{ and } \frac{1}{\mathrm{f}_{2y}} = (n_{2y} - 1)\rho_2 \text{ so:}$$

$$\frac{\mathrm{f}_{2y}}{\mathrm{f}_{1y}} = -\frac{(n_{2B} - n_{2R})/(n_{2y} - 1)}{(n_{1B} - n_{1R})/(n_{1y} - 1)} \text{ or:}$$

$$\frac{\mathrm{f}_{2y}}{\mathrm{f}_{1y}} = -\frac{V_1}{V_2} \text{ (V is dispersive power of the glass)}$$

Supplemental: Dispersive Properties of Optical Glass



Supplemental: Designing an Achromat cont.

Now if we choose the Sodium d-line for yellow light:

$f_{1\mathrm{d}}V_{1d} + f_{2d}V_{2d} = 0$ and since:

$\frac{1}{f_{1d}} + \frac{1}{f_{2d}} = \frac{1}{f_d}$ we can combine them:

$\frac{1}{f_{1d}} = \frac{V_{1d}}{f_d(V_{1d} - V_{2d})}$ and also:

$$\frac{1}{f_{2d}} = \frac{V_{2d}}{f_d(V_{1d} - V_{2d})}$$

Note that $(V_{1d} - V_{2d})$ is chosen to be large, ~ 20.

Procedure is to:

1) select the focal length of the combination,

2) select the glass types $(V_{1d} - V_{2d})$,

3) compute the focal lengths of each lens (f_{1d}, f_{2d}),

4) select a design type (Fraunhofer: $R_1 = -R_2 = -R_3$)

and then compute radii $(R_{11}, R_{12}, R_{21}, R_{22})$

5) Now enter preliminary design into optical design software for optimization.