OPTI340, Spring 2009
Design Project 2

Due: February 6, 2009

Design Project 2: Chromatic Aberration (CA)

This design project explores chromatic aberration and the use of different glasses to mitigate chromatic aberration. You will be looking at two different lens configurations: a singlet (A), and a doublet (B). The first-order specifications for these configurations are given below. Set five field angles for each configuration (H= 0.0, 0.5, 0.7, 0.85, 1.0). The object will be located at infinity. Define the Entrance Pupil Diameter (EPD) to produce an F/6 lens.

Configuration	**F/number**	**EFL**	**Semi-FOV**	**Spectrum**	**Weighting***
A(singlet)	6	150.0mm	1.0˚	d,F,C	2, 1, 1
B(doublet)	6	150.0mm	1.0˚	d,F,C	2, 1, 1

*Weighting: **C**-656.2725: 1; **d**-587.5618: 2; **F**-486.1327: 1

Table 1. First-order design constraints

Design/Analysis Tasks:

1. Design a plano-convex singlet lens using different glasses that satisfy the first-order constraints using different glass types
    - Schott N-BK7
    - Schott N-SF8

    Determine the radius of curvature of the lens surface for each glass type using a lens center thickness of 6mm. Use CODE V to design your singlet and use a paraxial image solve in your design.

    Include the following in your optimization function:
    - Use *constraints only solution*
    - *Effective focal length* = 150
    - *Axial color* = 0.0
- Provide a layout, a ray aberration diagram, field curve plot, and prescription for each of these lenses
- What is the longitudinal axial color of each lens?
    - Hint generate a *Field Curves* plot with *longitudinal spherical aberration.*
- How does the longitudinal axial color (LCH) compare to the quantity:
  $L'_{ch} = -f/\nu$
  Where f = focal length of lens
  ν = Abbe number of glass
- What is the third-order transverse spherical aberration of each lens?
- Which glass would you use if you wanted to generate the best image of a star?

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As you've learned in class, axial chromatic aberration occurs when different colors of light focus at different axial locations and results in the blurring of the image of a polychromatic point source. Fortunately, by using first-order optics we can determine the specific glasses that will help us achromatize or focus the red and blue light to the same plane.

2. Design a cemented achromatic doublet. This lens consists of two lenses, a positive power lens and a negative power lens, that are cemented together. We will use Schott N-BK7 for the positive lens (CT=6mm). The second negative lens (CT=4mm) will be selected from the following:
    - Schott N-PSK53
    - Schott N-KF9
    - Schott N-SF8
    - Schott N-SF6

   Using what you've learned about the Abbe number of different glass type, select from the above list the two most likely glass candidates that will provide achromatic correction. Show how you arrived at your selection

   Now use CODE V to 'optimize' the cemented doublet by correcting only the focal length and axial color and by making your positive lens bi-convex (R1 = -R2). Your only variables should be the first and last surfaces of the doublet. After optimization which glass combination yields the best performing cemented doublet?

   Include the following in your optimization function:
    - Use *constraints only solution*
    - *Effective focal length* = 150
    - *Axial color* = 0.0

   Examine the ray fan diagram and the field curves (including longitudinal spherical aberration) plots of your achromatic doublet. What features in these plots indicate to you that your doublet is achromatized for the red and blue wavelengths?

   - Provide a 3D-layout, a ray aberration diagram, field curve plot and prescription for your achromat
   - What is the <u>longitudinal</u> axial color of your achromat?
   - How does the longitudinal axial color (LCH) compare to that produced by your singlets?
   - Compare your value for LCH with the rule of thumb for an achromatic doublet where the LCH is approximately given as:

     $L'_{ch\ ach} = -f/2400$

     Where f = focal length of lens

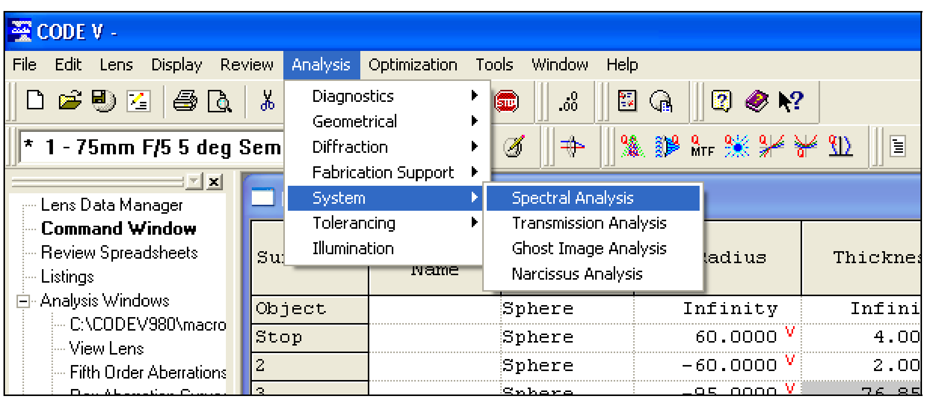
3. Spectral Analysis

In this project we've been investigating the role chromatic aberration has on the complexity of a lens design. Specifically how much should be color be corrected and how can we balance complexity (i.e. number of lenses, different glasses) and still achieve acceptable performance. An important concept to understand and implement in the lens design process is *spectral weighting*. In Table 1, we defined the spectral weighting for C, d, F as 1,2,1. Why? This weighting is defined by convention based on the applications that involve the spectral response of the human eye. Choosing glass types to correct chromatic aberrations are a very important part of lens design. Recall in Design Project 1, a "Photopic 5-wl" spectrum was used to represent the photopic or daylight response of the human eye.

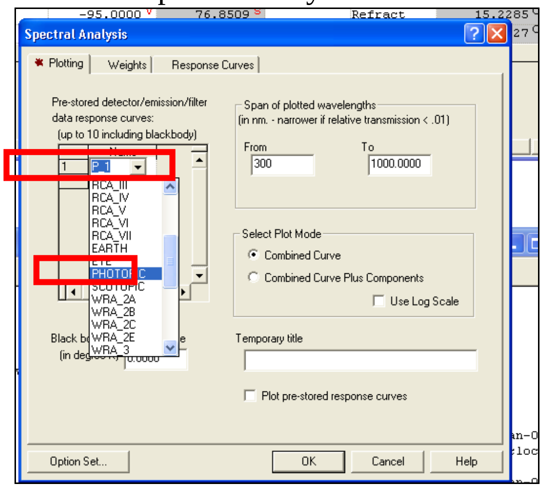
Specifically when designing an optical system, we need to consider the lighting source along with the detector response to determine how important or how much "weight" we need to place on chromatic correction.

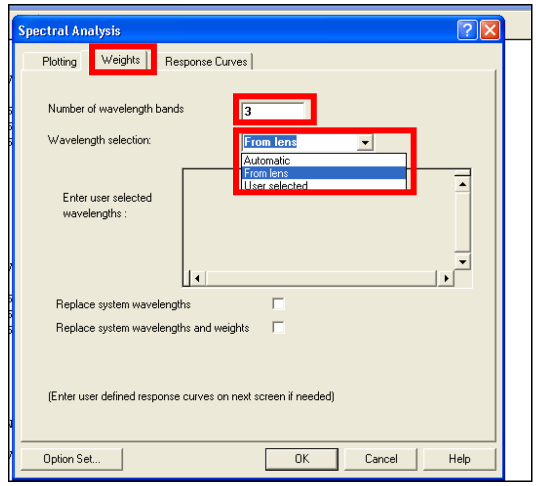
CODE V has a handy feature, *Spectral Analysis*, that allows the designer to define and use a spectral weighting consistent with the lens design's intended application. The d, F, C spectrum that you are currently using is historically traceable to Schott Glass Works. The wavelengths denoted represent wavelengths in the visible spectrum that were historically easy to produce so that the refractive index of glasses could be precisely measured. For example d-light is the yellow helium line, C-light is the red hydrogen line, and F-light is the blue hydrogen line.

As for why a 1:2:1 weighting is suggested, we need to look at the human eye response (detector) under normal or daylight conditions. This is known as the *photopic* response. CODE V can display this response using *Spectral Analysis* and can be accessed via the menus:



Selecting Spectral Analysis will bring up the "Spectral Analysis" window with the Plotting tab active. Double left mouse click on the "P_1" response box to reveal another menu of stored spectral responses. Select "Photopic" response as your detector. Also, define a blackbody color temperature of 6000K as your source. Select "Combined curve Plus Components" as the plot mode. Now go to the "Weights" tab.. Modify the "Number of wavelength bands" to 3 and change "Wavelength selection" to "From lens" then select "OK" to run the spectral analysis.





Tab 1 will display a plot of the spectral response as a function of wavelength while the "Text" tab will display the calculated spectral weighting based on this spectra and other parameters you've set on the "Weights" tab.

Generate a spectral response graph for your report and describe what a more appropriate spectral weighting for the photopic response is for the d, F, C spectrum.

- What three wavelengths would you use to represent a true 1:2:1 weighting of the photopic response?
- Do you think the 1:2:1 weighting of the d, F, C' spectrum is representative of the photopic response? Explain.
- How would your wavelength weighting change for d, F, and C' change if a RCA Type I response is used in place of the photopic resonse?