PHY 431 Homework Set #4

Due October 13 at the start of class

1) *Convex-Plano vs. Plano-Convex lens (25%)*

The rays incident on the outer edge of a lens (outside of the paraxial regime) suffer from spherical aberration. This is because the nonparaxial rays are too strongly bent. Consider the plano-convex lens as seen above. Depending on which surface faces the incident rays, the amount of spherical aberration can be reduced. In this problem, you will decide which lens configuration is better in terms of spherical aberration.

a. Find the focal length of the lens in the paraxial regime.
b. Let's assume we have a ray parallel to the optical axis incident on the lens as shown above. Calculate where the ray crosses the optical axis (L'). Neglect the thickness of the lens. (Hint: You will use Snell's law twice)
c. Now flip the lens around so light is incident on the planar side. Repeat parts (a) and (b). (Hint: You will use Snell's law only once)
d. Which one is better in terms of spherical aberration? (Hint: compare the focal length obtained in (a), (b), and (d))

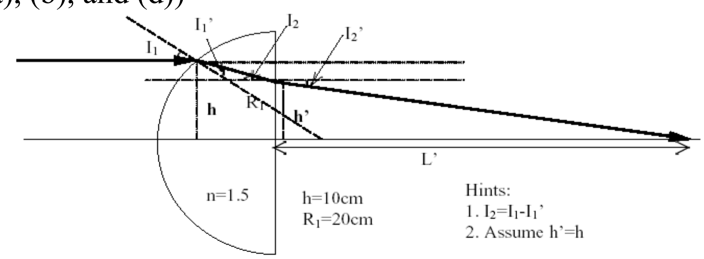
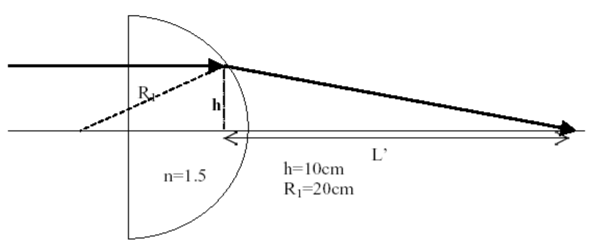
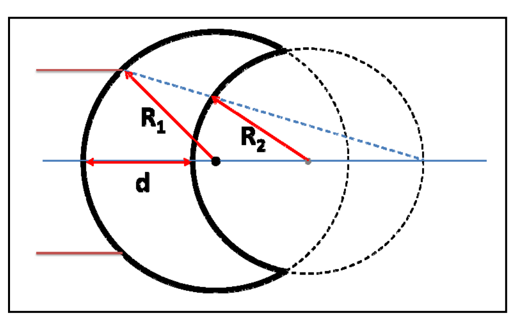


Fig.1-(a)



2) ***Thick Lens*** (Read Hecht Ch. 6.1) (20%)

[Hecht 6.9] A thick glass lens of index 1.50 has radii of *+23 cm* and *+20 cm*, so that both vertices are to the left of the corresponding centers of curvature. Given that the thickness is *9.0 cm*, find the focal length of the lens. Show that in general $R_1-R_2=d/3$ for such afocal zero-power lenses. Draw a diagram showing what happens to an axial incident parallel bundle of rays as it passes through the system. (Hint: (a) Use the lens maker's formula for a thick lens and check f=?, (b) afocal: describing an optical system in which an image is transferred without bringing it to a focus such as a telescope.)



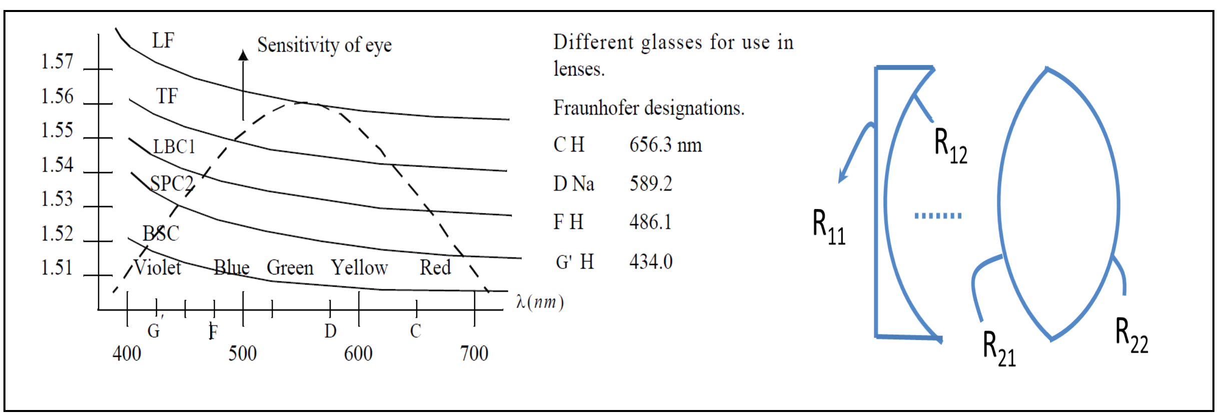
3) *Achromatic Doublet Lens (25%)*

Table : REFRACTIVE INDICES OF TYPICAL OPTICAL MEDIA FOR FOUR COLORS

Medium	Designation	ICT type	ν	n_C	n_D	n_F	$n_{G'}$
Borosilicate crown	BSC	500/664	66.4	1.49776	1.50000	1.50529	1.50937
Borosilicate crown	BSC-2	517/645	64.5	1.51462	1.51700	1.52264	1.52708
Spectacle crown	SPC-1	523/587	58.7	1.52042	1.52300	1.52933	1.53435
Light barium crown	LBC-1	541/599	59.7	1.53828	1.54100	1.54735	1.55249
Telescope flint	TF	530/516	51.6	1.52762	1.53050	1.53790	1.54379
Dense barium flint	DBF	670/475	47.5	1.66650	1.67050	1.68059	1.68882
Light flint	LF	576/412	41.2	1.57208	1.57600	1.58606	1.59441
Dense flint	DF-2	617/366	36.6	1.61216	1.61700	1.62901	1.63923
Dense flint	DF-4	649/338	33.9	1.64357	1.64900	1.66270	1.67456
Extra dense flint	EDF-3	720/291	29.1	1.71303	1.72000	1.73780	1.75324
Fused quartz	SiO_2		67.9		1.4585		
Crystal quartz (*O* ray)	SiO_2		70.0		1.5443		
Fluorite	CaF_2		95.4		1.4338		

An achromatic lens is to be made of BSC (crown) and DF-2 (flint) glasses and is to have a focal length of 8.00 cm (see Table above). If the flint glass lens is to have its outer face flat and the combination is to be cemented (i.e. set $R_{11}=\infty$ and $R_{12}=R_{21}$. Since the lens is to be cemented, one surface of the negative lens must fit a surface of the positive lens). Find (a) the power of the lens, (b) the *V* values of the two glasses [consider D-line (589.2nm/Yellow) as the center of the spectrum between C-line (656.3nm/Red) and F-line (486.1nm/Blue), then V-number/Abbe number $v=\frac{n_D-1}{n_F-n_C}$], (c) the powers of the two lenses, and (d) the radii of the three curved surfaces. The lens combination is to be corrected for the C and F lines.

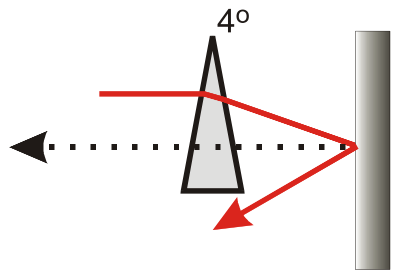
Recipe: (1) Start with desired f and P=1/f, (2) Choose the glass materials and calculate V-number, V_1 and V_2, (3) Find $P_1=1/f_1$ and $P_1=1/f_1$ (First, you need to derive $P_1=P\frac{V_1}{V_1-V_2}$ and $P_2=-P\frac{V_2}{V_1-V_2}$ by using $P=P_1+P_2$ (i.e. $\frac{1}{f}=\frac{1}{f_1}+\frac{1}{f_2}$) and $f_{1Y}\times V_1+f_{2Y}\times V_2=0$ derived in class), (4) Choose radii (here the radii are obtained by setting $R_{22}=\infty$ and $R_{21}=R_{12}$)



4) ***Prism*** (30%)

a. Derive the deviation angle for a prism immersed in liquid n_l.

b. A laser beam passes through a prism (n=1.5) immersed in liquid (n_l =1.3) is reflected by a mirror as shown in Fig. 1. How many degrees you should turn the mirror to make the reflected beam parallel to the incoming beam?



c. (*bonus point*) For immersion in water (n=1.333), design a prism that gives a deviation angle in the range of 20 to 30° for incidence at an angle of 30°. Also, make sure the reflection from the surface (for s-polarized light) from is less than 2%. Describe your design reasoning and show that your design meets specifications.