EE 119 Homework 4

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Due Tuesday, Feb 23rd 2010

(Please submit your answers in EE119 homework box located in 240 Cory Hall)

1. [Hecht 6.28] Figure P.6.28 shows the image irradiance distributions arising when a monochromatic point source illuminates three different optical systems, each having only one type of aberration. From the graphs identify that aberration in each case and justify your answer.

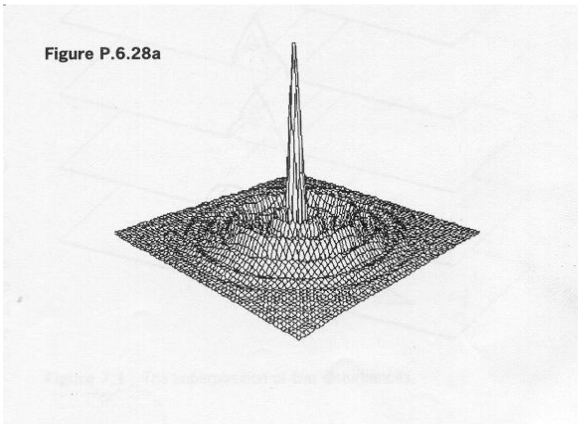

Figure P.6.28a

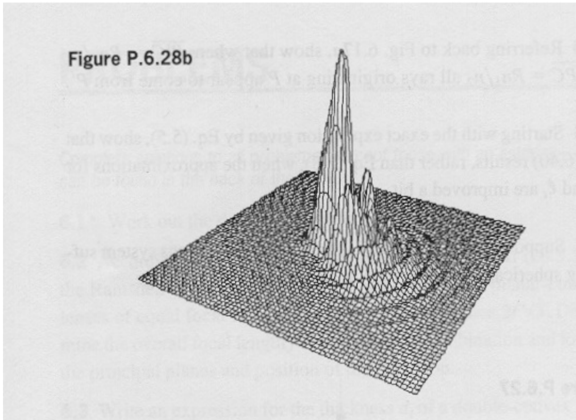

Figure P.6.28b

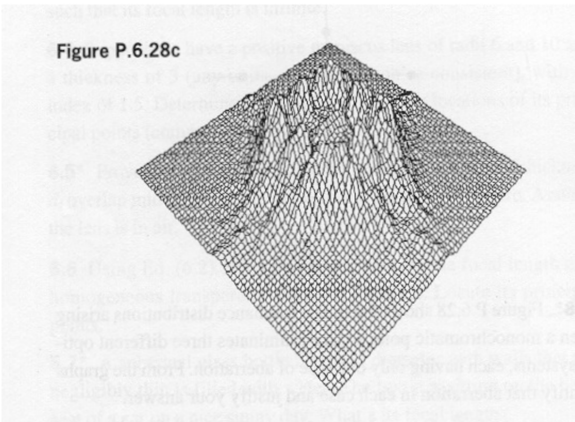

Figure P.6.28c

2. One way to construct an imaging system that is totally free of spherical aberration is illustrated in Fig. 1. The lens in the diagram consists of two spherical surfaces, of which the center of the front spherical surface F is at a distance of R/n from the center of the second spherical surface C, with R being the radius of the second spherical surface and n being the refractive index of the glass that the lens is made from. **Please show that all rays originating from point F towards the lens are refracted and focused at point G on the axis, whose distance from the center of the second surface C is equal to nR**. Since the image formed at point G from light emerging from point F is free of spherical aberration, these two points F and G are called the **aplanatic points** of this image system.

Hint: Consider an arbitrary ray FP that originates from point F, making an angle of i with the axis; using Snell's law and the ratio of FC over MC, prove that angle i' is the same as the angle i; then show that the triangle FMC is similar to the triangle MGC.

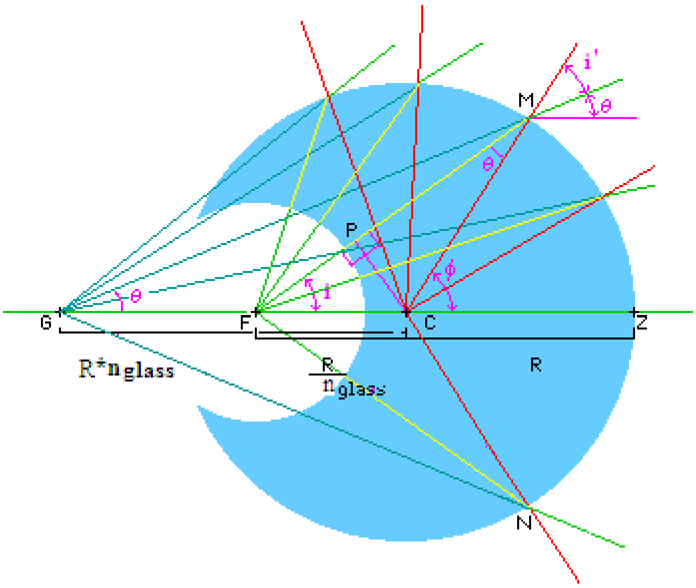

Fig. 1 Diagram for Prob 2.

3. You have a shiny broadband light source whose center wavelength is 486nm ('F' color). You want to focus its light to a point with a 12.5 cm converging lens that will minimize chromatic aberration in the region between G' and D light. So you decide to make an achromat from SPC-1 and DF-4 glasses. Refer to Table 1 for the refractive indices of the materials. The lens made of DF-4 glass should have its outer face flat, and the two lenses should be cemented, which means that the distance between them is zero and their inner radii are the same.

Table 1

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		

(a) Find the power of the lens in diopters.
(b) Find the dispersive power of the two lenses.
(c) Find the powers of the two lenses.
(d) Find the radii of the three curved surfaces.

4. Consider the following imaging system with an ideal lens and an aperture stop. Assume that the system is immersed in air.

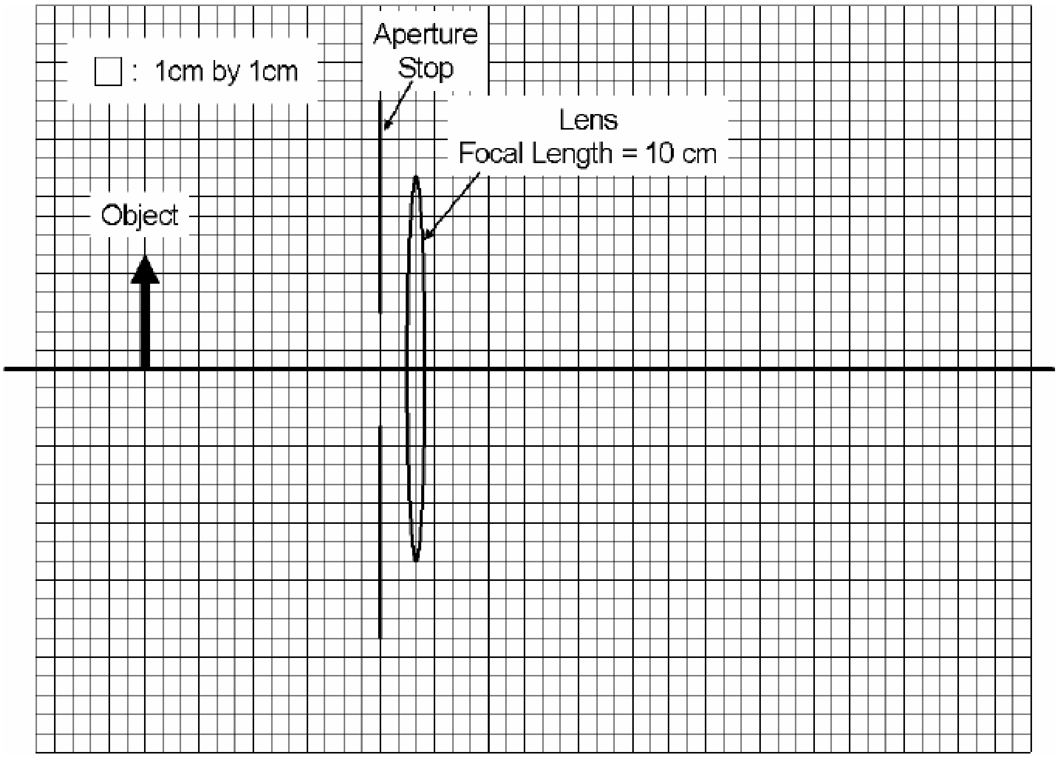

Fig. 2

(a) Find the position and size of the image formed by the system and draw it on the diagram below (Fig. 2). What is the magnification of the system?
(b) Find the position and size of the entrance pupil and draw it on the diagram.
(c) Find the position and size of the exit pupil and draw it on the diagram.
(d) Sketch in the diagram the chief ray and two marginal rays from the tip of the objects.
(e) Calculate the objective-side numerical aperture (entrance-side NA_1) of the system.
(f) Calculate the image-side numerical aperture (exit-side NA_2) of the system. Is NA_1/NA_2 equal to m, as we discussed in the lecture? If there is a discrepancy larger than 1%, explain the reason why.
(g) What is the smallest feature on the object that this imaging system can resolve according to Rayleigh's criterion? Assume that the center wavelength of the visible light is 520nm.
(h) Remove the aperture stop from the system and repeat part (b) – (f). Assume that the lens is ideal and aberration-free. Which system resolves smaller

feature, the system with the stop or the one without it? Explain the result.

5. An optical process called lithography is used for making integrated circuits. Assume the optical system has a reduction factor of 4X (makes the image 4X smaller than object).

   (a) Assuming the optical system is diffraction limited, what is the image resolution of a system that uses a DUV laser at 193nm, and $NA_{image} = 0.85$.
   (b) What is the corresponding resolution on the object side?
   (c) Qualitatively, what does this tell you about how a square object with side dimensions 400nm, and a circular object with diameter 400nm, will be imaged?
   (d) Immersion lithography has been proposed to make smaller features on integrated circuits. Immersion lithography will place water (n = 4/3) between the last optical element and the image plane. What is the new resolution of the same system from part (a)?