MASSACHUSETTS INSTITUTE OF TECHNOLOGY

2.71/2.710 Optics **Spring '14**

Problem Set #2 Posted Feb. 19, 2014 —Due Wed Feb. 26, 2014

1. **(modified from Pedrotti 18-9)** A positive thin lens of focal length 10cm is separated 5cm from a thin negative lens of focal length -10cm.

   a. Sketch your optical system to scale.

   b. Find the equivalent focal length of the composite lens, together with the position of the front focal plane, back focal plane and principal planes. You may use ray tracing or matrix methods.

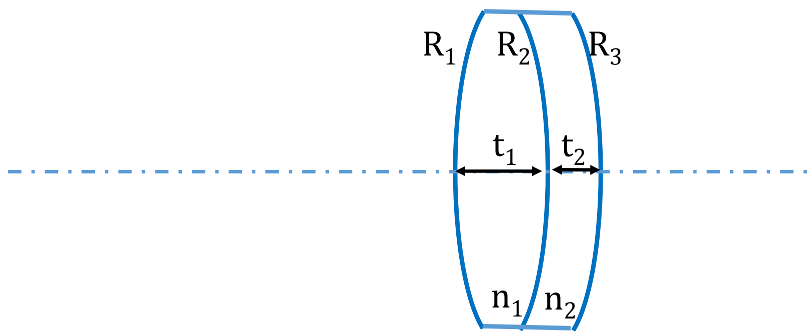
   c. For an arbitrary object placed in front of the system, please use your findings in b) to find the image.

2. A 25.4mm diameter precision plano-convex achromat doublet lens from Newport is made by N-BK7 and SF5 glass. It has the following specifications:

   R_1=60.741 mm,
   R_2= -89.718 mm,
   R_3= -268.159 mm,
   t_1= 3.8 mm, t_2= 2.5 mm,
   n_1= 1.51947 (@λ=532nm),
   n_2= 1.64570 (@λ=633nm).

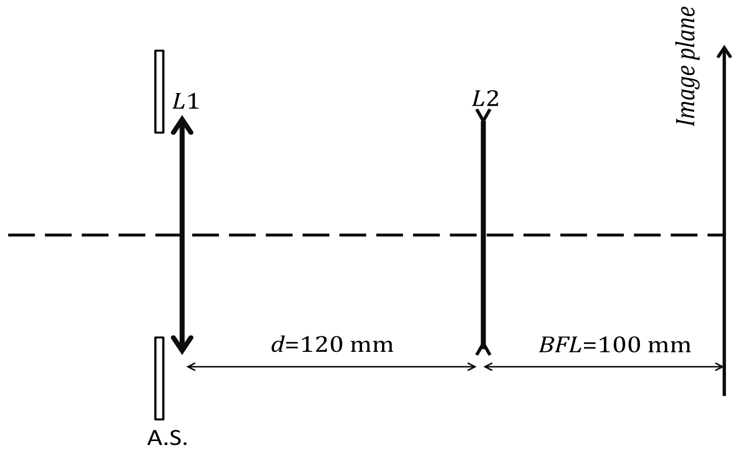
   a. What is the optical power of this composite element?

   b. If a plane wave is incident from the left, where will it focus?



3. **A Telephoto Lens.** For an object placed at infinity, we need to design a composite lens system with the following specifications.

- The spacing from the front lens to the rear lens is 120 mm.
- The working distance (from the rear lens to image plane) is 100 mm.
- The effective focal length (EFL) is 300mm.



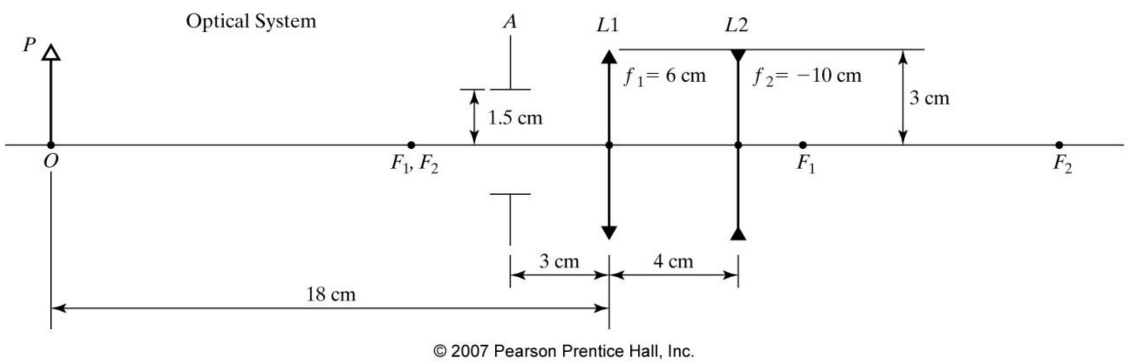
a. Assuming all elements are thin lenses, determine the focal length of each individual lens.

b. Locate the principle planes of the lens system.

c. The aperture *stop* (A. S.) of this system is located at the front lens. In order for the system to operate at F-number of $f/4.0$, what should be the diameter of the aperture?

d. If two objects are separated by 10^{-3} radians at infinity, how far apart will their images form on the screen?

4. **(modified from Pedrotti 3-5)** A optical system is made up of a positive thin lens $L1$ of diameter 6cm, and focal length f_1=6cm, and a negative thin lens $L2$ of diameter 6cm and focal length f_2=-10cm, and an aperture A of diameter 3cm. The aperture A is located 3cm in front of the lens $L1$, which is located 4cm in front of the lens $L2$. An object OP, 3cm high, is located 18cm to the left of $L1$.



a. Determine the location and the size of the field stop **FS**.

b. Determine the location and the size of the entrance and exit windows.

c. Using the *chief ray* from object point P to image point P" as shown in the example, draw the two *marginal rays* from P to P", which, together with the chief ray, determine the cone of light that successfully get through the optical system.

5. Camera lens and Image Stabilizer system: Professional or semi-professional cameras are usually designed to be used with interchangeable lenses. In this problem, we will study a simplified model of how the camera works, as well as the mechanism of the Image Stabilizer, which is state-of-art technology to improve the photography quality when shooting with weak light.

For simplicity, we assume that the lens with our camera is a "prime" lens. This means that the focal length of this lens is fixed. As shown in Figure 5*a*, we want to shoot an image of a flower which is d = 36cm away from us. (More rigorously, the plane normal to the axis near the center of the flower is located distance d from the film plane of the camera.) In today's digital cameras, electronic chips such as CCD or CMOS are placed at the image plane. We assume that the refractive index of the air is n = 1, and the glass used for the lens has n_g = 1.5. The lens is assumed to be thin (the distance between the two curved surface is negligible) and symmetric (the curvature of the two refractive surfaces are the same, with radii R = 50mm). In this problem, we only consider the imaging of an on-axis point A on the flower.

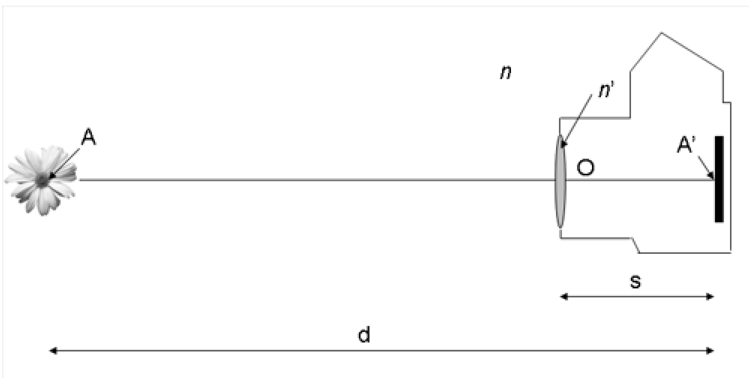


Figure 5a

a. In order to form a sharp image A′ of A exactly at the film plane, the lens has to be moved longitudinally to a proper position to satisfy the imaging condition (focusing). Calculate the distance between the lens nodal point O (center) and film plane which satisfying the imaging condition (Note: The image is demagnified in camera, which means the valid solution of s satisfies $s < d - s$).

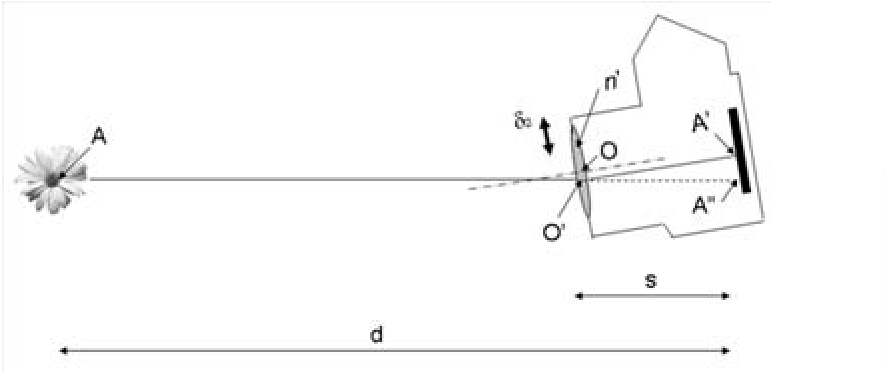


Figure 5b

b. At dim environments, e.g. indoors or during sunrise, sunset, and at night time, the exposure time must be increased to let the film or CCD/CMOS capture enough photons. However, with long exposure time (> 0.1s), it is usually impossible to keep the hand–held camera stationary, resulting in a smeared image. Recently, camera companies developed various techniques to reduce the effect of camera shaking on image quality. In general, these techniques use a micro-gyroscope to detect the shaking of the camera during exposure; then the on-board micro computer drives an actuator to move the lens with respect to the film/CCD/CMOS. Ideally the motion should exactly compensate the camera shaking, i.e. freeze the image at the same position on the film/CCD/CMOS. CANON's Image Stabilizer (IS) technology moves the lens to achieve this compensation, as shown in Figure 5b. With the lens moved by δ_2, the ray is bent and deflected to position A'. Assume the camera shaking is a counter clockwise rotation of 1° respect to the lens center, as shown in Figure 5b. In which direction and by how much (δ_2) does the IS system have to move the lens to keep the image of A fixed at the same position (A') on the CCD?

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