MASSACHUSETTS INSTITUTE OF TECHNOLOGY

2.710 Optics **Fall '05**

Problem Set #3 Posted Sept. 21, 2005 — Due Wednesday, Sept. 28, 2005

1. A parallel ray bundle of width a_1 is incident from the left on a two-lens system composed of two lenses **L1** (focal length f_1) and **L2** (focal length f_2) as shown in Figure 1. What should the separation between the two lenses be in order for a parallel ray bundle to emerge from the system? What is the width of this outgoing ray bundle?

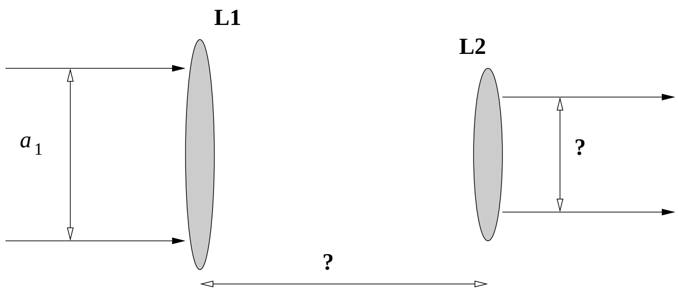

Figure 1

2. Work out the system matrix for the composite element shown in Figure 2 and use it to answer the following questions.

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

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

c) This system is used to image an object at infinity. Is the image real or virtual?

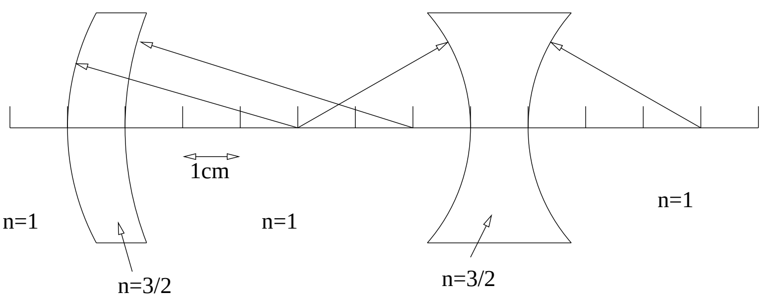

Figure 2

3. A double concave lens made of glass with refractive index $n = 1.53$ has surfaces of power 5D (*i.e.*, 5 diopters) and 8D. The lens is used in air and has an axial thickness of 3cm.

a) A small point object is placed on-axis at infinity on the left-hand side of this lens. Where is the image formed?

b) Where should a small on-axis point object be placed for the image to be formed at infinity on the right-hand side of this lens?

c) An object is placed at 30cm to the left of the first lens vertex; where is the image formed and what is the magnification?

d) Repeat the last question using the thin lens approximation (*i.e.*, ignoring lens thickness). What is the percent error in determining the image location with this approximation?

4. A thin bi-convex lens of index 1.5 is know to have focal length of 50cm in air when immersed in a transparent liquid medium, the focal length is measured to be 250cm. What is the refractive index n of the liquid?

5. You'd like to look through a lens at your pet Kitter and see it standing right side up shrunk to 1/3 its normal height. If the absolute value of the focal length is f, determine what kind of lens is needed(*i.e.* positive or negative) as well as the object and image distances in term of f.

6. We intend to use a spherical ball lens of radius R and refractive index n as magnifier in an imaging system, as shown in Figure 6. The refractive index satisfies the relationship $1 < n < 4/3$, and the medium surrounding the ball lens is air (refractive index = 1).

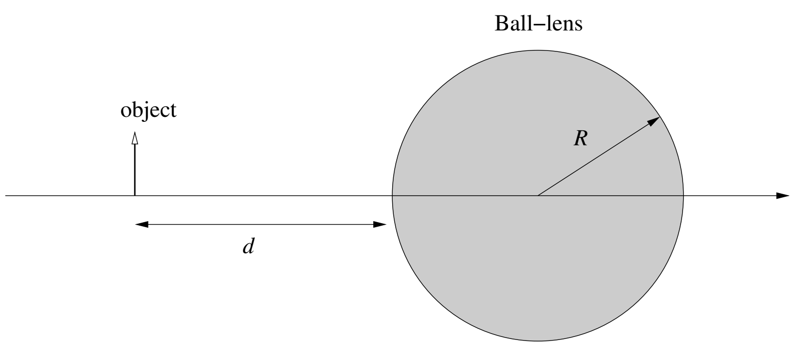

Figure 6

a) Calculate the effective focal length (EFL) of the ball lens. Use the thick lens model with appropriate parameters.

b) Locate the back focal length (BFL), the front focal length (FFL) and the principal planes of the ball lens.

c) An object located at distance d to the left of the back surface of the ball lens, as shown in Figure 6, where

$$d = R\frac{4 - 3n}{4(n-1)}$$

Show that the object is one half (EFL) behind the principal plane, and use this fact to find the location of the image plane.

d) Is the image real or virtual? Is it erect or inverted? What is the magnification?

e) Locate the aperture stop and calculate the numerical aperture (NA) of the optical system of Figure 6.

f) Sketch how a human obeserver using the optical system of Figure 6 as input to her eye would form the final image of the object on her retina.

7. **Camera lens and Image Stabilizer/Anti Shake system** Professional or semi-professional cameras are usually designed to be used with interchangeable lenses. The leading camera companies such as CANON, NIKON, KONICA-MINOLTA, etc. provide a large selection of interchangeable lenses from wide–angle lenses to telephoto lenses for their camera system. In this problem, we will study a simplified model of how the camera works, as well as the mechanism of the Image Stabilizer/Anti Shake system, 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 7.a, we want to shoot an image of a flower which is $d = 36$cm 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, there is no traditional film inside the camera, but the electronic imaging chips such as CCD or CMOS play the same role as the film does. We assume that the refractive index of the air is $n = 1$, and the glass used for the lens has $n' = 1.5$. 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 $R = 50$mm). In this problem, we only consider the imaging of an on-axis point A on the flower.

   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. This process is called 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 $s < d - s$).

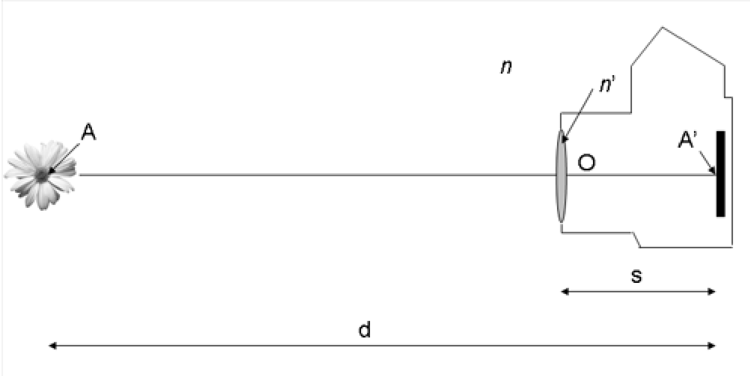

Figure 7.a

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, while Konica-Minolta's Anti Shake (AS)method moves the CCD. In this part, we study how AS works with a simple camera shaking example. Assume the camera shaking is a counter clockwise rotation of 1° respect to the lens center, as shown in Figure 7.b. In which direction and by how much (δ_1) does the AS system have to move the CCD to keep the image of A fixed at the same position (A$'$) on the CCD?

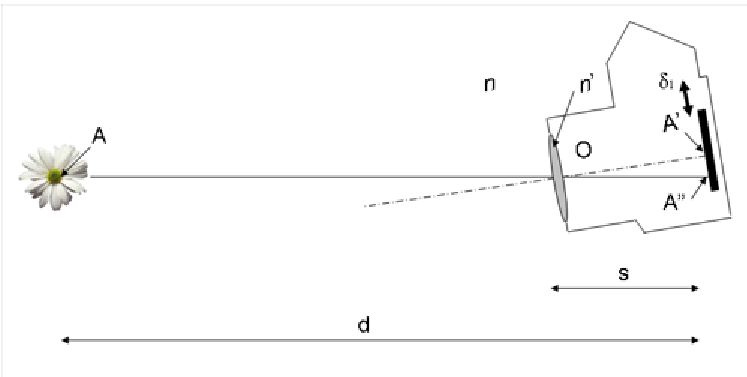

Figure 7.b

c) To compensate the camera shaking, CANON's IS technique moves the lens laterally, as shown in Figure 7.*c*. With the lens moved by δ_2, the ray is bent and deflected to position A′. Calculate the desired lens movement δ_2 to cancel the same camera shaking given in part (b).

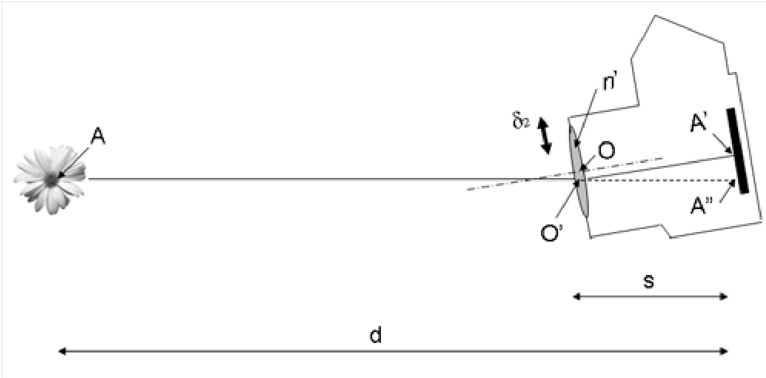

Figure 7.*c*

References:
Canon Image Stabilizer:
http://www.canon.com/technology/dv/02.html
Konica-Minolta Anti shake:
http://konicaminolta.com/products/consumer/digital_camera/slr/dynax-7d/02.html