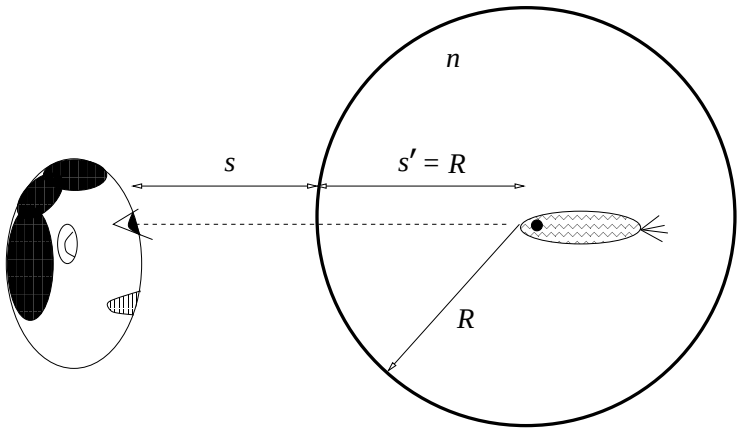
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

2.710 Optics **Spring '09**
Problem Set #3 Posted Feb. 23, 2009 — Due Wednesday, March 4, 2009

1. **Wanda's world** Your goldfish Wanda happens to be situated at the center of her spherical waterworld. At the same time, your friend Olive happens to have her gaze aligned with Wanda's. If Olive is located a distance s from the edge of the sphere, the sphere radius is R, and the refractive index of water is n, then answer the following questions about Olive and Wanda's mutual perception of each other.



   a) How does Wanda look like to Olive? That is, where is Wanda's image formed, what is the magnification, and is the image real or virtual?

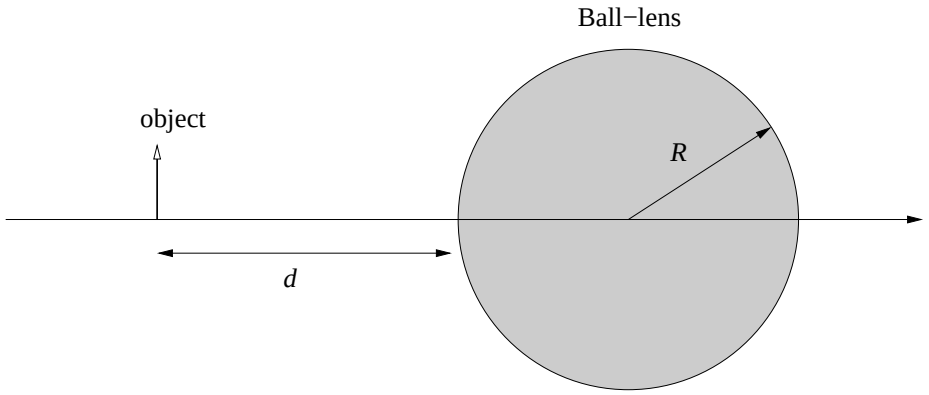
   b) How does Olive look like to Wanda? That is, where is Olive's image formed, what is the magnification, and is the image real or virtual?

   c) The data given to you seem to neglect the presence of the glass sphere that contains the water. Discuss the conditions that this negligence is justified under.

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

   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 the schematic, where

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

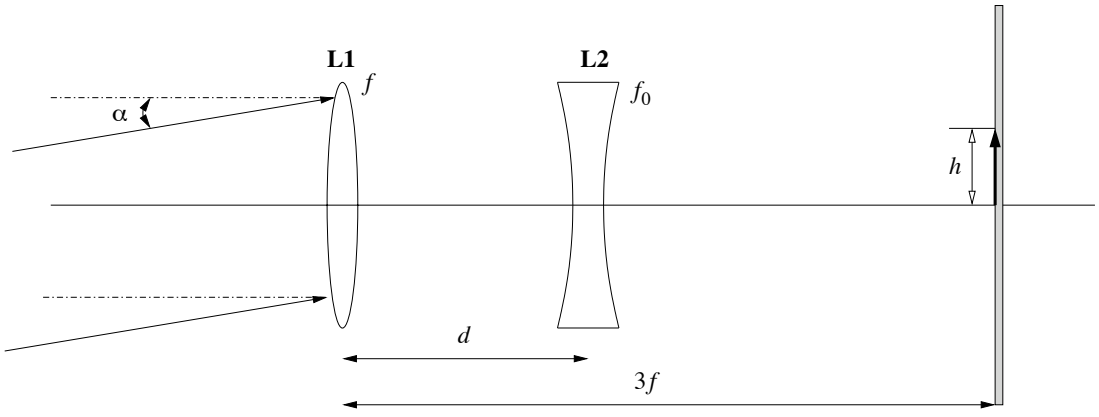
Show that the object is one half (EFL) behind the principal plane, and use this fact to find the location of the image plane.

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 ball lens magnifier optical system.

f) Sketch how a human obeserver using the optical system of Figure 4 as input to her eye would form the final image of the object on her retina.

3. Telephoto lens design Consider the telephoto lens system shown below. Lens L1 has known focal length f, and lens L2 has unknown focal length f_0. The distance d between the two lenses is also unknown. Specify the telephoto system according to the following requirements:



i) An object at infinity, placed off–axis at angular deviation $\alpha = 10^{-2}$ radians must produce a real image of size $h = 5 \times 10^{-2} f$ (cm).

ii) The real image specified in part (i) must be located at a distance $3f$ from L1.

Given the above requirements, design and verify the telephoto lens as follows:

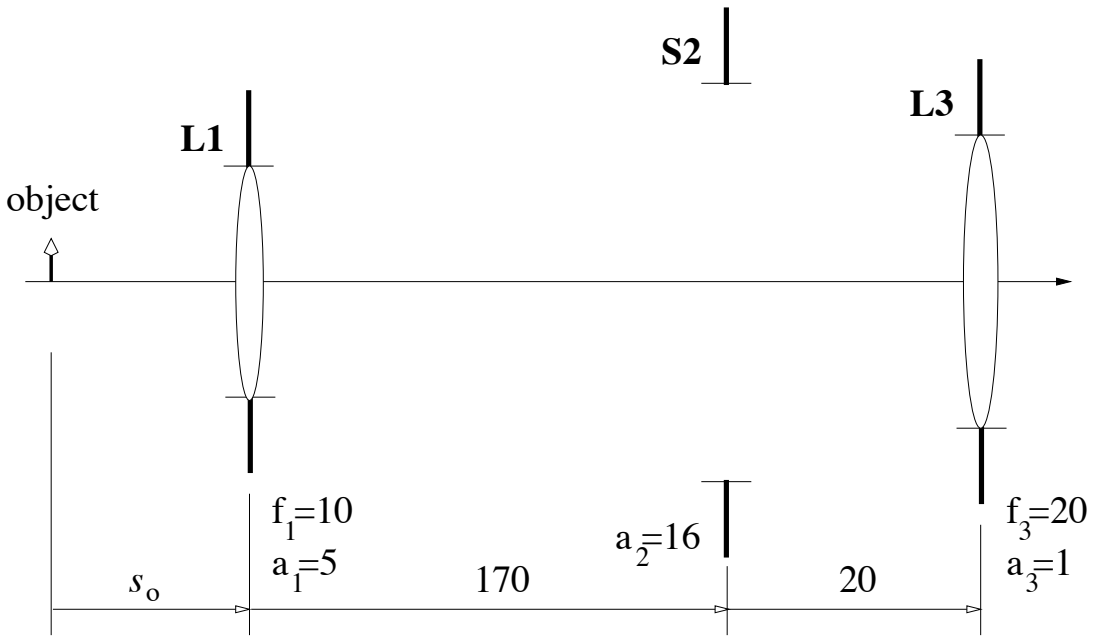
3.a) Specify the two unknowns f_0, d in terms of f.

3.b) Locate the principal planes.

3.c) What is the effective focal length (EFL)?

3.d) If an object is $24f$ to the left of lens L1, where is the image plane and what is the magnification? Is the image real or virtual, erect or inverted?

4. Microscope design The optical instrument shown below, consisting of lenses L1, L3 and stop S2, is intended for direct viewing by human observers, with the observer's eye located to the right of L3. The symbols $\{f_1, a_1\}$, $\{f_3, a_3\}$ denote the focal lengths and radii of L1, L3, respectively, and a_2 is the radius of S2. All distance units are in millimeters, and the schematic is not drawn to scale.



4.a) Determine the object distance s_o so that a human observer's unaccommodated eye may focus the image on the observer's retina.

4.b) What is the best way to use this instrument? Based on your answer, define the instrument's magnifying power (MP) appropriately, and calculate the MP according to your definition.

4.c) Locate the aperture stop, the entrance and exit pupils, and the field stop. What is the maximum lateral size of an object that can be imaged by this instrument?

4.d) Where should the observer's eye be located for optimum viewing by this instrument? Would that optimum location change if L1 were to be "stopped up" so that its radius became $a_1 = 10$? Explain why and argue that the latter instrument (*i.e.*, with $a_1 = 10$) is not practical.

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