

1. **Wanda's world** Your goldfish Wanda lives in a sphere of water (refractive index $n = 1.3$, radius $|R| = 20\text{cm}$). At one instance, Wanda has wandered to the center of here water world (see Fig. 1 below). Model Wanda as a stick perpendicular to the optical axis and the water sphere as a thick lens. You may ignore the effect of the glass container of Wanda's world

- a) Where is Wanda's image formed?
- b) Is the image real or virtual?
- c) Is the image erect or inverted?
- d) What is the magnification?

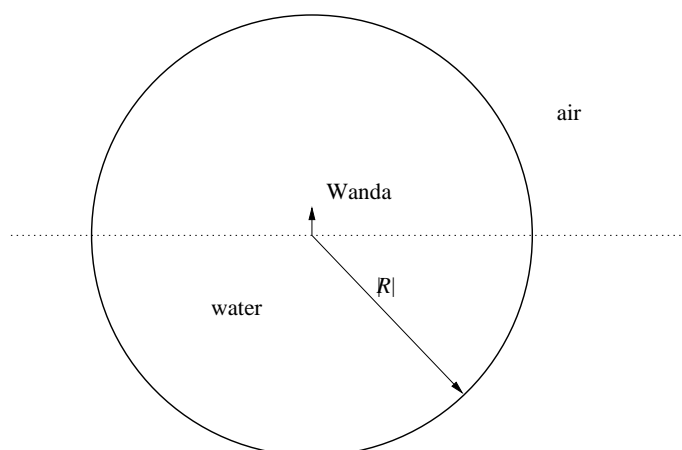


Figure 1: Wanda's world

2. 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 2. 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?

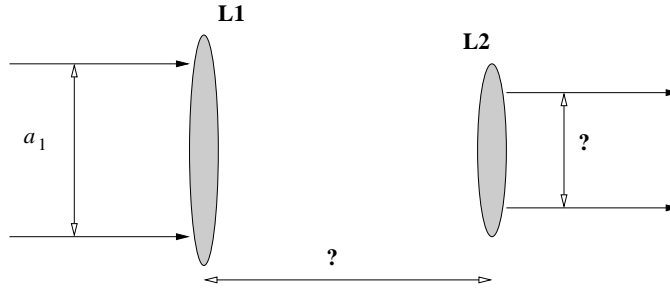


Figure 2

3. Work out the system matrix for the composite element shown in Figure 3 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?

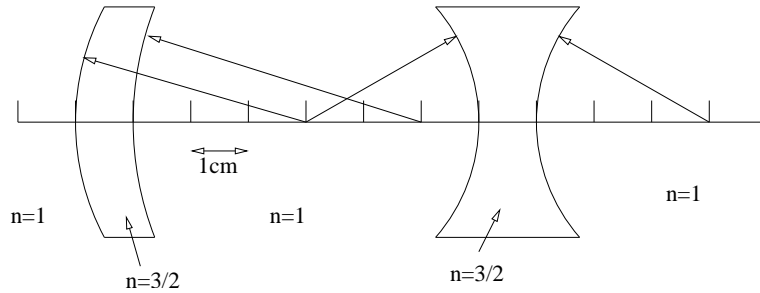


Figure 3

4. 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?
5. A thin bi-convex lens of index 1.5 is known 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?
6. You'd like to look through a lens at your pet Kitten 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 terms of f .
7. We intend to use a spherical ball lens of radius R and refractive index n as a magnifier in an imaging system, as shown in Figure 7. The refractive index satisfies the relationship $1 < n < 4/3$, and the medium surrounding the ball lens is air (refractive index = 1).

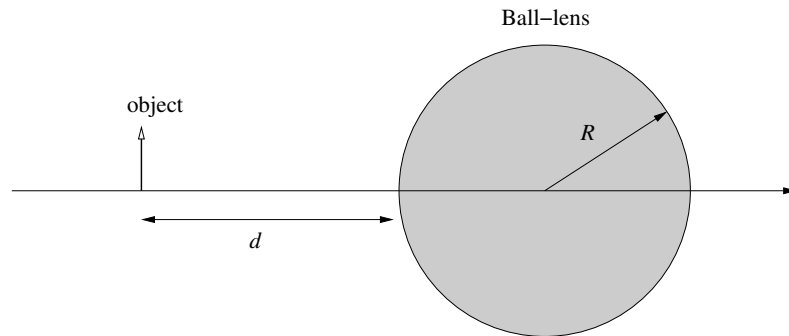


Figure 7

- 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 7, 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 7.
- f) Sketch how a human observer using the optical system of Figure 7 as input to her eye would form the final image of the object on her retina.