

MASSACHUSETTS INSTITUTE of TECHNOLOGY  
Department of Electrical Engineering and Computer Science

*6.637 Optical Imaging Devices & Systems*

Problem Set No. 1  
Fall Term, 2024

**Safety and Geometric optics**

Issued Tues. 09/10/2024  
Due Tues. 09/17/2024

**Reading recommendation:** (a) Safety Handouts, and (b) Class Notes Chapter 1. Be neat in your work!

**ALL students must do Problem 1.0. Additionally, 6.237 STUDENTS may do any three (total of 4), and 6.637 STUDENTS should do all 5**

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**Problem 1.0** - Safety Training Module

Based on your reading of the Lab Safety procedures document (Lab 0) and your additional research, please answer the following questions:

- (a) Shorter wavelength optical radiation, such as UV, contains \_\_\_\_\_ energy per photon than IR radiation, and is therefore \_\_\_\_\_ likely to cause damage to ocular tissues.
- (b) What band of radiation includes the wavelength range 200-400nm?
- (c) What type of damage is blue laser light (488nm) most likely to cause? (Hint: It's the official term for optical cooking of tissue.)
- (d) Ultraviolet laser light will most likely cause damage to what part of the eye?  
What kind of damage will it do?
- (e) Infrared laser light will most likely cause damage to what part of the eye?
- (f) What is the human blink reflex time in seconds?
- (g) What are minimum power levels below which you do not need to wear safety glasses in the lab?
- (h) What is OD and how does it relate to protective eye wear?
- (i) What are the preferred ODs for protective laser goggles while working with lasers?
- (j) ANSI ocular laser exposure limits are based on an assumed pupil size of \_\_\_\_\_ mm.

- (k) What is the ANSI standard (reference number) on the Safe Use of Lasers?
  
- (l) Only you and a lab partner are in the lab. If you feel a sharp pain in your eye, hear a pop emanating from your eye or suddenly experience cataract-like occluded vision you should:
  - (1)
  - (2)
  - (3)
  
- (m) List 3 steps you must take before turning on a high power laser in the lab
  - (1)
  - (2)
  - (3)
  
- (n) What is a class III laser
  
- (o) What defines a class IIIb laser (list two things)? Give an example.
  
- (p) What defines a class IV laser (list two things)? Give an example.
  
- (q) All laser beams should be confined within what volume? (Answer in relation to the optics table as well as your colleagues.)
  
- (r) What is the maximum amount of time you may work alone with a class IV laser or a high-voltage power supply?

**Problem 1.1**

Cross hairs are used in scopes of rifles to aid with aiming. A simple telescopic rifle consists of two or three lenses along with the cross hairs. Both the distant object and the cross hairs need to be in focus at the same time.

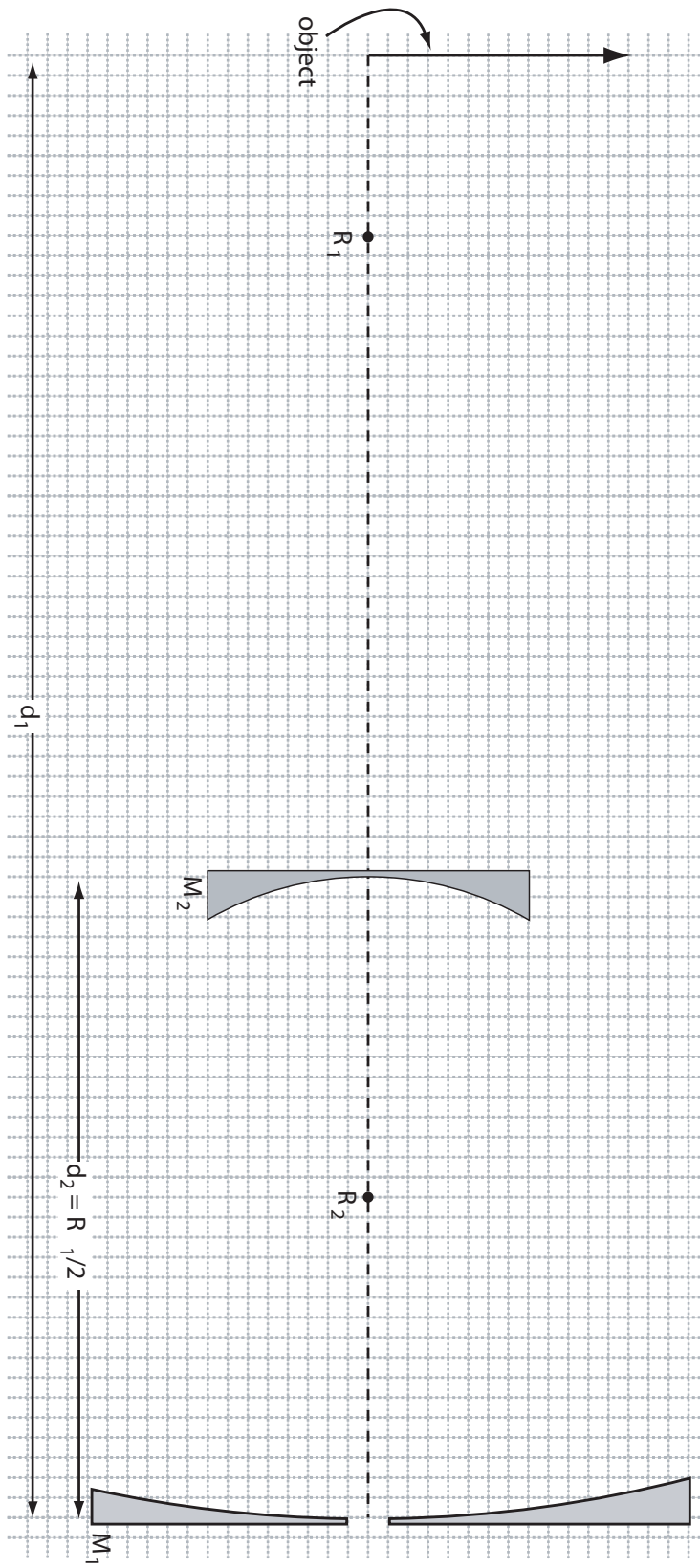
- (a) Design a telescopic system for a rifle that accomplishes this task. Please clearly state your specific design goals and assumptions and show your optics design in a diagram.
- (b) Given the size of a typical rifle, please choose reasonable values for the focal lengths and diameters of your lenses.
- (c) How would you choose the width of the cross hairs so they occlude less than 1% of the image?

**Problem 1.2**

The two-mirror imaging system shown on the next page consists of a large primary mirror,  $M_1$ , with radius of curvature,  $R_1$ , and a small secondary mirror,  $M_2$ , with a radius of curvature,  $R_2$ . Both mirrors are concave. In the system,  $d_1$  is the distance of the object from the primary mirror,  $d_2$  is the separation between the mirrors, and  $d_3$  (not shown) is the distance of the final image from  $M_2$ .

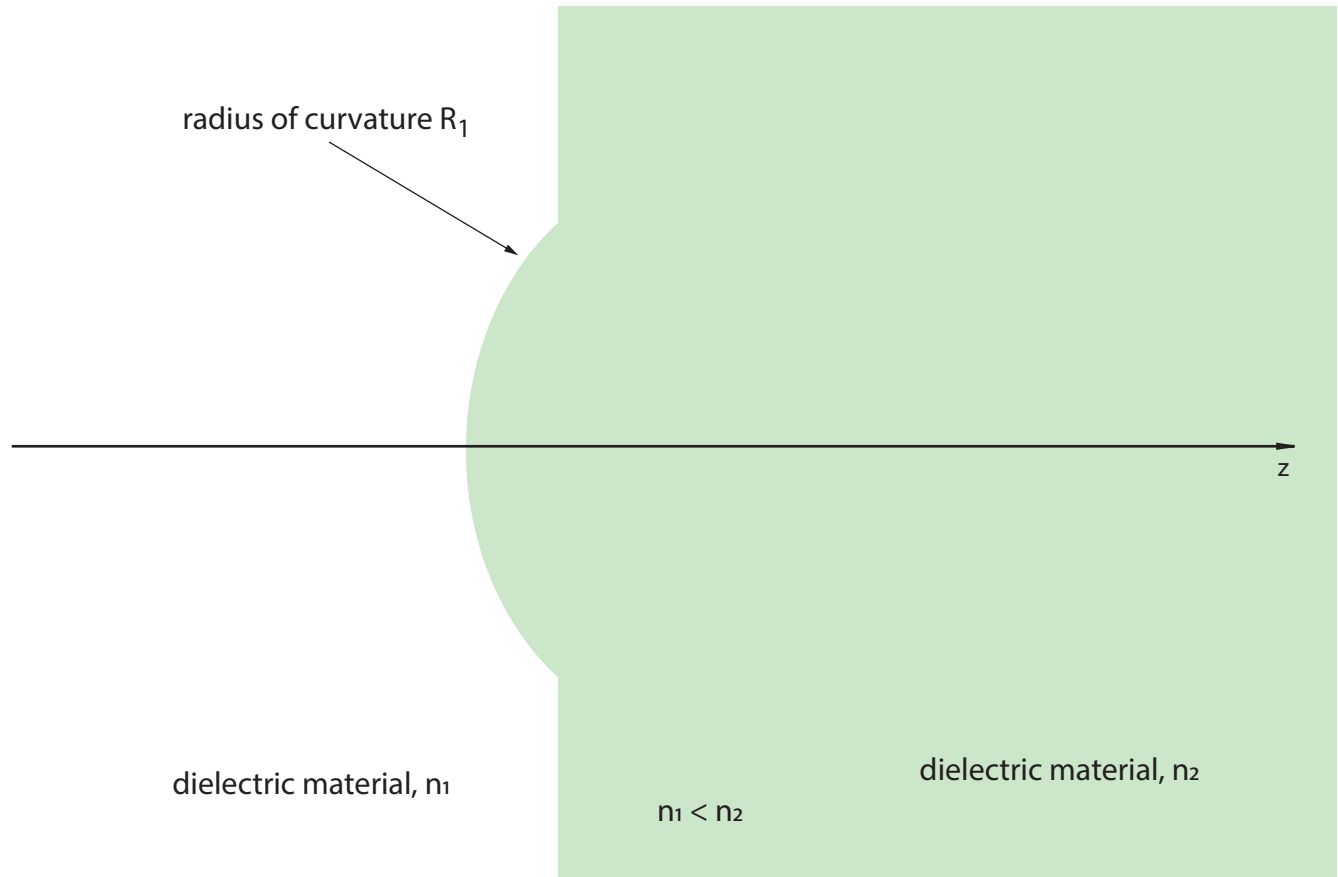
- (a) In the figure, you are given the special case where  $d_2 = \frac{R_1}{2}$ . Perform a geometric (ray-optics) construction (i.e., draw in the rays on the diagram) to show where the final image is formed. Assume that the desired image is formed after only one reflection from each mirror (ignore any possible multiple reflections between the mirrors)
- (b) Is the final image real or virtual?
- (c) Show the position and orientation of intermediate images, if any, and label them as real or virtual on the diagram.
- (d) For the case where both the mirror separation,  $d_2$ , is arbitrary and  $d_1 \gg \{d_2, R_1, R_2\}$ , and with the help of the class notes, write down and simplify an expression for the final image distance,  $d_3$ , in terms of  $d_1$ ,  $d_2$ ,  $R_1$ , and  $R_2$ .

Problem 1.2, Continued...



### Problem 1.3

- (a) Derive the ABCD matrix from first principles for a convex interface with radius of curvature,  $R_1$ , separating two media of refractive indices  $n_1$  and  $n_2$  when the light is traveling from medium 1 to medium 2.



- (b) When the radius of curvature,  $R$ , goes to  $\infty$ , show that you get the correct answer for a planar interface
- (c) Now let us make a thin biconvex lens out of this medium  $n_2$  by carving out a second surface boundary which is concave and of radius  $R_2$  (not shown) to the right of the first convex boundary of radius,  $R_1$ . Throw away the residual unused material. Derive an expression for the focal length of the lens thus formed which is still fully embedded in medium  $n_1$
- (d) From your expression in (c) what is the focal length of this lens when  $n_1 = 1$ ? Does it agree with the lens maker's formula?

### Problem 1.4

Assume fish have a rigid lens their eyes, and that their eyeballs are also rigid. Further assume that the vitreous humor (gelatinous tissue that fills the region between the lens and the retina) has the same refractive index as water. When a fish is out of the water, draw ray optics diagrams to prove your case as to whether the fish is near sighted or far sighted when out of the water.

### Problem 1.5 Zoom Lens

An object is located in the  $z = 0$  plane of the 3-lens imaging system shown below.

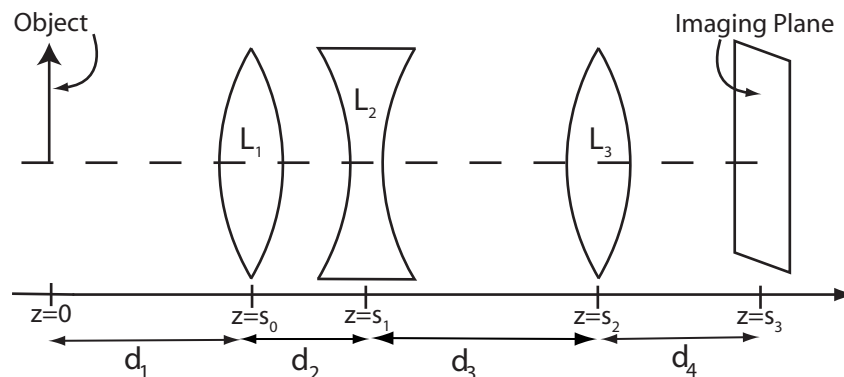


Figure 1: Diagram of a three-lens imaging system, with a biconcave thin lens between two biconvex thin lenses.

- Derive the ABCD ray-optics matrix (in terms of the focal lengths of the lenses and  $d_1$ ,  $d_2$ ,  $d_3$  and  $d_4$ ) for the system bounded by the given object and image planes. To help eliminate algebraic errors, you may want to use *Mathematica*, *Maple* or *Matlab* for this exercise.
- Write an expression for the location of the image plane,  $s_3$ .
- Write an expression for the image magnification.

Given that the focal lengths of the lenses are  $F_1 = 50\text{mm}$ ,  $F_2 = -50\text{mm}$ ,  $F_3 = 100\text{mm}$ , and the positions of the lenses, respectively, along the  $z$ -axis are  $s_0 = 100\text{mm}$ ,  $s_1 = 150\text{mm}$ ,  $s_2 = 300\text{mm}$ , answer the following questions.

- Is the image real or virtual?
- What is the total magnification of the system? Given this magnification, is the image upside-down, or right-side up?
- Let us now change the system so that  $L_2$  is a positive lens with focal length  $F_2$ . In the special case where  $d_1 = F_1$ , and  $d_3 = F_2 + F_3$ , what is the condition on  $d_2$  such that the image is at infinity?