MASSACHUSETTS INSTITUTE of TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.637 Optical Imaging Devices & Systems

Problem Set No. 1	**Safety and Geometric optics**	Issued Tues. 9/14/2021
Fall Term, 2021	**-**	Due Tues. 9/21/2021

Reading recommendation: Safety Handouts and Class Notes, Chapter 1. Be neat in your work!

Problem 1.0 - Safety Exam

Based on your reading of the Lab Safety procedures document (Lab 0) and your additional research, please answer thee 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 lenses along with the cross hairs. Both the distant object and the cross hairs need to be in focus at the same time. Design a telescopic system for a rifle that accomplishes this task, and in which the cross hairs occlude less than 1% of the image. Given the size of a typical rifle, please choose reasonable values for the focal lengths and diameters of your lenses as well as the size of the cross hairs. Also, please clearly state your specific design goals and assumptions. Draw as many diagrams as you need to give clarity to your design.

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.

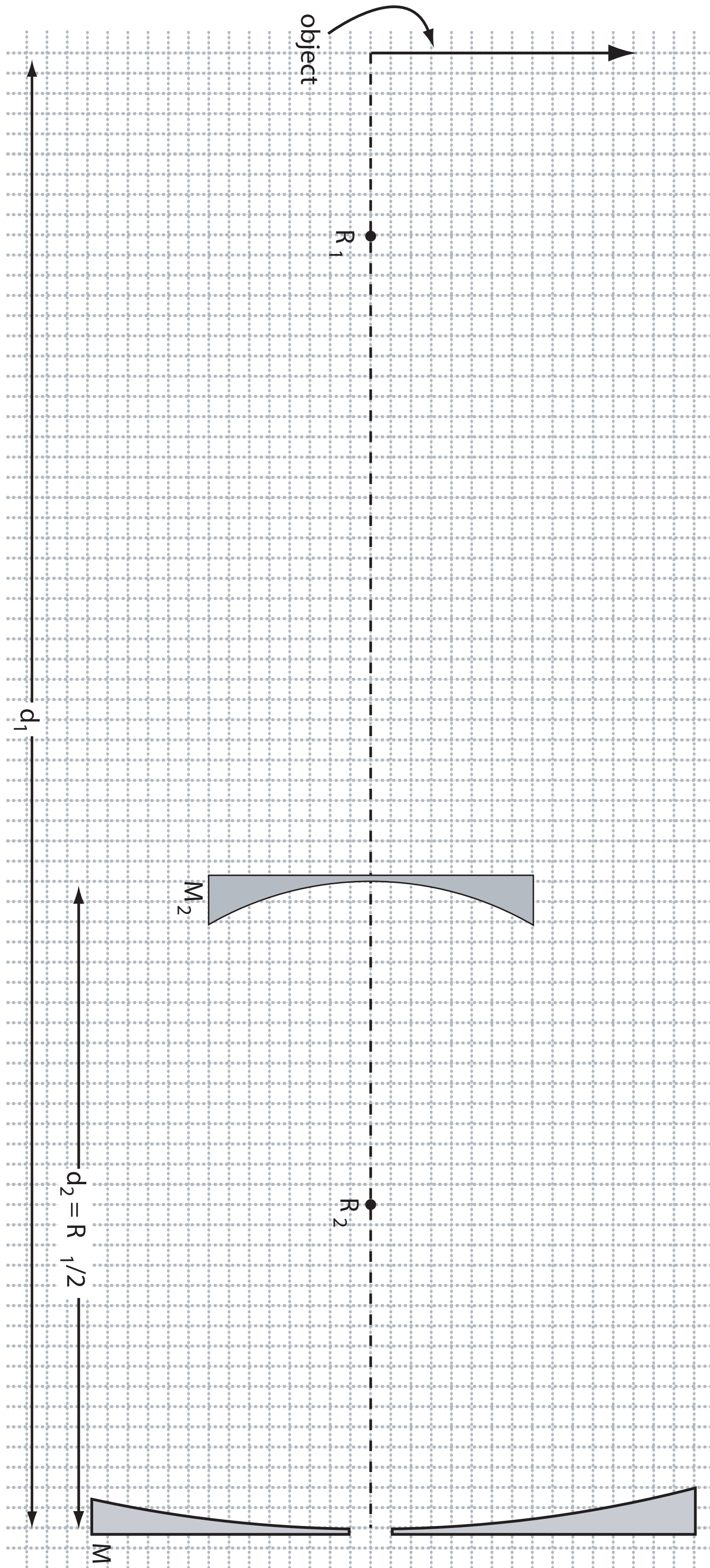
(a) In the figure, you are given the special case where $d_2 = \frac{R_1}{2}$. Perform a geometric (ray-optics) construction (i.e., draw in the rays on the diagram) to show where the final image is formed. Assume that the desired image is formed after only one reflection from each mirror (ignore any 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.

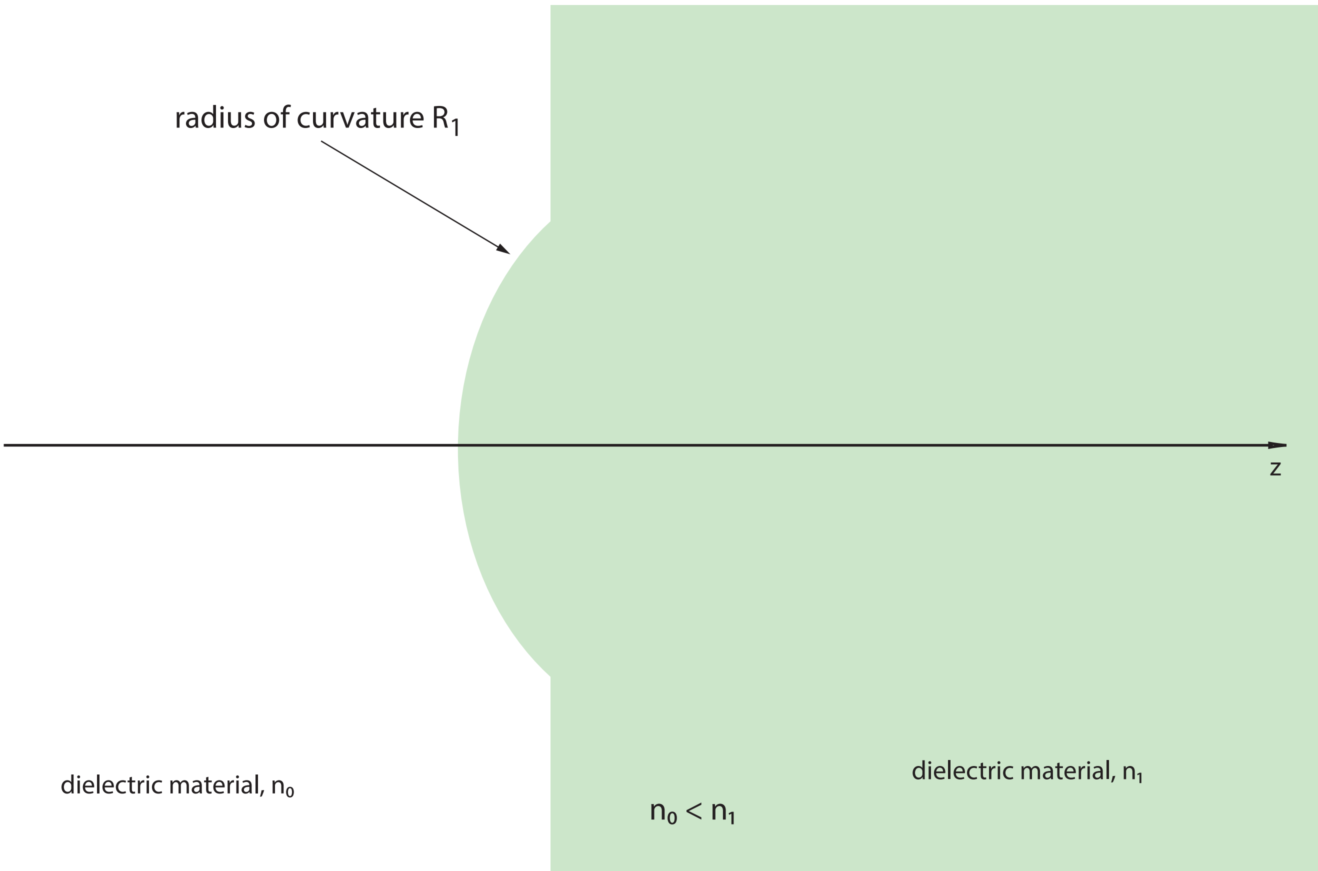
(d) For the case where both the mirror separation, d_2, is arbitrary and $d_1 \gg \{d_2, R_1, R_2\}$, and with the help of the class notes, write down and simplify an expression for the final image distance, d_3, in terms of d_1, d_2, R_1, and R_2.

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 inf, 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

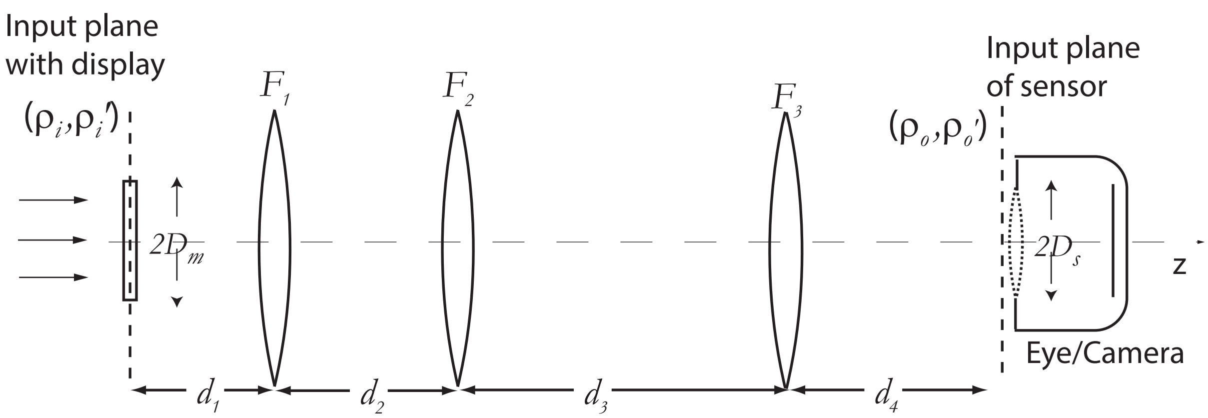
(d) From your expression in (c) what is the focal length of this lens when $n_1 = 1$? Does it agree with the lens maker's formula?

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 Matching FOV and entrance pupil of cameras

When creating synthetic scenes, projection optics are often used to manipulate the source image (typically formed on a real-time display). The figure below shows a 3-lens system that is designed to couple the image on a display into an imaging sensor (the eye or a camera). The display has a diameter $2D_m$ and emits light over a full cone angle of $2\theta_m$. The camera has a fixed full angular field of view (FOV) of $2\theta_s$ and a fixed entrance pupil of diameter $2D_s$. It is assumed the eye/camera has its own lens F_4 (shown as a dashed outline) and can therefore form an image of the object generated by the display.



The goal is to design the 3-lens projection optics so that no light leaving the display is wasted, and that maximum image size is achieved inside the eye/camera. That is, we want to incoming light to match the FOV and the pupil diameter of the camera.

(a) First write a user friendly computer program to compute A, B, C, D in symbolic form for a 3 lens system (7 matrices). That is, Derive A, B, C, and D of 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 the input plane to the eye/camera. To help eliminate algebraic errors, you may want to use *Mathematica*, *Maple* or *Matlab* for this exercise (Note: *These 4 equations are also very helpful for designing zoom lens systems, especially when one has constrains such as a limited choice of lenses with specific focal lengths and diameters, a maximum overall system design length, and require a specific angular or linear magnification.*)

(b) Consider the special imaging case where we want to make the image on the display appear to the eye/camera as if the object was infinitely far away. That is, when the eye/camera is focused at infinity, the eye/camera output image must be sharp. In this case, the region between F_3 and the camera is often referred to as "collimated space". What condition on the matrix elements A, B, C, and D would have to hold so that this is the case?

(c) To match the FOV and the input aperture dimensions of the eye/camera, what constraints on the matrix elements A, B, C, and D would have to hold to realize these two conditions?

(d) For the special case where $d_1 = F_1$, and F_1 and F_2 are identical, draw the ray-optics system corresponding to the matched projection system.

(e) Assuming Case (d), d_2, d_3 and d_4 are unconstrained. What are the conditions on these 3 variables so that matching FOV and entrance pupil occurs simultaneously?

Problem 1.6 Zoom Lens - 6,637 only

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

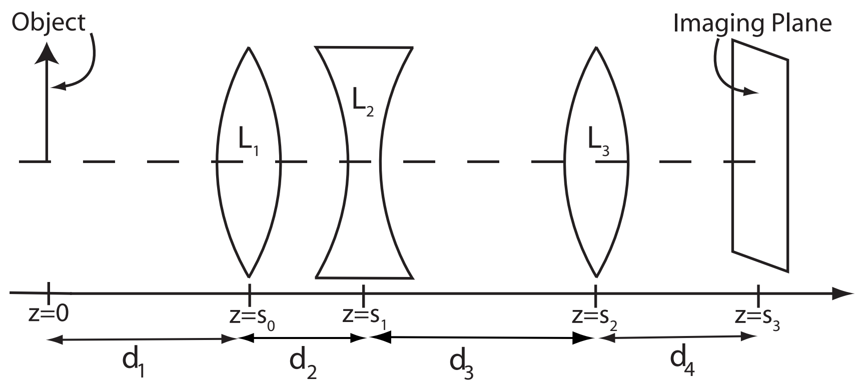


Figure 1: Diagram of a three-lens imaging system, with a biconcave thin lens between two biconvex thin lenses.

(a) 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.

(b) Write an expression for the location of the image plane, s_3 .

(c) Write an expression for the image magnification.

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

(d) Is the image real or virtual?

(e) What is the total magnification of the system? Given this magnification, is the image upside-down, or right-side up?

(f) 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?