Student Name _____   Date _____

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.161 Modern Optics Project Laboratory - Fall 2019

Laboratory Exercise 1A - Single-lens Imaging
Laboratory Exercise 1B - Geometric Optics: Zoom-Lens for 2-D Imaging Systems

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Get Prepared to Start the Lab Exercises

To get the most out of your in-lab experience, you must come to Lab prepared (makes life easier for you and the TA, and minimizes your time in the Lab). Please read this **entire** laboratory handout, and be prepared to answer questions before, during and after the lab session. Determine all the equations and constants that may be needed in order to perform all the laboratory exercises. **Write** them all down in your laboratory notebook before entering the Lab. This will ensure that you take all necessary data while in the Lab in order to complete the lab write-up.

You should also complete the Pre-Lab Exercises, and answer all the Pre-Lab questions BEFORE entering the Laboratory. Remember to answer all questions in your lab notebook in a neat and orderly fashion. This preparatory work will also count toward your Lab Exercise grade.

When doing the experiments, no data are to be taken on these laboratory sheets. Tables provided herein are simply examples of how to record data into your laboratory notebooks. In your lab notebook record data, explain phenomena you observe, and answer the questions asked. Expect the in-lab portion of this exercise to take about 3 hours.

LAB EXERCISES - No. 1A

Prelab Exercises No. 1A
PL1A.0 - Safety
Read the entire <u>Laboratory and laser Safety Packet</u> that was handed out in Lab 0. Be prepared to answer questions about high-voltage and laser safety before arriving at the MOL.

PL1A.1 – Prelab Questions
(a)   If two lenses of focal length F_1 and F_2 are abutted, what is the focal length of the combination? Show your calculation.

(b)   How would you go about measuring the focal length of a biconcave lens?

"Two brothers bought a cattle ranch and named it "Focus." When their father asked why they chose that name, they replied: "It's the place where the sons raise meat."

-- Prof. W. B. Pietenpol, Physics Department, University of Colorado, Boulder, Colorado

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In-Lab Exercises - No. 1A

Lab 1A.1. Imaging Properties of a Convex Lens

In this exercise, we will explore the imaging properties of a simple symmetric biconvex lens. The setup we will use is shown in 1. It consists of a white light source a transmission object (slide), a biconvex lens, and a screen, all mounted along an optical rail.
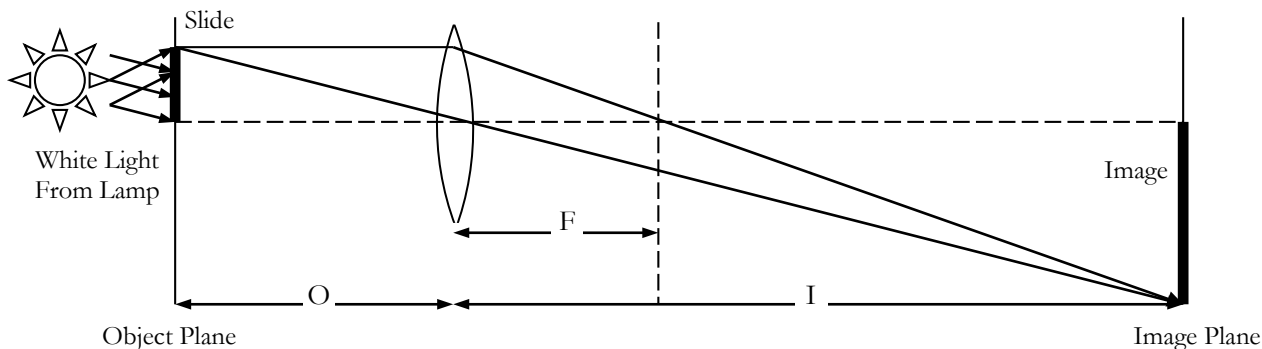

Figure 1 - Setup to explore the imaging properties of a convex lens.

In-Lab Assignment

Using the setup in 1, and keeping the light source (slide) and object (lamp) fixed, select five different object distances, O, (distance from the lens to the object) by moving the lens. For each object distance, measure: (1) the corresponding image distance, I, for sharply defined image on the screen, and (2) the size of the image. Show your data in a table.

Post-Lab Questions for the Convex lens

(1)   Point us to the answers to the prelab questions in your notebook.

(2)   For the biconvex lens, make a plot of 1/I versus 1/O and from your plot determine the focal length of the lens (use all your data points – if you are not sure how to fit the data, please ask). Include the raw data, the plot and your calculation of the focal length in your report.

(3)   If the refractive index of the biconvex lens is 1.52, what is the radius of curvature of its convex surfaces?

(4)   Why is a sharp image not seen when the object distance is less than the focal length of the lens?

Lab 1A.2. Imaging Properties of a Concave Lens

Design and set up an experiment that will allow you to measure the focal length of the given biconcave lens.

Draw a diagram of your setup, show your data in a table, and describe how you used the data to find the focal length of the concave lens.

LABORATORY EXERCISES - No. 1B

Geometric Optics: Zoom-Lens for 2-D Imaging Systems

Pre-Lab Exercises -1B

PL1B.1. Choose one of the instruments below that you would like build, and carry out the design portion of the work before coming to the Lab. For this exercise, you may work in groups of 2.

You may design your zoom-optic system for fabrication with the components listed in Table 1 in the Appendix. With a zoom-optic system, you can adjust the magnification of your telescope by moving a central lens while keeping the outermost lenses at *approximately* the same location – basically the same setup as is used in binoculars.

Hints: Remember to use larger lenses at the input of your system (the side facing the world), and smaller lenses close to the eye. Also, before you start designing, determine which element in the ABCD matrix must equal zero for angular magnification to occur.

In-Lab Exercises – 1B

In Lab 1B you will be designing and building either: (1) a zoom lens projector for a conference room, or (2) a near-eye zoom lens terrestrial telescope. For this exercise, you may work in groups of 2 people.

In a zoom-optic system, you can adjust the magnification of your instrument by moving one or more inner lenses while keeping the outermost lenses at *approximately* their same locations.

Be sure to use the ABCD matrix approach to simplify the design of your instrument. You should include all of your system specifications in your pre-lab write-up for Lab 1B – including any computer code, hand-calculations or other materials used in the design. Be sure to specify the focal lengths, total system magnification as well as the locations of the lenses, the object and the image. Remember, there is no one 'correct' way to design your instrument. Also, before you start designing, determine which element in the ABCD matrix must equal zero for your system.

The Lab staff will be very sad if everyone designs exactly the same instrument. Simplicity, flexibility and robustness of design will be appreciated. Additional points will be awarded for ingenuity and thoughtfulness in design. Also, be sure not to use too many elements; each additional element in your system will lead to decreased contrast and decreased resolution, and increased cost. "Ingenuity and thoughtfulness" means designing smart, and minimizing complexity.

Lab 1B.1 – Zoom-Lens Conference Room Projector
1B.1(a) – Projector Design
For the conference room projector, you will keep the image distance fixed at 10 meters, and you may move one or two (preferably no more) lenses to change the magnification of the image on the screen (preferably without affecting image sharpness).

Try to get the job done using components from the list in Table 1 (Appendix) as possible. If you decide to go outside the table, specify the vendor and the cost of your lens. Who knows, we may buy it for you.

In a table, specify the metrics of your system such as (a) magnification/$, (b) magnification/length, (c) magnification/weight, etc. So please compute these and any other metrics you like, to "sell" your design as optimum to us. If you have come up with several good designs, do what engineers do: Add them to the table and compare those designs in one or two paragraphs.

1B.1(b) Projector Fabrication & Lab Report
1. Now we would like you build and test the conference room projector you designed in part PL1B.1. Explain the operation of your projector to the TA

2. Record the focal lengths of the lenses you finally settled on for your projector.

3. For one of the adjustments that you like:
   (a) Measure the linear magnification of the system
   (b) Record the distances between the lenses as well as the object distance, and plug these values into your ABCD matrix results so as to compute the magnification.
   (c) Does the computed magnification agree with the experimentally measured magnification?

4. Draw the ray-tracing diagram for your final system

5. Comment on the performance of your projector Did it operate as you expected? Why or why not?

6. Comment on the distortions/aberrations in the image. What should be done to correct or prevent these?

Lab 1B.2 – Near-Eye Zoom Telescope
1B.2(a) – Telescope Design
Here you are to design a terrestrial telescope (meaning that the image as seen by a viewer must be erect) using the optical components listed in Table I, or similar. For the terrestrial projector, the image will be formed on the human eye, and the object may be near or far. This design is also basically the same that is used in binoculars.

You may have used a large terrestrial telescope at a national park, or if you were a pirate at sea in a former life. Also the same basic concept is used in binoculars (smaller in size).

Your telescope must be a refractor (lenses-only). The entire telescope assembly must not be any longer than the 60 cm (the shorter, the better). Your telescope must contain no more than 5 lenses. Your system's total angular magnification must be adjustable from at least 4x to at most 40x and be useful over an imaging distance ranging from 15 meters to infinity (a collimating telescope – this is the most common form of telescope).

Try to get the job done using components from the list in Table 1 (Appendix) as possible. If you decide to go outside the table, specify the vendor and the cost of your lens. Who knows, we may buy it for you.

1B.2(b) - Telescope Fabrication & Lab Report

1. Now we would like you build and test the telescope you designed in part 1B.2(a). Explain the operation of your telescope to the TA

2. Record the focal lengths of the lenses you finally settled on for your telescope.

3. For one of the adjustments that you like:
   (a) Measure the angular magnification of the system (if you can)
   (b) Record the distances between the lenses as well as the object distance, and plug these values into your ABCD matrix results so as to compute the angular magnification.
   (c) Does the computed magnification agree with the experimentally measured magnification?

4. Draw the ray-tracing diagram for your final system

5. Comment on the performance of your telescope. Did it operate as you expected? Why or why not?

6. Comment on the distortions/aberrations in the image. What should be done to correct or prevent these?

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APPENDIX

The list below is a typical set of low-cost lenses you may find in and optics lab. Please note that off-the-shelf lenses do not come in all diameters and focal lengths.

TABLE I. Optical elements that may be available for building your instrument

Diameter	Type	Focal Length	Unit Cost	Weight (gm)
2"	Bi-Convex	200mm	$ 50	200
2"	Bi-Convex	100mm	$ 60	180
2"	Bi-Convex	75mm	$ 70	170
1"	Bi-Convex	200 mm	$ 45	160
1"	Bi-Convex	150 mm	$ 50	155
1"	Bi-Convex	100 mm	$ 55	150
1"	Bi-Convex	75 mm	$ 60	140
1"	Bi-Convex	50 mm	$ 65	120
1"	Bi-Convex	35 mm	$ 70	100
1"	Bi-Convex	25.4 mm	$ 75	100
1"	Bi-Concave	-100mm	$ 75	100
1"	Bi-Concave	-75mm	$ 80	90
1"	Bi-Concave	-50mm	$ 85	80
1"	Bi-Concave	-25mm	$ 90	70