PHY170: OPTICS

INTRODUCTORY REMARKS

The optics experiments consist of two major parts.

- Setting up various components and performing the experiments described below.
- Computer simulation of images generated by light of different wavelengths passing through various sizes and shapes of mirrors, lenses and prisms.

Bad & good news: There is no set recipe on which part should be done first. The best thing is to start with something simple. As you get familiar with the lab, you will discover that you may have to go back and forth between experiments and simulations to obtain a better understanding of the concepts. Things get easier soon and one starts to appreciate all aspects of the lab. (Trust us ... we have gone through these same confusions ourselves!!)

Hints: a) If the measured value of a certain quantity is very different from the expected value, stop and think about it; then consult with an instructor if you are stumped.

b) Don't waste your time repeating BEAM4 simulations for every value of the experimental parameters you choose in the lab. Rather, use BEAM4 to understand the general concepts, and to provide quantitative comparison with your experimental results for a few specific examples.

c) **A summarized comparison between data obtained by different methods (e.g. experimental and simulation) in the lab notebook impresses the instructors at the time of grading.**

Things to do in the lab

OPTICS SIMULATIONS

Doing a computer simulation has many advantages. For example, it helps you visualize how images are formed and what kind of magnification you can obtain from a particular lens/mirror/prism combination. You can also predict the final outcome of an experiment before you actually carry it out. Furthermore, you can set up hypothetical optics experiments that are not possible to perform with the equipment in the lab. At first, you should try to use the actual dimensions of the components you will use in the lab. However, you are encouraged to be creative and try out any combination that you believe would give useful information.

You have to learn how to use BEAM4 before you can take full advantage of this powerful optics simulation software. Unfortunately, the BEAM4 manual is not tutorial in nature, so it is best to use it as a reference guide. To get started call up the LENS .opt and .ray files. Play with the parameters in the tables to figure out what they do. Now open the PRISM .opt, .ray and the GLASS.med. Similarly play with the parameters to see how the angle of the refraction depends on wavelength and type of glass.

EXPERIMENTS

The following gives you a general guideline on the minimum number of experiments that we expect you to perform in the OPTICS section. It is extremely important that you make careful drawings of each experimental setup and that you note down the components used. Use tables as much as possible for summarizing and comparing results. We encourage you to be creative with these optical components and design your own experiments, once you have acquired some skills. Feel free to discuss your ideas with an instructor.

Important: **Read** about images formed by curved mirrors and lenses in the books on the shelf. Your life will be a lot easier in the lab if you know how the position and quality of images depend on the optical components.

I. Concave Mirror

Objective: Characterize the images formed by a curved mirror of focal length, f. Compare experimental data with the results of simulations.

Things to know before actually performing the experiments:

a) How to estimate *focal length*, f, of mirrors with just a ruler.
b) What is the relation between f and the *radius of curvature*, R, of a curved mirror?
c) What is the relation between f, p (*object distance*) and q (*image distance*)?
d) How is *magnification*, M, related to q and p?
e) For q & M, what is special about the case $p = 2f$?
f) For the case of $p > 2f$, find q & M, by hand ray tracing. Include each of the following rays:
   1. A ray passing through the center of curvature
   2. A ray parallel to the central axis
   3. A ray passing through f
   4. A ray striking the vertex of the mirror
g) How to obtain R directly using a *spherometer*.

Experiments and Simulations:

1) Set up flashlight, concave mirror and screen on the “optical breadboard”.

2) Describe the images formed when the object is:
   a. At ∞
   b. Between ∞ and R
   c. Between R and f
   d. Between f and the mirror

   Hint: Images could be

   - REAL/VIRTUAL
   - ENLARGED/REDUCED
   - RIGHT SIDE UP/UPSIDE DOWN

3) Choose several (at least three!) different object distances that span (a) to (c); and for each ***p***, measure ***q*** and the image height (from which you can compute ***M***). Do theory and experiment agree with each another? That is, do your ***p*** and ***q*** data imply a single value of ***f*** and do the ***M***s obtained from ***p*** and ***q*** data agree with your experimental values of ***M*** obtained from the *image* and *object heights*?
4) Do some BEAM4 simulations of your experiment, using your actual values of ***p*** and the object height. Since ***R*** is needed for your simulation, use your experimental value of ***f*** to compute ***R***. How close do your resulting ***M*** and ***q*** agree with your actual experimental values? Also simulate the situation when the object is between ***f*** and the mirror.
5) Use a spherometer to obtain ***R*** directly.
6) Summary of your results. Discuss their accuracy. A summary table is extremely useful.

II. DOUBLE CONVEX OR PLANO CONVEX LENS

Objective: Characterize the images formed by a lens of focal length, ***f***. Compare experimental data with the results of simulations.

Things to know before actually performing the experiments:

a) What is the relation between ***f***, the radii of curvature, R_1 and R_2, and the *index of refraction* ***n*** for a thin lens?
b) What is the relation between ***f***, ***p*** (*object distance*) and ***q*** (*image distance*)?
c) How is magnification, ***M***, related to ***q*** and ***p***?

Experiments and Simulations:

1) Identify your lens by the labels on the edge and choose a lens with **f** ≥ 20 cm.
2) Describe the images formed when the object is:
   a) At ∞
   b) Between ∞ and ***f***. 2***f*** is a special place, **why?**
   c) Between ***f*** and the lens
3) Choose at least three different object distances that span (a) to (b); and for each ***p***, measure ***q*** and the image height (from which you can compute ***M***).
4) Answer the same questions posed in question 3, above, for the mirror.
5) Use a spherometer to obtain R_1 and R_2.
6) Use the *Lensmakers* equation, with R_1, R_2, and ***f*** from experiment, to obtain a number for the *index of refraction*, ***n***. On BEAM4 look at the “glass.med” file that tabulates ***n*** for various glasses. What kind of glass do you have?
7) Now that you have ***n***, R_1 and R_2, do the same kind of BEAM4 simulations requested in question 4 for the mirror, including the situation where the object is between ***f*** and the lens. Compare and discuss simulation and experiment.
8) What is a *collimator*? How does it work? How many lenses would you need to make a simple collimator?

9) Make a collimator using a large diameter lens of long ***f*** and the Zirconium lamp. Think about what measurements you could make to prove it is a collimator. Once you have done this, we will let you use a specially-built, easy-to-use collimator for more advanced experiments.

III. PRISM

Read about the bending and dispersion of light by prisms.

1) Devise an experiment to observe bending of light with a prism. Start with monochromatic light (red HeNe laser) and find the *angle of minimum deviation* of the prism. Repeat this for the green HeNe laser.
2) What is the index of refraction, n, of your prism for the HeNe wavelength? From BEAM4, find the nearest n for the HeNe wavelength and compare with the experimental result. What kind of glass is closest?
3) Repeat the same experiment using the collimator with polychromatic light (Zirconium lamp). Can you measure n for the prism for different colors of light? What is the relationship between n and the wavelength, λ of light and how does it compare with the λ dependence of n from the media table of BEAM4?

IV. PRISM SPECTROMETER

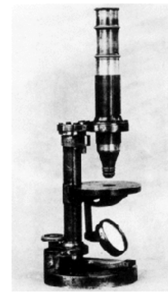
We have a high-quality spectrometer with which you can measure the emission spectra of certain gasses. After you calibrate the instrument, we'll give you "*mystery gasses*" to study.

V. IMAGE QUALITY OF MIRRORS AND LENSES

Read about the Aberration of light due to (a) *Spherical* and (b) *Chromatic* Aberrations. These aberrations affect the image quality.

1) Set up an experiment to observe spherical aberration in the image formed by a PLANO CONVEX lens with ***f*** ≤ 10 cm. Does the aberration depend upon which face (plane or convex) the light enters first? Do the same with a BEAM4 simulation.
2) A challenge! Set up an experiment to observe spherical aberration in the image formed by a CONCAVE MIRROR. Or perhaps do a BEAM4 simulation first to see how difficult the actual experiment might be.
3) Do a simulation showing chromatic aberration of light. Devise and perform an experiment where you can observe this effect.

VI. OPTIONAL PROJECTS



Ask us about the following: NEWTONIAN TELESCOPE, GALILEIAN TELESCOPE.

Propose other advanced projects.