GAUSSIAN LASER BEAMS

WEEK 1 INTRO: MEASURING A GAUSSIAN BEAM; CALIBRATING YOUR PHOTODETECTOR

GOALS

In this lab, you learn about mounting optics and photodetectors and try out some techniques that are generally useful in optics labs and elsewhere. In particular, you will set up a simple optics system for measuring the width of your laser beam and in the process will have to mount and align the laser and optics.

- Proficiency with new equipment
  - Laser: mounting it to table, plugging it in, turning it on.
  - Mounting optics:
    - Mirrors
    - Lenses
    - Post, post holders, bases
  - Aligning optics
    - Mirrors (using two mirrors to adjust a beam to any desired position and angle)
    - Lenses
  - Translation stage
    - Mounting it to the optics table
    - Mounting optics on it
    - Reading the micrometer position
    - Measuring micron-scale displacements
  - Amplified photodetector
    - Using it
    - Understanding how it works
    - Modeling its behavior
    - Reading the specification/data sheet.
- New skills to apply from Lab Skill Activities
  - Entering data into Mathematica or importing data
  - Non-linear least-squares fitting
  - Plotting data and fit function together
  - Extracting basic fit parameters with standard uncertainties
- Experimental design
  - Calibration of the photodetector
  - Modeling the photodetector

LAB NOTEBOOK GUIDELINES

The lab notebook will play an important role in this course. You will use your notebook for keeping records of many things including

- Answering pre-lab questions from the lab guide
- Answering in-lab questions
- Recording data
- Including plots of data
- Analysis and results

- Diagrams and pictures
- Procedures of experiments that you design

The lab notebook will be an important part of your grade because learning to keep a good lab notebook is an important part of your professional development. You may find it helpful to write up many of your notes on the computer, for example, within Mathematica or another program. This is fine. However, before your notebook is turned in, the notes, plots, and analysis should be transferred to the lab notebook by printing and taping the pages or keeping them in a three-ring binder. There will also be formal lab reports and oral presentations, but these will be restricted to a limited portion of the experimental work you have conducted in the lab.

DEFINITIONS

Optic – Any optical component that manipulates the light in some way. Examples include lenses, mirrors, polarizing filters, beam splitters, etc.

Optomechanics – This category includes optics mounts and the components to align them. Examples in the lab include post, post holders, bases, lens mounts, adjustable mirror mounts, rotation mounts, and translation stages.

SETTING UP YOUR LASER AND MOUNTING OPTICS

When you start working in the lab you should have an empty optics breadboard. The shelf above the breadboard should have

- An oscilloscope
- A waveform generator
- Triple output DC Power Supply
- Set of ball drivers
- Optics caddy to hold optics already mounted on 0.5" posts.
- Set of 1/4-20 and 8-32 screws, setscrews, washers, and nuts.

Question 1	a. Get a laser and power supply from the “He-Ne Laser” drawer in the colored drawer cabinet found in your chosen or assigned optics bay (each of the five optics bays has been color coded). You’ll also need two sets of laser tube mounts which you can find in the same drawer. The bottom mount first gets mounted to an optical post and then the top of the mount can be assembled with ¼-20 socket head cap screw and nut. After both sets of tube mounts are attached to the laser, insert the optical posts into post holders and attach the assembly to the optical table. b. Each person in your group is responsible for assembling a mounted lens or mirror as shown in Figure 1. In the end, you will need at least 2 mirrors to complete the next task. It's very important that you do not handle optical components (lenses, mirrors, polarizers, wave plates, beam splitters, etc.) with your bare hands. The oils on your skin can damage the optics and degrade the light in your experiment. Always handle these components while using latex/nitrile gloves or finger cots. *As you are mounting the optics, choose the heights so that the laser hits the center of each optic and the beam horizontal.*
Question 2	**"Walking a beam"** Mount two 3D printed beam alignment discs onto the optical table at the same height above the table. a. Use only two mirrors to get the beam to pass through the center of each disc. This technique is commonly called "walking a beam." Having two mirrors allows you to independently adjust the angle and position of your beam. b. Draw a diagram of the configuration of your laser, mirrors, and tube.

<table>
<tr>
<td>Question 3</td>
<td>Lens alignment. Using your setup from Question 2, add a lens after the mirrors.
a. Using your setup from Question 2, insert a lens to change the divergence/convergence of the beam but keep its propagation direction the same.
b. When this condition (the beam propagation is unchanged) is met, where does the beam intersect the lens?
Note: This is the preferred method of adding a lens to an optical set up.</td>
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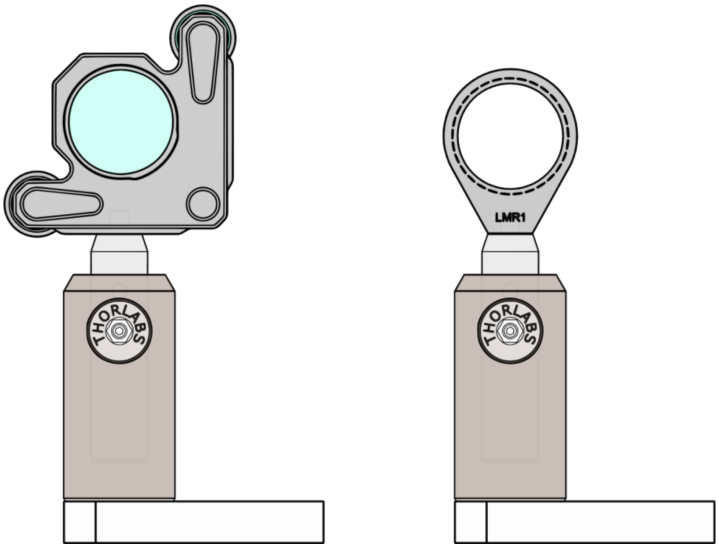

Figure 1 Mounting assemblies for a mirror (left) and a lens (right).

MODELING CHARACTERISTICS OF THE PHOTODETECTOR

The goal of this part of the lab is to understand a lot about the specifications given on the datasheet for the Thorlabs PDA36A Switchable Gain Amplified Photodetectors. It is important to realize that data sheets (also called spec sheets or specification sheets) provide a model for the realistic behavior of the device. This model can be tested and improved, a process more commonly called "calibration." Note that there are **two** power switches, one on the power supply and one on the photodetector. The photodetector will respond to light with the power off but it won't work well and changing the gain will have little effect.

<table>
<tr>
<td>Question 4</td>
<td>Basic function of the amplified photodetector

a. Spend a few minutes (no more than 10) to write an explanation using words and diagrams to explain the physical mechanism for how the photodetector converts light into voltage. You may use the manufacturer’s specifications sheet, trustworthy online resources, a book, etc. The specification sheet available at www.colorado.edu/physics/phys4430/phys4430_sp18/datasheets/Thorlabs_PDA36A.pdf
b. Use the data sheet to estimate the conversion of Watts of light into Amps of current for Helium Neon red wavelength (632.8 nm) and for the Frequency doubled Nd:YAG laser (Green laser pointer wavelength, 532 nm)?
i. How would you convert “Amps per Watt” into “electrons per photon”?
ii. What is the electron/photon conversion efficiency for the red HeNe and green doubled Nd:YAG lasers?
iii. Is this number less than, equal to, or greater than one? What does this number tell you about how the photodiode works?</td>
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Question 5	**Calibrating the Thorlabs PDA36A photodetector offset and gain.** Calibrating the photodetector is especially important when you take a data set that uses multiple gain settings. Having an accurate calibration of the gain and offset will let you stitch the data together accurately. a. Here you will encounter gain values that are presented on a logarithmic dB (decibel) scale, which is obtained by taking $20\times\log(V_{out}/V_{in})$. For example, 20 dB of gain corresponds to electronic voltage amplification by a factor of 10. A dB scale could also be defined as $10\times\log(P_{out}/P_{in})$, where P is the power. Explain the conversion between these two scales and why this makes sense. b. Calibrating the offset voltage is the output of the photodetector when no light is incident upon the device. i. Calibrate the offset of the photodetector as a function of gain setting. ii. Quantitatively compare it to the specifications given in the table. Is your measured value within the specified range given on the PDA36A photodetector data sheet? iii. What measures did you take to eliminate stray light? Were your measures sufficient for an accurate calibration? c. Calibrating the gain i. Is it possible to measure the V/A gain for each setting, or can you only measure the change in gain as you switch the settings? Why? Note that this lab only requires relative gain. ii. Make a measurement of the gain or relative gain settings for most of the gain settings. If you need to adjust the laser power, try blocking part of the beam. Note, you will need to make two measurements at one gain setting when you block the beam. What systematic error sources are of most concern? iii. Quantitatively compare your results with the range of values given on the data sheet. Do you believe your results provide a more accurate estimate of the photodetector gain than the data sheet? Why or why not? iv. Using the PDA36A spec sheet and your measurements, what is the power of your laser? Does this agree with the laser power shown on the laser? v. Hypothetically, how would you measure the absolute gain?
Question 6	**Follow up:** Write mathematical expressions that converts the incident power (the light) P_{in} to the photodetector voltage V and the photodetector voltage V to input power P_{in}. Take into account all relevant parameters such as the photodetector gain setting (in dB) and offsets.

MEASURING THE BEAM WIDTH

Note: *Many of the data analysis techniques in this section will use skills from the class Activities.*

The goal of this section is to develop a measurement technique and analysis scheme to measure the width of a beam. The scheme will let you measure the width in one direction. The technique is most useful for beams that are approximately Gaussian profile in intensity. In the second week of the lab you will use this technique to experimentally answer questions about Gaussian beams.

The basic scheme involves measuring the power in the laser beam as the beam is gradually blocked by a razor blade using a setup similar to Figure 2

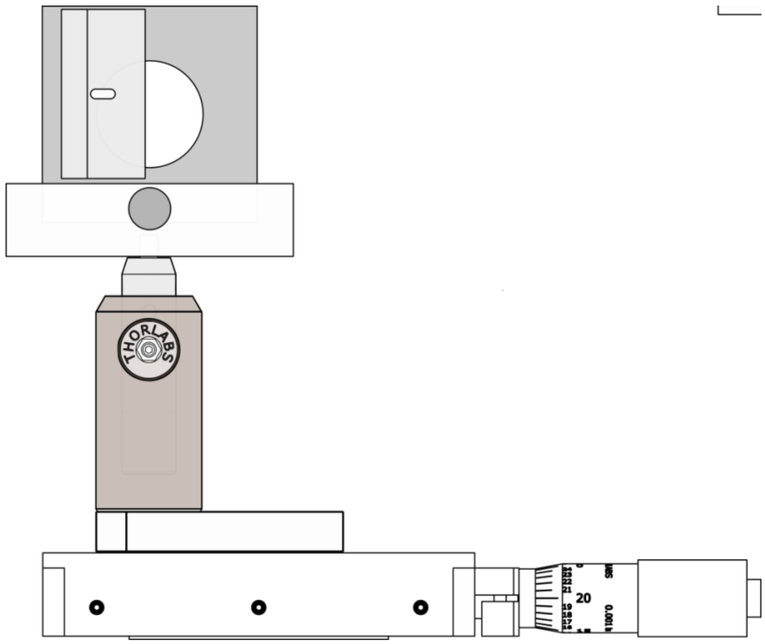

Figure 2: Razor blade mounted on a translation stage

Question 7	Suppose a laser beam has a Gaussian intensity profile $I(x,y) = I_{max}e^{-2(x^2+y^2)/w^2}$, and is incident upon a photodiode. What is the expression for the power hitting the photodiode when a portion of the beam is blocked by a razor blade (see Figure 2: Razor blade mounted on a translation stage)? a. Draw a diagram showing the beam and the razor. b. Using the above expression for $I(x,y)$, write the mathematical expression for the power incident on the photodiode as a function of razor position. Note, to address this question, you will need to become familiar with the Error Function, erf(x). What assumptions, if any, did you need to make in evaluating the integral? Hint: if you are moving in the x direction, what is going on in the y direction?
Question 8	**Before you take data: Create an analysis function to fit a test set of data.** *Note: Nonlinear least squares fitting is covered in Mathematica Activity 2 available on the course website. There is also a YouTube video available on least squares fitting at www.youtube.com/compphysatcu.* a. What is the functional form for your fit function? b. Is it a linear or nonlinear fit function? Why? c. What are the fit parameters? Why do you need this many? d. How do the fit parameters relate to the beam width? e. Download the data set from: www.colorado.edu/physics/phys4430/phys4430_sp18/sample_data/Test_Profile_Data.csv i. Make a plot of the data. ii. Make a fit and plot it with the data. iii. Check that the fit looks good and you get a beam width of $w = 4.52 \times 10^{-4}$ m. If you get a different value, check with your instructor to understand the problem. What is the uncertainty on your measurement?

Question 9	**Build your setup for measuring the beam width of your laser.** a. Draw a detailed schematic of the setup (from the laser all the way to the photodetector). Do not use a lens for this measurement. b. After assembling your experiment, but prior to taking a lot of data, how can you quickly determine if the measurement is working? c. Is it preferable to use a digital multimeter or oscilloscope? Why? d. Use the measurement scheme to take data of power vs position of the razor. Pay attention to the units of the translation stage. Pick a position where your beam has a measurable width, and measure it. Justify your choice.
Question 10	**Analysis of the random uncertainty sources** a. What are possible sources of random uncertainty in the photodetector voltage? b. How would you estimate the uncertainty in the photodetector voltage measurement? c. What is the largest source of uncertainty? Why?
Question 11	**Analysis of the real data.** a. Use the analysis procedures verified in Question 8 to find the beam width for your data. Be sure to include the uncertainty. b. Plot your fit together with your data to make sure it is good.

WEEK 2: DEVELOPING A QUANTITATIVE MODEL OF THE SPATIAL PROPERTIES OF LIGHT

GOALS

In week 1, we measured the profile of the laser and found it to be Gaussian to a good approximation. However, we don't have any model for how the profile changes as the beam propagates. Also, we will apply automation to more rapidly take data. The full set of learning goals includes:

1. Automated data acquisition.
    a. LabVIEW
    b. USB DAQ (NI USB-6009)
2. Fitting and analysis of data in Mathematica
3. Using a predictive model of Gaussian laser beams
    a. Contrast Gaussian beams with geometric optics
4. Measure profiles of a Gaussian beam, and extract the Gaussian beam parameters
5. Effect of a lens on Gaussian beams.
    a. Is it still Gaussian?
    b. Does the thin lens equation apply to Gaussian beams?
    c. What limits the minimum achievable spot size?

PRELAB: INTRODUCTION

Question 12	**Answer these before reading ahead in the lab guide based on your experience from last week** a. Does the beam always stay a Gaussian as it propagates? b. Does the beam stay Gaussian after it goes through a lens? c. Does the beam stay Gaussian after it reflects from a mirror? d. How small does the beam get when it is focused by a lens? Does it focus to a point? Why or why not?

Light is a propagating oscillation of the electromagnetic field. The general principles which govern electromagnetic waves are Maxwell's equations. From these general relations, a vector wave equation can be derived.

$$\nabla^2\vec{\boldsymbol{E}} = \mu_0\epsilon_0\frac{\partial^2\vec{\boldsymbol{E}}}{\partial t^2} \tag{1}$$

One of the simplest solutions is that of a plane wave propagating in the $\hat{\boldsymbol{z}}$ direction.

$$\vec{\boldsymbol{E}}(x,y,z,t) = E_x\hat{\boldsymbol{x}}\cos(kz-\omega t+\phi_x) + E_y\hat{\boldsymbol{y}}\,\cos\left(kz-\omega t+\phi_y\right) \tag{2}$$

But as the measurements from last week showed, the laser beams are commonly well approximated by a beam shape with a Gaussian intensity profile. Apparently, since these Gaussian profile beams exist, they must be solutions of the wave equation. The next section will discuss how we derive the Gaussian beam electric field, and give a few key results.

PARAXIAL WAVE EQUATION

One important thing to note about the beam output from most lasers is that the width of the beam changes very slowly compared to the wavelength of light. Assume a complex solution, where the beam is propagating in the $\hat{\boldsymbol{z}}$-direction, with the electric field polarization in the $\hat{\boldsymbol{x}}$-direction.

$$\vec{\boldsymbol{E}}(x,y,z,t) = \hat{\boldsymbol{x}}\,A(x,y,z)e^{i(kz-\omega t)} \tag{3}$$

The basic idea is that the spatial pattern of the beam, described by the function $A(x,y,z)$, does not change much over a wavelength. In the case of the HeNe laser output, the function $A(x,y,z)$ is a Gaussian profile that changes its width as a function of z. If we substitute the trial solution in Eq. (3) into the wave equation in Eq. (1) we get

$$\hat{\boldsymbol{x}}\left[\left(\frac{\partial^2 A}{\partial x^2}+\frac{\partial^2 A}{\partial y^2}+\frac{\partial^2 A}{\partial z^2}\right)+2ik\frac{\partial A}{\partial z}-k^2A\right]e^{i(kz-\omega t)} = \hat{\boldsymbol{x}}\mu_0\epsilon_0A(-\omega^2)e^{i(kz-\omega t)} \tag{4}$$

This can be simplified recognizing that $k^2=\omega^2/c^2=\mu_0\epsilon_0\omega^2$, where the speed of light is related to the permeability and permittivity of free space by $c=(\mu_0\epsilon_0)^{-1/2}$. Also, the $\hat{\boldsymbol{x}}e^{i(kz-\omega t)}$ term is common to both sides and can be dropped, which results in

$$\left(\frac{\partial^2 A}{\partial x^2}+\frac{\partial^2 A}{\partial y^2}+\frac{\partial^2 A}{\partial z^2}\right)+2ik\frac{\partial A}{\partial z}=0 \tag{5}$$

So far, we have made no approximation to the solution or the wave equation, but now we apply the assumption that $\partial A(x,y,z)/\partial z$ changes slowly over a wavelength $\lambda=2\pi/k$, so we neglect the term

$$\left|\frac{\partial^2 A}{\partial z^2}\right| \ll \left|2k\frac{\partial A}{\partial z}\right| \tag{6}$$

And finally, we get the paraxial wave equation

$$\frac{\partial^2 A}{\partial x^2}+\frac{\partial^2 A}{\partial y^2}+2ik\frac{\partial A}{\partial z}=0 \tag{7}$$

One set of solutions to the paraxial wave equation are Gauss-Hermite beams, which have an intensity profiles like those shown in Fig. 3. These are the same solutions as for the quantum simple harmonic oscillator, a topic that could be further explored as a final project.

The simplest of these solutions is the Gaussian beam, which has an electric field given by

$$\vec{\boldsymbol{E}}(x,y,z,t) = \vec{\boldsymbol{E}}_0\frac{w_0}{w(z)}\exp\left(-\frac{x^2+y^2}{w^2(z)}\right)\exp\left(ik\frac{x^2+y^2}{2R(z)}\right)e^{-i\zeta(z)}e^{i(kz-\omega t)} \tag{8}$$

Where $\vec{\boldsymbol{E}}_0$ is a time-independent vector (orthogonal to propagation direction $\hat{\boldsymbol{z}}$) whose magnitude denotes the amplitude of the laser's electric field and the direction denotes the direction of polarization. The beam radius $w(z)$ is given by

$$w(z) = w_0\sqrt{1+\left(\frac{\lambda z}{\pi w_0^2}\right)^2} \tag{9}$$

$R(z)$, the radius of curvature of the wavefront, is given by

$$R(z) = z\left(1+\left(\frac{\pi w_0^2}{\lambda z}\right)^2\right) \tag{10}$$

And the Guoy phase is given by

$$\zeta(z) = \arctan\frac{\pi w_0^2}{z\lambda} \tag{11}$$

The remarkable thing about all these equations is that only two parameters need to be specified to give the whole beam profile: the wavelength λ and the beam waist w_0, which is the narrowest point in the beam profile. There is a more general set of Hermite Gaussian modes which are shown in Figure 3. The laser cavity typically produces the (0,0) mode shown in the upper left corner, but an optical cavity can also be used to create these other modes – a topic that can be explored in the final projects.

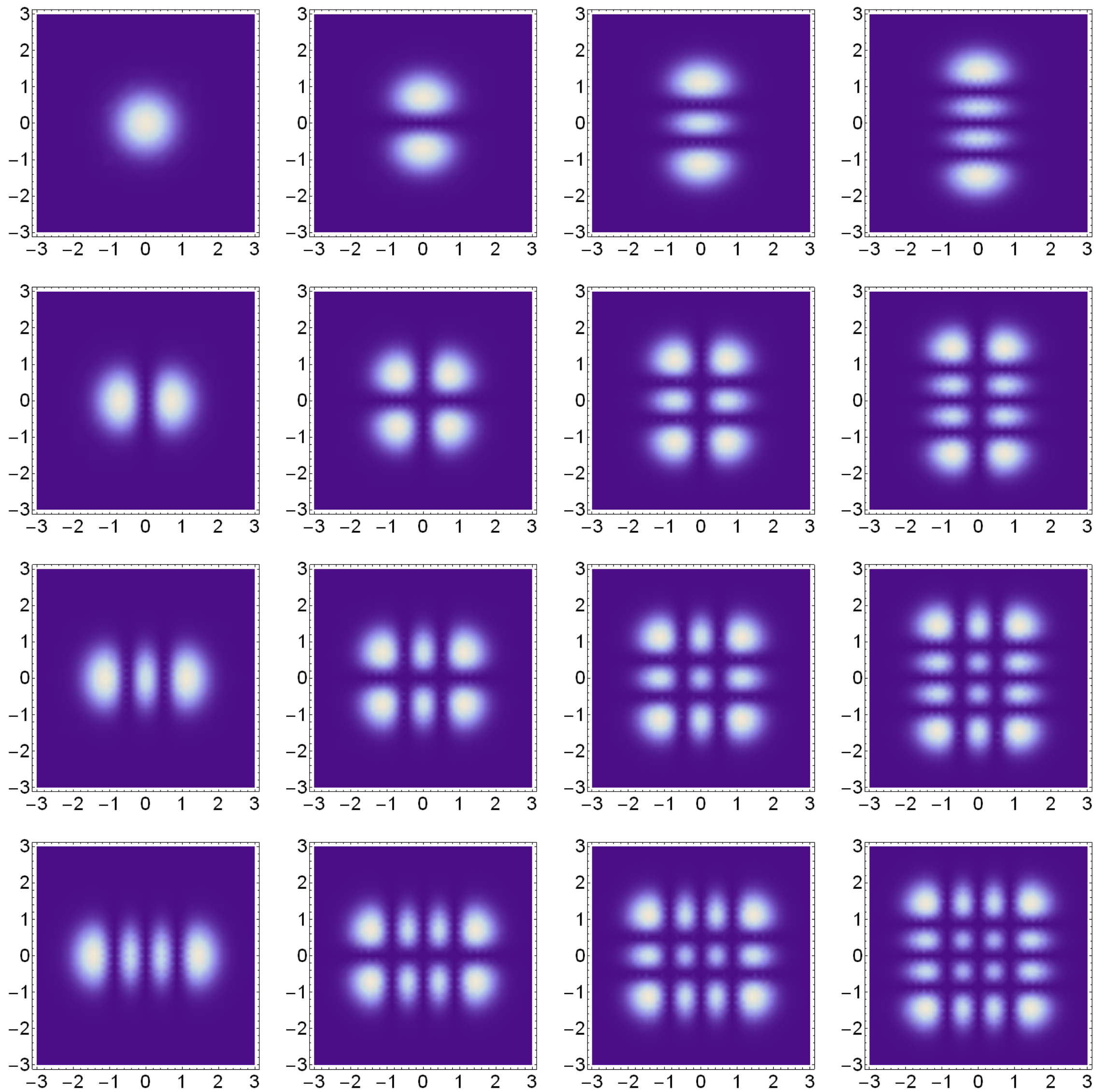

Figure 3 Intensity distributions for the lowest order Gauss-Hermite solutions to the paraxial wave equation. The axes are in units of the beam width, w.

MORE PRELAB: TRYING OUT THE GAUSSIAN BEAM MODEL

Question 13	In week 1 of the lab, we assumed the intensity profile of the Gaussian beam was given by $I(x,y) = I_{max}e^{-2(x^2+y^2)/w^2}$. The equation for the electric field of the Gaussian Beam in Eq. (8) looks substantially more complicated. How are the expressions for electric field and intensity related? Is Eq. (8) consistent with the simple expression for intensity $I(x,y) = I_{max}e^{-2(x^2+y^2)/w^2}$?
Question 14	The Gaussian beam equations given in Eqs. (8)-(11) assume the beam comes to its narrowest width (called the beam waist) at $z = 0$. a. How would you rewrite these four equations assuming the beam waist occurs at a different position $z = z_w$? b. One way to check your answer is to make sure the equations simplify to Eqs. (8)-(11) in the special case of $z_w = 0$.
Question 15	a. Write a function to fit the following data set available at: www.colorado.edu/physics/phys4430/phys4430_sp18/sample_data/Test_beam_width_data.csv. Assume the wavelength is $\lambda = 632.8$ nm. i. What is the functional form for your fit function? ii. What are the different fit parameters and what do they mean? iii. Is it a linear or nonlinear fit function? Why? b. You should get that a beam waist of $w_0 = (93.9 \pm 0.1) \times 10^{-6}$ m and occurs at a position $z_w = 0.3396 \pm 0.0003$ m.

AUTOMATION OF THE MEASUREMENT AND ANALYSIS

Question 16	a. In week one, how long did the total process of data taking through analysis take to make a measurement of the beam width w? b. In this lab, you may have to take 20-30 beam profiles in order to measure w_0 and z_w. How long would this take with your current method? c. What are the most time consuming portions of the process? Which parts of the process would benefit from automation?

In the next step, you will use LabVIEW and your NI USB-6009 data acquisition card to automate the procedure for measuring the width of the laser beam. You can do this with your own laptop or with the laptops in lab. If for some reason you cannot get this to work, you can still complete the lab in a much less efficient fashion by taking data manually.

Question 17	You should have already completed at least the first LabVIEW lab skill activity during the lecture time. In order to set up your measurement automation you will need to do two things: a. Do questions 1 and 2 of the LabVIEW Lab Skill Activity 2. The activity goes over connecting your NI USB-6009 Data Acquisition device to your computer. The activity is available on the "Activities" page on the course website. b. Create a LabVIEW VI that performs the automated data taking (moving the translation stage, recording the position, recording the voltage from the photodiode, repeat). Instructions can be found in the Appendix.
Question 18	a. Test and run the automated LabVIEW program and evaluate the result using the same Mathematica analysis as before. b. Before you go on, make sure the automated acquisition and analysis routine gives the same result as the method you used last week. c. How long does your new measurement method take? (2-3 minutes per w measurement is very good.)

THE EXPERIMENT

The Gaussian beam model of light is useful because it often describes the beam of light created by lasers. This section will test the validity of the model for our HeNe laser beam. Also, the effect of a lens on a Gaussian beam will be tested, and the Gaussian beam model will be compared with predictions from the simpler ray theory. Lastly, the Gaussian beam theory can be used to describe the minimum possible focus size for a beam and a lens.

<table>
<tr><td>Question 19</td><td>Measuring the beam profile of your HeNe laser without any lenses. There is a straight-forward reason that a HeNe laser should produce a Gaussian beam. The laser light builds up between two mirrors, and the electromagnetic mode that best matches the shape of the mirrors is the Gaussian beam.
a. Considering Eq. (8)-(11), which aspects of the Gaussian beam model can you test? Are there any parts of the model you cannot test?
b. Measure the beam width w versus distance from the laser. Consider carefully what distance should be varying. Is it the distance from laser to razor, the distance from razor to photodetector, or the distance from laser to photodetector? How did you decide what positions z to measure the width at? (meter sticks are available)
c. Fit the data to $w(z)$, the predicted expression for a Gaussian beam given in Eq. 9.
d. What is the value of the beam waist w_0 (including uncertainty)? Where does the beam waist z_w occur relative to the laser?</td></tr>
<tr><td>Question 20</td><td>How does a lens change a Gaussian beam? Pick a non-compound lens (not the fancy camera lenses) with focal length in the range 100-200 mm. Design and carry out an experiment to quantitatively answer the questions below. Consider carefully where to put the lens. Your data for this question can be used in the next question.
a. Does the beam retain a Gaussian profile after the lens?
b. What is the new beam waist w_0 and where does it occur?
c. What factors affect the beam profile after the lens?
d. Does the measured $w(z)$ match the Gaussian beam prediction given in Eq. (9)?</td></tr>
<tr><td>Question 21</td><td>Quantitatively modeling the effect of a lens. One of the simplest ways to model the effect of a lens is the thin lens equation, which is based on a ray model of light. (see Figure 4)
$$\frac{1}{S_1}+\frac{1}{S_2}=\frac{1}{f}$$
a. Redraw Figure 4 to show how it would change when the light is modeled as a Gaussian beam, rather than rays. In particular, where should the beam waists occur? What determines the relative width of the beam waist?
b. Experimentally test the accuracy of the thin lens equation for the imaging of Gaussian beams. Your data from the previous question can probably be used. Is the agreement within the estimated uncertainties?
c. Systematic errors: Under what conditions should the thin lens equation be most valid? How do these conditions compare to conditions of your actual measurements? Can you get better agreement?</td></tr>
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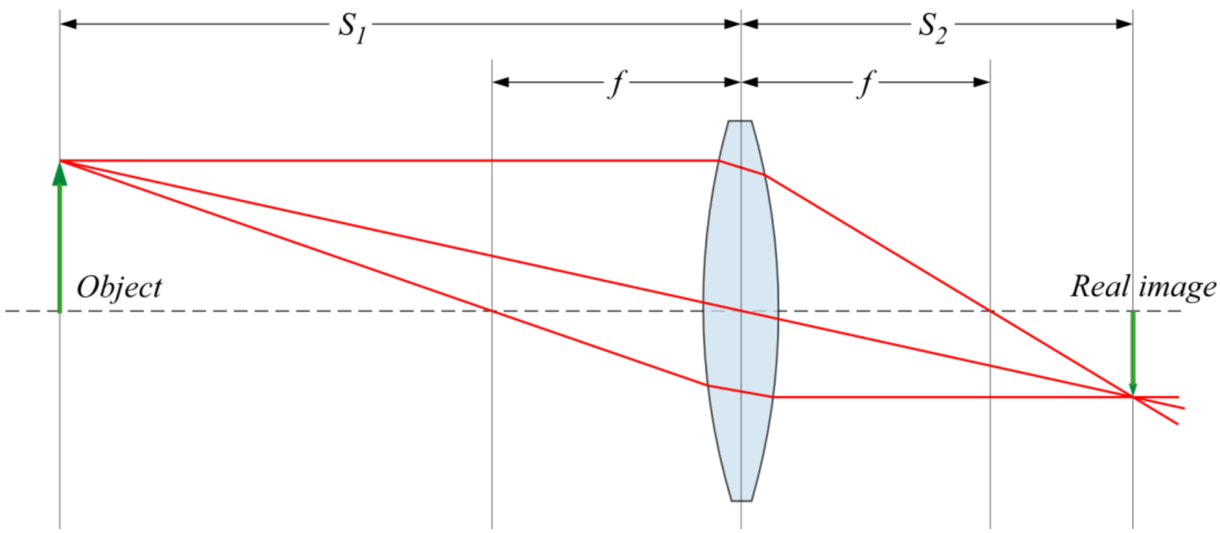

Figure 4 Diagram showing the focusing of light by a thin lens in the ray approximation. The diagram identifies the quantities in the thin lens equation: image distance, object distance, and focal length.

PROJECT IDEAS

1. Predicting the behavior of complex optical systems using ABCD matrices to transform Gaussian Beams.
2. Build an optical cavity. Study the coupling of light into the cavity, and spatial filtering into different TEM modes. Replicate the awesome pictures.
3. Analogy between paraxial wave equation in free space and 2D Schrodinger wave equation. Solving the Schrodinger equation optically. Adding a potential. Tunneling. Etc.
4. Using a translatable, rotatable slit to map out the beam profile of a funky pattern using the Radon transform, which is used in reconstructing CT scans. Perhaps there is some better application of tomography also.

REFERENCES

1. http://people.seas.harvard.edu/~jones/ap216/lectures/ls_1/ls1_u3/ls1_unit_3.html (Gaussian Beam theory)
2. http://en.wikipedia.org/wiki/Gaussian_beam

APPENDIX: LABVIEW AUTOMATION GUIDE

SETTING UP THE MOTOR

You will likely need to download additional device drivers for LabVIEW. You should download the 32-bit on 64-bit Windows APT software from www.thorlabs.com/software_pages/ViewSoftwarePage.cfm?Code=Motion_Control in order to get the MGMotor library used below. Once you have done this, follow the next steps:

1. Start with LabVIEW closed on your computer and no cords connected to the motor cube.
2. Connect the USB to the KST101 controller cube, THEN turn on the power.
3. Open APT Config on the computer. Your motor should be seen by the software. Click the motor drop down menu and select your motor. Now, in the drop down menu for Stage, find ZST225(B) and select it. With these options in place, select the Add/Change Stage Association button.
4. Close APT Config

This should connect the motor correctly, but to verify, open APT User. This will open a LabVIEW VI with a motor control on the front panel. This motor control should have your serial number in the top right corner and should also have "STAGE: ZST225(B)". Clicking the arrow pointing up and arrow pointing down should move the motor in either direction. If none of this is seen when you open APT User, the motor was not set up correctly and you should disconnect the USB and power supply from the motor and start again step 1.

LABVIEW VI IMPLEMENTATION

To understand how to automate the data taking process using LabVIEW, consider what you do while taking data by hand. The process includes: moving the razor (stage), reading the position, reading the photodiode voltage, repeat. In order to automate this process, two pieces of equipment are used: the motor to move the stage and the NI-DAQ to read the voltage.

I. The first step in data taking is moving the razor. To automate this, we need to use the motor cube. To connect the cube to LabVIEW, follow these steps:
   A. On the front panel, place an `ActiveX Container` (Under the ".NET & ActiveX" tab)
   B. Right click the ActiveX Container → `Insert ActiveX Object...` → `MGMotor Control`
   C. Right click `MG17Motor` in the block diagram → `Create` → `Property for MG17MotorLib…` → `HWSerialNum`
   D. Right click `HWSerialNum` → `Change to Write`
      1. Wire the `MG17Motor` reference out to the reference in of `HWSerialNum`. This allows us to tell the LabVIEW to look for the motor cube with your serial number (i.e. your cube)
   E. Add a Numerical Control to the front panel
      1. Rename to *HWSerialNum*
      2. In the block diagram, wire it to the input of `HWSerialNum`. This control allows you to input your motor's serial number easily on the front panel in case you change cubes.
   F. Right click `MG17Motor` in block diagram → `Create` → `Method for MG17MotorLib…` → `StartCtrl`
      1. Wire the **reference out** of `HWSerialNum` node to **reference in** of `StartCtrl`.
      2. At this point, our LabVIEW is basically saying "Look for a motor with *this* serial number (input in the front panel numerical control) and start controlling it." Now we have to make it move.
   G. Right click `MG17Motor` in block diagram → `Create` → `Method for MG17MotorLib…` → `SetJogStepSize`
      1. This node allows us to tell the motor how much to move and it uses units of millimeters.
      2. Wire the **reference out** of `StartCtrl` to **reference in** of `SetJogStepSize`.
   H. Add a Numerical Control on front panel
      1. Rename it *Set Jog Step Size (mm)*
      2. In the block diagram, wire this control to **fStepSize** input of `SetJogStepSize`.
      3. Connect **reference out** of `StartCtrl` to **reference in** of `SetJogStepSize`.
   I. Add a Numerical Constant of 0 in the block diagram
      1. Wire to the **lChanID** input of `SetJogStepSize`
      2. This concludes the initialization portion of the LabVIEW.
   J. Right click `MG17Motor` icon in block diagram → `Create` → `Method for MG17MotorLib…` → `SetJogVelParams`
      1. Wire the reference out of `HWSerialNum` to reference in of this block.
   K. Add three Numerical Controls to the front panel
      1. Rename one to *Min Velocity (mm/s)* and wire it in the block diagram to the **fminVel** input of `SetJogVelParam`
      2. Rename one to *Max Velocity (mm/s)* and wire it in the block diagram to the **fmaxVel** input of `SetJogVelParam`
      3. Rename the last numerical constant *Acceleration (mm/s/s)* and wire it in the block diagram to the **faccn** input of `SetJogVelParam`.

    4. These control how the motor moves. They should be set to a minimum velocity of 0 mm/s, a maximum velocity of 1 mm/s, and an acceleration of 1 mm/s/s.

II. The next step involves the action that we want the motor to execute, as well as the data taking process

  A. In order to separate the 'action' part of the LabVIEW from the 'initialization', first add a `Flat Sequence Structure` in the block diagram under the `Structures` tab
    1. Drag the `Flat Sequence Structure` to include everything in the block diagram so far (the initialization part)
    2. Right click the `Flat Sequence Structure` and select `Add Frame After`. The second frame in this sequence loop will contain all the action of moving the motor and taking the data.

  B. The data taking process has one key feature that should be addressed at this point, the "repeat" part (Move razor, take data, repeat). In order to make our LabVIEW repeat this process:
    1. Add a `While Loop` (from the `Structures` tab) inside the second frame of the Sequence
    2. Add a `Stop` button to the front panel and, in the block diagram, wire the stop button to the red stop circle in the corner of the `While Loop`. This loop will execute its contents repeatedly *while* the loop has a Boolean "true" value. Once the LabVIEW is running, pressing this stop button on the front panel will stop the While Loop from continuing.

  C. We need to put our other actions inside this `While Loop`. We want these actions to be performed in a sequence, so inside the `While Loop`, add another `Flat Sequence Structure` (we will refer to this loop as sequence #2)
    1. Add 3 frames to sequence #2 for a total of 4 frames

  D. Inside the first frame of sequence #2, we want the razor to move one Jog Step.
    1. Right click `MG17Motor` → `Create` → `Method for MG17MotorLib…` → `MoveJog` and place inside 1st frame of sequence #2
    2. Wire **reference out** from `SetJogStep` node to **reference in** of `MoveJog`
    3. Add a Numerical Constant of 0 to the block diagram and wire it to the **lChanID** input
    4. Add one Numerical Control to the front panel and rename it *Jog Direction*
    5. Wire it to the **lJogDir** input and enter its value as either 1 or 2 (the values correspond to extending or retracting)

  E. The next step in the data taking process to wait some amount of time to ensure we do not read the photodiode voltage while the razor is moving.
    1. Add the `Wait` function (under the `Timing` tab) to the 2nd frame of sequence #2
    2. Add a Numerical Control to the front panel, rename it *Wait (ms)*
    3. Wire this control to the `Wait` function. This allows you to change the wait time from the front panel.

  F. At this point we need to introduce the NI-DAQ. First, find a working DAQ. Plug it into the computer via the USB. Wire the BNC output from the photodiode into the +/- analog inputs of the DAQ labeled AI0
    1. In the 3rd frame of sequence #2 add `Measurement I/O` → `NI-DAQmx` → `DAQ Assist`
    2. A window should pop and you should click `Acquire Signal` → `Analog Input` → `Voltage` → Channels *ai0*
    3. A new window should pop up for additional setting options called DAQ Assist Properties. Under *Timing Settings*, change the *Acquisition Mode* to *1 Sample (On Demand)*
    4. Click OK to close the window and save your settings.

  G. In the 4th frame of sequence #2 select `File I/O` → `Write to Measurement File`

  H. A window should open for properties of this node, if it does not then right click the Write to Measurement File icon and select "Properties"
    1. Under the *Filename* section, select *Ask User to Choose* and check the box *Ask Only Once*. This allows you to enter the file name when LabVIEW is run.
    2. Under *If a file already exists* select *Append to file*. This makes it so each data point is added to the same file, instead of overwriting or deleting old data points
    3. The file format should be left as text format because it's easiest to upload into Mathematica
    4. Under the header option, select *No Headers*. At this point all the settings should be as we want so close this window

I. Now we need to feed our data into this icon so it knows what to write to file. The data that we want should be in the form (position, voltage)
   1. In sequence #2 frame 4 add `Express → Sig. Manip. → Merge Signals`

J. This merged signal will output to the Write to File node and we want the position value in the upper input of Merge Signals and the voltage value in lower input
   1. Wire the **Data** output from the `DAQ-Assist` icon in frame 3 to the lower input of the `Merge Signals` operator
   2. Add a Numerical Indicator on the front panel and rename it *Voltage (V)* and wire the data output of the `DAQ-Assist` to it in the 3rd frame of sequence #2 in the block diagram. This provides a real-time check of the photodiode voltage from the front panel

K. We want to know the position of the stage. Right click `MG17Motor → Create → Method for MG17MotorLib… → GetPosition` and place the icon in the 3rd frame of sequence #2
   1. Wire the **reference out** from `MoveJog` to the **reference in** of `GetPosition`
   2. Wire a Numerical Constant to the **lChanID** input and enter its value as 0
   3. Right-click on **pfPosition** and select `Create → Indicator` to give us a real-time indicator of the position.
   4. Right-click the new indicator and select `Create → Local variable`
   5. Right-click on the new local variable and select `Change to read` and wire it to the input of **pfPosition**
   6. Wire the output of **pfPosition** to the upper input of the `Merge Signals` operator

L. Now the data is in the form (position, voltage) and the merged signal should be wired into the **Signals** input of the `Write to File` node.

And with that, the LabVIEW is complete!

At this point, take a step back and take a look at the big picture of the LabVIEW and how it operates. There are many different approaches to automating this specific process and there is always more than one way to approach any problem. In this case what we did was we broke up the LabVIEW into 2 major parts; the initialization and the action. To initialize, we said "look for a motor with *this* serial number, start controlling it and set its jog step size to be *this* size." With that done, we move to the action part. The While Loop says "continue doing this until I press the stop button" and what we are telling it to do is; move the razer, wait for it to stop moving, read the photodiode voltage and combine it with the position measurement, and finally write the data to a file. Once it executes that process the While Loop starts it all over again.

Some tips on how to actually use the LabVIEW.

1. Make sure the move velocity on the motor control cube is maxed out at 1mm/s. This is changed on the motor cube itself through the menu.
2. The Jog Step Size can be very small (0.05 mm for example).
3. To determine a good amount of time to wait, you can start with the kinematic equation: $x = ½\ a\ t^2$. For a step size of 0.05mm, this indicates a time of 316 ms. You may also need to worry about the maximum velocity if you have a large step size. In general, you probably want to add another 200 ms for safety. This will ensure that vibrations from the movement have damped out.
4. Check where a good starting position is on the control cube display. Then, once a data set is taken you can quickly move the motor to the start position using the control wheel on the cube. You definitely want to include data before, during, and after the razor starts to block the light.

The final LabVIEW requires you to input the serial number, step size, and wait time on the front panel. With those values in place, running the LabVIEW and selecting the file save location are all that needs to be done to start the process. To stop, press the stop button and it will cut off the While Loop and end the process.

For more details on how LabVIEW and Thorlabs products interact, you can look at:
www.thorlabs.us/images/TabImages/GuidetoLabVIEWandAPT.pdf