Physics 180Q Week 1: Basic Skills

1 Introduction

The first lab you will perform in 180Q is designed to familiarize you with basic skills for the safe use and handling of lasers and optical components. You will also get some experience in the manipulation of laser beams, as well as taking simple measurements. You will learn how to position a laser beam in space, properly align it through optical elements (such as lenses), and characterize it with a photodiode and oscilloscope. These skills will become second nature to you as you gain experience with the hardware of quantum optics.

2 Prelab (due when you show up in the lab this week)

Typically, your prelabs will be due at the beginning of the week's lecture. However, for week 1, your prelab will be handed to your TA later this week when you show up to perform the first experiment. Some helpful materials for completing this week's prelab are available on the course website.

1. **Laser safety.** Answer the following questions

   (a) Define Class I, II, III, and IV lasers. Define optical density and MPE.

   (b) The value of MPE depends on the duration of the exposure. When working with a visible wavelength, the time it takes to blink is obviously a reasonable timescale to judge if a laser's intensity is dangerous or not. What is the MPE for a 650 nm laser for the time it takes an average human to blink?

   (c) What areas of the eye are most susceptible to damage?

   (d) What region of the electromagnetic spectrum is most dangerous to the eye?

   (e) How should you select laser safety goggles?

2. **Back-reflection from optics.** Optics are made from dielectric materials with $n \neq n_{\mathrm{air}}$. The impedance mismatch between the dielectric and the air means that some of the light incident on the optic will be reflected ("Fresnel reflection"), even for transparent optical components such as lenses, wave plates, prisms, and windows. Modern high-quality optics are frequently made from a material called fused silica. Estimate

the fraction of power reflected when a 635 nm laser beam enters an uncoated fused silica optic from the air. How much power is "lost" when the same beam goes through a typical lens?

3. **Photodiodes.** You will be using the Thorlabs DET36A2 silicon photodiode to measure laser power. If this photodiode is producing 4 V into a 100 kΩ termination when a 635 nm laser is impinging on the detector, how much power is in the laser beam? Why is this laser power and not energy?

4. **Please write and sign the following if you agree to what is written:** I understand that the equipment in this laboratory class is both potentially dangerous and extremely expensive. I will therefore work diligently to ensure the safety of all people in the lab as well as the lab equipment. If I have questions about how to proceed, I will ask the TA or professor BEFORE I act.

3 Procedure

3.1 Materials

The TA will provide all of the necessary materials. If you are missing something, please ask for help.

- laser system
- laser safety goggles (Wear them!)
- 2 apertures (these will be pre-bolted to the table – please do not adjust)
- 2 kinematic mirror mounts with mirrors
- Si photodiode DET36A2, BNC cable, variable impedance terminator, and oscilloscope
- one lens and lens mount
- one 50:50 non-polarizing beamsplitter cube

3.2 Set up the laser

The laser should already be mounted (possibly via a fiber) in a kinematic mount with two knobs to adjust its angle. Making sure the laser is off first for safety, attach this mount to a 3 in pedestal and secure it to the table with a fork clamp. Safely turn on the laser and adjust the knobs so the beam is roughly parallel to the table.

3.3 Aligning a laser beam through two points in space

Two apertures are already mounted to the table at roughly the same height. Your task in this section is to use mirrors to send your beam straight through both simultaneously – a task that is common and requires the ability to position the beam properly in position and direction, both vertically and in the horizontal plane.

The mirrors you have are provided with what are called "kinematic mounts," each of which has a knob to adjust the vertical tilt and a knob for the horizontal tilt. With two of these, you will have 4 degrees of freedom to match the 4 constraints presented to you (the vertical and horizontal positions of the 2 apertures, or, alternatively, the horizontal and vertical positions of the first aperture and the vertical and horizontal tilt required to hit the second one from the first). You will therefore be bouncing your beam off both mirrors before the beam enters the first aperture.

The technique you will use is called "upstream, downstream." The idea is that the first mirror the beam hits (the upstream mirror) will primarily be used to put the beam spot on the first aperture (the upstream aperture) and the downstream mirror will be used to align it through the downstream aperture. You will have to iterate back and forth (upstream, downstream, upstream, downstream,...) because these two are not independent. If you get confused and start to use the up(down)stream mirror to hit the down(up)stream aperture, this technique will not converge!

1. Mount the two kinematic mirror mounts on 3 in posts, then position and fasten them to the table such that the laser bounces off both mirrors and gets somewhat close to making it through both apertures. Make sure the beam is roughly level with the table at all times (this is also important for safety!). Using a scrap of paper to follow the beam spot around in space is very helpful here, but please do remember not to let the paper contact any optics directly (dielectric coatings are incredibly fragile). *Hint: align the laser source so that it first propagates parallel to the desired beam path (maybe* ≈ 10 *cm off to the side) at roughly the correct height, then install your two mirrors to make at approximately* $45°$ *from the beam to make two right turns into the aperture system, taking care to roughly center the beam on each mirror.*

2. Use the two mirrors to align the laser beam through the apertures. Remember to use the upstream mirror for only the upstream iris and vice versa. If you run out of room on the second mirror, loosen its fork, move the post, and fork it back down with the beam centered and going roughly the desired direction.

3. The laser beams should now be going through the center of both irises.

3.4 Using a photodiode and oscilloscope

You will now use a photodiode, which converts incident photons to photoelectrons that produce a current, along with an oscilloscope, to measure the power in your laser beam at several locations in your setup.

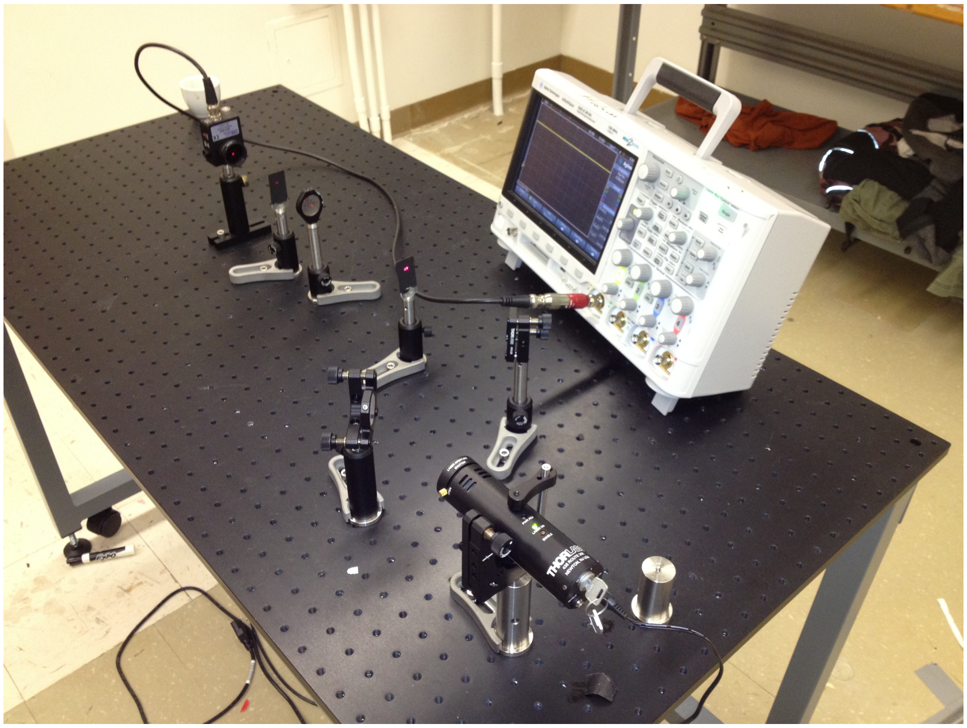

Figure 1: A laser beam is directed through two apertures onto a photodiode. The two "bending mirrors" before the first aperture allow this alignment for pre-positioned apertures.

1. Mount the photodiode on a half-inch post held in an adjustable post holder. Connect the output of the photodiode to the variable impedance terminator via the BNC cable. Connect the terminator to the oscilloscope and make sure the oscilloscope's input impedance is set to 1 MΩ.

2. Position the mounted photodiode on the table so that the whole laser beam hits the active area. Set the variable impedance terminator to 50 kΩ and use the oscilloscope to verify that the voltage coming out of the terminator is roughly 11.5 V. Be sure that not background signals, such as the room lights, are substantially contributing to your signal.

   Next, record the scope voltage for each impedance setting of the terminator. Also record the scope reading when the terminator is removed and the photodiode is connected directly to the 1 MΩ input impedance. Explain your results, including why you had to set the scope impedance to 1 MΩ for the variable terminator to work. What class of laser is this?

3. Using the same basic procedure, measure the power exiting the first and second apertures. Calculate the fraction of light you coupled through each aperture and the total coupling efficiency through the two-aperture system.

3.5 Aligning a lens to a beam

To minimize aberrations and astigmatism introduced by spherical lenses, laser beams should go through their centers and be incident roughly perpendicular to their surface. Here you will learn a few tricks to properly align a lens in a beam path.

1. All lenses reflect some light, called back reflection. When the back reflection overlaps the incident beam (far from the lens), the lens surface is roughly perpendicular to the beam. From your earlier experiments, you should have a beam that is well-aligned to two apertures. Mount a lens on a post between the apertures about a focal length upstream of the final aperture. Adjust the vertical and horizontal position of the lens until the transmitted spot again goes through the final aperture. This roughly confirms that the beam is hitting close to the center of the lens. Explain why this is true.

2. Using a strip of paper, look for the back reflection from the lens near the upstream aperture. Rotate the lens about a vertical axis (*i.e.* rotate the post) while watching how the back reflection moves. Rotate the lens until the back reflection is aligned vertically with the incoming beam. Ideally, the back reflection would also be at the same height as the incoming beam; however, lens mounts such as these don't permit vertical tilt adjust, and your back reflection is likely to be slightly higher or lower than the incoming beam. Make sure your transmitted spot is still getting through the downstream aperture and try to get both the transmitted light spot and the back reflection aligned as well as possible.

3. Now measure the fraction of light getting through the final aperture. How much did the lens degrade or improve your coupling efficiency, and why?

4. Now rotate the lens to send the back reflection onto the photodiode (feel free to move the photodiode to make this convenient). Measure the fraction of incident power that is in the back-reflected beam.

5. The lens is made from fused silica and is uncoated. Does this back-reflected power make sense for what you would expect?

3.6 Aligning a beam splitter

Another optic we will use often in this class is the beamsplitter. There are two types of beam splitters: the polarizing beam splitter (PBS) that directs horizontal and vertical polarizations in different directions and the power beam splitter, which divides the incident light into two beams with a predetermined fraction. A special case of the latter that we will use for this lab is the 50:50 beamsplitter, which splits the beam into two with roughly half the power in each. Since beam splitters are deigned for a particular angle of incidence (remember Fresnel reflections?), this experiment will teach you how to align a beam splitter properly.

1. Install the 50:50 beamsplitter cube between the two apertures. Use the back reflection from the cube surface to ensure that the light is incident perpendicular to the cube surface by adjusting the vertical and horizontal tilts.

2. Measure the actual power splitting ratio and compare it to the 50:50 specification.