Quantum Optics Lab – 180Q

Week 2 – Polarization

There are many important technologies that rely on manipulation of the polarization of light – telecommunications, screens, advanced sensors, etc. Further, understanding and manipulating the polarization of light is critical in a modern laboratory (such as this quantum optics lab course). This lab will familiarize you with some of the basic techniques for manipulating polarization.

The basic tools for measuring and manipulating the polarization of light are polarizers and polarization rotators. These come in many different forms. In the case of polarizers, there are film polarizers, polarizing beam splitters (the kind we will use), Glan-Thompson polarizers, Wollaston prisms, etc. Like polarizers there are also many different implementations for transforming polarization, but the half-wave and quarter-wave plates are by far the most common; we will use both.

Polarizing Beam Splitters

A polarizing beam splitter (PBS for short) splits an incident beam into two beams of orthogonal polarizations. The PBS in this lab will split incoming light into horizontal and vertical beams. It works on the principle of Brewster's angle. By examining the geometry of the PBS, you will be able to determine which beam is vertically polarized and which is horizontally polarized.

Wave Plates

The half-wave plate (HWP) and quarter-wave plate (QWP) work on the same principle. They are birefringent materials, with an optical axis parallel to the surface of the plate. If you map an x-y plane to the surface of the plate such that light polarized along the x axis will have a maximally different index of refraction than the y axis, these two perpendicular axes are called the fast and slow. (The name comes from the fact that the index of refraction is larger for one of the two. Which one do you think has the largest index of refraction, the fast or the slow?) Light polarized along the fast axis propagates faster than the slow axis. Because of this, if light has a component of polarization along both the fast and the slow axis, those components will fall out of phase, and the polarization of the beam is modified. The degree of this phase shift (and resulting change in polarization) depends on the thickness of the material and the difference in index of refraction.

A half-wave plate creates a relative 180-degree phase shift, and a quarter wave plate creates a 90-degree phase shift (as the names imply). Practically, this has two major implications. The half-wave plate reflects the polarization vector about the fast axis (a rotation by 2θ, where θ is the angle between the polarization vector and fast axis). The quarter-wave plate induces a circular polarization, when aligned 45 degrees to the polarization vector. (Why 45 degrees? What effect does the half wave plate have on circularly polarized light?)

Prelab

1. **Crossed polarizers.** See part 1 of the procedure. Use Jones calculus to derive an expression for the transmission of the crossed polarizers as a function of angle of the middle polarizer's polarization axis.
2. **Polarizing Beam splitter.** Use the Jones calculus to describe the effect of a polarizing beam splitter on an arbitrary polarization of light.
3. **Waveplates and a PBS.** Suppose a vertically polarized laser beam goes through a HWP with fast axis oriented θ from the vertical and then goes into a PBS. Calculate the transmitted power as a function of θ. Replace the HWP with a QWP and redo the calculation.
4. **Optical isolator.** Consider a system consisting of a perfect horizontal transmission polarizer, followed by a quarter wave plate with its fast axis oriented at +45 degrees, followed by a retroreflecting mirror.
    a. Assuming that the waveplate is exactly quarter wave at the operating wavelength, what is the reflection backwards through the polarizer? Why?
    b. (Optional) If the waveplate has a retardance that deviates away from 90 degrees by a small deviation δ, solve approximately for the reflected power as a function of δ for small δ.
5. **Arbitrary polarization.** Design an experimental arrangement of waveplates that will produce an arbitrary state of polarization, characterized by an ellipticity b/a, where a is the major axis and b is the minor axis, and an orientation angle Φ of the major axis clockwise from the vertical.

Materials

The TA will provide the necessary materials.

- Laser system
- Laser safety goggles. Wear them!
- Three film polarizers
- Three rotatable mounts
- Two polarizing beam splitters
- One half-wave plate at 670 nm
- Two quarter-wave plates at 670 nm

- Photodiode, BNC cable, variable impedance terminator, and oscilloscope

Procedure

In this lab, you will perform five tasks. Study the effect of wave plates, prove that a light beam is circularly polarized using a HWP and QWP, determine the handedness of circularly polarized light, and learn a technique to rotate the polarization of light 90 degrees with a quarter waveplate. **Note: If you use the 635 nm laser in the lab, the wave plates, which are designed for 670 nm, will not be perfect half and quarter wave plates. You can "fake it" by rotating the wave plate about its pedestal so that the beam is not at normal incidence to make a pretty good correction for this. Your TA can show you how to do this if you have trouble.**

1. **Crossed polarizers.** Illuminate a pair of crossed polarizers. What is the residual transmission in the crossed state, and what is the transmission when the two polarizers are aligned? What is the extinction ration of these polarizers at your laser's wavelength? With the two polarizers in the crossed state, insert another polarizer between them and plot the transmission of the system as you rotate the central polarizer. How do your results compare with the results of the Prelab?
2. **The behavior of waveplates.** To study the wave plates individually (the first two tasks), you will need to set up some optics that will define a known polarization to put into the waveplate and allow you to analyze the polarization that comes out of the waveplate. First, place and level a laser beam. Shoot the laser into a PBS. There should be two beams coming out. Find the beam that is perpendicular to the incident beam, and insert another PBS roughly 20 inches downstream. Monitor each split beam of the second PBS with a photodiode.
    a. Insert a mounted HWP between the two polarizers. Rotate the HWP in 10-degree increments and record the power in both arms of the PBS. Compare this to theory (using e.g. the Jones matrices techniques). Determine the location of the fast and slow axes. Can you distinguish which one is the fast and which one is the slow? If not, try to think of a trick to do this.
    b. Insert a mounted QWP between the two polarizers. Rotate the QWP in 10-degree increments and record the power in both arms of the PBS. Compare this to theory (using e.g. the Jones matrices techniques). Determine the location of the fast and slow axes. How do you know when the light is circularly polarized? Can you distinguish which one is the fast and which one is the slow? If not, try to think of a trick to do this.

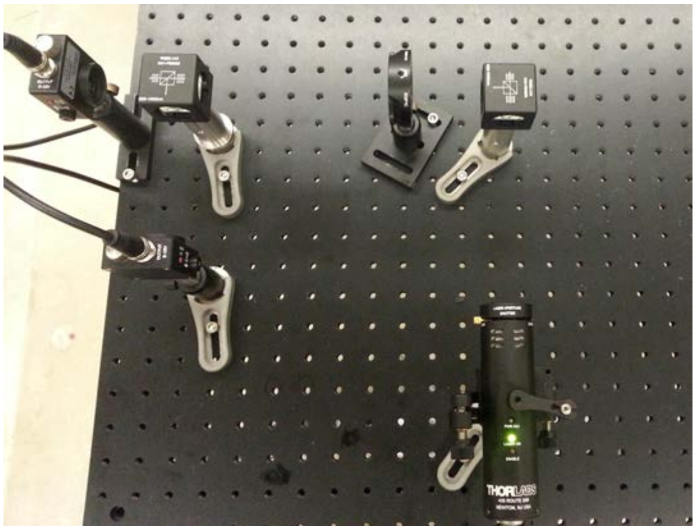

Figure 1. Example setup for measuring wave plates.

3. **Verifying the creation of circularly polarized light.** Based on the results of part 1, create what you believe to be circularly polarized light.
    a. Insert a HWP into your circularly polarized light beam and repeat the measurement of part 2a. Compare the results to theory. Did you make circularly polarized light?
    b. Remove the HWP and insert a QWP (use the one with the fast axis labeled) into your circularly polarized light beam. Repeat the measurement of Part 2b. Compare the results to theory. Did you make circular polarized light? Can you identify the handedness of the polarization?
    c. Slightly rotate the waveplate you used to make the circularly polarized light so that you are now making elliptically polarized light. Redo the measurement of part 3a. Compare the results to theory. What can you say about the polarization you have created?

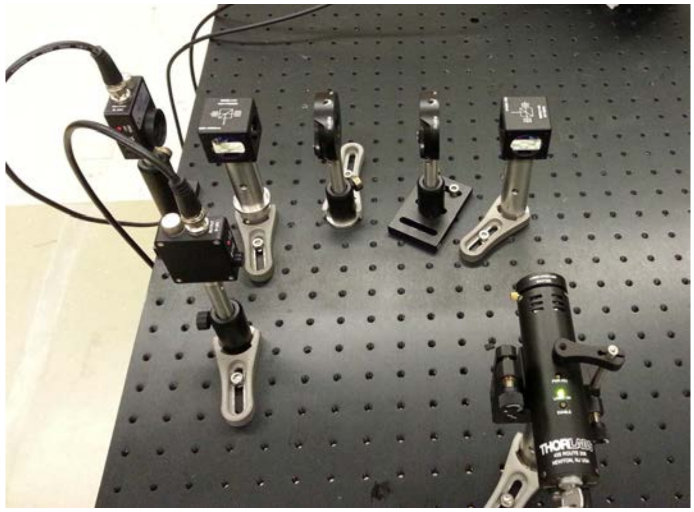

Figure 2. Example configuration to prove circular polarization of light.

4. **The poor man's optical isolator.** In many modern laboratory experiments it is very important to keep any light reflected from the experiment under study from coming back into the laser system. As we will see in later weeks, this back reflected light will often significantly degrade the performance of the laser (typically it makes it very noise in amplitude and frequency) and can even damage the laser. Thus, most experiments employ an optical isolator, which prevents any back-reflected light from making it back into the laser. Modern optical isolators, which work on the Faraday effect, are very expensive and they can take months to arrive once ordered! So, in day-to-day lab work it is important to know how to construct a quick and cheap (though not optimal) optical isolator. One way to do this is to use a QWP and PBS in the configuration drawn below. This arrangement works by converting linearly polarized light into circularly polarized light on the first bounce. Observe that the optical axis is at 45 degrees to the polarization. This circularly polarized light is then sent to the experiment. If the circularly polarized light is reflected back through the same waveplate, it is phase shifted by a quarter again and the light exits the opposite port of the PBS and does not return to the laser. (Effectively, the QWP acts like a HWP at 45 degrees, giving a 90-degree rotation.)
    a. Construct the double pass configuration drawn below (the mirror is playing the role of the experiment which may reflect some light back) and measure the power transmitted through the PBS in 10-degree increments on the QWP. Compare to theory and identify which configuration gives the best performance as an optical isolator.

b. This scheme for optical isolation has several significant drawbacks. For example, what would happen if the experiment changed the polarization of the back-reflected light? How could you improve on this design?

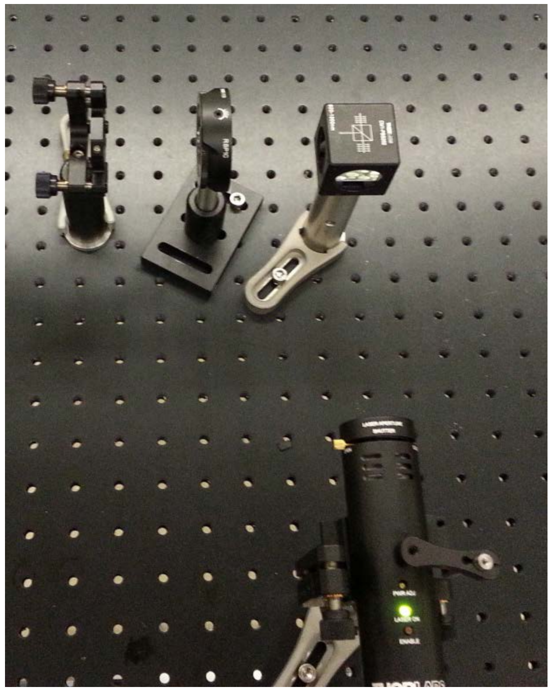

Figure 3. Example of a double pass configuration. Notice the mirror in the beam path.

5. **Creation of an arbitrary polarization of light.** Using the results from your Prelab, set up a quarter wave plate and half wave plate to produce light with ellipticity of 0.25 and an orientation of 45 degrees away from vertical. Verify that this is the state of polarization that you obtained. Describe your procedure that demonstrates this.