Physics 476 (G): Experimental Quantum Measurements (Fall 2023)

Lab #1: Polarized Light Manipulation

In this lab we will study the transferring properties of some special optical devices when polarized light is used in the experiment. These devices are important in quantum optics experiments, which include 1) fixed delay fiber, 2) rotated fiber coupler, 3) variable delay fiber, 4) polarizing beam splitter, 5) 45°-polarizing beam splitter, 6) beam splitter, and 7) liquid crystal variable retarder. We will use a home-made opto-mechanical setup mounted on a small breadboard to conduct our study.

1. Laser source, polarizer and analyzer

The transmission axes of the polarizer and analyzer are along their 0°–180° lines. This can be easily tested by observing the glare of a ceiling light reflected by the floor.

1.1 Laser source

Use a single polarizer to determine the polarization of the laser source. Currently it is a small 635 nm red diode laser. What is the polarization state of the laser?

1.2 Polarizer and analyzer

Set the polarizer so that its transmission axis is horizontal in the lab system. It now produces a horizontally polarized laser beam. Rotate the analyzer slowly and observe the transmitted light. Does your observation agree with Malus' law? At what orientation of the analyzer does the transmitted light extinct? This configuration is called crossed polarizers.

2. Fixed delay fiber, rotated fiber coupler, and variable delay fiber

Replace the analyzer by a straight fiber coupler, such that the notch of the fiber coupler is oriented horizontal. Although a fiber coupler may be free to rotate in an experiment, we define the status where the notch is oriented horizontal as the normal state of the fiber coupler. Finely adjust the screws of the laser holder so that the laser beam goes through the fiber coupler right through its center hole. We will call this fiber coupler the input coupler. Similarly, at the right-hand side of the breadboard, set up another straight fiber coupler, called the output coupler, with its notch oriented also horizontal. The final output light is studied by an analyzer.

2.1 Fixed delay fiber

Confirm that the polarizer is set into horizontal. Connect a fixed delay fiber between the two straight fiber couplers. First check that there is an output light by directly looking into the output end of the fiber by your eyes. This only is safe because the laser is weak and the diameter of the fiber is small. Then investigate the polarization of the output light using the analyzer. You may need to turn off the ceiling light. What is the polarization state of the output light from the fiber?

Now set the polarizer into vertical, i. e., let it produce a vertically polarized laser beam. Guess what is the polarization state of the output light from the fiber. Use the analyzer to confirm your prediction.

2.2 Rotated fiber coupler

Replace the straight fiber coupler at the output end of the fiber by a 90°-rotated fiber coupler. This is the same fiber coupler, but with its notch oriented vertically. Repeat step 2.1, first using a horizontally polarized input light, and then a vertically polarized input light. In each case analyze the polarization state of the output light from the fixed delay fiber using the analyzer. What is your conclusion on the function of the rotated fiber coupler?

2.3 Variable delay fiber

Replace the 90°-rotated fiber coupler at the output end of the fiber back into the original straight fiber coupler whose notch is oriented horizontally. Replace the fixed delay fiber by a variable delay fiber. By changing the gap between the two intermediate ends of the fiber, the overall length, and thus the delay provided by the fiber can be finely adjusted. However, we do not need to vary the delay of the fiber now because we are only interested in its property in dealing with polarized light. Repeat step 2.1, first using a horizontally polarized input light, and then a vertically polarized input light. In each case analyze the polarization state of the output light using the analyzer.

3. Beam splitters

3.1 Polarizing beam splitter

Suppose the internal reflection surface of a beam splitter is vertically standing on the lab table. An *ideal* polarizing beam splitter (PBS) will split an arbitrarily polarized input light beam into a vertically polarized reflected beam and a horizontally polarized transmitted beam. That is, it reflects V-polarized light and transmits H-polarized light. A picture is given on P.21 of the current lab manual, and is copied and pasted here. A PBS has four ports: 1, 2, R, and T, with its internal reflection surface bisecting ports 1 and 2, or R and T. Normally, ports 1 and 2 are used for the input of light, while R and T are for the output. However, the beam splitters can be used reversely.

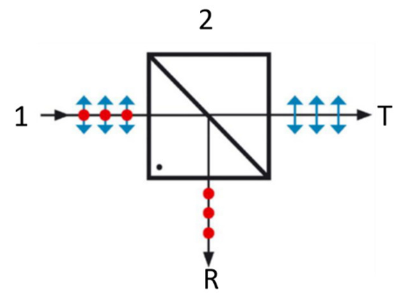

Fig.1 Top view of an ideal PBS where port 1 is used as the input

Table 1 Polarization property of an ideal PBS

Input-Output Ports	Input Polarization	Output Polarization
1 →R	H	0
	V	V
1 →T	H	H
	V	0
2 →R	H	H
	V	0
2 →T	H	0
	V	V

From the discussion above, the performance of an ideal PBS is shown in Table 1. However, an actual PBS may have additional features included internally. This is particularly true because from step 2.2 we know that an internal twist of the fiber, which is invisible externally, can well change the polarization state of the light.

Write down the series number of the PBS we are using. Confirm that at nature untwisted state the key teeth of the four fiber connectors are oriented approximately horizontally. Connect the 1 and R ports of the PBS to the input and output straight fiber couplers, respectively. First use a horizontally polarized input light, and analyze the polarization state of the output light. Next use a vertically polarized input light, and analyze again the polarization state of the output light. Record your results in the following table. Complete the table by designing the rest of the ports as input and output. Note that the PBS is specifically made for the wavelength of 810 nm, and consequently it usually does not work well at our laser wavelength. Because of this, a relatively weak output light, instead of complete extinction, may be considered as no light, and in this case we write “0” for the output polarization.

Table 2 Polarization property of our PBS

PBS serial number: ____________________

Input-Output Ports	Input Polarization	Output Polarization
1 →R	H	
	V	
1 →T	H	
	V	
2 →R	H	
	V	
2 →T	H	
	V	

Compared to the ideal PBS, it seems that the 2 and R ports of our PBS have an additional internal polarization rotation (H↔V). Confirm that you understand this conclusion. We need this fact in some of our future experiments.

3.2 45° Polarizing beam splitter

An ideal 45°-PBS is like a PBS, but with the polarization of one of its ports, here port 2, being rotated by 45°. Therefore, either an H or V input light at port 2 will be rotated by 45° before striking on the internal reflection surface of the beam splitter, which makes the light contain both H and V polarizations.

Because we do not have enough time for the lab, here I will directly provide the result of my experimental observation on our 45°-PBS (S/N 255333-05). Compared to an ideal 45°-PBS, it seems that again the 2 and R ports of our 45°-PBS have an internal polarization rotation (H↔V).

3.3 Beam splitter

A beam splitter (BS), or non-polarizing beam splitter, is a device which split the input light into two beams without changing its polarization state. My observation shows that our BS (S/N 255336-02) is just like an ideal BS, with no internal polarization rotations.

4. Liquid crystal variable retarder

A retarder, also called a waveplate, introduces phase retardation between two polarization components, usually the horizontal and the vertical polarizations. When the phase retardation is π, it is called a half-wave plate. When the phase retardation is $\pi/2$, it is called a quarter-wave plate. When the input light is either H or V polarized, the normally oriented retarder will not change its polarization. For any other polarized input light, e. g., a light linearly polarized at 45°, because of the introduced phase retardation, the polarization state of the light will be changed by the crystal.

We will study the performance of a liquid crystal variable retarder (LCVR, Thorlabs LCC1113-B), which is driven by a controller (LCC25). The LCVR controller produces a 2 kHz

AC square wave with an amplitude adjustable from 0 to 25 V_{rms}, which determines the phase retardance. Phase retardance curves are given in the lab manual (p. 76). In a normal operation, set the controller output mode into V1, set the INT/EXT switch into INT.

4.1 Half-wave voltage

Set the optics as in step 1.2, i. e., let the laser, the polarizer and the analyzer be in a train. Set the polarizer at 45°. The transmitted light is now linearly polarized at 45°.

Set the analyzer also at 45°, i. e., parallel to the polarizer, so that the overall light transmission is the maximum. Insert the LCVR in-between the polarizer and the analyzer. Our goal is to find the half-wave voltage of the LCVR at our laser wavelength. If we exert the half-wave voltage on the LCVR, it will behave like a half-wave plate, so that the 45° input light is transferred into 135° polarized light when exiting the crystal. Because the analyzer is set at 45°, in this situation the overall transmitted light will be minimized.

Finely adjust the voltage on the LCVR to minimize the output light from the analyzer. Note that the voltage adjustment knob is not linear. Also it freezes after a short while of inactivity. Record this half-wave voltage of the crystal. For our wavelength there may be multiple values of half-wave voltage satisfying our requirement, but we are interested in the voltage between 1 and 3 V.

4.2 Full-wave voltage

Set the analyzer at 135°, i. e., perpendicular to the polarizer, so that the overall light transmission is minimized if the LCVR were not existing in-between. However, although the LCVR is in-between, if we exert a full-wave voltage on the crystal, it will behave like a full-wave plate, so that the 45° input light does not change its polarization when exiting the crystal. Because the analyzer is perpendicular to the polarizer, in this situation the overall transmitted light is again minimized.

Finely adjust the voltage on the LCVR to minimize the output light from the analyzer. Record this full-wave voltage of the crystal. Again we search for the voltage that is between 1 and 3 V. Discuss how reasonable your measured half-wave voltage and full-wave voltage are when compared to the retardance curves shown on p. 76 of the lab manual.