880 Quantum Electronics Lab – Pockel's Cell Alignment And Use

The goal of this lab is to give you a chance to align and use a Pockel's Cell.

You may not take this lab unless you have read the laser safety manual for my laboratory. A link to this manual is on the class web page.

Introduction.
This lab will use a Pockel's Cell (PC) to modify the light from a doubled Nd:YLF pulsed laser. This is the same laser you used to pump the dye laser in the Dye Laser lab. It delivers 527 nm pulses at a 1 kHz repetition rate. The pulse energy can be as high as 15 mJ, however you'll only need enough to see. We've covered Pockel's Cell operation in class in more than sufficient detail to understand its optical characteristics. Since PCs are driven by an applied electric field, they are electrical devices as well and that aspect of their operation must be considered. This lab involves the use of high voltage, but it is contained. Please do not open the electronics while high voltage is present. You are welcome, however, to inspect the apparatus with the voltage off. Please bear in mind that 30 seconds should pass between the time you turn the high voltage off and open the PC driver. This is sufficient time for the high voltage to leak off.

This is a much simpler lab than the dye laser lab. I have outlined some simple extensions should you want more practice, but the main goal is simply to learn how to align a PC. PCs use electric field induced birefringence to change the phase of one or both polarization components of an optical beam to change its phase, polarization, and amplitude. The problem is that PCs use crystals that are necessarily birefringent even in zero field. In most applications this natural birefringence is a nuisance and implementations are designed to avoid its presence.

**Pockel's Cell Alignment And Use For Amplitude and Direction Control**
Make sure you have read this entire write-up before doing the lab.

Reduce the 537 nm light intensity as much as possible so that it is still easy to see on a card. Align the beam through two crossed Glan-Thompson polarizers spaced about 10 cm apart. The first polarizer should be aligned to pass horizontal polarization and the second, sometimes called the analyzer, to pass vertical.

A little on terminology and Glan-Thompson polarizers. When a beam reflects or transmits through a surface, Maxwell's equations place constraints on the normal and tangential components of the electric and magnetic field at the interface. It is natural, then, to divide reflection into two cases using the plane containing the incident and reflected **k** vectors (this plane also contains the transmitted **k** vector and the normal to the interface.) If the polarization vector is in this plane, you have p-polarization, if it is perpendicular you have s-polarization. Many optical properties can be organized using this distinction, for example, the Fresnel coefficients. S-polarization preserves the polarization direction upon reflection and p-polarization does not. Brewster's angle occurs only for p-polarization. Glan-Thompson and thin film polarizers pass p-polarization and reflect s-polarization. For Glan-Thompson polarizers, the interface between the two triangular wedges that make up the polarizer is the one that distinguishes between the two polarization types, not the input and output faces. Since these polarizers take advantage of the differing angles for total internal reflection between s- and p-polarization, they must only be used with collimated light that is carefully aligned to be normal incident on the polarizer. The angular tolerance of these components is typically 5°.
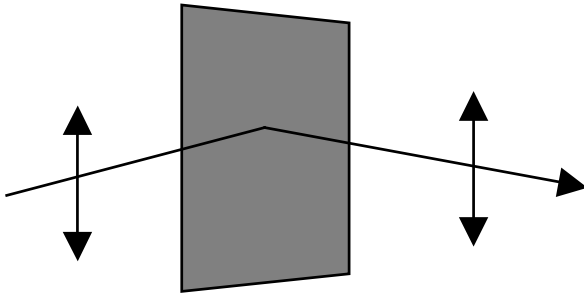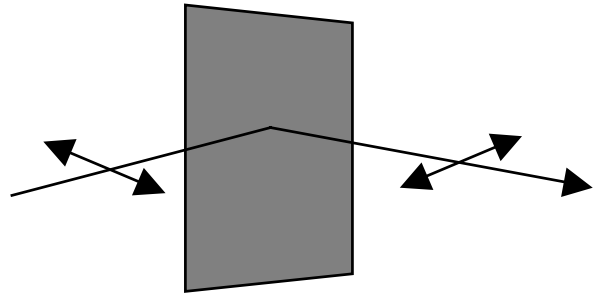
s-polarization   p-polarization
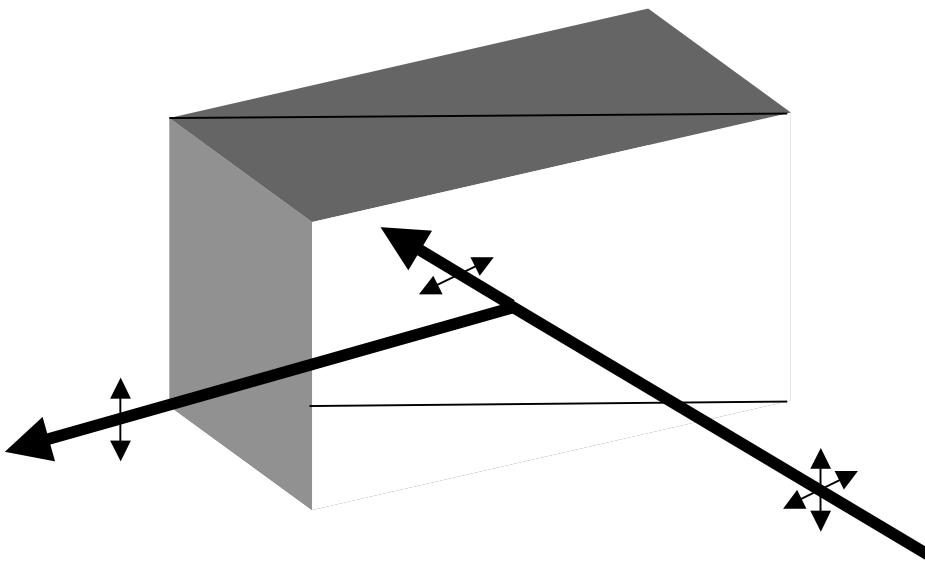
Glan-Thompson Polarizer

In the following you will need to rotate a Glan-Thompson polarizer to optimize your signal or to try various configurations. Don't forget that a Glan-Thompson doesn't absorb the rejected polarization. It redirects it out a side port. Be careful that this rejected beam is blocked. So long as you keep the intensity low, it can be blocked with a card taped in place.

Place a photodiode after the second polarizer and rotate the polarizer for maximum extinction. (For an exercise in dynamic range, you can try measuring the extinction ratio = I_{min} / I_{max}. You should be able to do better than 10^{-3}. Make sure your measurement is unsaturated.)

Now, install the PC in between the polarizers with the z-axis parallel to the k-vector, as best you can determine by eye. It will help if the PC is close to the second polarizer. The PC is in a mount that provides pitch and yaw degrees of freedom. The "roll" of the PC has been set for you, although you are welcome to modify this. Loosen the structure enclosing the PC, with the voltage off, and it will roll. Most likely, the signal on the photodiode will be much larger now. The next step is to fine align the PC.

Place a diffuser directly in front of the PC and a card after the second polarizer. Two choices for diffuser are scotch tape and lens tissue. Tape is the stronger diffuser and probably the one you should start with. It's actually too good a diffuser as it makes it impossible to see the direction of the outgoing beam. You may want to do the final alignment using lens tissue. You should see a pattern like the following on the card. The will be a large diffuse region of light with a pattern of dark lines on it.
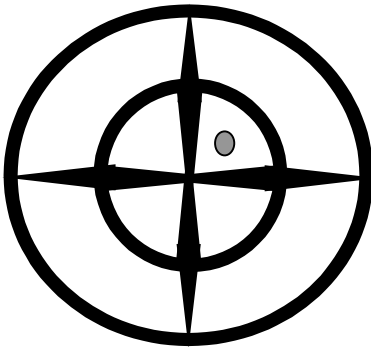
The small gray circle indicates the position of the outgoing beam were the diffuser not present. You can actually see this if you use the lens tissue as diffuser. If you use the tape, you will have to periodically remove it to see how the outgoing beam is positioned. The PC is aligned when the outgoing beam is positioned at the center of the pattern, which some have been known to call the "Maltese Cross." It is also called a Lissajous figure. Use the pitch and yaw adjustments to steer the Cross over the outgoing beam.

Here's the big question: why is the Maltese Cross formed? Once you answer this, it will be clear why aligning it to the outgoing beam aligns the PC. Some hints:

- Explain the vertical and horizontal stripes first. Remember, the z-axis is roughly parallel to the input **k** vector. The diffuser preserves the polarization direction to good approximation. Its action is to break the beams into a bundle of rays each at some angle about the original **k** vector. That does mean, of course, that the polarization direction changes somewhat, but the divergence of the beam is more important. Separation of each ray into ordinary and extraordinary rays is the next step.
- Now explain the rings. Imagine starting with a ray that is aimed at the middle of the pattern. Having explained the vertical and horizontal stripes, hopefully it is clear that this ray will be blocked by the polarizer. If you were to steer this ray up and down or left and right it would remain blocked. What happens if you steer it diagonally? Again, you should separate the beam into ordinary and extraordinary rays.

Given that the KD*P crystal length is 1 cm, you can use the Maltese Cross the estimate the difference between n_o and $n_e(\theta)$ for as many values of θ as these are rings in the pattern. This allows you to estimate a value for n_e itself.

If you rotate the PC about its optic axis, will the Cross rotate as well? What happens if you rotate one or the other of the polarizers?

Now you can test the PC. Here are some things you can try. The first is obvious, the rest are for your amusement. The last item shows you a trick that is not often used, but is interesting and occasionally helpful

1. Apply the high voltage and measure the voltage needed for maximum transmission. You can invert the operation of this apparatus by rotating the second polarizer by 90°, of course. Now applying a voltage reduces the transmission. Note that in this configuration, the sign of the voltage is not important.

2. Place the PC in a configuration appropriate for cavity dumping. The easiest way to do this would be to replace the second polarizer with a mirror. Before you apply the high voltage, make sure you know what should happen and what voltage will be required.

3. Take the configuration in (2) and make a Q-switch by adding a quarter-wave plate. You'll need to decided how to place the wave plate at the correct angle.

4. Here's a trick that gives you the same effect as that in (3), but without having to use a quarter-wave plate. Remove the wave plate and mirror and restore the second polarizer, card, and diffuser so that you can see the Maltese Cross again. Instead of aligning the cross so that it is centered on the outgoing beam, align it so that the beam appears halfway in between the center of the cross and the first circle and also so that it is between the vertical and horizontal stripes. In other words, position it so that the outgoing beam is as illustrated on the previous page. Now restore the mirror and see what happens. Is the effective quarter-wave plate that you've introduced zero-order or multi-order?

Some comments on PC electronics.

If high-voltage is maintained across a PC for a long period of time, it will break down causing irreversible damage to the PC. There are several strategies taken to combat this, but all involve pulsing the high voltage just for the time needed. It may be possible to simply pulse the voltage with a circuit that schematically looks like this:

low voltage pulse

matching network   PC
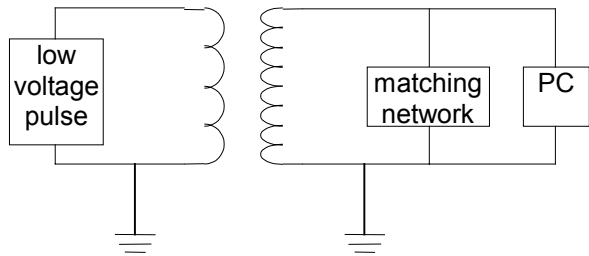
Explicit or not, there will be capacitive, inductive, or resistive impedance on the circuit connected to the secondary of the transformer. The PC itself is mostly capacitive, for example. It can happen that the full potential drop across the secondary of the transformer does not appear across the PC. A matching network is sometimes added to correct for this.

With proper choice of input pulse shape and matching network, a voltage will appear across the PC whose width is of order of μs, with a voltage that is relatively constant at the peak for of order 100 ns. For low repetition rates (10's of Hz), a high voltage relay can be used.

Pulse slicing, cavity dumping, and Q-switching all generally require a fast change in retardance. For cavity dumping, for example, the switch time must be small compared to the round trip travel time, so of order 1 ns. Typically a high voltage tube or a switch made from a chain of transistors is used to apply the voltage or to short it out. Here are a few configurations.

(a) high voltage pulse   PC   switch   trigger

(b) high voltage pulse   PC   switch   trigger
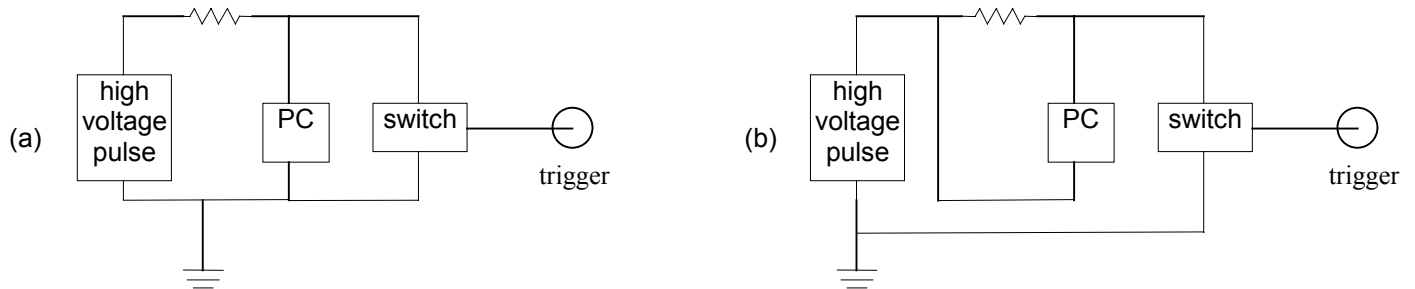
The switch acts like an open circuit until it is triggered, after which it acts like a short. Configuration (a) induces a retardation in the PC which is suddenly switched to zero. Configuration (b) does the reverse: the retardation is initially zero, and then suddenly switched to some value. More sophisticated circuits can apply several voltage levels, with the rapid switch from one to the next controlled by a separate trigger. The following circuit switches from zero retardation to non-zero when one switch is triggered, and back to zero when the second is triggered. Again, the voltage that appears across the PC is typically not the same as that across the high voltage pulse source, and ring must also be taken into account.

high voltage pulse   PC   switch 1   trigger 1   switch 2   trigger 2
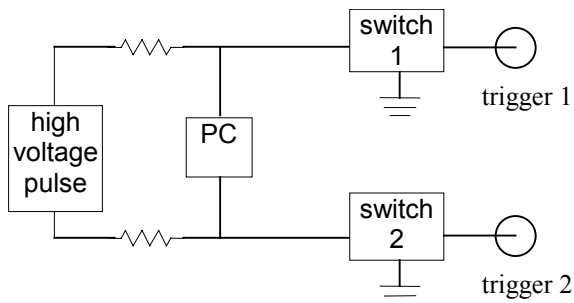
The electronics for these circuits can be purchased from a variety of manufacturers, with costs ranging from ~ $500 to $5000 depending on the specifications. In my lab, we can build simple implementations of these circuits that range in cost from $10 to $200, although there are trade-off's as you might imagine.