# Physics 15c Lab 8: Polarization

Due Friday, December 8, 2006

This is the last lab!

REV 1[1]; December 4, 2006

## Contents



*Help Lab Hours*

Help lab hours are same as for labs 6 and 7:

- Monday, 7 pm
- Tuesday, 3 pm
- Wednesday, 7 pm

At the end of these lab notes you will find some figures illustrating the effect of a half-wave plate on light polarized at 45° (either sign) relative to the axes of the plate.[2] We hope these will help your understanding of this rather-puzzling effect. The texts cited under § 2.2 also may help, if you want further help. The lab TF's also can guide you, of course, if you choose to come in to help lab.

# 1 Objective

In this experiment you will investigate the various polarization states of light with the help of polarizers and retardation plates.

[1]Revisions: amend question re 1/4-wave plate; add contents & ref to Land, inventor (12/06); Add Andrey's figures illustrating effect of half-wave plate (3/06); remove reference to color filters (3/05).

[2]Thanks to Andrey Pashin (March 2006) for these pretty drawings.

# 2 Experiments

## 2.1 Polarizers

The Polarizers in your kit are made from a Polaroid material, (described in various texts, such as Georgi, pp. 322-23; plastic polarizer sheets were invented by Land, who left Harvard after his freshman year to work on his invention [3]. The material is shipped with a thin plastic protective sheet on each side. Remove this covering if you find it on your Polaroid sheets and ”wave plates” (the smaller, clear rectangular pieces). The “easy axis” of the material, along which the electric field suffers the least attenuation, should be parallel to the long edge of your rectangular pieces. BUT you should check this, as we suggest just below!

Using two polarizers, observe the transmission and extinction as one is rotated relative to the other throughout the full 360°. Check the consistency of the alignment of the easy axis with respect to an edge for your three polarizers by observing the orientation corresponding to the maximum extinction. It is conceivable that some of them were not cut square to the easy axis. As you try to check the squareness of cut, make sure that your method would work even if all the mis-cuts of sheets were consistent: if all the sheets were off-square to the same degree.

**In this section of the lab please describe qualitatively all of your observations while exploring the behavior of light transmitted through polarizers.** Use one polarizer to search for sources of polarized light. First try primary light sources: light bulbs, fluorescent lamps, discharges, and flames. DO NOT LOOK AT THE SUN! Examine the polarization of the blue sky, particularly in the direction directly overhead. Some creatures, whose vision is sensitive to polarization of light, are able to exploit this ability as they navigate: the sky’s polarization reveals (rather indirectly!) the sun’s position. (These are invertebrates with light receptor cells consistently oriented, like the polymer molecules of Edwin Land’s stretched plastic.) With a Polaroid sheet, you could emulate these resourceful creatures (of course, you could get the same result by glancing up to see where the sun is: too bad!).

What about clouds in the same position on the sky? (You can appreciate, probably, why photographers sometimes use polarizing filters to enhance contrast.)

Look for some polarization in light reflected from various materials: water, metallic surfaces, glass or plastic. The light reflected from book covers shows striking polarization–and illustrates the appeal of polarized sunglasses to fishermen: if the surface of your book cover were a glaring stream surface, a polarizer would give you a better chance of seeing fish under that surface.

Try looking, through a Polaroid sheet, at a liquid-crystal-display (“LCD”): either a digital watch face (usually dark characters on a light-grey background) or the display on a notebook computer.

Now try an arrangement that delivers what is perhaps the first surprising result: orient two polarizers at right angles, so as to block nearly all the light. Then insert a third polarizer between the crossed polarizers and rotate it. **Why, for some orientations of the third polarizer, do you see transmitted light even though the first and last polarizer are crossed? What orientation of the central polarizer maximizes transmission? Can you achieve a similar effect by having the third polarizer outside the two crossed ones?**

[3] He took a year off in New York City, where he lacked a laboratory, but found one at Columbia University where a window often was left unlocked at night, allowing him to climb in. See http://en.wikipedia.org/wiki/Edwin_Land

## 2.2 Quarter Wave Plate

The so-called "half wave" and "quarter wave" plates in your kit are made of a birefringent plastic. (The quarter-wave plate is the one, of the two rectangular plates, whose corner has been nipped off.) The fast and slow axes should be parallel to the edges of the rectangular samples. The difference in the optical path lengths for the two orthogonal directions of incident polarization is 140 nanometers for the "quarter wave" material; this distance is 1/4 wavelength for a color midway in the visible spectrum (somewhere between yellow and green). **At the extremes of the visible spectrum, 400 and 700 nanometers, what fraction of a wavelength will the so-called "quarter-wave" plate provide as a phase difference between the two orientations?**

Place the quarter wave plate between two polarizers. Hold the plate at various angles, $\theta$ with respect to the first (polarizer) while rotating the second (analyzer) through a full 360°. (This procedure resembles what you did earlier when you placed a third *polarizer* between two crossed polarizers: you want to be sure that you understand the difference between the two procedures–and particularly that you understand that you can indeed be sure that the "quarter-wave plate" is not simply another polarizer, showing you the same old effect.) **For what values of $\theta$ can you achieve complete extinction? For what values of $\theta$ is transmitted intensity least sensitive to the orientation of the analyzer? How should one set $\theta$ so that the polarizer and quarter wave plate produce circular polarization? Linear polarization? Elliptical polarization? Cross the polarizer and the analyzer, and then rotate the quarter wave plate between them. At what angle $\theta$ is the transmission a maximum?**

**Explain how the use of a 1/4-wave plate between two crossed polarizers *differs* from the effect of placing a third *polarizer* between two crossed polarizers.** (Georgi, pp. 325-26 may help you; so might Crawford, Waves (Berkeley Physics Series, Vol. 3, 1968), pp. 423-24.)

You may have noticed that the color of a white object being viewed through the stack changed slightly during the rotations carried out above.[4] **Why is that?**

### Hide-the-coin Trick

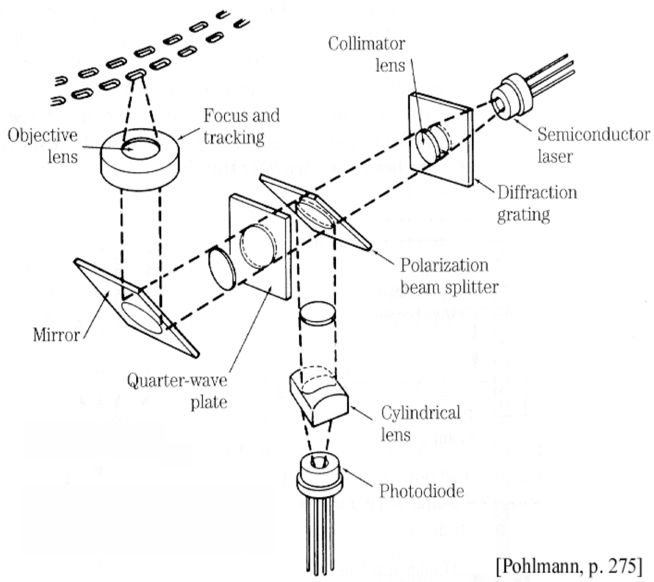
Set up the polarizer and analyzer to produce circularly polarized light. Try the following coin trick. Place a silver coin on a piece of black paper. Hold the quarter wave plate and a Polaroid together with their edges rotated by 45°. Place the stack on the coin, plate side up. Now you see it. Place the stack on the coin, plate side down. Now you don't. **Why is this? Can you think of a way of using a Polaroid and a quarter wave plate to make an anti-glare filter to use with computer screens?** If you can, don't rush to patent it; someone else got there first.

*Note*, because the coin sends the reflected light through the 1/4-wave plate a second time, it may be helpful to think of the effect as passing the light through a 1/2-wave plate, with the result noted in §2.3, below. The same observation may help in your analysis of the CD pickup, as well.

[4] We should confess that in some cases we were unable to see this effect.

**A Practical Application: the CD pickup, again**

Here is a diagram showing the way a 1/4-wave plate is used in many CD pickups.




[Pohlmann, p. 275]

The object labelled "polarization beam splitter" reflects light that is polarized at right angles to its favorable axis.

**Explain how the 1/4 wave plate delivers to the photodiode array only the light that is returned from the CD.**

## 2.3 Half Wave Plate

Test the claim that a half wave plate rotates the plane of polarization of linearly polarized light through an angle which is twice the angle one of its axes makes with the incident polarization. The material used for these plates has a retardation of 280 nanometers (again assuming a wavelength close to the middle of the visible spectrum).

### Make Your Own Wave Plates (optional)

It turns out that clear cellophane tape (it has to be glossy, but not all clear glossy tape is cellophane) and saran wrap develop birefringence during their manufacture. The retardation should be of the order of a quarter or half wave. Try some saran wrap. Its retardation is less. It may take several layers to build up a quarter wave of retardation. Beware of Scotch Magic Tape. It is great stuff, but not for this application. The substrate is not very birefringent, and it depolarizes the light by scattering.

## 2.4 Stress Birefringence

Plastics which may not naturally be birefringent can develop birefringence when stressed. The total path length difference through the sample can be 1000 nanometers or more, thus the effect on linearly polarized incident light can be much more wavelength dependent than you saw in the above experiments. This can lead to some very colorful displays. Set up two crossed polarizers separated by an inch or two. Taping them to the opposite covers of a thick textbook is one possibility. Now place various objects between them and look at the transmitted light. Try some of the following: drafting tools such as triangles and French curves, hard plastic boxes such as CD and audio tape cases, a clear plastic tape dispenser, a clear plastic picture frame, eyeglass lenses, and stretched or crumpled plastic or cellophane sheet.

### 2.5 Laser Polarization

Determine whether the light coming from the laser is polarized, and if so in what orientation. DO NOT look into the laser. Shine the laser through the polarizer onto a white piece of paper in order to do your measurement. A summary explanation for the result appears in Georgi, sec. 12.3.

(lb8_oct06c.tex; December 4, 2006; Appendix illustrating effect of half-wave plate follows.)

# 3 Figures illustrating the effect of half-wave plate on a particular case

The three figures below illustrate the way a half-wave plate (that is, a plate that retards a waveform by a half-cycle as it passes along the "slow" axis relative to the "fast" axis) affects an incoming linearly-polarized waveform incident at 45-degrees to one axis.

## 3.1 Preliminary points re: $E$ and $B$ fields

- These field components shown at right angles, below, do *not* represent $E$ and $B$ fields.

  Instead, these represent components of an incident $E$ field projected on each of two axes (the "slow" and the "fast"). (Perhaps you didn't need to be told this—but we were struck with the misleading likeness to representations of propagating $E$ and $B$ fields, and feared sowing confusion.)
- We represent only the $E$ field, because only this field has substantial effect.

## 3.2 A particular case: waveform through half-wave plate

**First, the incident wave, coming in at 45°:**

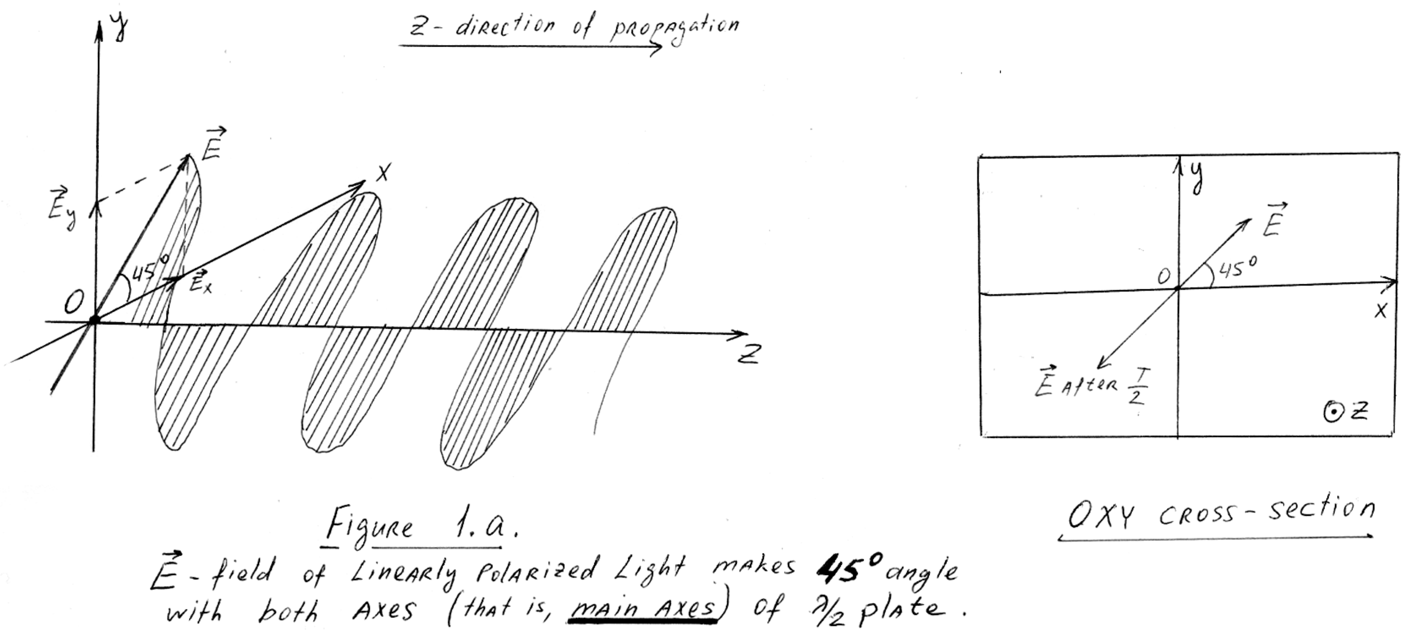



**Figure 1: Incident linearly-polarized light, coming in at 45-degrees relative to plate's axes**

**Second, the incident wave's components along the two axes**

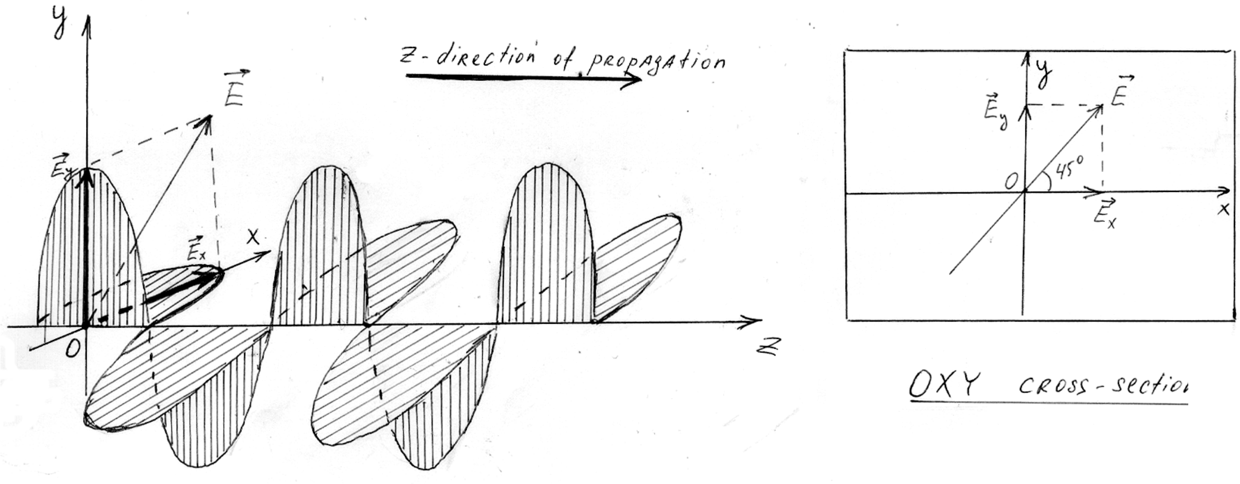



**Figure 2: Components of incoming linearly-polarized light, projected onto the plate's two axes**

**Finally, the phase-shifted components, along the two axes**

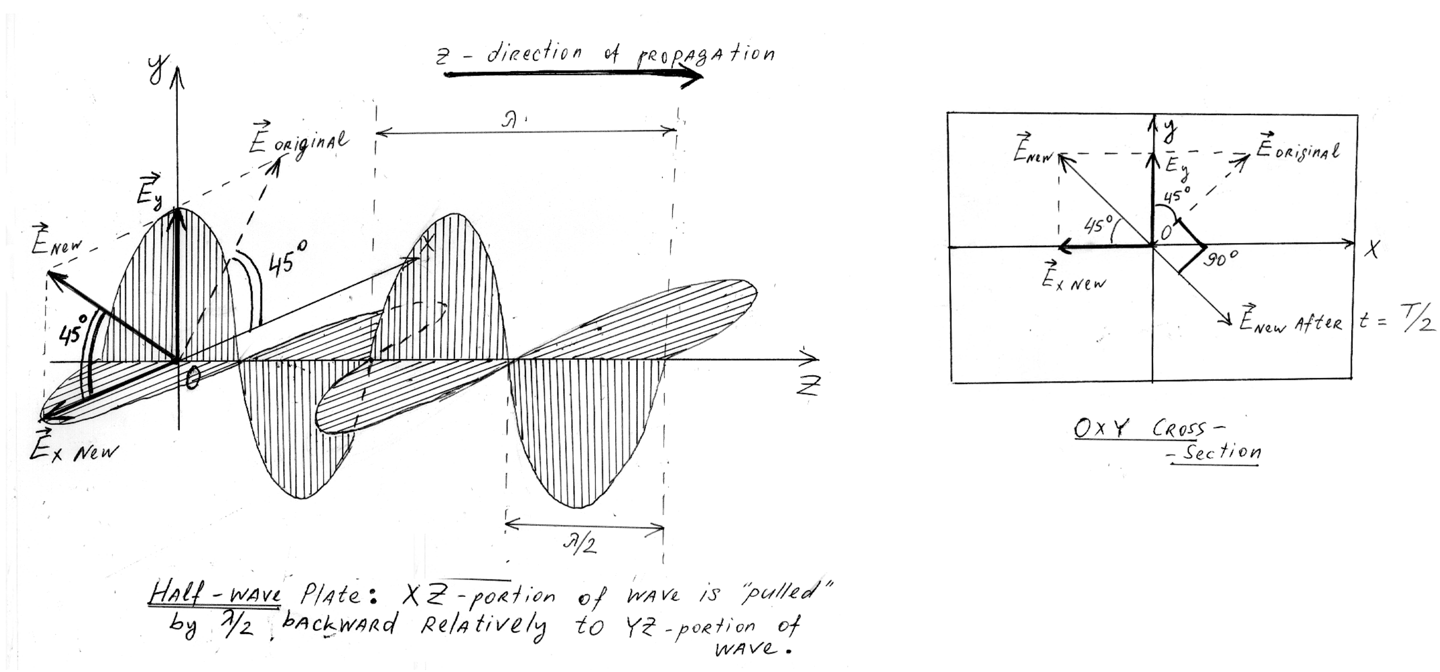



**Figure 3: X and Y components of incoming linearly-polarized light, phase-shifted differently; resulting sum is the input reflected about one axis**