Laboratory #8 Week of March 3

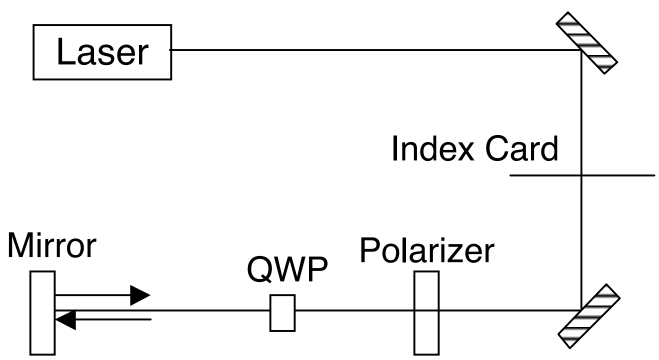
Read: pp. 336-344, 352-356, and 360-365 of "Optics" by Hecht

Do:
1. Experiment VIII.1: Birefringence and Optical Isolation
2. Experiment VIII.2: Birefringent crystals: double refraction
3. Experiment VIII.3: Optical activity: rotary power of sugar

Experiment VIII.1: Birefringence and Optical Isolation

In this experiment the birefringence of a material will be used to change the polarization of the laser beam. You will use a quarter-wave plate and a polarizer to build an optical isolator. This is a useful device that ensures that light is not reflected back into the laser. This has practical importance since light reflected back into a laser can perturb the laser operation.

A quarter-wave plate is a specific example of a retarder, a device that introduces a phase difference between waves with orthogonal polarizations. A birefringent material has two different indices of refraction for orthogonal polarizations and so is well suited for this task. We will refer to these two directions as the fast and slow axes. A wave polarized along the fast axis will move through the material faster than a wave polarized along the slow axis. A wave that is linearly polarized along some arbitrary direction can be decomposed into its components along the slow and fast axes, resulting in part of the wave traveling faster than the other part. The wave that leaves the material will then have a more general elliptical polarization.



A quarter-wave plate is designed so that the fast and slow components of a wave will experience a relative phase shift of $\pi/2$ (1/4 of 2π) upon traversing the plate. Light that enters the plate linearly polarized at 45˚ with respect to the fast and slow axes will then leave the plate circularly polarized. Think of an experiment which would confirm circular polarization – but don'.

If this circularly polarized light is reflected by a mirror back through the quarter-wave plate, then the component along the fast axis will accumulate an additional $\pi/2$ phase shift relative to the component along the slow axis. The light is now linearly polarized along a direction 90˚ from the initial direction of polarization, and so will be blocked by the polarizer that produced the original polarized beam.

The figure above shows the arrangement you will use to build the optical isolator. Adjust the polarizer so nearly all the laser light is transmitted (use the unmounted polarizer, as the mounted one will be needed later). Use an index card with a hole in it to observe the light reflected back toward the laser (make sure to do this between the laser and the polarizer). Adjust the retro-reflecting mirror so the reflected beam is next to the hole in the index card. Now rotate the quarter-wave plate until the reflected beam disappears. You will probably have to rotate the angle of incidence of the quarter-wave plate as well as the orientation angle in order to make this work. This is because the phase retardance is proportional to the thickness of material that the light traverses and you can adjust the effective thickness by changing the angle of incidence. Once you have found the right position you can use the second polarizer to convince yourself that the light is indeed circularly polarized. How did you go about this?

Now attempt to produce normal incidence on the quarter-wave plate. How many different positions of the wave plate can you find that result in circularly polarized light? How many should there be? Can you find the positions that leave the linearly polarized light unchanged? If you have two quarter-wave plates, how do you make a half-wave plate?

Experiment VIII.2: Birefringent crystals: double refraction

Observe double refraction in a birefringent crystal by examining some text. Rotate the crystal around different axes and explain what you see. Now put a polarizer in front of the crystal, rotate it and explain what you see.

Experiment VIII.3: Optical activity: rotary power of sugar

A solution of sugar (sucrose) exhibits optical activity and will rotate the plane of polarization of a light beam. The angle of rotation (β) is given by

$$\beta = (\pi/\lambda_0)\, d\, (\Delta n)\,, \quad \text{Eqn. (8.38) Hecht}$$

where λ_0 is the wavelength of light in vacuum, d is the path length, and Δn is the difference in refractive index between left and right circularly polarized beams waves (see Chapter 8.10 of Hecht). The index difference Δn scales linearly with the concentration c of sugar in water, which is typically given in grams of solvent per milliliter of mixed solution. The angle of rotation that a solution causes for a sample length of d=1 decimeter (10 cm) and concentration of c=1 g/ml is defined as the specific rotation (at a given wavelength and temperature). The equation relating the specific rotation and the measured rotation is

$$[\alpha]_\lambda^T = \frac{\beta}{d\,c}$$

The units of the specific rotation are degrees/dm/(g/ml). The specific rotation of sucrose is +66.5 degrees/dm/(g/ml) at 589 nm and 20˚C, where positive rotation (*dextrorotary*) is clockwise looking onto the beam.

To measure the rotation, insert two polarizers (polarizer and analyzer) in the laser beam and cross them, so that there is no light transmitted. Place a sugar solution between the polarizers and measure the angle by which you need to rotate the analyzer to achieve zero transmission.

1) Based on your measurement of the angle, what is the specific rotation of sugar at 633 nm? Is it consistent with the value at 589 nm?
2) Repeat your measurement at several concentrations. Plot the observed angle of rotation as a function of concentration, fit it with a linear function and determine the specific rotation from the slope.
3) Are your observations consistent with sucrose being dextrorotary?

Return the polarizers to their default position. Place a highly concentrated solution of corn syrup or sugar between them, but replace your laser source with a white light source. Slowly turn the polarizer and explain what you see.

Equipment needed:

Item	Qty	Source (part #)
Helium-Neon Laser	1	Melles Griot 05 LHP 121
Al mirror	3	Newport 10D10ER.1
Polarizer	2	Edmund A38,396
Microscope cover slip	1	Edmund A40,002
Rotation Mount	1	Thor Labs RSP1
Filter holder	1	Thor Labs DH1
Photodetector	1	Thor Labs DET1-SI
Voltmeter	1	Fluke 75
Quarter-wave plate	2	MWK F17NS2
Cuvette	1	
Cane Sugar packets	2-3	