Optical Activity

Introduction

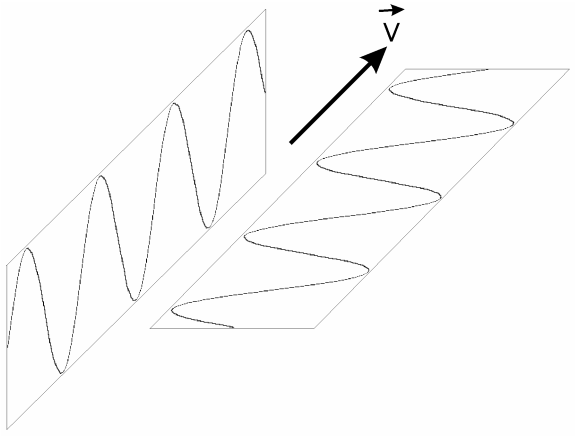
"Optical Activity" refers to the property of some materials, particularly biological ones, to rotate the plane of polarization of light waves. In this experiment you will:

- Explore the phenomenon of polarization of light, and then
- Study the optical activity of ordinary table sugar (sucrose).

Background Information

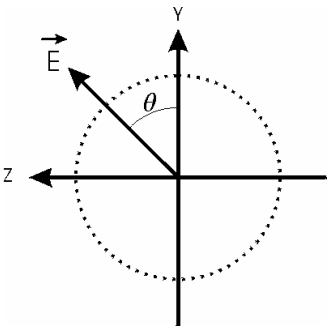
Polarization of Light

As you may know, there are two different types of waves, *longitudinal* and *transverse*. In a longitudinal wave, the thing that is "waving" is in the same direction as the wave velocity. Examples of longitudinal waves include a sound wave and a wave travelling down a slinky. For a transverse wave, the thing that is waving is perpendicular to the wave velocity. Examples include a wave travelling down a string and a water wave.



For transverse waves, the amplitude may have different orientations. The figure to the right shows two perpendicular orientations for waves travelling down a string with velocity $\vec{\mathbf{v}}$. We call these different orientations different *polarizations*.[1]

Light is a transverse wave of electric field $\vec{E}$ and magnetic field $\vec{B}$. By convention, the direction of the electric field defines the direction of the polarization for light. In the figure to the right, we show the electric field of a light wave that is moving out of the paper. The direction of the polarization can be given by specifying the angle θ.



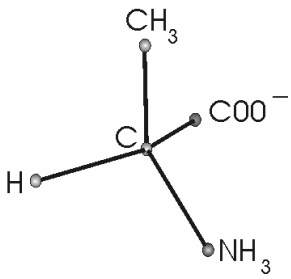
[1] Technically, these are called *plane* or *linear polarizations*

Light from a normal incandescent light bulb is *unpolarized*, by which we mean that all possible polarizations from 0 to 360^0 are equally present. This is different than light from a laser, which is typically completely polarized in one direction.

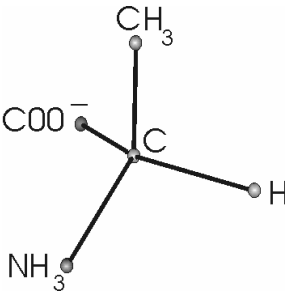
For further information on this topic, you may consult almost any First Year University Physics textbook.

Optical Activity

Many biological molecules can exist in two forms, which are mirror images of each other. For example, to the right we show the two different forms of the amino acid *alanine*: a central Carbon atom has four bonds to the other groups, so that the overall shape of the molecule is a *tetrahedron*. There is no set of translations and rotations that can turn the upper form of the molecule into the lower form. The two forms have identical chemical properties.



It turns out that in biological systems, only the upper form of the molecule is found. This is as opposed to the result of chemically synthesizing alanine, where the usual methods will end up with equal amounts of the two forms of the molecule. It is common for molecules in biological systems to have only one of two mirror image forms of an asymmetric molecule.



If polarized light is incident on a solution containing one form of an asymmetric molecule, the plane of the polarization will be rotated. This property is called *optical activity*. The opposite form of the molecule rotates the plane of polarization in the opposite direction. Exactly how the asymmetry of optically active molecules gives rise to the rotation of the plane of polarization is somewhat advanced; a discussion can be found in, for example, Mikhail V. Vol'kenshtein, **Molecules and Life** (Plenum/Rosetta, 1974), ISBN 0-306-20007-4, pg. 91 or Russell K. Hobbie, **Intermediate Physics for Medicine and Biology** (Wiley, 1978), ISBN 0-471-03213-0, pg. 359.

Exercises

We begin with some exercises on polarization. We shall also become familiar with the apparatus. The exercises are purely qualitative, and you should answer all questions in your lab book.

The *Optical Bench* that you will use both here and in the experiments is magnetic: the light source and the holders for the lenses and filters are held in place with magnets. Be sure that any holders that you are using are placed so their axes are perpendicular to the axis of the optical bench.

The *Photometer* that you will use for quantitative measurements of light levels measures light energy in units of *Lux*; this unit is discussed in Appendix 1 of this Guide Sheet. To use the photometer:

- The probe is plugged in to the socket on the upper-left of the meter, labeled *LUX, UV, IR*. Note that a label on the probe specifies a value for the parameter *F*.
- Simultaneously hold down the *CAL* button and the *ON/OFF* button.
- The display should read the value of *F* for the probe. If not, use the buttons with arrowhead-like symbols on them to adjust the reading on the display.
- Press the *CAL* button. After a brief delay the light level entering the probe will be shown.

Note that the photometer is battery powered, so please do not leave it on for long periods of time when you are not actually making measurements.

The *Polarizers* that you will use select one particular polarization of light. Sometimes we shall refer to these as *filters*.

Mount the *Incandescent Light Source* on the far left-hand side of the bench and turn it on. There is a knob on the top of the light source that adjusts the position of the light bulb. Align the bulb so it is right in the middle of the hole that lets the light out.

If you wear glasses with an anti-reflective coating, you should take them off. Take one of polarizers in your hand and look through it at the light source. Rotate the polarizer about its axis. What happens? Now you may put your glasses back on.

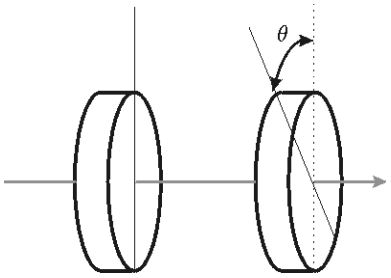
Two of the *Component Carriers* have been modified by gluing a “slick” plastic face to one surface. These carriers are for the polarizers, and the modification allows them to be easily rotated about their axis. Mount the polarizer on one of the modified Component Carriers. Note the markings on the polarizer and the carrier that indicate the alignment of the polarizer. Align it to 0 degrees. Now place it on the bench. Take the second polarizer in your hand and look through it and through the mounted polarizer into the light source. Rotate the polarizer in your hand about its axis. What happens?

In the hallway outside the lab you may see the light from the overhead lights reflected from the floor. Take one of the filters out to the hall and look at the reflected light through it. Rotate the filter about its axis. Change the angle at which

you are viewing the reflected spots. What happens? Now explain why many good sunglasses have polarizing lenses.

Experiments

1. Exploring Polarization



To the right we show an unpolarized light beam incident from the left on a polarizer whose axis of polarization is oriented vertically. The light from that polarizer is incident on a second one oriented at an angle θ relative to the first.

As you discovered in the Exercises, when the two polarizers have the same relative orientation, the second one passes the maximum amount of light. The mounts have a marker under the filter. Place both polarizers on mounts and align them both to 0 degrees. Then place *one* of them approximately in the middle of the bench.

Mount the lens on a holder and place it towards the right-hand side of the bench. To the right of the lens place the holder for the optical fiber that is connected to the photometer. Adjust the position of the lens so that the circle of light is just a little bigger than and completely illuminates the end of the fiber.

As mentioned above, light from an incandescent light bulb, such as in the light source for this experiment, is unpolarized: all possible polarizations are present equally. If the polarizer were perfect, then, it would pass exactly one-half of the light incident from such a source. By what amount do our filters differ from perfection?

Place the second polarizer on the bench next to and to the right of the first one.

Check that the alignment of the second polarizer is the one that passes the maximum light intensity by varying its orientation by a small amount and measuring the intensity with the photometer. Remember to set the photometer to minimum sensitivity before removing the filter and its mount from the bench. If the angle for maximum transmission by the second filter is not measured to be 0^0 then you will need to apply a correction to all measurements of θ.

Measure the background light level by turning off the light source and measuring the intensity.

Turn the light source back on. We shall call I_0 the intensity when the filters are oriented for maximum transmission, and by definition the 'true' value of θ is 0 at this orientation.

If the second filter were perfect, if would pass all of the light incident on it from the first filter. What is the difference from perfection of the filter measured this way? Note this is the second measure of imperfection of the filters that you have done.

Now investigate how the light intensity I from the second filter depends on θ. The intensity varies with angle according to:

$$I = I_0 \, f(\theta)$$

where you must determine *f*. Vary θ from 0 to 180 degrees.

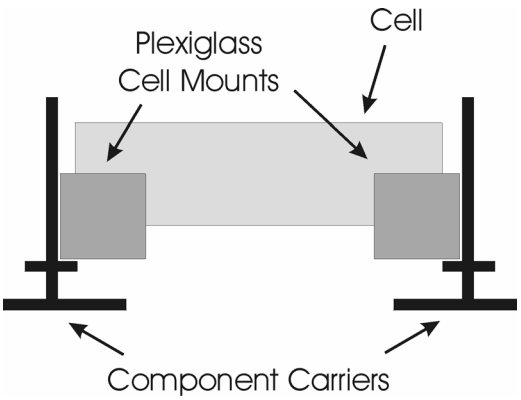
Assume, correctly, that *f* involves fairly simply trigonometric functions. A graph of *I* versus θ may help you determine *f*. You may also use the *Linear Fit* program on Faraday: this is discussed in the Appendix 2 of this Guide Sheet.

When the two filters are at right angles, if the filters were perfect no light would pass the second one. From the Exercises, are our filters perfect? Measure the degree of imperfection. Note this is the third measure of imperfection of the filters that you have done.

2. Optical Activity

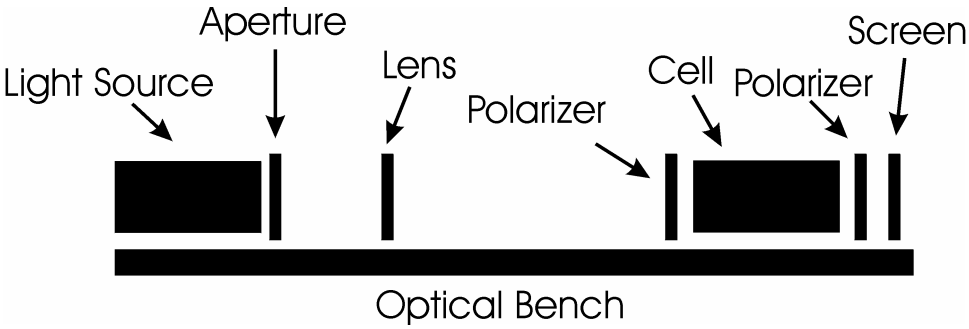
Mount the Apertures component on a carrier and place it to the left and close to the light source. Adjust the position so that the 0.75 mm aperture is centered and passes the maximum amount of light. Mount the Viewing Screen on a carrier and place on the right side of the bench. Take the lens that is mounted on a carrier and place on the bench at the most leftward position that gives a sharp image of the aperture on the screen.

You are supplied a number of Plexiglas *cells* having various lengths and containing various concentrations of sugar water. The two locally constructed Plexiglas mounts for the cells are held to the carriers with magnets. Each mount should be placed on a carrier and placed on the bench slightly to the left of the screen. The figure to the right



shows how the mounts are placed on the carriers to hold a cell.

Now place the two mounted polarizers on either side of the cell. The setup should be consistent with the following diagram.



Be sure that the light that is incident on the cell is smaller than the face of the cell, so that all light from the aperture passes through the cell.

Verify that the empty cell does not exhibit optical activity, i.e. that the light that emerges from it is the same polarization as the light that enters it.[2]
There are at least two different ways of doing this measurement.

- Rotate the second polarizer until the light observed at the screen is a maximum.
- Rotate the second polarizer until the light observed at the screen is a minimum.

You should choose the method that is most precise. Also, note that for an accurate measurement you may need to correct for measured angles by some factor determined in the first part of the experiment.[3]

Should you use the photometer to increase the precision and/or accuracy of this determination?

Now mount the cell filled with plain tap water and determine its optical activity. Repeat with the 10 cm cells with varying given concentrations of sugar, and determine the relationship between the concentration and the optical activity.

Now use cells with the same sugar concentration but which have different lengths to determine the relationship between path length and optical activity.

---

[2] There is an ambiguity here. If the plane of polarization of the light is rotated by any integer multiple of π radians the angle of rotation is not observable.
[3] You, of course, remember the difference between *precision* and *accuracy*.

Finally, the *specific optical rotatory power* α is defined as:

$$\alpha \equiv \frac{\theta}{lC}$$

where θ is the angle of rotation in radians, l is the path length (meters) and C is the concentration (kg/m^3).[4] Determine α for the table sugar used in this experiment. A single straight-line fit of θ versus lC for all your data is one way to do this determination.

The cell labeled *Saturated* is a saturated solution of sugar, which is about 0.88 gm/cm^3 of sugar. Mount the cell and observe what happens as you rotate the second polarizer about is axis, paying particular attention to when the transmitted light is close to zero. What happens? Can you explain? From your determination of α, predict the angle of rotation for this cell. Measure the angle of rotation and compare to the predicted value.

Appendix 1 – Definition of the Lux

The photometer measures light a unit called Lux. This is the SI unit for *illuminance*, and is in the form of energy per time per area. However, surprisingly, one Lux is not 1 Joule per second per meter squared. The remainder of this appendix goes through the somewhat gory definition of the Lux.

First, we need to review solid angles and the *steradian*. You will recall that an angle of a semicircle, measured in radians, is the arc length of the circle divided by the radius of the circle. Similarly, a solid angle of part of a sphere, measured in steradians, is the surface area of the sphere divided by the radius squared of the sphere.

Imagine that a light source emits a constant amount of energy per second, and that the emission is equal in all directions. The *luminous intensity* is a measure of the total amount of energy emitted per second, and in the SI system is measured in *candelas*. The candela is defined in terms of a standard measurement protocol. The fact that 1 candela is not 1 Joule per second is the major reason why the Lux is not anything like 1 Joule per second per meter squared. One *lumen* is the energy per second from a 1 candela source into a 1 steradian spatial angle.

Finally, the Lux is number of lumens per square meter.

---

[4] As is common, the chemists sometimes use different units involving angles measured in degrees and/or lengths in centimeters and/or molar concentrations.

Appendix 2 – Using Faraday's Linear Fit Program

By default, the *Linear Fit* program fits to polynomials:

$$y = A_0 + A_1 x + A_2 x^2 + \ldots$$

The polynomials x^n are called the *basis* functions of the fit, and the A_n are the parameters that are returned as the result of the fit.

The interface to the fitter allows you to choose the values of *n*, which the program calls the *powers for the fit*.

The program also allows a selection of *Advanced Options*, one of which is the basis function to use. Imagine you wish to fit your data to:

$$I = A_1 \sin(\theta)$$

If you have measured the angle θ in radians, set the basis to:

```
Sin[n * x]
```

If the angle θ is measured in degrees, then the basis should be:

```
Sin[n * x * Degree]
```

Note that the sine function in *Mathematica* begins with a capital letter and the angle is enclosed in square brackets. Also, the symbols *x* and *n* are "placeholders" and must appear exactly as shown.

When you return to the main *Fit Setup* screen you will see that the section previously labeled *Select the powers for the fit* now is *Select the factors for the fit*. Choose a factor of *1* and the fitter will fit to the desired relation.

To fit to, say:

$$I = A_1 \tan^2(\theta)$$

set the basis function to:

```
Tan[n * x]^2
```

or:

```
Tan[n * x * Degree]^2
```

Again choose a factor of *1*. Note that the power that the tangent is being raised to comes after the right square bracket.

Finally, a few words on a technical matter. The word *linear* in the name of the fit program refers to the fact that the parameters of the fit, the A_n, are linear in the equation to which we are fitting the data. The fact that the basis functions are not linear is not relevant.

Apparatus

1m Optical Bench, Pasco OS-9103 or equivalent.
Photometer with optical fiber input, Leybold 666 230 or equivalent.
Incandescent Light Source, Pasco OS-9102C or equivalent.
(8) Component Carriers, Pasco OS-9107 or equivalent. Two of these have been locally modified by having a "slick" plastic surface.
Light Source Apertures (0.5mm and 0.75 mm), Pasco OS-9118 or equivalent.
127mm Convex Lens, Pasco OS-9134 or equivalent.
(2) Polarizers, Pasco OS-9109 or equivalent.
Viewing Screen, Pasco OS-9138 or equivalent.
10 cm cells:

- empty and dry.
- filled with tap water.
- Approx. 0.137 gm/cm^3, 0.275 gm/cm^3, 0. 402 gm/cm^3 and saturated (0.88 gm/cm^3) table sugar dissolved in water

15 cm and 20 cm cells with approx. 0.137 gm/cm^3 table sugar dissolved in water.
Holders to mount the optical fiber and the cells on the Component Carriers.
30 cm ruler.

Authors & Copyright

This Guide Sheet was written by David M. Harrison, Department of Physics, University of Toronto, mailto:harrison@physics.utoronto.ca, in 2001. The locally constructed parts of the apparatus were designed and fabricated by Robert Smidrovskis.