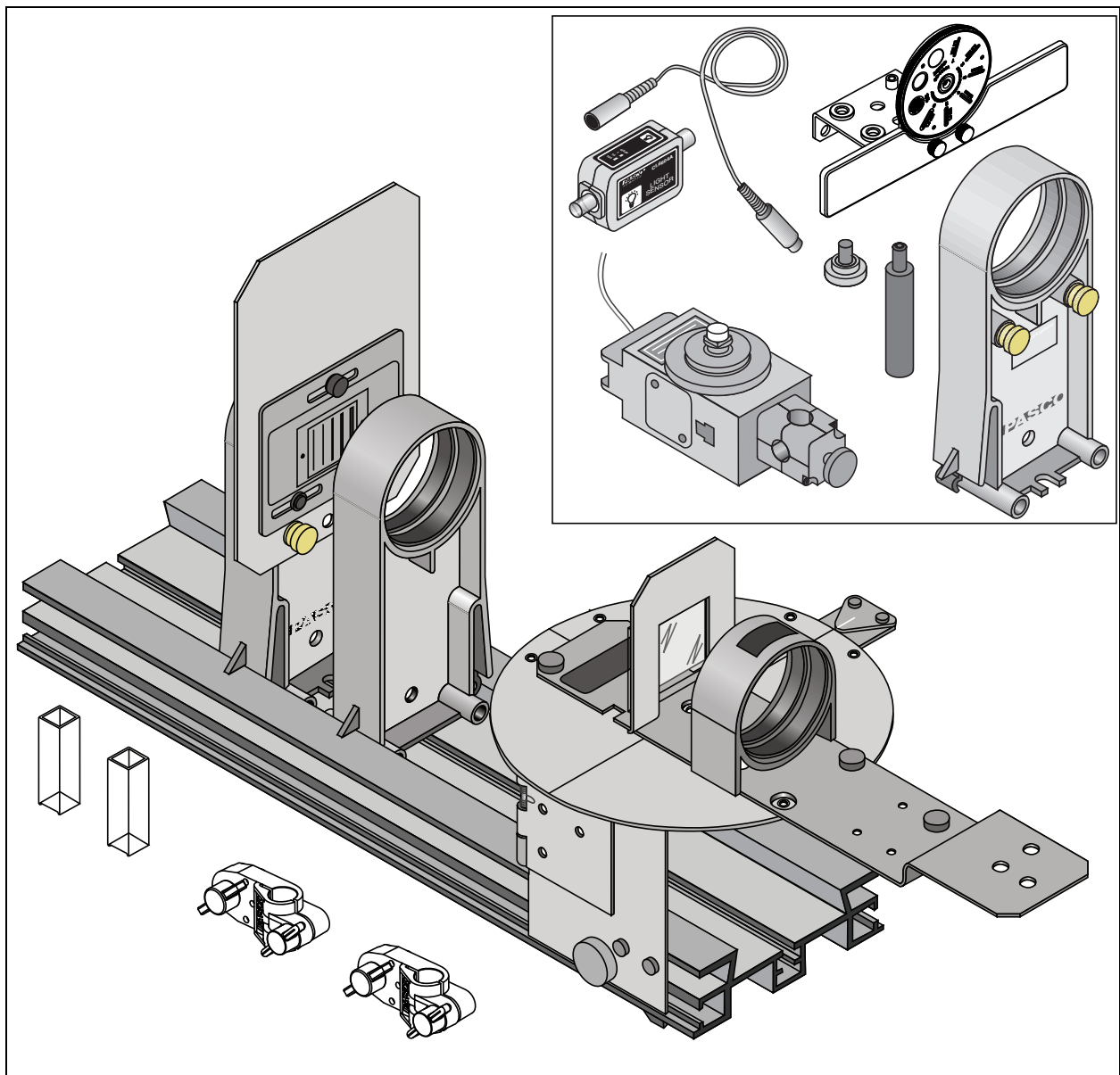




Educational Spectrophotometer Accessory Kit and System

OS-8537 and OS-8539

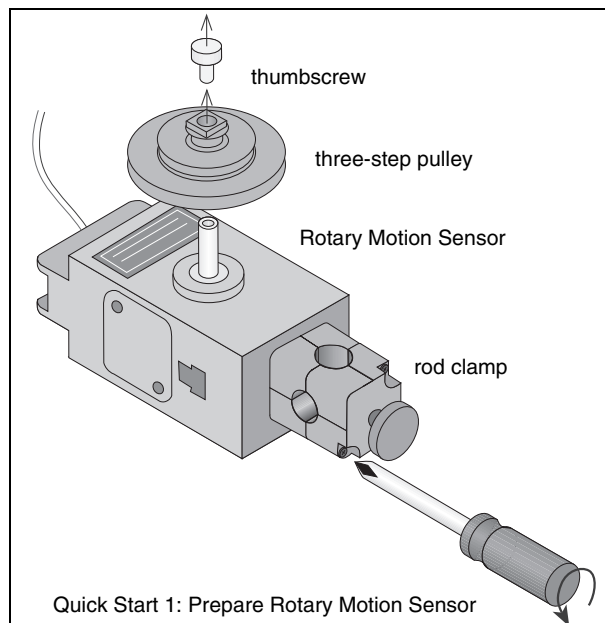


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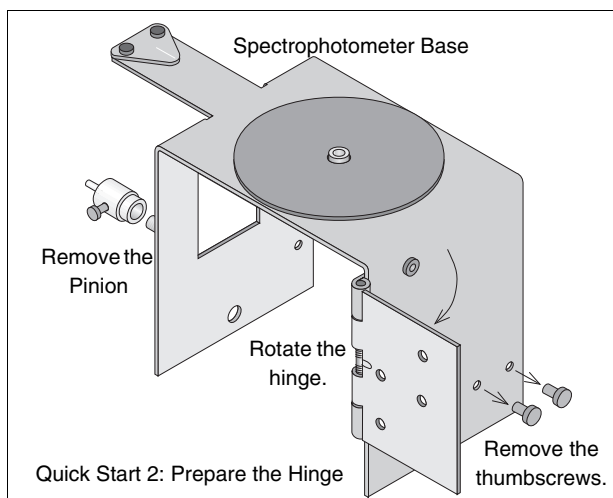
Quick Start

The following pages give an overview of the Spectrophotometer equipment setup.

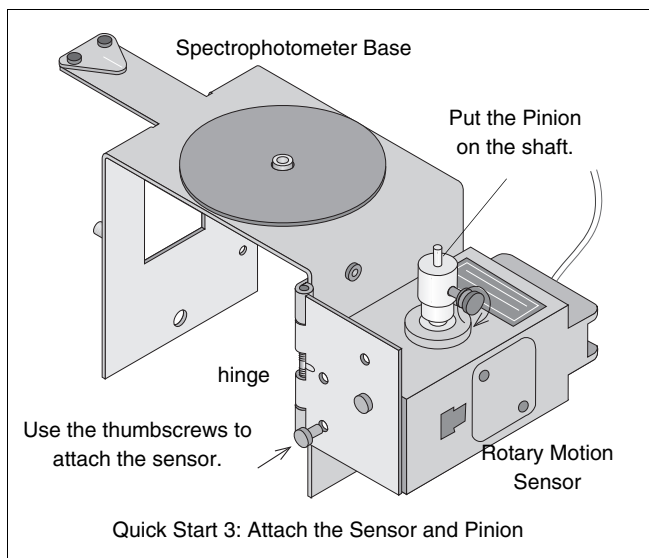
Step One: Prepare the Rotary Motion Sensor by removing the thumbscrew, three-step pulley, and rod clamp.



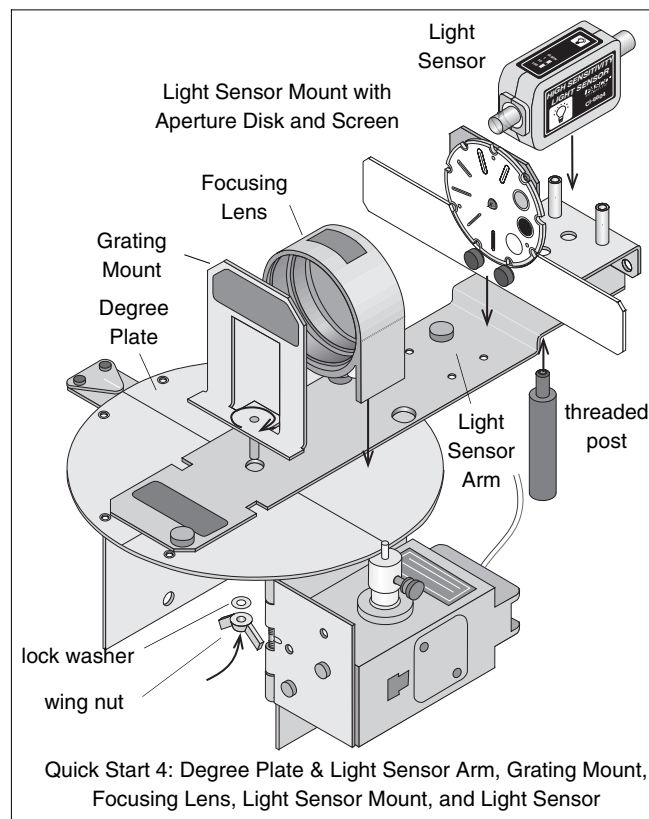
Step Two: Prepare the Spectrophotometer Base by removing the two small thumbscrews and Pinion and by rotating the hinge away from the Base.



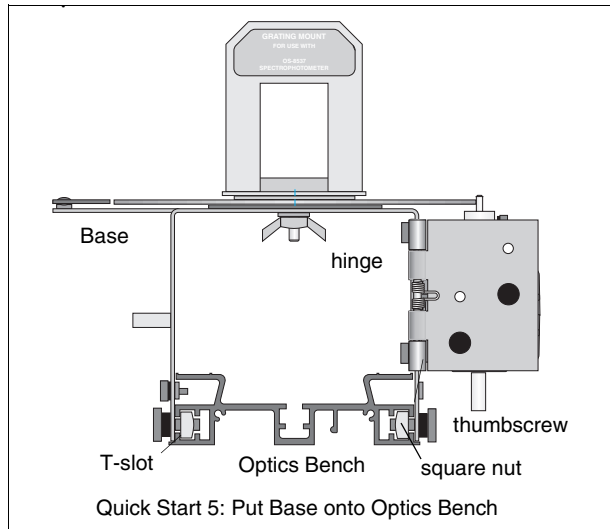
Step Three: Attach the Rotary Motion Sensor to the Base hinge with the two small thumbscrews and attach the Pinion to the Rotary Motion Sensor shaft.



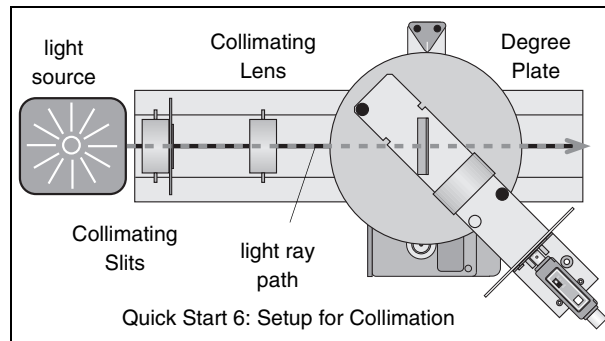
Step Four: Put the Degree Plate/Light Sensor Arm on the Base. Attach the Grating Mount, Light Sensor Mount, and Light Sensor. Position the Focusing Lens.



Step Five: Put the Spectrophotometer Base onto one end of the Optics Bench

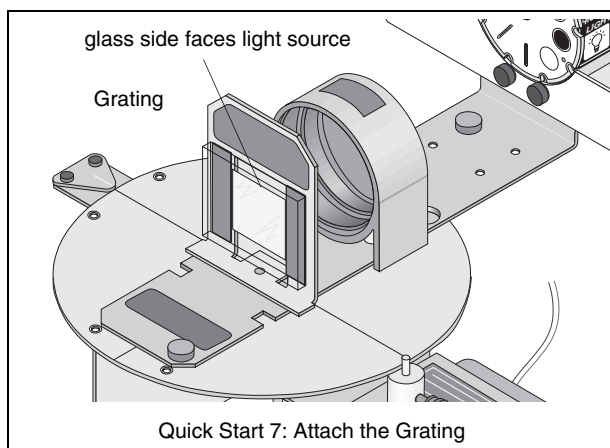


Step Six: Mount the Collimating Slits and Collimating Lens onto the Optics Bench. Set up a light source. Adjust the Collimating Slits and Collimating Lens to collimate the light beam.



Step Seven: Attach the Grating to the mount so the glass side of the Grating faces the light source.

CAUTION: Avoid touching the Grating surface.

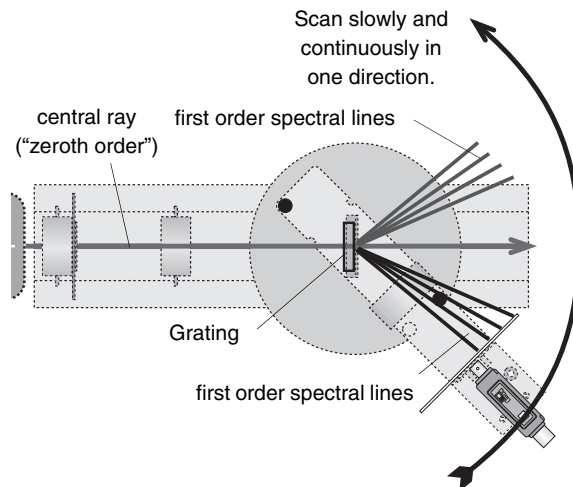


Step Eight: Set up the experiment in the data acquisition program.

1. Select the Light Sensor for Analog Channel A.
2. Select the Rotary Motion Sensor for Digital Channels 1 and 2.
3. Set the Rotary Motion Sensor to high resolution (1440 Divisions/Rotation).
4. Create a calculation for “Actual Angular Position” based on the Angular Position data from the Rotary Motion Sensor *and* the ratio of the radius of the Degree Plate to the radius of the small post on the Pinion (typically, a 60 to 1 ratio).
5. Select a Graph display. Set the *vertical* axis to Light Intensity and the *horizontal* axis to your calculation of “Actual Angular Position”.
6. Set the sampling rate to 20 Hz (20 measurements per second).

Step Nine: Scan the Spectrum

1. Mask or hood the light source if necessary.
2. Move the Light Sensor Arm so the Light Sensor is beyond the edge of the first order spectral pattern.
3. Start recording data. Slowly and continuously scan the spectrum. Scan the first order spectrum on one side of the central ray, through the central ray, and through the first order spectrum on the other side.



Step Ten: Analyze Your Data

Introduction

About This Manual

This manual describes the PASCO OS-8537 Educational Spectrophotometer Accessory Kit and the PASCO OS-8539 Educational Spectrophotometer System. The OS-8537 Accessory Kit is designed to be mounted on the Optics Bench of the OS-8515 Basic Optics System.

Components of the Kit

The OS-8537 Educational Spectrophotometer Accessory Kit (see Figure 1a) includes the following items:

Spectrophotometer Base	Degree Plate with Light Sensor Arm
Grating Mount	Grating (~600 lines per mm)
Focusing Lens	Collimating Lens
Collimating Slits	Cuvettes (2)
Rod Stand Mounting Brackets (2)	

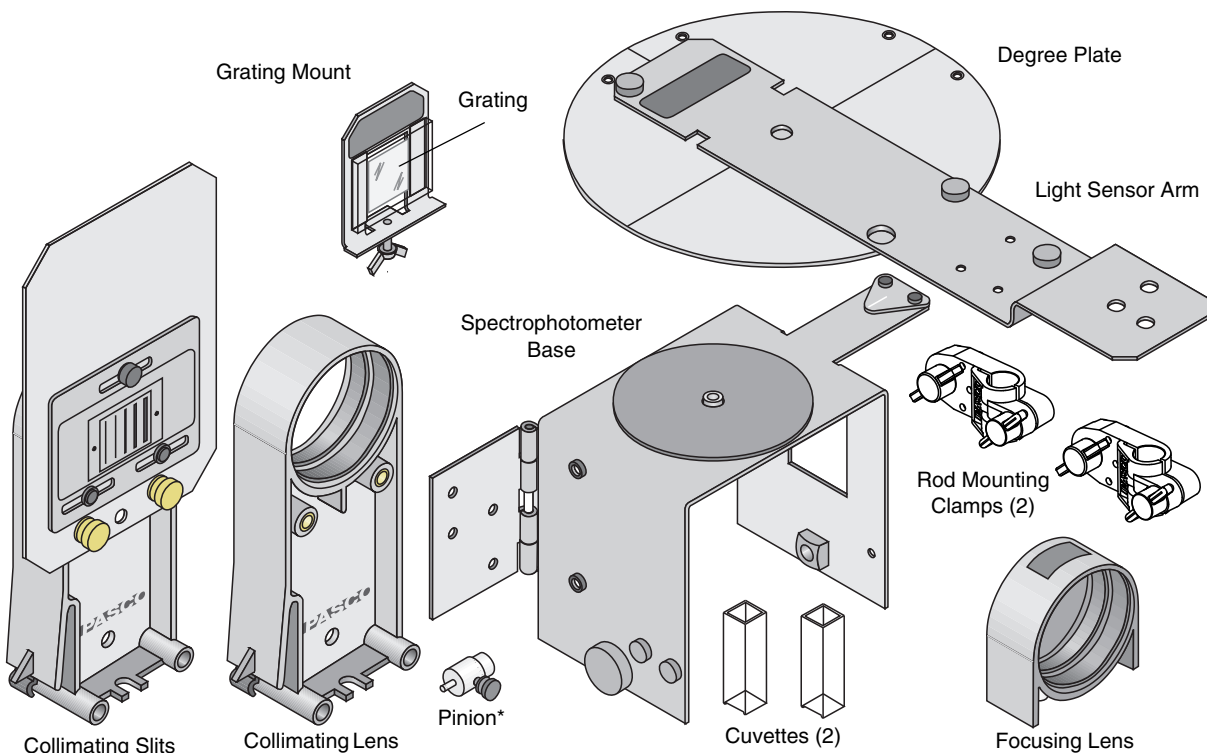


Figure 1a: Educational Spectrophotometer Accessory Kit

(*The pinion shown in Figure 1a can be mounted on a post on the Spectrophotometer Base when not in use.)

Recommended Equipment for use with the Spectrophotometer Accessory Kit:

Basic Optics System (OS-8515)	High Sensitivity Light Sensor (CI-6604)
Aperture Bracket (OS-8534)	Rotary Motion Sensor (CI-6538)

Components of the System

The OS-8539 Educational Spectrophotometer System includes the items in the Spectrophotometer Accessory Kit plus the following:

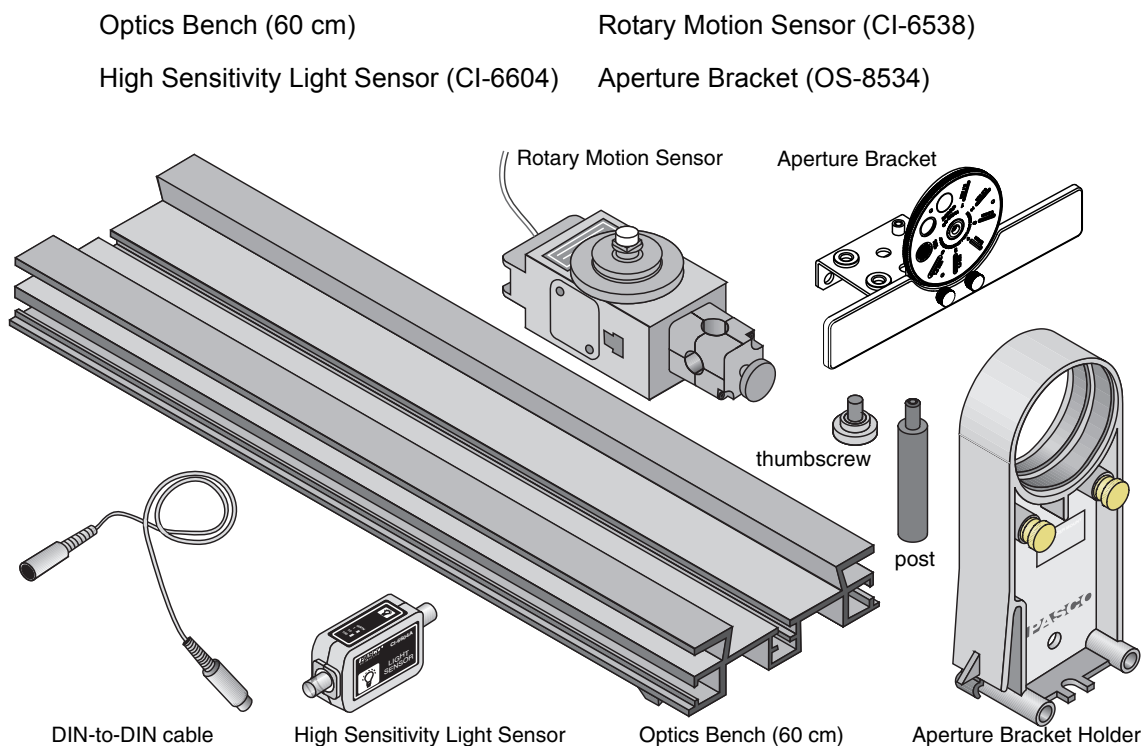


Figure 1b: Additional Components of the Spectrophotometer System

Recommended Equipment for use with both the Kit *and* the System:

Light Source (such as SE-9466 Mercury Spectral Tube)	Rod, 45 cm (ME-8736) (2)
Spectral Tube Power Supply and Mount (SE-9460)	Large Rod Stand (ME-8735) (2)

Description

The Spectrophotometer allows you to view and measure the spectral pattern (spectrum) produced by a light source. The Collimating Slits and Collimating Lens produce a narrow beam of parallel light rays. The Grating disperses the beam of light into a spectrum with different colors at different angles but with all of the light of a given color in a parallel beam. The Focusing Lens focuses these parallel beams of color into spectral lines (see Fig. 2). The narrow slit on the Aperture Disk (part of the Aperture Bracket) allows light of a single color to enter the High Sensitivity Light Sensor. The High Sensitivity Light Sensor (included with the Spectrophotometer System) measures the intensity of the light while the Rotary Motion Sensor (included with the Spectrophotometer System) measures the angle to which the light is diffracted by the Grating.

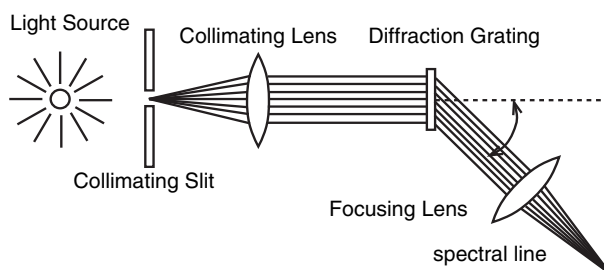


Figure 2: Grating Spectrometer

You can find the wavelength of each color of light using the measured angle and the Grating spacing “d”.

$$m\lambda = d \sin \theta, m = 0, 1, 2 \dots$$

where d is the distance between the rulings on the Grating, m is the order of the particular principal maximum, θ is the angle of the diffracted light, and λ is the wavelength.

The Grating disperses the beam of light into a first order spectrum and higher order spectra. The higher order spectra are broader and less bright than the first order spectra, and may overlap.

The Grating is *blazed*, so one side of the spectrum is much brighter than the other.

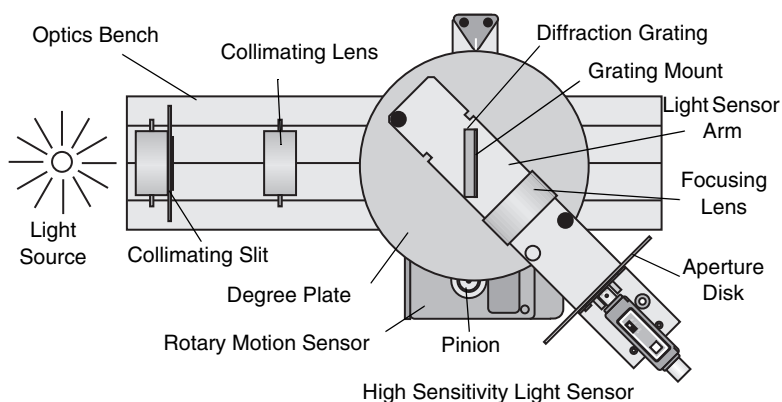


Figure 3: Spectrophotometer System (top view)

Set Up

This part of the manual describes how to set up the Spectrophotometer System (see Fig. 3).

Mounting the Rotary Motion Sensor

This describes how to mount the Rotary Motion Sensor to the hinge on the Spectrophotometer Base.

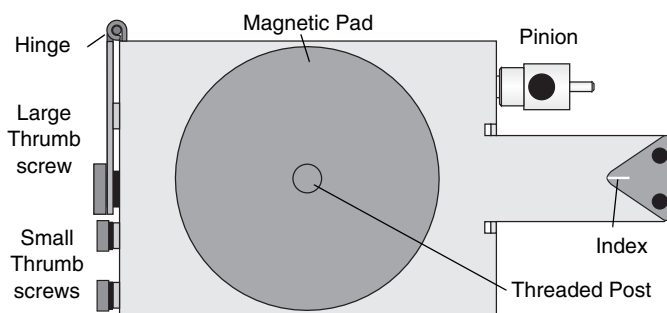


Figure 4: Spectrophotometer Base (top view)

The top of the Spectrophotometer Base has a short threaded post for centering the circular Degree Plate and for holding the Grating Mount. It also has a magnetic pad for holding the Degree Plate, and a triangular shaped index marker. One side of the base has a post upon which the Pinion can be stored when it is not in use. The other side has a spring-loaded hinge and two small thumbscrews for mounting the Rotary Motion Sensor (included in the Spectrophotometer System). On both sides of the base are large thumbscrews and square nuts used for mounting the Spectrophotometer Base on the Optics Bench (see Fig. 4)

The Rotary Motion Sensor has a three step pulley attached to its shaft with a small thumbscrew. The sensor also has a rod clamp attached at one end.

First, remove the small thumbscrew and three step pulley from the Rotary Motion Sensor shaft. Then, remove the rod clamp from the Rotary Motion Sensor (see Fig. 5).

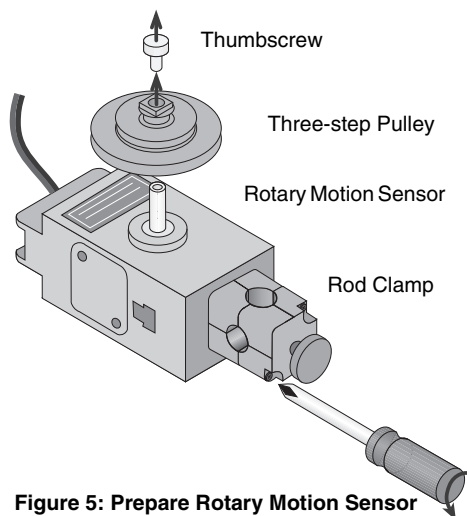


Figure 5: Prepare Rotary Motion Sensor

Remove the two small thumbscrews from the threaded storage holes on the side of the Spectrophotometer Base and set them aside for the moment. Remove the Pinion from the storage post on the opposite side of the Spectrophotometer Base and set the Pinion aside for a moment (see Fig. 6).

Rotate the hinge away from the side of the base until the hinge is almost perpendicular to the base. Use the two small thumbscrews to fasten the Rotary Motion Sensor to the *lower* set of holes on the inside of the hinge.

Place the Pinion all the way onto the Rotary Motion Sensor shaft and tighten the Pinion on the shaft by turning the small thumbscrew on the side of the Pinion (see Fig. 7).

Connect the Rotary Motion Sensor to the PASCO interface.

Mounting the Degree Plate and Light Sensor Arm

The Degree Plate and Light Sensor Arm are shipped as a unit. The Light Sensor Arm is attached to the circular Degree Plate with two small thumbscrews. The hole in the center of the Degree Plate fits over the short threaded post on the top of the Spectrophotometer Base.

Hold the Rotary Motion Sensor slightly away from the base so the small diameter post on top of the Pinion is not in the way of the edge of the Degree Plate. Position the hole in the plate over the short threaded post on the top of the base. Place the Degree Plate onto the Spectrophotometer Base. Let the small diameter post on the top of the Pinion rest against the *edge* of the Degree Plate (see Fig. 8).

More Information About the Degree Plate

The ratio between the radius of the Degree Plate and the radius of the small post on the top of the Pinion is designed to be 60 to 1. In other words, the Pinion rotates 60 times for one rotation of the Degree Plate.

This assumed ratio of 60 to 1 is included in a calculation for the actual angular displacement of the Degree Plate as it turns during the measurement of a spectrum (see “Using the data acquisition program” in the Procedure section).

Using the exact ratio of the Degree Plate to the small Pinion post can slightly improve the accuracy of measurement. To determine the *exact* ratio of the Degree Plate to the small Pinion post, do the following to calibrate the Degree Plate:

1. Remove the Light Sensor Arm from the Degree Plate by unscrewing the two small thumbscrews. (You can store the thumbscrews in the empty threaded holes on the Light Sensor Arm.) Turn the Degree Plate so the zero degree mark is *exactly* aligned with the index mark on the arm that extends from the Spectrophotometer Base.
2. Start the data acquisition program. (See the software’s Help system or User’s Guide for more information.)
3. In the program, select “Rotary Motion Sensor” to be connected to the PASCO interface. If possible, set the resolution of the Rotary Motion Sensor to 1440 Divisions/Rotation.

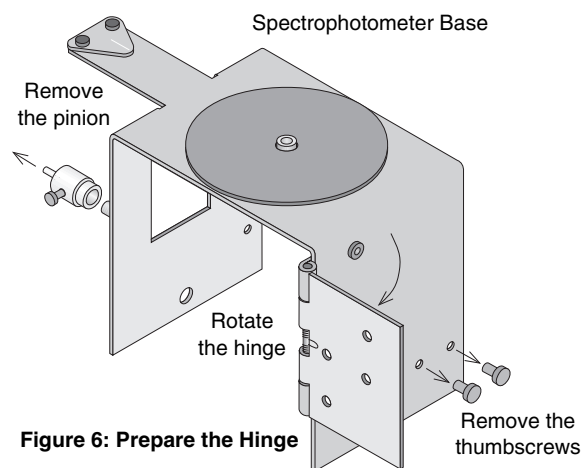


Figure 6: Prepare the Hinge

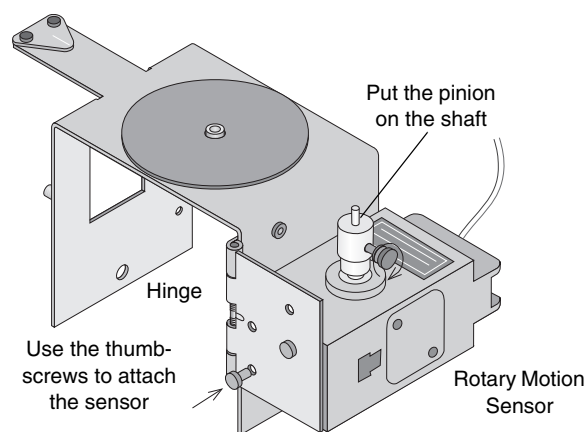


Figure 7: Attach the Sensor and Pinion

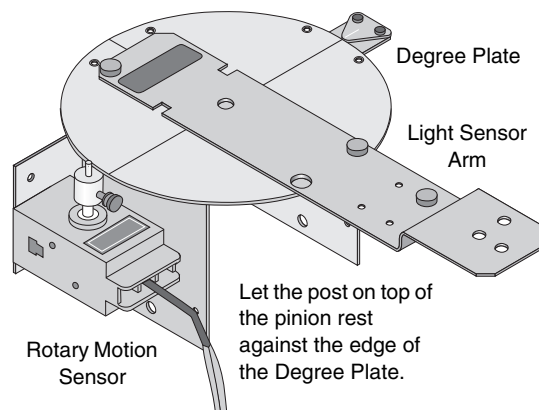
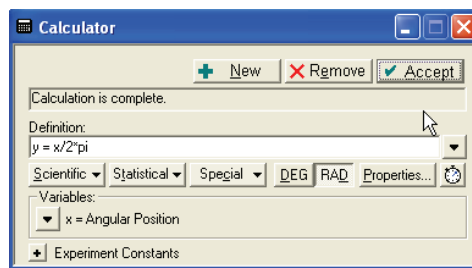


Figure 8: Degree Plate onto Base

- In the data acquisition program, use the built-in Calculator to create a calculation. Base the calculation on the “Angular Position” measurement from the Rotary Motion Sensor. In the calculation, divide “Angular Position” by 2π , where π is approximately 3.1416... Label your calculation “Ratio of Radii” (see Fig. 9).

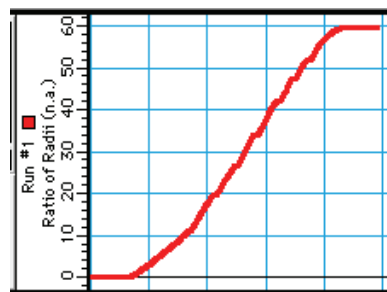


NOTE: The calculator in your program may differ in appearance. Refer to your User's Guide.

Figure 9: Calculation of Ratio of Radii

- In the program, select a Graph display and set it to show the calculation “Ratio of Radii” on its vertical axis.
- Start recording data. Turn the Degree Plate in one direction slowly and continuously for exactly one complete rotation. Stop recording data.

- In the Graph display, use the built-in Statistics tools to find the maximum value of the “Ratio of Radii” (i.e., the maximum of y - see Fig. 10). This value is the exact ratio of the Degree Plate radius to the small Pinion post radius. (Note: This value should be close to 60.) Record the actual ratio.



NOTE: The Graph display in your program may differ in appearance. Refer to your User's Guide.

Figure 10: Sample Degree Plate Calibration Data

Ratio of Radii = _____

- Replace the Light Sensor Arm on the Degree Plate and fasten it to the plate with the two small thumbscrews.

Mounting the Aperture Bracket Light Sensor Mount and Light Sensor

The Aperture Bracket has two main parts: the Light Sensor Mount and the Holder. (The Holder and thumbscrew are not used and can be put aside.) An Aperture Disk and Aperture Screen) are attached to the front of the Light Sensor Mount.

The Light Sensor Mount has two holes: one hole in the center of the mount and a second hole at the rear of the mount. The end of the Light Sensor Arm has three holes: two holes along the centerline of the arm and one hole to the side of the centerline. Line up the center hole of the Light Sensor Mount with the centerline hole in the Light Sensor Arm that is closest to the Degree Plate.

Line up the High Sensitivity Light Sensor so the threaded hole in its base is above the center hole of the Light Sensor Mount. Use the threaded post (included with the Aperture Bracket fasten the High Sensitivity Light Sensor and Light Sensor Mount to the Light Sensor Arm (Fig. 11).

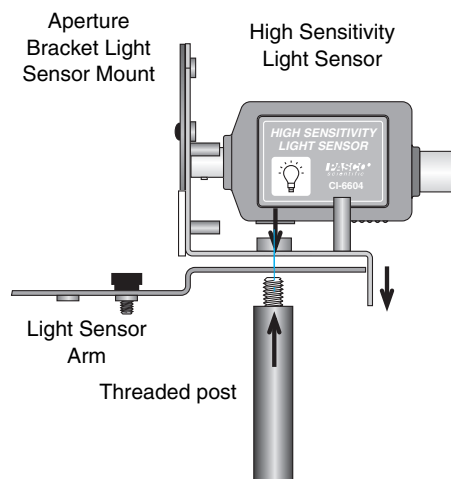


Figure 11: Sensor and Aperture Bracket onto Light Sensor Arm

Rotate the Aperture Disk on the front of the Light Sensor Mount so that the narrowest slit is in line with the opening to the sensor.

Connect the High Sensitivity Light Sensor to the PASCO interface.

Mounting the Grating Mount

The threaded rod on the bottom of the Grating Mount has a lock washer and a wing nut. Remove the lock washer and wing nut from the threaded rod, and screw the threaded rod into the short threaded post in the center of the Degree Plate. Do *not* screw the Grating Mount all the way down onto the Light Sensor Arm. The Grating Mount must be slightly above the Light Sensor Arm so the Degree Plate can move.

Use the Light Sensor Arm to rotate the Degree Plate until the zero line on the Degree Plate is aligned with the index mark on the Spectrophotometer Base. Turn the Grating Mount so it is aligned with the zero line on the Degree Plate and the label side of the Grating Mount faces *away* from the sensor on the Light Sensor Arm.

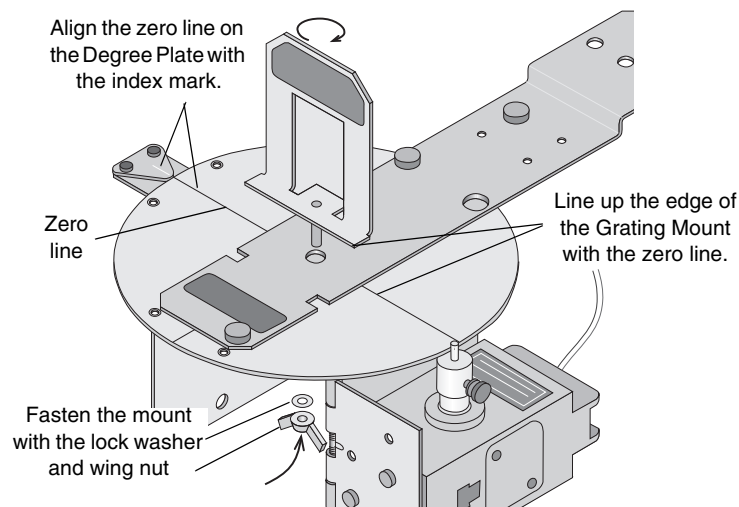


Figure 12: Grating Mount onto Rotating Table

Put the lock washer and wing nut back onto the threaded rod and tighten the wing nut until the Grating Mount remains in place when the Degree Plate is rotated in either direction (Fig. 12).

Mounting the Spectrophotometer Base on the Optics Bench

You can mount the components of the Spectrophotometer on the 1.2 meter Optics Bench that is part of the OS-8515 Basic Optics System, or the 0.6 meter (60 cm) Optics Bench that is included with the OS-8539 Spectrophotometer System. The Spectrophotometer Base mounts into the T-slots on the sides of the Optics Bench and the Collimating Slits and Collimating Lens snap into the center of the Optics Bench.

To mount the Spectrophotometer Base on the Optics Bench, loosen the thumbscrew on each side of the Base so the square nuts can slip into the T-slots on the sides of the Optics Bench. Insert the square nuts into the slots and slide the Base along the bench until it is about 20 cm from the end (Fig 13). Tighten the thumbscrews to hold the Base firmly on the bench.

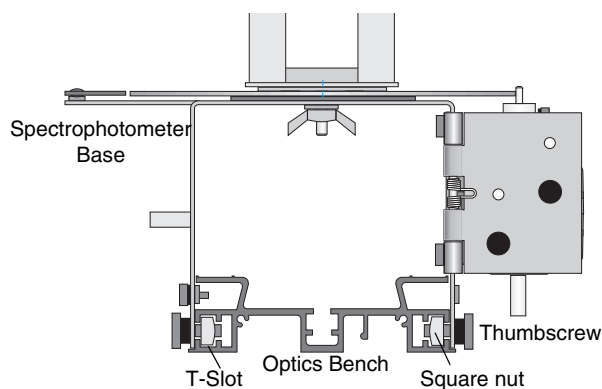


Figure 13: Base onto Optics Bench (end view)

Rod Stand Mounting Clamps

You can adjust the height or angle of the Optics Bench using the Rod Stand Mounting Clamps and two rods and bases (not included). Each clamp has a thumbscrew and a square nut at one end, and a second thumbscrew at the other end. The thumbscrew with the square nut holds the clamp onto the bench, and the other thumbscrew holds the clamp onto a rod. The clamp has grooves on one side that match the lower lip of the optics bench.

To mount the clamp on the bench, loosen the square nut and then slide the square nut into the T-slot at the end of the optics bench. Line up one of the grooves in the clamp with the lower lip of the optics bench. Tighten the thumbscrew (Fig. 14).

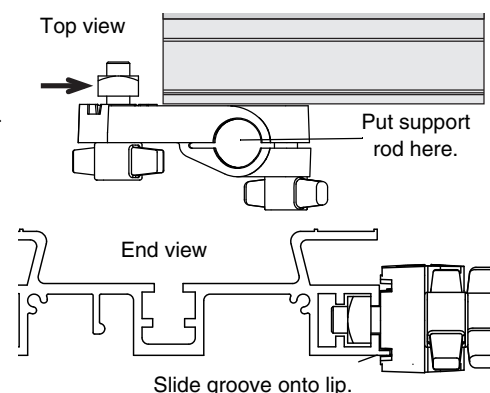


Figure 14: Mounting Clamp onto Optics Bench

To mount the clamp on a support rod, loosen the other thumbscrew. Put the support rod through the hole, and then tighten the thumbscrew (Fig 15).

Mounting and Adjusting the Collimating Slits and Lens

The Collimating Slits consist of two parts: the Collimating Slits Plate and the Collimating Slits Holder. The slits are in a piece of metal that is attached to a moveable slide. The slide is held on the Collimating Slits Plate with a small thumbscrew and two permanently attached socket screws. The Collimating Slits Plate is attached to the Collimating Slits Holder with two brass thumbscrews. Loosen the small thumbscrew in the Collimating Slits Plate in order to move the slits slide back and forth. The narrow slot in the Collimating Slits Plate lets light through one slit at a time. The top half of the Collimating Slits Plate helps to prevent extra light from being measured.

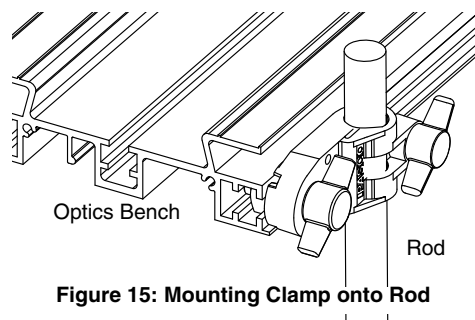


Figure 15: Mounting Clamp onto Rod

Snap the Collimating Slits Holder into the Optics Bench near the end of the bench that is closest to the light source you are using. To move the holder, grasp the holder at the base and push in on the locking clip on one side of the holder (Fig. 16). Slide the holder along the center section of the bench while squeezing the clip. Release the clip to lock the holder firmly in position.

Snap the Collimating Lens Holder into the Optics Bench between the Collimating Slits Holder and the Spectrophotometer Base. Position the Collimating Lens Holder about 10 cm from the Collimating Slits Holder.

Positioning the Collimating Slits and Lens

The focal length of the Collimating Lens is *about* 10 cm so the lens should be positioned about 10 cm from the slits. Use the following procedure to position the lens more precisely.

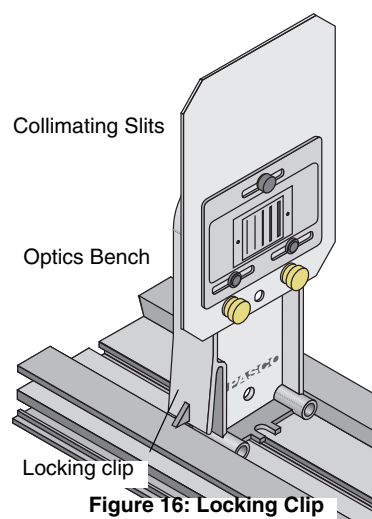


Figure 16: Locking Clip

Set up a light source so that light from the source passes through one of the slits on the Collimating Slits and then through the Collimating Lens. Rotate the Light Sensor Arm so the Aperture Bracket and Light Sensor are out of the way and the beam of light can shine onto a distant vertical surface such as a wall (Fig. 17).

Adjust the distance between the Collimating Slits and the Collimating Lens so that the beam of light is neither converging nor diverging (i.e., light rays are parallel). The beam of light should stay about the same width all the way to the distant vertical surface. Hold a piece of paper in the light beam's path at various distances along the beam's path. Check to see that the light beam's width is about the same at each point along its path. Note that the light may not be in focus during this process.

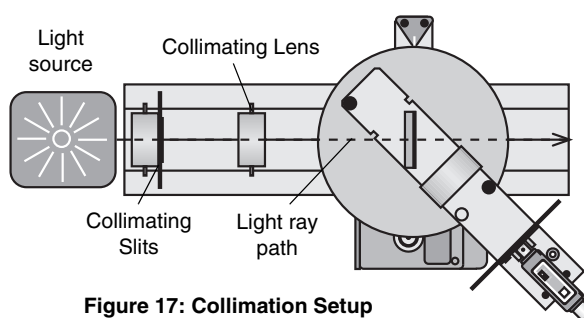


Figure 17: Collimation Setup

If the light beam is not perfectly vertical, loosen the small thumbscrew that holds the Collimating Slits slide and adjust the slide, or loosen the brass thumbscrews that hold the Collimating Slits Plate onto the holder and adjust the plate until the collimated beam is vertical. Remember to tighten the thumbscrews after you make the adjustment.

The distances between the light source and the Collimating Slits and between the Collimating Slits and the rest of the Spectrophotometer are not critical. However, the closer the light source, the brighter the spectrum.

Mounting the Grating

Caution! Handle the Grating carefully. Avoid touching the Grating or the glass plate to which the Grating is attached *except by the edges* of the glass plate.

The Grating is mounted on one side of a rectangular glass plate. There are two magnetic pads on the same side of the glass plate as the Grating. These pads hold the Grating in place on the Grating Mount.

Once the light from the source is collimated, attach the Grating to the Grating Mount so that the glass side of the Grating faces the light source (Fig. 18).

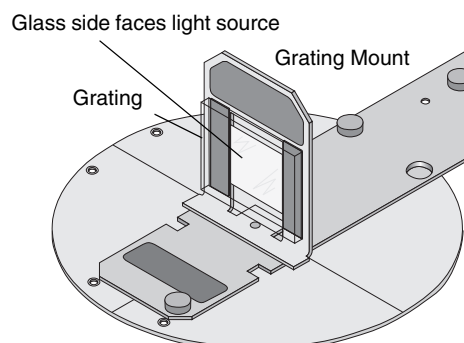


Figure 18: Grating onto Mount

Mounting and Positioning the Focusing Lens

The Degree Plate has markings on either side of the Light Sensor Arm that indicate the approximate position in which to place the Focusing Lens. The Focusing Lens has two small magnets in its base that hold it in place on top of the Light Sensor Arm. Place the Focusing Lens on the Light Sensor Arm between the Grating Mount and the High Sensitivity Light Sensor.

The Focusing Lens focal length is *about* 10 cm so the lens should be positioned on the Light Sensor Arm about 10 cm from the front of the Aperture Disk (Fig. 19).

Set up the light source, Collimating Slits, and Collimating Lens so a beam of light shines through the Grating and Focusing Lens. Darken the room so you can see the spectral lines more clearly. Move the Light Sensor Arm so the central ray of light (called the “zeroth order”) is centered on the slit at the bottom of the Aperture Disk. You should be able to see the first order spectral lines on the Aperture Screen on either side of the central ray of light. Adjust the position of the Focusing Lens until the spectral lines are sharply focused.

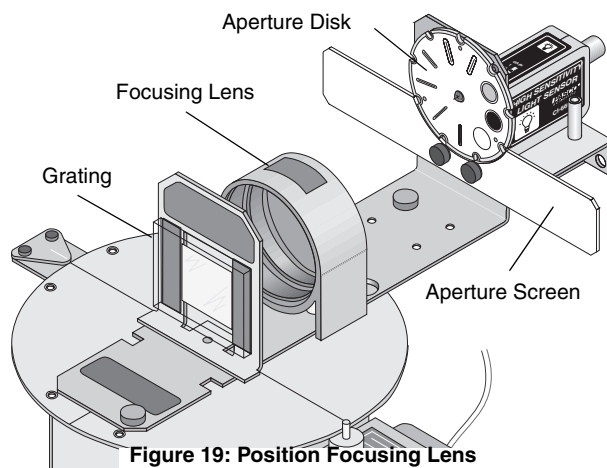


Figure 19: Position Focusing Lens

Note: Because the Grating is strongly blazed, the spectral lines on one side of the central ray (“zeroth order”) will be less bright than the spectral lines on the other side.

Procedures

Grounding

1. If you use an AC powered spectral light source, plug the power cord for the light source into a different outlet than the outlet used for your PASCO interface and computer.
2. For a very dim light source you may need to use the 100 GAIN setting on the High Sensitivity Light Sensor and the 100x sensitivity setting in the data acquisition program. If so, connect a wire from the Spectrophotometer Base to an earth ground in order to reduce electrical “noise”. You can use one of the small thumbscrews from the Light Sensor Arm to connect a ground wire (not included) to the threaded hole on the side of the Spectrophotometer Base opposite to the Rotary Motion Sensor.

Turning the Degree Plate

The spring in the hinge on the Spectrophotometer Base is strong enough to keep the Pinion in contact with the edge of the Degree Plate as you move the Light Sensor Arm to turn the plate. If the small diameter post on the Pinion slips rather than turns, make sure that the thumbscrews that hold the Rotary Motion Sensor onto the hinge are tight. You may need to loosen the screws and then push the Rotary Motion Sensor so it is as close to the Base as possible before re-tightening the screws.

Masking the Light Source or the Spectrophotometer

When using a bright spectral light source such as the PASCO Low Pressure Sodium Light Source, cover the source with an opaque cloth hood to block out ambient light. Cover the light source opening with a mask that has a 0.5 to 1.0 cm wide rectangular slot in it to reduce ghost images. Use clothespins or binder clips to attach the edge of the cloth hood to the plate on the Collimating Slits (Fig. 20).

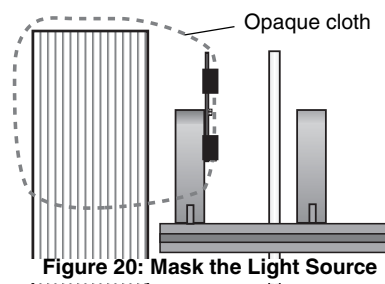


Figure 20: Mask the Light Source

When measuring solar spectra, put an opaque cloth hood over the entire Spectrophotometer so that the only opening to the sunlight is the Collimating Slit. Use clothespins or binder clips to attach the edge of the cloth hood to the plate on the Collimating Slits. Use one hand to hold up the center of the cloth hood (Fig. 21).

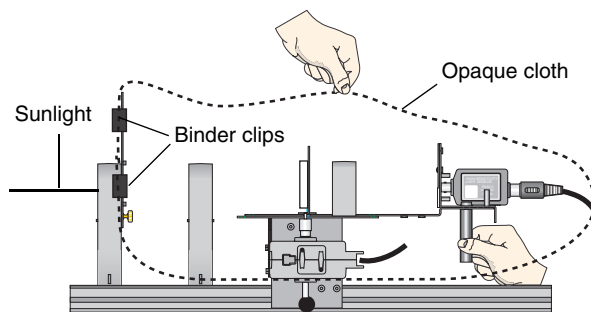


Figure 21: Mask the Spectrophotometer

Using the Data Acquisition Program

Note: See the data acquisition software’s User’s Guide for detailed information about using the program.

1. Start the program. Select the Light Sensor to be connected to Analog Channel A and select the Rotary Motion Sensor to be connected to Digital Channels 1 and 2.
2. In the program, set the Rotary Motion Sensor so it can record 1440 divisions per rotation.
3. In the program, select a Graph display and set it to show “Light Intensity (% max)” on its vertical axis.
4. Use the Calculator in the program to create a calculation of the actual angular position of the Degree Plate. If the small post on the top of the Pinion is in contact with the edge of the Degree Plate, the Angular Position of the Rotary Motion Sensor must be divided by the ratio of the radius of the Degree Plate and the radius of the small post on the Pinion*. The ratio is approxi-

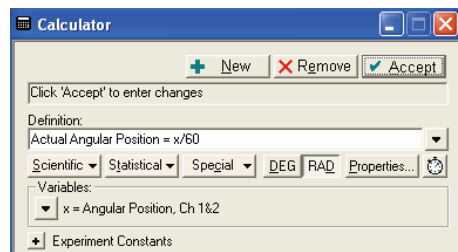


Figure 22: Create a Calculation

mately 60 to 1. If the larger diameter section at the bottom of the Pinion is used, the Angular Position of the Rotary Motion Sensor must be divided by 15* (see Fig. 22 for an example from *DataStudio*).

5. Change the Graph display to show your calculation of Actual Angular Position on its horizontal axis.

(*See “Calibrating the Degree Plate” earlier in the Set Up section for more information on measuring the ratio of the radius of the Degree Plate and the radius of the Pinion.)

General Information About the Light Sensor

The High Sensitivity Light Sensor has a GAIN (amplification) select switch on the top with three settings (1, 10 and 100). When you measure a spectrum, start with the lowest GAIN setting to measure the brightest lines. Then switch to the next setting and re-scan the spectrum to measure the dimmer lines. Then re-scan again at the highest GAIN setting to measure the dimmest lines.

It may also be possible to amplify the signal (increase the sensitivity) from the Light Sensor using the data acquisition program. For example, in *DataStudio*, the normal sensitivity setting is “Low (1x)”. The other settings are “Medium (10x)” and “High (100x)”.

In general, you will record better data if you increase the GAIN setting on the Light Sensor *before* you increase the sensitivity setting in the data acquisition program.

General Information About Slit Widths

There are five slits on the Collimating Slits slide and six slits on the Aperture Disk. You can select wider slits in order to increase the amount of light that passes through the Grating and into the Light Sensor, but this will make a wider spectral pattern and decrease the accuracy of your measurements.

Scanning a Spectrum

To scan a spectrum, use the threaded post under the Light Sensor to move the Light Sensor Arm so the Light Sensor is beyond the far end of the first order spectral lines, but not in front of any of the spectral lines in the second order.

In the data acquisition program, begin recording data. Then, scan the spectrum continuously but slowly in one direction by pushing on the threaded post to rotate the Degree Plate. Scan all the way through the first order spectral lines on one side of the central ray (“zeroth order”), through the central ray, and all the way through the first order spectral lines on the other side of the central ray (Fig. 23).

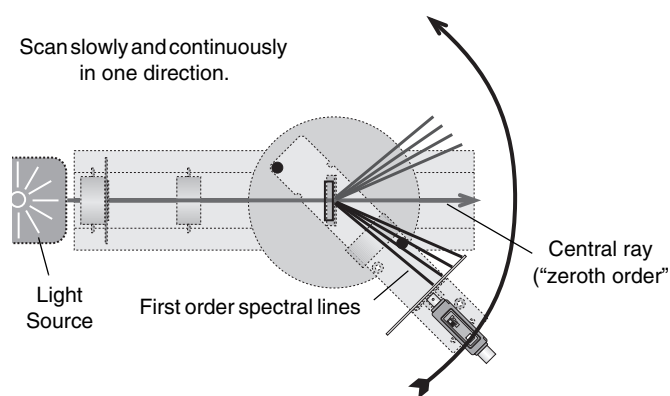


Figure 23: Scan the Spectrum

The angle θ of a particular line in the spectral pattern is one-half of the difference of the angle between the chosen spectral line in the first order on one side of the central ray and the matching spectral line in the first order on the other side of the central ray. Use the built-in analysis tools in the data acquisition program’s Graph display to find the angle between the two matching spectral lines. The angle, θ , is one-half of the angle between the two lines. Use $m\lambda = d \sin \theta$ (and let the order, m , be 1) to calculate the wavelength of the chosen spectral line.

If a dim spectral line only appears on one side of the central ray (“zeroth order”), calculate where the central ray is using a brighter spectral line that is visible on both sides of the central ray. Then determine the angle from the central ray to the dim line to find the angle, θ , for that spectral line (Fig. 24).

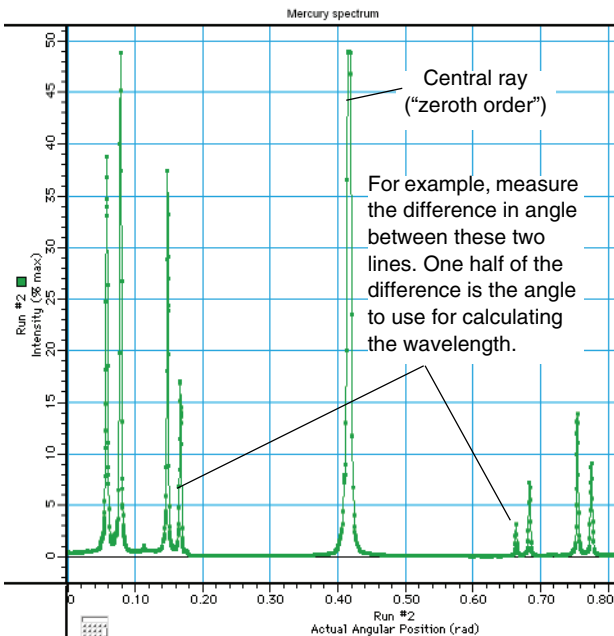


Figure 24: Measure the Angles for both First Order Spectral Patterns

Calibrating the Grating

The number of grating lines on the Grating is approximately 600 lines per millimeter. This translates to a Grating line spacing of $d = 1666 \text{ nm}$ ($1.666 \dots \times 10^{-6} \text{ m}$).

To find the *exact* Grating line spacing, use a sodium lamp to calibrate the Grating. The average wavelength, λ , of the yellow sodium doublet is 589.3 nm. Solving $m\lambda = d \sin \theta$ for the line spacing, d , assuming $m = 1$ (for the first order) gives

$$d = \lambda / \sin \theta$$

where λ is the known wavelength of the sodium doublet. To determine the angle, θ , find the difference in angle between the two first order yellow lines and divide by two.

Using the calibrated Grating line spacing, d , the wavelength of any spectral line in any other spectrum can be more accurately determined using $m\lambda = d \sin \theta$ where the order, m , is 0,1,2,...

Angular Resolution

When the Rotary Motion Sensor is fastened to the *lower* set of holes on the hinge on the Spectrophotometer Base (as described earlier), the small diameter post of the Pinion will make contact with the edge of the Degree Plate. The shaft of the Rotary Motion Sensor will rotate approximately 60 times for every rotation of the Degree Plate (or $360\frac{1}{2}$). One rotation of the Rotary Motion Sensor shaft represents approximately $6\frac{1}{2}$ of angular displacement of the Degree Plate. The maximum resolution of the Rotary Motion Sensor is 1440 divisions per rotation. Since one rotation is $6\frac{1}{2}$, the angular resolution is $6\frac{1}{2}$ divided by 1440, or one quarter of a minute ($0.25'$) or fifteen seconds of arc. This translates to a wavelength resolution of 2 nm, given a grating line spacing of approximately 1666 nm for the Diffraction Grating included with the Spectrophotometer.

If the Rotary Motion Sensor is fastened to the *upper* set of holes on the hinge, the larger diameter part of the Pinion will make contact with the edge of the Degree Plate. The shaft of the sensor will rotate 15 times for every rotation of the Degree Plate. The maximum angular resolution is one minute or sixty seconds of arc. This translates to a wavelength resolution of 8 nm, given a grating line spacing of approximately 1666 nm.

Cuvettes

The Educational Spectrophotometer Accessory Kit includes two plastic cuvettes. These flat sided containers can hold about five milliliters of liquid. You can use the Spectrophotometer and a cuvette to measure a substance's characteristic pattern of absorption and transmission.

To set up the Spectrophotometer and cuvette for measuring an absorption spectrum, do the following:

1. Unscrew the threaded post that holds the Light Sensor and Light Sensor Mount onto the Light Sensor Arm.
2. Move the Light Sensor back so its threaded hole is lined up with the rear centerline hole on the Light Sensor Mount. Use the threaded post to reattach the Light Sensor and Light Sensor Mount to the Light Sensor Arm.
3. Place the empty cuvette in front of the opening to the Light Sensor between the sensor and the backside of the Aperture Disk. Make sure that the cuvette is turned so that the smooth sides are in line with the Light Sensor (Fig. 25).
4. Scan the spectrum from an incandescent light source (such as a bulb powered by a regulated DC power supply).
5. Fill the cuvette with the liquid to be tested and then rescan the spectrum of the incandescent light that is transmitted through the liquid.

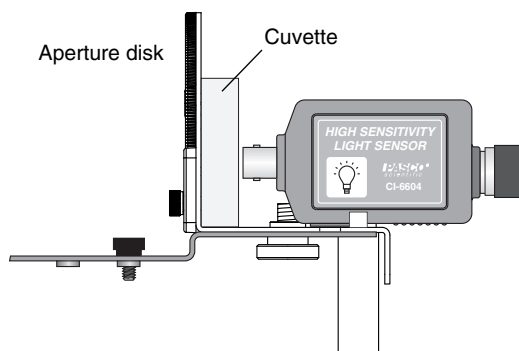


Figure 25: Cuvette with Light Sensor

Other Information

The material on the front of the Aperture Disk may “fluoresce” under ultraviolet (UV) light. It may produce a faint violet color when UV light shines on it. This faint violet color might be seen on the Aperture Disk when you use a mercury light source, for example. The violet line of color appears to be a part of the spectral pattern when the light falls on the disk, but disappears when the light falls only on the Aperture Screen. The High Sensitivity Light Sensor cannot measure ultraviolet light.

The data acquisition program interprets the starting position of the Rotary Motion Sensor as the “zero” angular (or linear) position. For some measurements it may be important to put a mark or stop on the edge of the Degree Plate for reference so you can begin each trial of measurement from the same position. The Degree Plate has several threaded holes near its outer edge. You can put one of the small thumbscrews that are stored on the Light Sensor Arm into one of these threaded holes to use as a reference point for beginning or ending a scan.

Activity 1: Emission (Bright Line) Spectrum

EQUIPMENT NEEDED

Spectrophotometer System (OS-8539)

or

Spectrophotometer Kit (OS-8537)

Rotary Motion Sensor (CI-6538)

Aperture Bracket (OS-8534)

Mercury Spectral Tube and Power Supply

PASCO Interface

High Sensitivity Light Sensor (CI-6604)

Basic Optics Bench (part of OS-8515)

Rod, 45 cm (ME-8736) (2)

Large Rod Stand (ME-8735) (2)

Data acquisition software

Introduction

The purpose of this activity is to determine the wavelengths of the colors in the spectrum of a mercury vapor light.

Theory

An incandescent source such as a hot solid metal filament produces a continuous spectrum of wavelengths. Light produced by an electric discharge in a rarefied gas of a single element contains a limited number of discrete wavelengths - an emission or "bright line" spectrum. The pattern of colors in an emission spectrum is characteristic of the element. The individual colors appear in the shape of "bright lines" because the light that is separated into the spectrum usually passes through a narrow slit illuminated by the light source.

A grating is a piece of transparent material on which has been ruled a large number of equally spaced parallel lines. The distance between the lines is called the grating line spacing, d .

Light that strikes the transparent material is diffracted by the parallel lines. The diffracted light passes through the grating at all angles relative to the original light path. If diffracted light rays from adjacent lines on the grating interfere and are *in phase*, an image of the light source can be formed. Light rays from adjacent lines will be in phase if the rays differ in path length by an integral number of wavelengths of the light. The first place that an image can be formed is where the path length between two adjacent light rays differs by one wavelength, λ . However, the difference in path length for two adjacent light rays also depends on the grating line spacing, d , and the angle, θ , at which the two light rays were diffracted by the grating.

The relationship between the wavelength of the light, λ , the grating line spacing, d , and diffraction angle, θ , is as follows:

$$\lambda = d \sin \theta$$

In the diagram (Fig. 1.1), the path length for Ray A is one wavelength longer than the path length of Ray B.

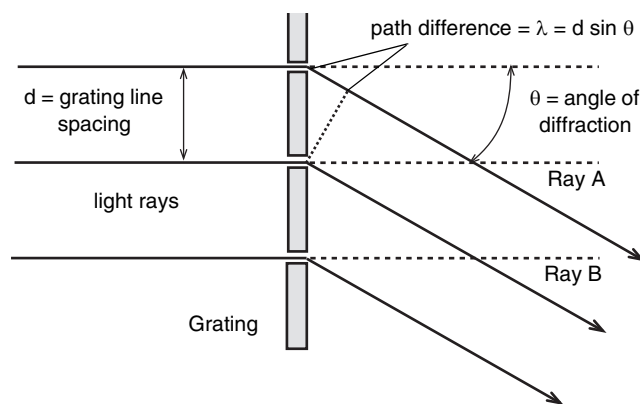


Figure 1.1: Ray diagram for first order diffraction pattern

Procedure

In this activity, the High Sensitivity Light Sensor measures the relative intensity of colors of light in an emission spectrum produced by light from a mercury vapor light source passing through a grating. The Rotary Motion Sensor measures the angle, θ , of each band or “bright line” of color.

The data acquisition program records and displays the light intensity and the angle. You can use the program’s built-in data analysis tools to find the angle for each color, and then you can determine the wavelength, λ , of each color.

Equipment Setup

1. Set up the Spectrophotometer next to a mercury vapor light source as shown (Fig. 1.2). If needed, use the Rod Stand Mounting Clamps, two rods, and two bases to raise the Spectrophotometer to the same level as the opening to the light source. (Refer to the Introduction for more information.)

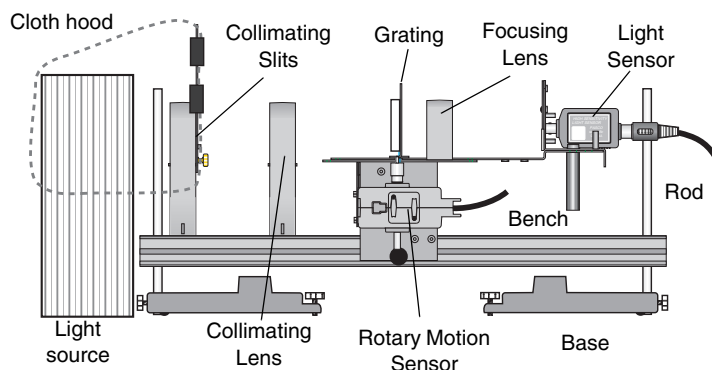


Figure 1.2: Equipment Setup

2. If the light source has a large opening, mask the opening so it transmits a narrow (0.5 to 1.0 cm) beam to the Collimating Slits. Put a cloth hood over the light source and attach the edge of the hood to the plate on the Collimating Slits.
3. Turn on the light source. Once it is warmed up, adjust the light source, Collimating Slits, Collimating Lens, and Focusing Lens so clear images of the central ray and the first order spectral lines appear on the Aperture Disk and Aperture Screen in front of the High Sensitivity Light Sensor. Turn the Aperture Disk so the smallest slit on the disk is in line with the central ray.
4. Connect the PASCO interface to the computer, and turn on the interface. Start the data acquisition software.
5. Connect the High Sensitivity Light Sensor cable to Analog Channel A. Connect the Rotary Motion Sensor cable to Digital Channels 1 and 2.

Experiment Setup

Select the Sensors, Set the Sample Rate, and Create a Calculation

Refer to the User’s Guide for your version of data acquisition software for detailed information on selecting sensors, changing the sample rate, and creating a calculation.

1. In the program, select the Rotary Motion Sensor and connect it to Digital Channels 1 and 2 and select the Light Sensor and connect it to Analog Channel A.
2. In the program, set up the Rotary Motion Sensor for high resolution (1440 Divisions per Rotation) and set the sample rate to 20 Hz, or 20 measurements per second.
3. In the data acquisition program, use the Calculator to create a calculation of Actual Angular Position based on the Angular Position measurement made by the Rotary Motion Sensor and the ratio of the radius of the Spectrophotometer’s Degree Plate to the radius of the small post on the Pinion (Fig. 1.3). (Refer to the Set Up section for more information.)

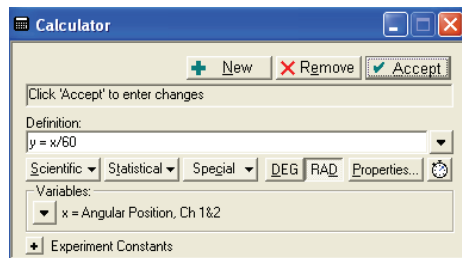


Figure 1.3: Create a Calculation

Select the Display

Refer to the User's Guide for your version of the PASCO data acquisition software for detailed information on displays.

1. Select a Graph display.
2. Set the axes of the Graph display so *Light Intensity* is on the vertical axis and *Actual Angular Position* is on the horizontal axis.

Prepare to Record Data

Refer to the User's Guide for your version of the PASCO data acquisition software for detailed information on monitoring and recording data.

1. Darken the room. Examine the spectrum closely. Determine which of the two first order spectral patterns is brightest. In the Data Table, list the colors you see in order starting with the color that appears farthest from the central ray.
2. Use the Light Sensor Arm on the Spectrophotometer to turn the Degree Plate until the light sensor is beyond the last line in the brightest first order spectral pattern.

Record Data

1. Set the GAIN select switch on top of the High Sensitivity Light Sensor to 1.
2. Start recording data.
3. Push on the threaded post under the light sensor to slowly and continuously scan the spectrum in one direction. Scan all the way through the first order spectral lines on one side of the central ray, through the central ray itself, and all the way through the first order spectral lines on the other side of the central ray (Fig. 1.4).
4. Stop recording data.
5. Set the GAIN select switch on top of the light sensor to 10. Put the light sensor back at its starting point. Repeat the data collection procedure.
6. Set the GAIN select switch on top of the light sensor to 100 and repeat the data collection procedure.

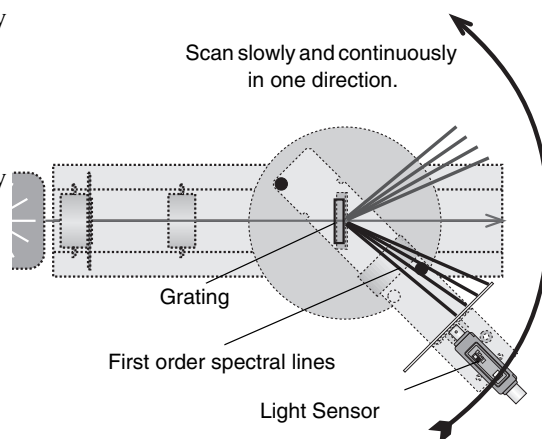


Figure 1.4: Scan the Spectrum

Analyze the Data

Refer to the User's Guide for your version of the PASCO data acquisition software for detailed information on using the software for data analysis.

1. Use the Graph display to examine the plot of Light Intensity versus Actual Angular Position for the first run of data (GAIN select switch = 1).
2. Use the built-in analysis tools to determine the angle of the first line in the spectral pattern, and the angle of the matching line in the first order spectral pattern on the other side of the central ray.
3. Determine the difference in angle between the two lines and use one-half of the difference as the angle, θ , to determine the wavelength, λ , of that color. (If you did not calibrate the Diffraction Grating, assume $d = 1666$ nm.)
4. Repeat the process for the other colors in the first order spectral pattern.

- Examine the plot of Light Intensity versus Actual Angular Position for your other two runs of data. Look for other lines in the spectral pattern that may be too dim to record when the sensor was set to GAIN = 1.

Data Table

Record your data here:

Color	θ_1	θ_2	$\Delta\theta$	$\theta = \Delta\theta/2\lambda = d \sin \theta$

Conclusion

Compare your values for the wavelengths of color in the mercury vapor light spectrum to the accepted values for wavelengths.

Extensions

Repeat the process for a different gaseous element, such as hydrogen or helium.

Activity 2: Absorption (Dark Line) Spectrum

EQUIPMENT NEEDED

Spectrophotometer System (OS-8539)

or

Spectrophotometer Kit (OS-8537)

High Sensitivity Light Sensor (CI-6604)

Rotary Motion Sensor (CI-6538)

Basic Optics Bench (part of OS-8515)

Aperture Bracket (OS-8534)

and

Incandescent Light Source, DC, regulated

Large Rod Stand (ME-8735) (2)

Rod, 45 cm (ME-8736) (2)

Colored Liquid Sample (about 5 mL)

PASCO Interface

Data acquisition software

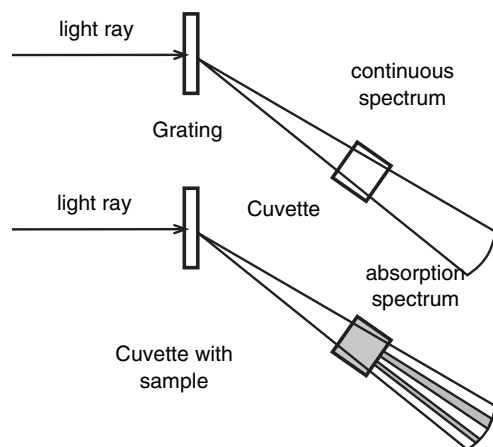
Introduction

The purpose of this activity is to determine the wavelengths of the colors absorbed by a liquid sample.

Theory

One of the most important applications of spectrophotometers is to identify substances by their absorption spectra. For example, it is possible to identify tiny amounts of sodium dissolved in a complicated liquid (such as beer) because sodium has a unique absorption spectrum.

An incandescent source such as a hot solid metal filament produces a continuous spectrum of wavelengths. A substance placed in the path of light from a continuous spectrum source will absorb certain colors from the continuous spectrum. The individual colors that are absorbed appear as gaps or “dark lines” in the otherwise continuous spectrum (Fig. 2.1).



Procedure

In this activity, the High Sensitivity Light Sensor measures the relative intensity of colors of light in an continuous spectrum produced by an incandescent light. Then, the sensor measures the relative intensity of colors of light in an absorption spectrum produced when light from the incandescent source passes through a liquid sample. The Rotary Motion Sensor measures the angle, θ , of each part of the continuous spectrum and then the absorption spectrum.

The data acquisition program records and displays the light intensity and the angle. You can use the program’s built-in data analysis tools to find the angle for each “gap” or dark line in the absorption spectrum, and then you can determine the wavelength, λ .

Equipment Setup

1. Set up the Spectrophotometer next to a DC powered incandescent light source as shown. Move the High Sensitivity Light Sensor to the second position on the Light Sensor Arm so there is room for a cuvette between the back of the Aperture Disk and the opening to the sensor. (Refer to the Set Up section for more information.)

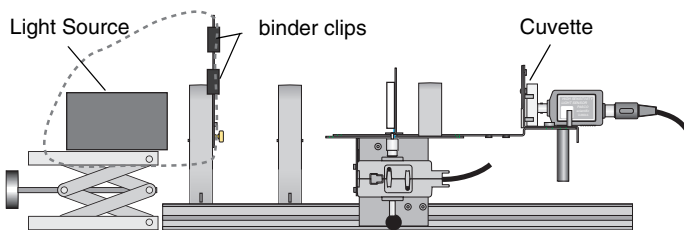


Figure 2.2: Equipment Setup for Absorption Spectrum

2. Put an empty cuvette in front of the High Sensitivity Light Sensor between the sensor and the back of the Aperture Disk. Make sure that the smooth sides of the cuvette are in line with the opening to the sensor (Fig. 2.2).
3. If the light source has a large opening, mask the opening so it transmits a narrow (0.5 to 1.0 cm) beam to the Collimating Slits. Adjust the Collimating Slits slide so the number 2 slit is in line with the light source. Put a cloth hood over the light source and attach the edge of the hood to the plate on the Collimating Slits.
4. Turn on the light source. Once it is warmed up, adjust the light source, Collimating Slits, Collimating Lens, and Focusing Lens so clear images of the central ray and the first order spectral pattern appear on the Aperture Disk and Aperture Screen. Turn the Aperture Disk so the second smallest slit on the disk is in line with the central ray.
5. Connect the PASCO interface to the computer, turn on the interface. Start the data acquisition software.
6. Connect the High Sensitivity Light Sensor cable to Analog Channel A. Connect the Rotary Motion Sensor cable to Digital Channels 1 and 2.

Experiment Setup

Select the Sensors, Set the Sample Rate, and Create a Calculation

Refer to the User's Guide for your version of the data acquisition software for detailed information on selecting sensors, changing the sample rate and sensitivity, and creating a calculation.

1. In the data acquisition program, select the Rotary Motion Sensor and connect it to the interface.
2. In the program, set up the Rotary Motion Sensor for high resolution (1440 Divisions per Rotation) and set the sample rate to 20 Hz, or 20 measurements per second.
3. Set the Sensitivity for the High Sensitivity Light Sensor to 10x.
4. Use the Calculator to create a calculation of Actual Angular Position based on the Angular Position measurement made by the Rotary Motion Sensor and the ratio of the radius of the Spectrophotometer's Degree Plate to the radius of the small post on the Pinion. (Refer to the Introduction for more information.)

Select the Display

Refer to the User's Guide for your version of the data acquisition software for detailed information on displays.

1. Select a Graph display.
2. Set the axes of the Graph display so *Light Intensity* is on the vertical axis and *Actual Angular Position* is on the horizontal axis.

Prepare to Record Data

Refer to the User's Guide for your version of the data acquisition software for detailed information on displays.

1. Darken the room. Examine the spectrum closely. Determine which of the two first order spectral patterns is brightest.
2. Use the Light Sensor Arm on the Spectrophotometer to turn the Degree Plate until the light sensor is beyond the last color in the brightest first order spectral pattern.

Record Data - Empty Cuvette

1. Set the GAIN select switch on top of the High Sensitivity Light Sensor to 10.
2. Start recording data.
3. Push on the threaded post under the light sensor to slowly and continuously scan the spectrum in one direction. Scan all the way through the first order spectral pattern on one side of the central ray, through the central ray itself, and all the way through the first order spectral pattern on the other side of the central ray.
4. Stop recording data.

Record Data - Cuvette with Liquid Sample

1. Remove the cuvette and fill it three-quarters full with the liquid sample you are testing. Cap the cuvette and replace it in front of the sensor.
2. Start recording data.
3. Push on the threaded post under the light sensor to slowly and continuously scan the spectrum in one direction. Scan all the way through the first order spectral pattern on one side of the central ray, through the central ray itself, and all the way through the first order spectral pattern on the other side of the central ray.
4. Stop recording data.

Analyze the Data

Refer to the User's Guide for your version of the data acquisition software for detailed information on displays.

1. Use the Graph display to compare the plot of Light Intensity versus Actual Angular Position for the first run of data (empty cuvette) to the plot of Light Intensity versus Actual Angular Position for the second run of data (cuvette plus liquid sample).
2. Use the built-in analysis tools of the program to find the angle of the first gap or "dark line" in the absorption spectrum of the liquid sample. Find the angle of the corresponding gap or line in the first order on the other side of the central ray.
3. Determine the difference between the angles and use one-half of the difference as the angle, θ , to determine the wavelength, λ , of that gap or dark line. (If you did not calibrate the Diffraction Grating, assume $d = 1666$ nm.)

$$\lambda = d \sin \theta$$

4. Repeat the process for the other gaps (if any) in the first order spectral pattern.

Data Table

Record your data here:

“Dark Line”	θ_1	θ_2	$\Delta\theta$	$\theta = \Delta\theta/2$	$\lambda = d \sin \theta$

Questions

1. What color corresponds to the wavelength for each “dark line” in your absorption spectrum?
2. How does the color or colors that are absorbed out of the continuous spectrum compare to the naked eye color of your liquid sample?

Extensions

Repeat the process for a different liquid sample, such as chlorophyll extracted from a spinach leaf.