Aqua3D Lab Spectrometer.
Hardware and Software Manual -Rev. A

Introduction to Diffraction Grating Spectrometry

Portable CMOS-Based Spectrometer

This instrument is a compact diffraction grating spectrometer designed to observe and analyze the spectral composition of visible and near-infrared light sources. It uses a transmission diffraction grating, a defined entrance slit, and a USB CMOS image sensor to spatially separate wavelengths and record their relative intensities.

Principle of Operation

Light exhibits wave-like behavior. When light encounters a structure with many evenly spaced parallel lines—known as a **diffraction grating**—it is diffracted at angles that depend on its wavelength.

For a monochromatic (single-wavelength) light source, the grating produces a series of discrete diffracted beams at specific angles. For polychromatic light, each wavelength is diffracted at a different angle, causing the beam to spread into a continuous spectrum.

Longer wavelengths (red and near-infrared) are diffracted at larger angles than shorter wavelengths (blue and violet). This angular separation allows the different spectral components of light to be spatially resolved.

Diffraction Orders

The beam that passes straight through the grating without angular deviation is called the **zero-order diffraction** and is designated as

$$m = 0.$$

Additional diffracted beams appear symmetrically on either side of the zero order. These are called **diffraction orders** and are labeled by integer values

$$m = \pm 1, \pm 2, \pm 3, \ldots.$$

Each order corresponds to a specific interference condition between light waves diffracted by adjacent grating lines.

Grating Equation

The relationship between wavelength and diffraction angle is described by the grating equation:

$$d\sin(\theta) = m\lambda$$

Where:

- d is the spacing between adjacent grating lines (grating pitch)
- θ is the diffraction angle
- m is the diffraction order
- λ lambda is the wavelength of light

Because the diffraction angle depends directly on wavelength, a diffraction grating acts as a **dispersive optical element**, separating light into its spectral components.

Transmission Diffraction Grating

This spectrometer uses a **transmission diffraction grating**, consisting of a transparent substrate with a large number of fine opaque lines. These lines form an array of narrow slits that produce diffraction and interference.

The grating used has a density of **1000 lines per millimeter**, providing sufficient dispersion for resolving visible and near-infrared spectra with a compact optical path.

Entrance Slit and Optical Geometry

A **1 mm entrance slit** defines the incoming light beam before it reaches the grating. The slit improves spectral resolution by limiting the spatial width of the light source and establishing a repeatable optical geometry.

After diffraction, the dispersed light falls directly onto the CMOS sensor, where position along the sensor corresponds to wavelength.

CMOS Sensor and Infrared Sensitivity

The spectrometer uses a USB CMOS image sensor **with the factory infrared-blocking filter removed**. This extends sensitivity beyond the visible range into the **near-infrared**, typically up to approximately 900–1000 nm.

As a result, the recorded spectra may include infrared components that are not visible to the human eye.

Scope and Limitations

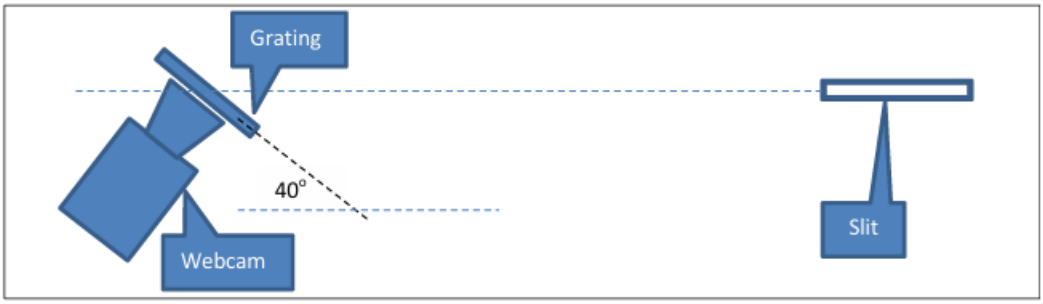
This spectrometer is intended for:

- Qualitative and relative spectral analysis
- Educational and experimental use
- Comparison of light sources
- Observation of emission and broadband spectra

It is not intended for:

- Absolute radiometric measurements
- High-resolution atomic spectroscopy
- Ultraviolet spectroscopy
- Precision wavelength measurement without calibration

Design diagram



Calibration

Theremino Software – Mercury CFL Reference

Accurate wavelength calibration is essential for meaningful spectral measurements. This spectrometer is specifically designed to operate with the **Theremino Spectrometer software**, which provides tools for real-time spectral display and wavelength calibration.

Calibration is performed using a **mercury-based compact fluorescent lamp (CFL)**, which produces well-defined emission lines at known wavelengths. Two prominent mercury emission lines—**436 nm (blue)** and **546 nm (green)**—are used as reference points to align pixel position on the CMOS sensor with physical wavelength.

Why a Mercury CFL Is Used

Mercury vapor lamps emit light at discrete, precisely known wavelengths. In common “white” CFL bulbs, these mercury emission lines remain clearly visible despite the presence of phosphors.

The lines at:

- **436 nm** (blue)
- **546 nm** (green)

are:

- Bright
- Well separated
- Easily resolved by a 1000 lines/mm diffraction grating
- Stable and repeatable

This makes a mercury CFL an ideal and widely available calibration source for visible-light spectrometers.

Calibration Concept

The CMOS sensor records the spectrum as an image, where each horizontal position corresponds to a specific wavelength. However, the raw image is initially uncalibrated.

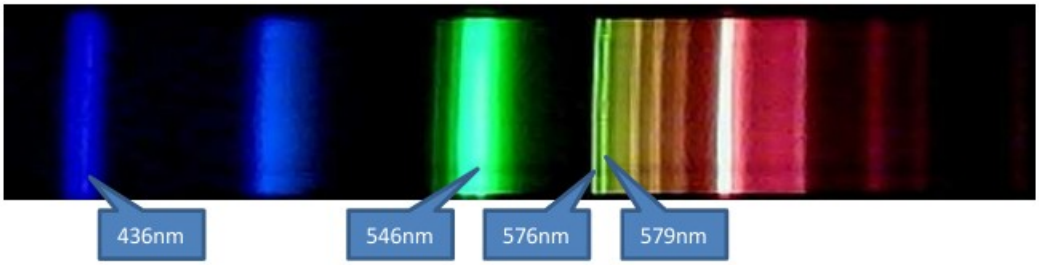
Calibration establishes a mapping between:

- **Pixel position** on the sensor
  and
- **Wavelength** in nanometers

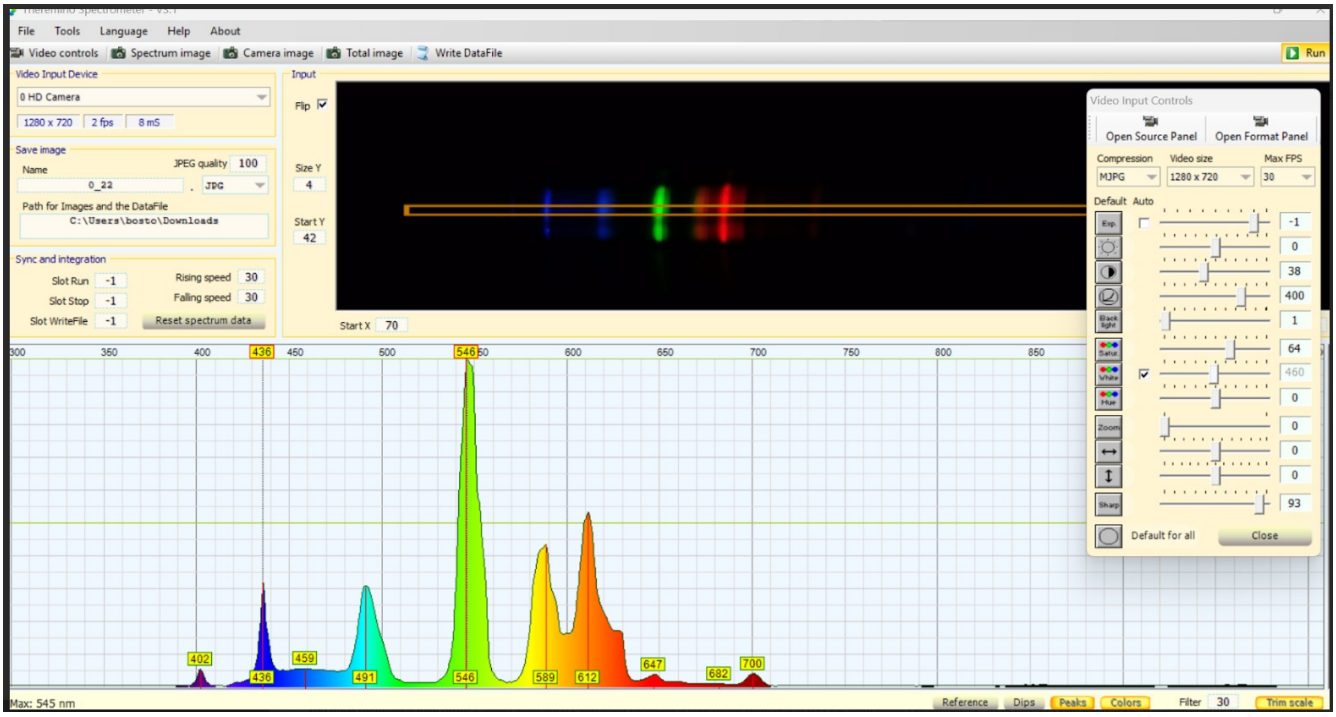
By assigning known wavelengths to known spectral peaks, the software can interpolate the full wavelength scale.

Calibration Procedure (Overview)

1. **Warm up the CFL lamp**
   Allow the mercury CFL bulb to warm up for several minutes to ensure stable emission.
2. **Acquire the spectrum**
   Position the lamp so that its light enters the spectrometer through the entrance slit. Adjust exposure and gain in the Theremino software to clearly resolve the spectral lines without saturation.
3. **Identify mercury emission peaks**
   In the live spectrum display, locate the strong emission lines near:
   - 436 nm (blue)
   - 546 nm (green)
4. **Set trim (calibration) points**
   Using the **Theremino Spectrometer calibration controls**, assign:
   - The pixel position of the blue line to **436 nm**
   - The pixel position of the green line to **546 nm**



5. **Apply and save calibration**
   Once the trim points are set, the software calculates the wavelength scale and applies it to the full spectrum.



Notes on Calibration Accuracy

- Calibration accuracy depends on:
    - Precise peak identification
    - Stable optical alignment
    - Consistent slit and grating positioning
- Re-calibration is recommended if:
    - The grating or slit position is changed
    - The camera focus or mounting is adjusted
    - The spectrometer is disassembled or transported
- For best results, always calibrate using the **same diffraction order** used during measurements (typically first order).

Software Compatibility

This spectrometer was **designed specifically for use with the Theremino Spectrometer software**. While other software may be used, the calibration workflow, trim-point method, and real-time spectral visualization are optimized for the Theremino system.

Custom Files and Project Resources

Additional files related to this spectrometer, including configuration files and supporting documentation, are available at the following link:

Theremino Spectrometer App V3.1 Google Drive Download:

Start with this version and move to 5 once you have become familiar with the app.
https://drive.google.com/file/d/10_cVhxmTQIlQ_J31EejjrloqEhlKTanZ/view?usp=sharing

Please download and extract the contents as instructed in the accompanying documentation.

DOWNLOAD THE APPLICATION

Latest Version

Theremino_Spectrometer_V5.0

Theremino_Spectrometer_V5.0_WithSources

Other Theremino documentation:

Theremino_Spectrometer_Help_ENG
Theremino_Spectrometer_LightSources_ENG
Theremino_Spectrometer_Spectrums_ENG
Theremino_Spectrometer_Gratings_ENG
Theremino_Spectrometer_Technology_ENG

Hardware Manual

Entrance Slit Expansion Bay

The spectrometer includes an **expansion bay** that allows the user to change the **entrance slit size**. Changing the slit width lets you balance **spectral resolution** and **light intensity** depending on the application.

- **Narrower slit** → higher spectral resolution, lower brightness

- **Wider slit** → higher brightness, lower spectral resolution

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Slit Replacement Procedure

Tools Required

- Small Phillips screwdriver (or appropriate driver for the screws)
- Clean workspace
- Optional: tweezers for handling small parts

Step-by-Step Instructions

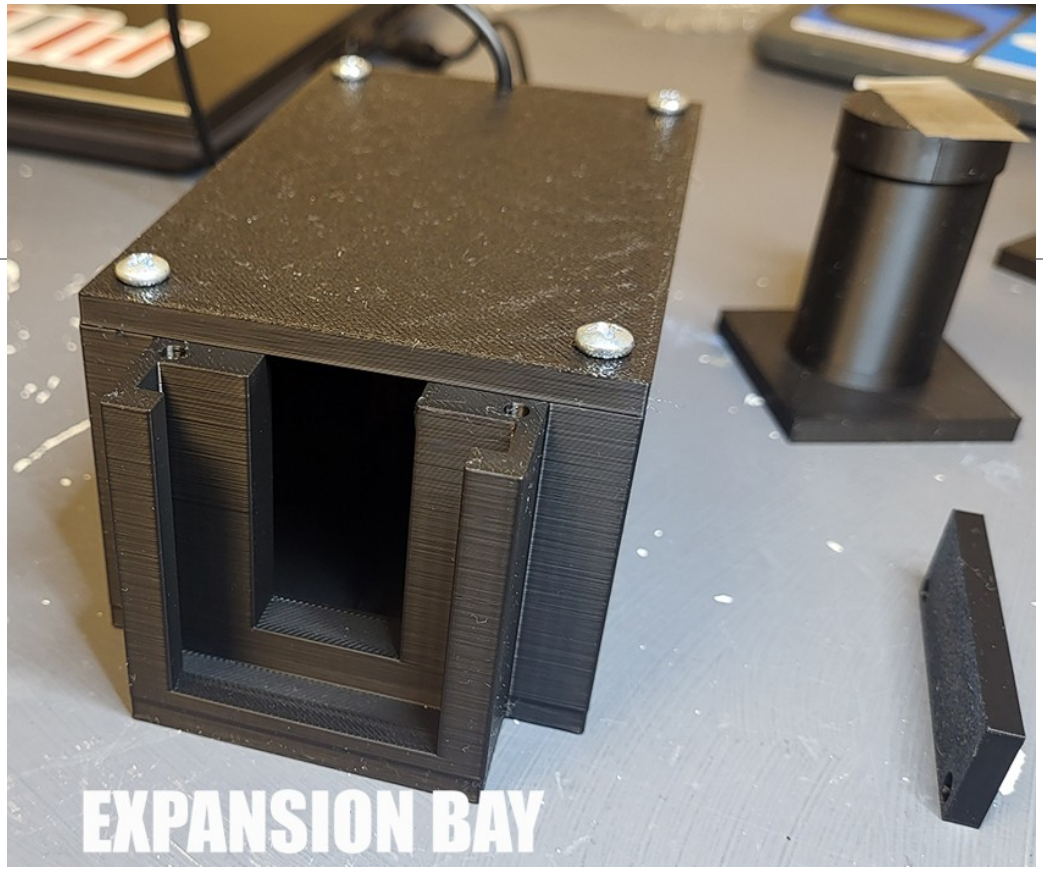
1. Power Down and Disconnect

- Disconnect the spectrometer from the USB port.
- Ensure the device is powered off before opening the expansion bay.

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2. Locate the Expansion Bay

- The expansion bay is located at the **entrance slit assembly** of the spectrometer.
- On the top of the bay, there are **two retaining screws** holding the slit cap in place.



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3. Remove the Retaining Screws

- Using the screwdriver, carefully remove the **two screws** on top of the expansion bay.
- Set the screws aside in a safe location to prevent loss.

⚠ Do not apply excessive force. The screws are small and can strip easily.

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4. Remove the Retaining Cap

- Once the screws are removed, gently lift off the **retaining cap**.
- The cap should come off easily without resistance.

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5. Remove the Installed Slit

- Inside the expansion bay, the entrance slit will be visible.
- Carefully remove the slit insert.
- Avoid touching the slit opening with fingers to prevent contamination or damage.

6. Install a New Slit

- Insert the replacement slit into the expansion bay.
- Ensure the slit is:
    - Fully seated
    - Properly aligned
    - Oriented correctly (slit opening centered)

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7. Reinstall the Retaining Cap

- Place the retaining cap back over the expansion bay.
- Align the screw holes.

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8. Secure the Screws

- Reinstall the two retaining screws.
- Tighten them **snugly**, but do not overtighten.

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9. Reconnect and Verify

- Reconnect the spectrometer to the USB port.
- Launch the Theremino Spectrometer software.
- Verify that the spectrum appears correctly.

Note: Changing the slit size may require **adjusting exposure** and may slightly affect calibration. Re calibration is recommended for best accuracy.

Handling and Care Notes

- Always handle slit inserts by their edges.
- Keep slit openings clean and free of dust.
- Store unused slits in a protective container.
- Avoid compressed air directly on the slit opening.

When to Change the Slit

Change the slit size when:

- Switching between bright and dim light sources
- Seeking higher spectral resolution
- Reducing noise from overly bright sources
- Performing calibration vs. measurement

Slit Selection Guide

The spectrometer supports interchangeable entrance slits to optimize performance for different light sources and measurement goals. The available slit sizes are:

- **0.5 mm**
- **1 mm**
- **2 mm**
- **3 mm**

Selecting the appropriate slit allows you to balance **spectral resolution** and **signal brightness**.

General Guidance

- **Narrower slits** provide higher spectral resolution but reduce light intensity.
- **Wider slits** increase brightness but broaden spectral features.

Recommended Slit Usage

Slit Width	Recommended Use	Characteristics
0.5 mm	Bright sources, fine spectral detail	Highest resolution, lowest brightness
1 mm	General-purpose measurements	Balanced resolution and brightness
2 mm	Moderate to dim sources	Increased signal, moderate resolution
3 mm	Very dim or diffuse sources	Maximum brightness, lowest resolution

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Practical Examples

- **Lasers / high-power LEDs:** 0.5 mm or 1 mm
- **Mercury CFL calibration:** 1 mm (recommended)
- **Household lamps / LEDs:** 1 mm or 2 mm
- **Flames, reflected light, dim sources:** 2 mm or 3 mm

Notes

- Changing slit size affects spectral line width and intensity.
- Exposure and gain settings may need adjustment after changing the slit.
- For best wavelength accuracy, **re calibration is recommended** after changing slit size.