

Fall 2014 PHYS 4580, PHYS 6/7280

August 26, 2014

Laboratory #1 Guide: Introduction to Laboratory Hardware and Software

Introduction

PHYS 4580, 6280, and 7280 will investigate the physical principles that govern the operation of photovoltaic devices (solar cells which generate electricity from light), and explore the properties of the materials used to fabricate these devices. Within these broad themes, we will study the optical, electrical, and mechanical properties of semiconducting and conducting thin film materials; charge carriers (electrons and holes) and electrical current flow; crystal structure, and more.

Many of the experiments and measurements included in these courses will rely on our own laboratory setups that include a lamp and monochromator (together these serve as a tunable light source), simple optics such as lenses and mirrors, detectors such as a thermopile detector or a silicon photodiode, and measurement hardware consisting of a multi-function DAQ (data acquisition) device. In addition, we will utilize LabVIEW software to control and automate our measurements. Lastly, we will learn to use an analysis software package, called Igor Pro, that is capable of powerful curve-fitting and permits the preparation of publication-quality graphs – in this case for use in your lab reports.

It will be important for you to use your laboratory/course notebook throughout the semester to record information about each scientific concept, document your ideas, and determine on how the collected data fits with the overall experimental goals of the lab. Your notebook should be used to record experimental facts and measurement settings and conditions, and provide descriptions of the experimental arrangement, the equipment and samples being used, etc. The more detail you capture, the easier it will be for you to reconstruct what was done. A good laboratory record book will be a great asset while preparing lab reports. To insure that maintenance of a good laboratory notebook is a priority, your lab notebook will be periodically inspected and graded by the instructors on a scale of 2, 1, or 0 points; your notebook's clarity, completeness, and organization will ultimately constitute 10% of your grade.

Goals of Lab #1: Determination of Time Constant

You will construct a simple computer controlled system that selects a portion (color slice) of the output of a broadband lamp and directs that slice onto a thermopile detector. During this lab, you will develop familiarity with elements of LabVIEW, the data acquisition hardware, the monochromator light source, lenses, and a thermopile detector. One specific goal of the lab is to use the light measurement setup to determine the time constant of the Dexter 2M thermopile detector. From the time constant of the 2M, you can deduce the encapsulation gas used within the 2M (see the application note on the course website).

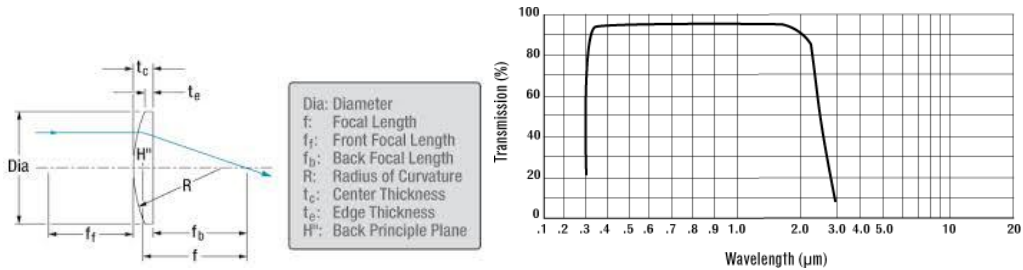
Major Components and Elements of the Lab

- Lamp and monochromator



(Left) ASB-W-030 30W High Stability Tungsten-Halogen Light Source, <https://www.spectralproducts.com/asbw030>. (Right) CM110 Compact 1/8 Meter Monochromator, <http://www.spectralproducts.com/cm110>.

- Plano-convex lenses, various focal lengths, made of BK-7 glass.



- High-sensitivity thermopile detector, Dexter Model 2M. Note that this detector is housed within the gray PVC tube assembly which is mounted on an optical post.



- Optical chopper, Thorlabs Model MC2000. The chopper wheel is fragile, so please take care not to bump or flex it. Gentle (careful) manual rotation when the motor is off is OK.



- Optical mounting hardware including posts, post-holders, base plates, and lens mounts.
- USB-6009 Data Acquisition device made by National Instruments.



Concepts

Time Constant: from Wikipedia (abbreviated WP in the future) – “Physically, the time constant represents the time it takes the system's step response to reach $1 - 1/e \approx 63.2\%$ of its final (asymptotic) value. In radioactive decay the time constant is called the decay constant (λ), and it represents both the mean lifetime of a decaying system (such as an atom) before it decays, or the time it takes for all but 36.8% of the atoms to decay. For this reason, the time constant is longer than the half-life, which is the time for only 50% of the atoms to decay.”

Experimental Steps

1. Review and consider the entire experimental workstation. Note the following major elements –
 - a. Breadboard onto which optomechanics and the monochromator are mounted. The breadboard has an array of $\frac{1}{4}$ ”-20 threaded holes on a 1” grid;
 - b. Monochromator which enables us to select a specific narrow wavelength range from the lamp light source, and output the light. The monochromator has a power supply and a communication cable for the motor, and there’s also a power supply with communication/power cable for the light source mounted on the “back” of the monochromator;
 - c. Lenses which have various focal lengths and allow us to collimate and/or focus light. A collimated beam will focus to a smaller spot size when using a smaller (shorter) focal length lens;
 - d. Various optomechanics, such as mounting posts (stainless steel, $\frac{1}{2}$ ” diameter), post-holders, base plates, lens mounts, and clamps. Proper use of the clamps is accomplished when a washer is used between the clamping screw head and the clamp slot, and when the clamps are adjusted to press down flat-against-flat onto the base plate:

less like this:







, and more like this:



Although the difference seems small, you’ll get the best stability this way as you clamp down flat on the base plate.

- e. The laptop – take note of the USB connections (and please do not change these, though you may plug in a USB drive as needed when the network cannot be used for file transfer): USB-6009 DAQ (small white device), a USB-to-Serial ports adapter, and a mouse. The laptop is configured with LabVIEW software, Igor Pro software, and Office software. Please ask if you feel the need to install new software.
- f. SR510 Lock-In Amplifier – not used yet. Includes a manual.
- g. Keithley 2401 SourceMeter – not used yet;
- h. Tools – each setup should have a 5/64” and a 3/16” ball driver for hex-socket screws, and a set of small screwdrivers. In addition, you should have sample cases, optics cases, and potentially some BNC and other connection cables and wires. The lab has a location for storage of additional components including optomechanical items and cables.
- i. Dexter Model 2M thermopile detector – this light detector works by absorbing incident light very efficiently and converting the absorbed light to heat which then induces a voltage signal proportional to the total incident light power (recall that power is energy per unit time); there’s also a Dexter Model 1010 low noise amplifier with a nominal gain of 1000 – this is useful at times when the signal is otherwise too low to measure directly on the DAQ;

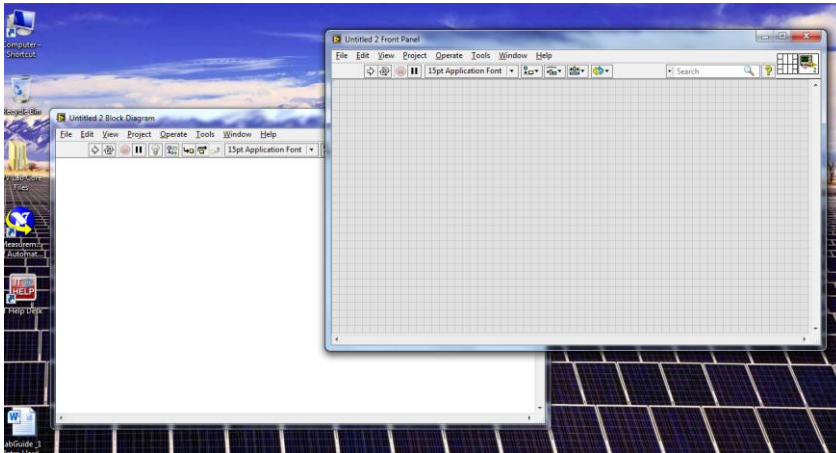
2. Log into the laptop as follows:

- a. Username: .\PV *case-sensitive*
- b. Password: 2013Lab2013 *case-sensitive*
- c. Note that there are icons along the bottom to launch LabVIEW  and Igor Pro . IrfanView  is also installed, which is handy for simple image handling (Fn-PrintScreen to capture the desktop to clipboard, then Ctrl-V to paste into IrfanView, then select what you want and Ctrl-Y to crop, and then save as .jpg).
- d. Measurement and Automation Explorer (a.k.a. “Max”, ) is on the desktop and allows you to view and test the attached DAQ device(s). Open Max and then expand Devices and Interfaces, then select NI USB-6009 “Dev1”. In Max, you can run the Self Test and Test Panels if and when necessary to confirm that the USB-6009 is functioning correctly.
- e. Note that the manuals and related documentation for many of the instruments and components we use in this course can be found on the Desktop, via this folder path: PV Lab Core Files ... Reference. By the way, the majority of the files needed for this lab are located within the Desktop/PV Lab Core Files folder, so look there first.

3. To review briefly: For this Laboratory #1, you will become familiar with many of the elements we’ll use in later labs. You will use LabVIEW to control the wavelength of the monochromator light source, and to digitize the voltage generated by the thermopile detector (2M) when the light beam is incident on the detector. The data you acquire will be graphed as a function of time, and also saved to disk for analysis in Igor Pro to determine the time constant of the 2M.

Let’s start by opening LabVIEW. Under “New”, choose Blank VI. You’re presented with two windows: the Front Panel (FP), and the Block Diagram (BD). The FP shows the user controls,

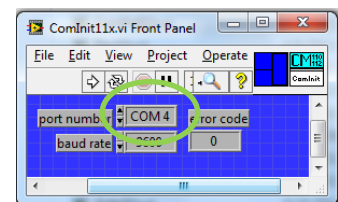
indicators, and data; the BD shows the details of the wiring that enables the VI's functionality (VI stands for "Virtual Instrument") – see below. Of course, there's nothing there just yet. Note that in LabVIEW, one creates .vi's, and then can also use a .vi as a "sub-vi" within another .vi. Let's get started to see how this works:



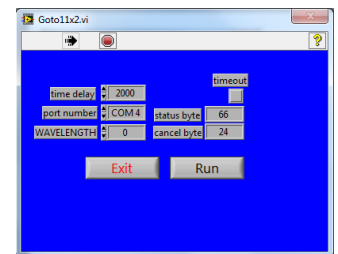
4. Familiarization and communication with the CM110 monochromator and light source. Turn on the power supply for the CM110; you should hear the CM110 initialize with a motor operating for several seconds. Also turn on the power to the lamp (ABS-W-030), and set the 2.0-3.5 knob approximately at the middle of the range – you'll hear the lamp housing fan running. At this point, inspect the output from the CM110 – you should see an orange-ish light. Note that the CM110 uses manually-swappable slits, one at the "entrance" where the lamp couples to the CM110 body, and one at the "output" from which the light emanates toward your experiment. Take good care of the slits, which are normally used as a pair; we have six pairs in each set, ranging in width from 0.15 mm to 2.4 mm.

Find the folder "SP Monochromator LabView Drivers", and then open "8-0138-e" (Please note that you should not save your LabVIEW or other work to any location within "PV Lab Core Files".

Instead, create a desktop folder called Team X where X is your Team number.) Let's look at how to communicate with the CM110 monochromator. Open the .vi called ComInit11x.vi. Check that the Port Number is set to COM4 (the most likely scenario), and run the .vi by clicking the Run button – see the arrow circled in green.

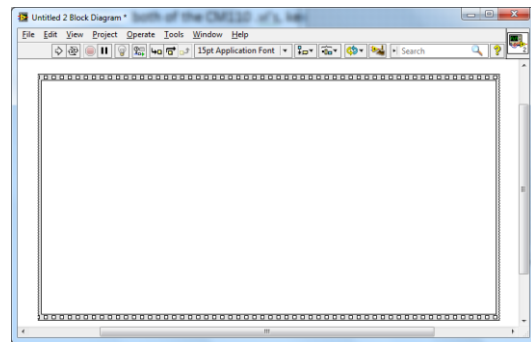
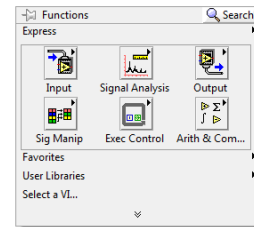


When you run the .vi, it should show a very boring error code of 0; if it shows anything else, communication was unsuccessful (see the troubleshooting guide). Once communication is working, open the .vi called Goto11x2.vi. This .vi commands the CM110 to tune the diffraction grating to a specific output wavelength. The wavelength is specific in Angstroms – a tenth of a nm. Since the human eye is quite sensitive to green light, enter a wavelength of 5000 Å, and run the

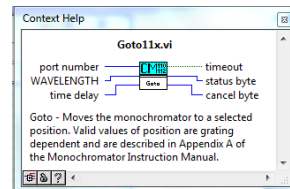


program. Inspect the output of the CM110 to see whether you've got green light as the output. Change the wavelength to other values in the range of visible light (~400 to 700 nm, or 4000 – 7000 Å), to test which wavelengths you can see in these lighting conditions. We can turn the room lights off for a while around this time to ease the viewing, and you can also adjust the lamp brightness.

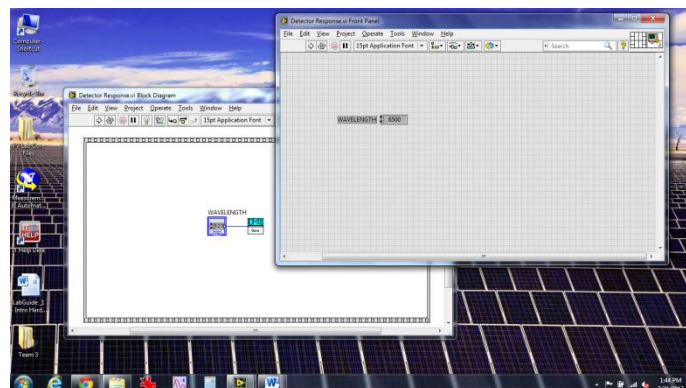
- OK, so now we know how to control the CM110 wavelength – a big step forward! Now close both of the CM110 .vi's, keeping your Untitled.vi windows open. Let's start building a small program as follows. On the BD, right-click in a blank spot to bring up the Functions dialog and choose the double down-arrow at the bottom (see image). Choose Programming, then Structures, then select Stacked Sequence. This "tool" allows you to draw a rectangular sequence structure on the BD. A stacked sequence can be compared with a single frame in a film strip. You'll see what we mean as we proceed. It starts out like this:



- Right-click on the blank space inside the sequence structure, and choose "Select a VI...". Now navigate to Goto11x.vi (not Goto11x2.vi – i.e., without the 2 – this version doesn't require one the click the extra "Run" button) and choose it. Place it inside the sequence structure and leave it there. Notice that when you hover the cursor over the icon, it shows stubs of "wires" sticking out at the left and right sides. Now turn on Context Help by using Control-H or selecting it from the Help menu. With Context Help ON, hovering over the .vi icon will bring up more information about the wiring connections available. Now you can wire up a Control (i.e., this element allows the user to control a parameter's value, as opposed to an Indicator which simply tells the user the current value of a parameter). Hover the mouse over the Goto11x icon, and near the stub for WAVELENGTH right-click and choose "Create Control".



The control can be seen on the BD but also on the FP, and it has a suitable name (you could change it if you wanted to). At this point, let's save the .vi and give it a name. From the File menu, navigate to thr Desktop, create a folder called Team X if it doesn't already exist, and then create a folder called Lab#1 – Thermopile Detector. Save the .vi as Detector Response.vi.



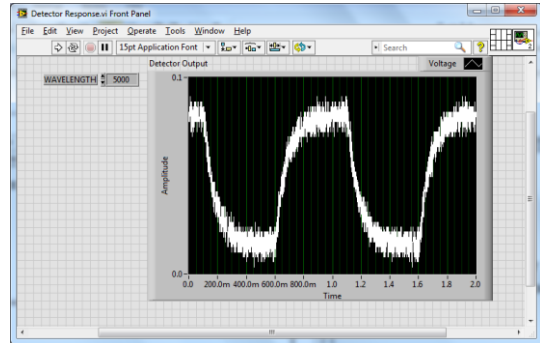
7. Test the .vi. Now go to the FP, and type in 5000 for the WAVELENGTH value. Then right-click on the number and choose data Operations...Make Current Value Default. Save the .vi. Now run the .vi a few times, confirming that it works to control the output wavelength.
8. Align the lenses to collimate and focus the output light onto the detector. Align the shorter focal length lens ($f \sim 25$ mm), with the curved side away from the CM110, so that it approximately collimates the light. Use a piece of paper to determine the width of the light beam at different distances from the lens surface. Adjust the height so that the “beam” is horizontal, and adjust the distance from the CM110 so that ~ 5 ” away from the lens you see a somewhat magnified vertical rectangle image of the light. Make certain that the lens is normal to the beam direction and centered on the beam (so the beam does not deviate from its original path).

Now insert the longer focal length lens (~ 125 mm) about 9” from the first lens, so that it is centered on the beam both horizontally and vertically, and normal to the beam direction. Now align the detector so that the maximum amount of light is incident on the central region. Next we’ll work to get a voltage signal so the alignment can be further optimized.

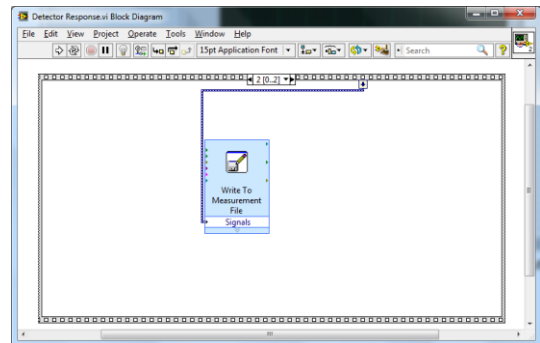
9. Connect the voltage to the USB-6009 on an analog input. Connect the 2M output to channel AIO (stands for Analog Input 0). You may, or may not need to also use the Model 1010 amplifier. You can try it with the amplifier and if the signal saturates (above 10 V), then remove it. You should connect the ground (black) to pin 1, and the red (positive lead) to pin 2. This is the correct setup for a “RSE = Referenced Single-Ended” analog-to-digital (A/D, or A to D) conversion. You can use Max to observe the voltage signal and determine whether or not, when you block the light, the voltage drops according to what you’d expect. Make sure you use RSE for the input configuration. If you see a signal within Max, you can optimize it through alignment.
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10. Position the optical chopper. Place the chopper into the beam path such that when rotating the wheel it will chop the beam completely. Take care with the chopper to insure the blade is not bent or flexed. Power up the MC2000, and adjust the Frequency setting to 1 Hz (1 on-off cycle per second). Now the light onto the detector is chopped, or modulated, so that the incident light turns “on” and “off” once per second.
 11. Implement data acquisition. Now return to the BD, right-click along the top of the sequence structure, and choose Add Frame After. You’ll see that the frames are numbered starting at 0. In frame #1, right-click, choose Input, and Select DAQ Assist. (note that I could not follow and do this in my version of LabVIEW) When you drop that into the frame, the assistant will open and allow you to choose Acquire Signals, then Analog Input, then choose Voltage. For the channel, choose “ai0”. Configure the input for RSE, and a voltage range of -1 V to 1 V initially (you edit these settings later if needed). Choose N Samples for the Acquisition Mode, and set the Samples to Read

and the Rate to different values. Experiment with entering different values while considering the data sheet for the NI USB-6009 which specifies the board's limitations. Also, the response time of the thermopile is such that chopping at too high of a frequency will not allow a complete transition from the illuminated to unilluminated states to be measured. Settle on some parameters that will give a clear picture of the detector's response during 1-2 cycles of the chopper.

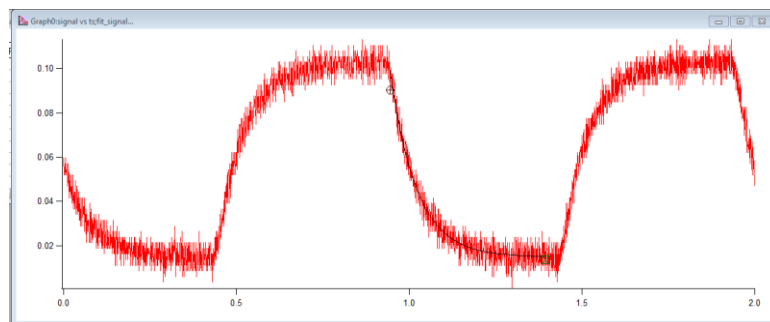
When you're ready to view the output, go to the DAQ Assist icon and wire the Data output to a Graph Indicator by right-clicking on the Data terminal. Rename the graph indicator to "Detector Output". Save your .vi, and then run it. Once the .vi completes, you should see something like this (right).



12. Save your data to a file that can be loaded into Igor Pro. Add another frame to your sequence structure, and then "Add Sequence Local" in frame #1 to bring the output data to frame #2 for saving the detector vs. time data. After you have added the Write Measurements to File assistant (under Output on the Functions palette) and configured that correctly to save a tab-delimited text file with a single time column of data, your .vi will look like this (at right) in frame #2. When configuring the writing of the file, please establish a "Data" folder within your Team X folder, and direct LabVIEW to use that folder when storing files. To determine if the data has been written to the file correctly, exit LabView and open/inspect the contents of the file with Notepad, the resident Windows text editor.



13. Determining the time constant. Assuming that you have acquired good data from the chopped detector signal, you can proceed to analyze it within Igor Pro. Try Data...Load Waves...Load General Text. Assign wave names for the two columns as *ts* (for timestamp) and *signal*. You can then use the Windows menu in Igor Pro to create a new graph using these two waves as the x and y values. At this point, use Ctrl-I to bring up the information and cursors below the graph. Grab the round cursor and place it near the beginning of a descent of the data when the chopper wheel has just blocked the beam. Place the 2nd (square) cursor near the bottom of the "run-out", just before the time when the chopper unblocks the beam. Go to Analysis, then choose Quick Fit



and exp_XOffset. The fit line will be added to the graph automatically, but you should change the color so it can be seen more easily (by default it is plotted in red).

Addendum (Additional Exercises):

Create front panel controls for rate and # of samples for the Daq Assistant you created in Step. 11

Explore the relationship between acquisition rate and number of samples for the USB 6009. With Chopper set to 1 Hz, and number of samples set to 1000, vary the rate of sampling from 100, 1,000, and 10,000 Hz and record the transients and report on your observations. What is the fastest rate at which the signal could be digitized with this DAQ board?

Consider how the physical chopping affects the measured time constant. What would be the fastest time constant that could be measured with the chopper moving at 1 Hz and a beam width of 1 mm? or 1 cm? Chop the light beam at a location where the beam is wide versus where the beam narrow and report on how this affects the measured time constants.

Explore the use of a manual shutter – can the time constant be more accurately measured this way? Could a manual shutter provide a better measurement of the thermopile's time constant?

For your lab report:

1) For every lab report, consider the most important topics addressed, covered, learned. What new skills were developed? What new science and/or technology was introduced? Describe these aspects of the work in an appropriate location within the report.

2) Describe the steps you followed to develop an experimental system to measure the time constant of the 2M thermopile detector. Include details of the light source (including how it is controlled, and how the wavelength is chosen), the LabVIEW software, optical chopper, DAQ hardware and configuration, and the electronic connections required to collect and record the signal. Determine the time constant of the detector, and identify the gas used for packaging. Useful resources are under “Effects of Encapsulation Gas on Thermopile Detectors” and “Thermopile Time Constant Determination” at:

<http://www.dexterresearch.com/?module=Page&SID=technical-library>